The Encyclopedia of Fruit & Nuts

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The Encyclopedia of Fruit & Nuts

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Preface

This work is a horticultural encyclopedia of fruit and nut crops in the broad sense. Entries have been contributed by authorities and we have attempted to adopt a uniform approach although this has not been possible in all cases. Entries are grouped alphabetically by family and then by species. Common names vary widely by language, region and locality and are therefore given in the index at the end of the volume. To find individual entries the reader is advised to check the combined index of species and common names.

The encyclopedia is intended as an authoritative compendium of information on economic, mostly edible, temperate, subtropical and tropical fruit and nuts. There are literally thousands of species with edible fruit and we could not include all of them but we have tried to include those that are considered to be economically significant. Coverage includes palms and cacti as well as vegetable fruit of the *Solanaceae* and *Cucurbitaceae*, often considered as vegetables in some cultures. The volume is intended for libraries, researchers, students and serious amateurs; it is not specifically intended for the average home gardener although many will find it useful.

It may be helpful to define fruit both botanically and horticulturally. Fruit in the botanical sense are mature ovaries and associated flower parts. Their morphological classification and terminology is complex and somewhat bewildering. When a single ovary is involved, they are defined as simple fruit that may be fleshy (succulent) or dry, that is made up of non-living scherenchyma cells with lignified or suberized walls. The ovary wall or pericarp is composed of three distinct layers from outer to inner as exocarp, mesocarp and endocarp.

When the entire pericarp of simple fruit is fleshy (Plate 1), the fruit is referred to as a **berry** (grape and tomato for example). A berry with a hard rind is called a **pepo** (squash). When the exocarp and mesocarp form a rind the fruit is called a **heperidium**, as in citrus, where the edible juicy portion is the endocarp. Simple fleshy fruit having a stony endocarp (peach, cherry, plum and olive) are known as drupes. Here the edible portion is the mesocarp. When the inner portion of the pericarp forms a dry paper-like core the fruit are known as **pomes**. The dry, dehiscent simple fruit (Plate 2) include such types as **pods** (pea), **follicles** (milkweed), **capsules** (jimson weed) or **siliques** (crucifers). Dry, simple fruit that do not dehisce (Plate 3) when ripe include **achenes** (sunflower), **caryopses** (maize), **samaras** (maples), **schizocarps** (carrot) and **nuts** (walnut). Aggregate fruit (Plate 4) are derived from a flower having many pistils on a common receptacle. Individual fruit may be drupes (stony) as in blackberries, or achenes (that is, one-seeded dry fruits) as in strawberry (note that in the strawberry the edible portion is the receptacle). Multiple fruit (Plate 4) are derived from many separate but closed clustered flowers in which the fruitlets coalesce and fuse such as in the pineapple, fig and mulberry.

Fruit crops in the horticultural sense are those plants bearing more or less succulent fruit or closely related structures. They are most often perennial and are usually woody but there are exceptions such as the banana, which is the fruit of a tropical herbaceous plant but appears tree-like. Horticultural groupings are varied. Temperate tree fruit of the *Rosaceae* are often referred to as **pome fruit** when their fruit are botanical pomes (apple, pear, quince, medlar) or **stone fruit** when their fruit are drupes (apricot, cherry, peach, plum). Fruit of small stature (such as strawberry, raspberry, blackberry, blueberry and currants) are often called **small** or **berry fruit**. Fruit from vines such as grape and kiwifruit are known as **vine fruit**. Nuts are a specialized category of fruit characterized by a hard shell that is separable from a firmer inner kernel.

Fruit are an important part of human culture, religious practices, mythology and art. Horticultural fruit are among the most beloved of plant products, acclaimed and desired for their delectable flavour, pleasing aroma and beautiful appearance. As a result, fruit have become important world industries. Fruit by their diversity are used in a myriad of forms: mostly fresh but also dried, canned, frozen, pickled and fermented. Most are consumed out-of-hand as snacks or desserts, but are often used in salads, cooked as a side dish, made into jams and preserves or consumed as wine or liqueurs. The great majority of fruit are considered an important source of calories and are often classed as functional foods or neutriceuticals. A few are rich in fats and oils (oil palm and avocado for example); most are low in protein. A few are sources of industrial products, olive for example.

Of the 30 most important world crops in terms of tonnes of fresh product, five are fruit crops (banana/plantain, orange, grape, apple and mango). Many fruit are considered important enough to be included in Food and Agriculture Organization (FAO) world agricultural statistics.

This work includes 292 entries covering information on over 322 fruit. We thank all the authors who have contributed entries and appreciate the helpful editing of Dr Priscilla Sharland that has helped make this work a reality.

Jules Janick and Robert E. Paull

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Plate 1

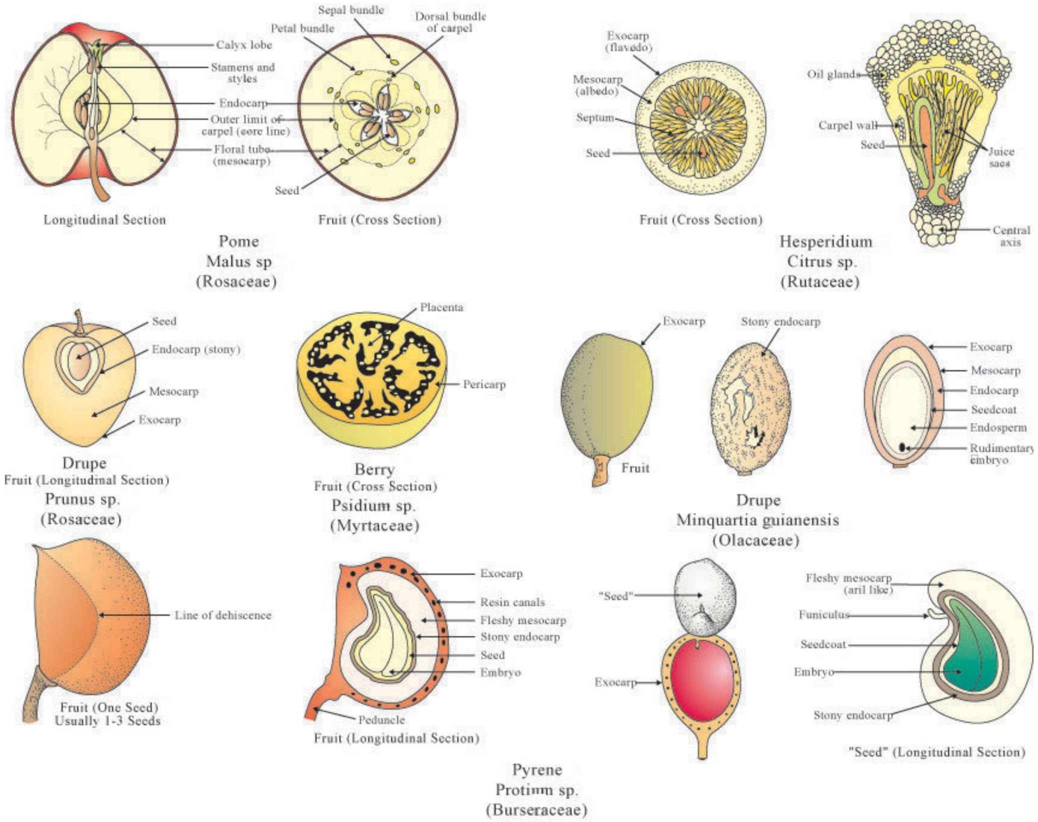

Plate 2

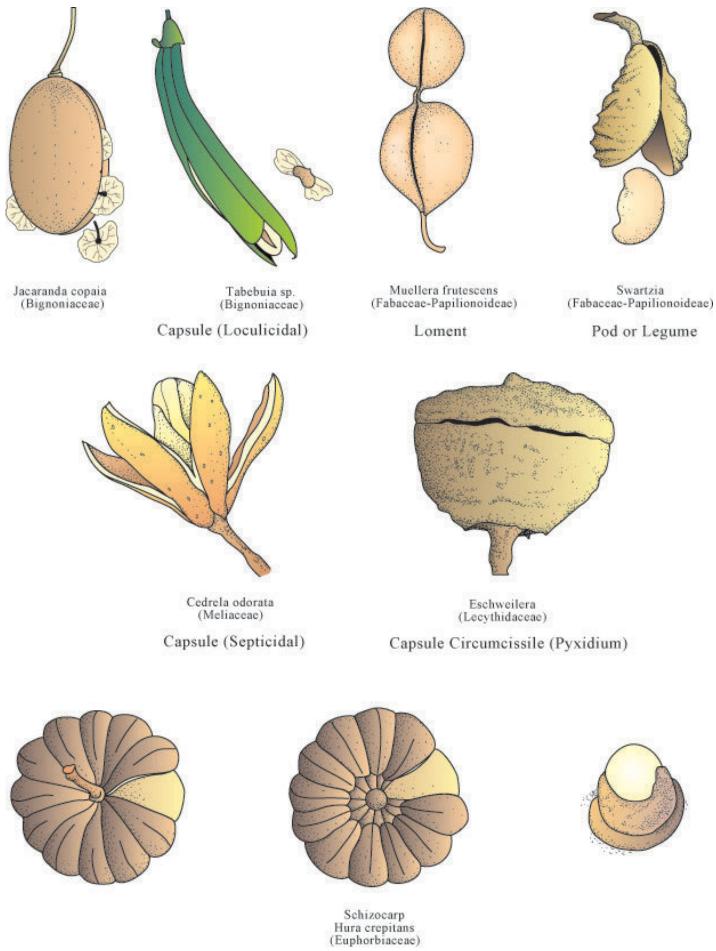

Plate 1. Types of fleshy fruit (source: Vozzo, 2002).
Plate 2. Types of dry dehiscent fruit (source: Vozzo, 2002).

Plate 3

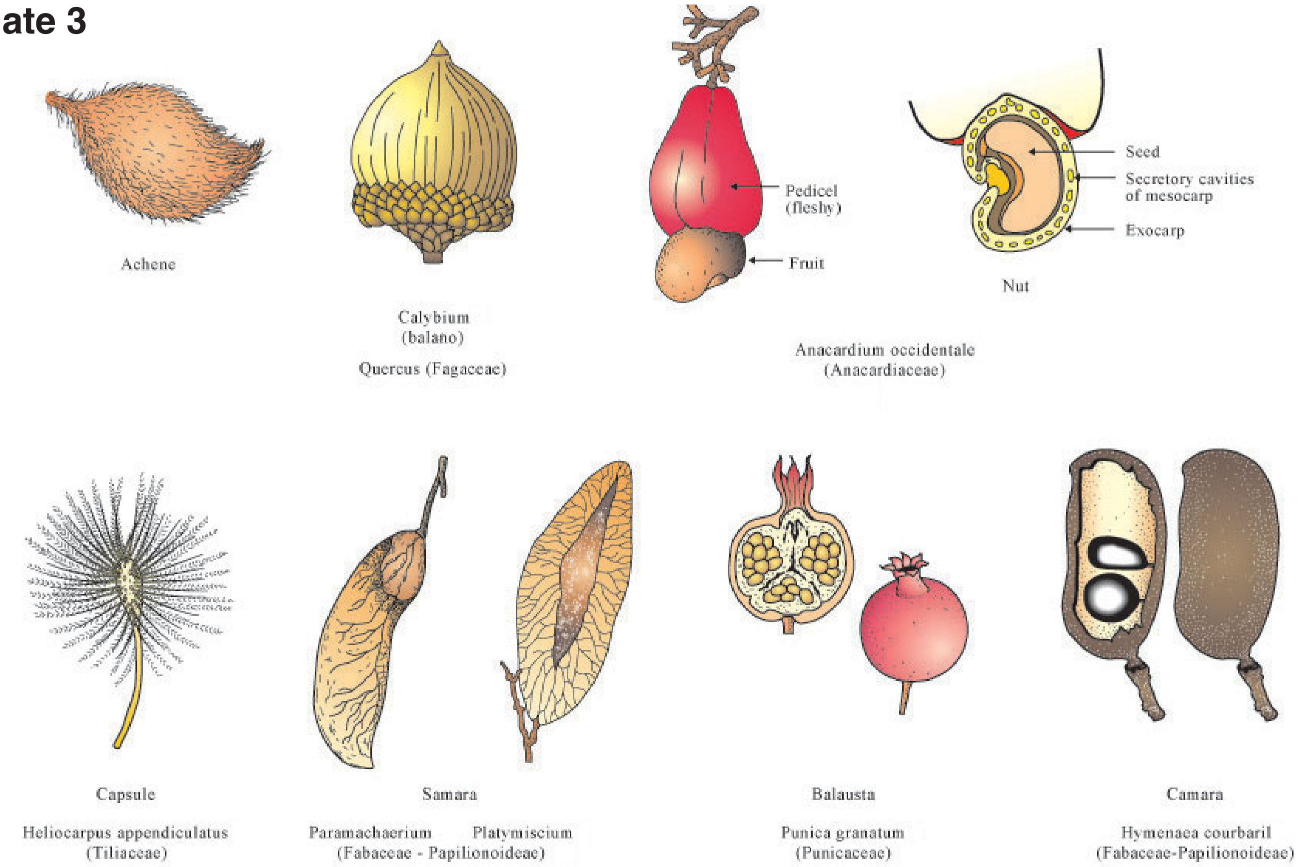

Plate 4

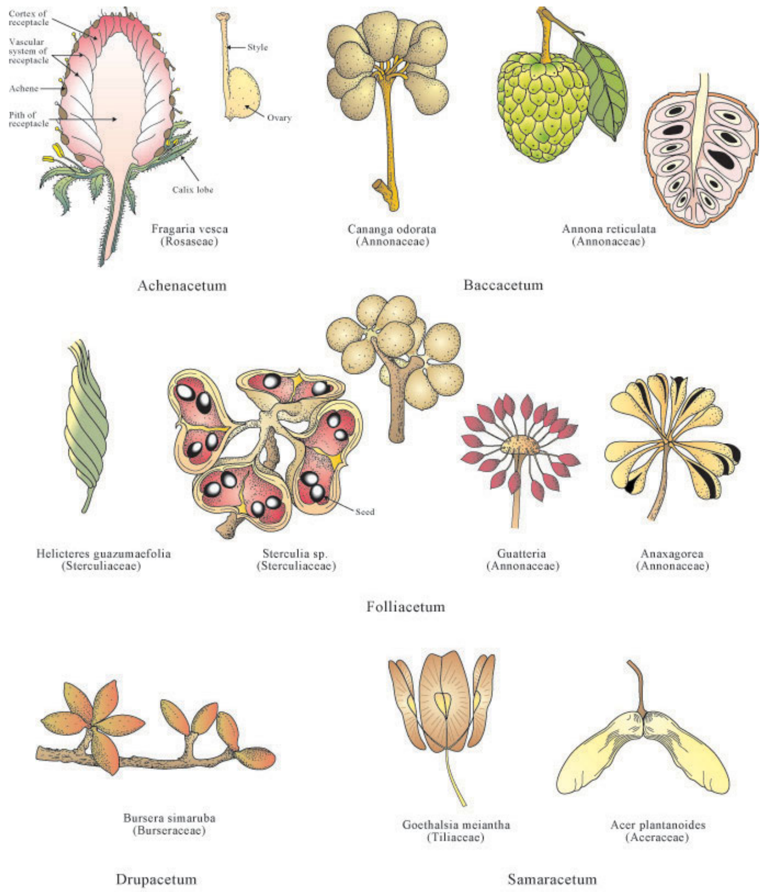

Plate 3. Types of dry indehiscent fruit (source: Vozzo, 2002).
Plate 4. Types of aggregate and accessory type fruit (source: Vozzo, 2002).

Glossary

Abaxial: the side or face away from the axis.
Abiotic: the absence of life or living organisms.
Abscission: separation of flowers, fruit and leaves from plants.
Accessory buds: buds found beside or above the true bud at a node.
Achene: small single-seeded dry fruit.
Acicular: needle-shaped.
Acorn: the fruit of oaks, a thick-walled nut with a woody cup-like base.
Acropetally: developing toward the apex.
Aculeate: armed with prickles as distinct to thorns.
Acuminate: elongated tapering gradually to a long, thin point.
Acute: applied to tips and bases that end in a sharp point less than 90°.
Adaptation: the evolutionary adjustments (genetic, structural, functional) that fit an individual or groups of individuals to their environment.
Adaxial: the side or face next to the axis.
Adnate: one organ united to another organ, e.g. ovary and calyx tube.
Adventitious: a plant organ that arises from an unexpected position, e.g. shoots that arise directly from true roots as in raspberry.
Adventitious buds: buds that form along a root or stem other than in the leaf axil, often after injury or pruning.
Aerenchyma: parenchyma cells that are surrounded by open air-filled canals.
Aerial roots: roots produced above ground, often used for climbing.
Aggregated: joined together.
Aggregate flower: a single flower or crowded into a dense flower cluster on a receptacle.
Aggregate fruit: a fruit formed by the coherence or the connation of pistils that were distinct in the flower.
Air layering (marcottage): multiplying a plant by inducing rooting on a root or shoot, often involving girdling and when the roots appear the stem is cut below the roots. The stem is enclosed in shooting media held in place by a sleeve closed at the two ends.
Alate: winged as a stem or seed.
Albus: white.
Aliform: wing-shaped.
Alternate: the arrangement of one leaf, bud or branch per node at opposite sides of the stem.
Ambient: the prevailing environmental conditions especially temperature.
Ament: spike of unisexual, apetalous flowers having scaly, usually deciduous, bracts; a catkin.
Anastomosed: joined.
Androecious [plants]: plants that bear staminate flowers only.
Androecium: the collective stamens of a flower as a unit.
Androgynophore: a stalk bearing both stamens and pistil above the point of perianth attachment.
Andromonoecious [plants]: plants that bear both staminate and perfect (hermaphroditic) flowers.
Anterior: on the front side, away from the axis, toward the subtending bract.
Anther: pollen-bearing part of a stamen at the top of a filament (or may be sessile).
Anthesis: the period when the flower opens, often used to refer to the bursting of the pollen sacs and pollen release.
Anthocyanin: water-soluble red, blue or purple pigments.
Apetalous: without petals.
Apex (pl. apices): the tip or terminal end of a leaf or stem.
Apical: at the apex or tip of an organ.
Apical buds: buds that produce stems and are located at the tip of the stem.
Apical meristem: meristem located at the tip of the stem.
Apiculate: ending with a short, sharp, abrupt point.
Apocarpous: carpels separate from each other.
Apogamy: a type of apomixis involving the suppression of gametophyte formation so that seeds are formed directly from somatic (body) cells of the parent tissue.
Apomixis: reproduction without fertilization or formation of gametes. An apomict usually is genetically identical with its source plant (ortet).
Appressed: lying flat against another organ, but not fused to it.
Approach graft or inarching: two independently growing, self-sustaining plants are grafted together; inarching is often used when replacing the root system and approach grafting when replacing the scion.
Arbor: a tree, a plant with distinct stem and branches.
Arboreal and arborescent: tree-like or pertaining to trees (> 6 m).
Arcuate: arched, bent like a bow.
Aril: a fleshy appendage of the seed, either on a seedcoat or arising from the base of a seed.
Arillate: having an aril or arils.
Articulate: having nodes or joints where separation may naturally occur leaving a clean scar.
Asexual (vegetative) reproduction: reproduction without fertilization such as tubers, bulbs or rooted stems, or from sexual parts such as unfertilized eggs or other cells in the ovule.
Attenuate: tapering gradually to a narrow end or base.
Auricle: small fingers of tissue at the base of the leaf blade of a grass that extend partially around the stem.
Awn: a stiff or flexible bristle, frequent in grasses.
Axial: located in the axis.
Axil: the angle formed between any two adjoining organs, such as stem and leaf.
Axillary: in an axil.
Axis: the main stem or central support of a plant.

Bare root: a plant dug up with bare roots for transplanting.
Bark: all tissues lying outward from the vascular cambium.
Berry: fleshy or pulpy indehiscent fruit with one or more seeds embedded in the fleshy tissue of the pericarp; may be formed from either a superior or an inferior ovary.

Bilateral symmetry: being divided into two equal, mirror-image parts.
Bisexual: having both male and female present and functional in the same flower or inflorescence, hermaphroditic.
Blade: the flattened lamina and expanded part of a leaf or parts of a compound leaf.
Bourse: the terminal portion of the shoot or spur that bears flowers and fruit. Axillary buds (bourse buds) develop below the flowers/fruit and grow into bourse shoots.
Brackish: somewhat salty.
Bract: reduced leaf, subtending a flower or flower stalk, often small.
Branchlet: small or secondary branch.
Bridge graft: graft used to bridge over girdled areas of a tree.
Bristle: hair-like structure.
Bud: an immature or embryonic shoot, flower or inflorescence, frequently enclosed in scales.
Budding: grafting by inserting a bud, into a slit or hole made in the bark of a stock plant.
Bud graft: *see* Budding.
Bulb: a leaf bud with fleshy scales.

Caducous: parts of a plant that are shed or drop off early in development.
Calcareous: applied to soils containing calcium carbonate.
Callus: a small hard protrusion of undifferentiated (parenchyma) tissue formed at a wounded surface.
Calyx: collective term for the outer separate or united sepals of a flower, the outer series of flower parts.
Cambium: the growing or dividing single layer of cells located between the wood and bark.
Camptodrome: leaf venation where the secondary veins bend forwards and anastomose before the end of the leaf.
Capitular: having a globular head; collected in a head.
Capsule: dry dehiscent fruit composed of two or more united carpels.
Carinate: having a keel or a longitudinal medial line on the lower surface.
Carpel: simple pistil or unit of a combined pistil.
Carpellody: stamens develop abnormally into carpel-like fleshy structures.
Cataphylls: scale-like leaves.
Catkin: a scaly spike of usually unisexual and reduced flowers, not applied to the male or staminate strobilus of conifers.
Cauliflorus: having flowers on the stem.
Cauliforous: stalk-like.
Chalaza: point of an ovule or seed where the integuments are united to the nucellus opposite the micropyle, to which the funiculus is attached.
Chimera: plant or parts of a plant whose tissues are of or from genetically different layers.
Ciliate: marginal or fringe of hairs along an edge.
Clavate: club-shaped, gradually thickened towards the end.
Clone: a group of individual plants asexually propagated from a single plant and, therefore, genetically identical.
Clonal test: evaluation of an individual (ortet) or a clone (ramets) by comparing clones.
Coleoptile: in monocotyledons, a sheath that covers the plumule.
Coleorhiza: in monocotyledons, a sheath that covers the radicle.
Columella: the persistent axis of certain capsules.
Comose: hairy.
Companion cells: phloem cell connected to a sieve-tube member by numerous plasmodesmata.
Compatible: plant parts (scion and rootstock) capable of forming a permanent union when grafted.
Complete flower: having all the components: pistils, stamens, petals and sepals.
Compound: composed of several similar parts (leaflets), or a paniculate inflorescence (florets) each attached to a petiole-like structure (rachis) or directly to the top of the petiole.
Compound leaf: divided into two or more blades (leaflets); palmately compound leaves have three or more leaflets arising from a common point, while pinnately compound leaves have leaflets arranged along a common axis.
Cone: mass of ovule-bearing or pollen-bearing bracts or scales arranged spirally on a cylindrical or globose axis; common to most conifers.
Conic: cone-shaped.
Conifer: plants with cones and naked ovules; any of an order of trees and shrubs bearing true cones or with arillate seeds.
Connate: parts of the same whorl grown together, as in sepals.
Coppicing: trees that are cut down or pruned severely to the stump and re-growth produces multiple stems called poles.
Cordate: heart-shaped in outline, such as a leaf with two rounded basal lobes.
Coriaceous: having a stiff leathery texture.
Corm: enlarged fleshy base of a stem, bulb-like but solid.
Corolla: the second floral whorl of a complete flower, collective term for all free or united petals of a flower.
Corymb or corymbose: flat- or round-topped flower cluster, outer pedicels are longer than inner pedicles with the outer flowers opening before the inner flowers.
Costa: the extension of the petiole through the lamina of a palmate leaf.
Costapalmate leaf: palm leaf in which the petiole extends into the leaf blade.
Cotyledon: primary or rudimentary embryonic leaf of seed plants.
Crenate: having margins with shallow, rounded teeth.
Crenatures: notches or indentations.
Cross-pollination: pollination by a genetically different plant. An outcross is a cross to an unrelated individual.
Crownshaft: the tightly packed tubular leaf bases of some feather-leaved palms sheath each other around the stem forming a conspicuous neck-like structure.
Crustaceous: having a hard covering or crust.
Cultivar: cultivated variety, synonymous with the term variety in the International Code of Nomenclature. Cultivars are always graced with a name and when written are usually capitalized and separated by single quotes or preceded by the word cultivar or abbreviation cv. A cultivar may be a clone or an F_1 hybrid or be seed-propagated, if uniform, but practically all cultivars of fruit are clones. The term cultivar was proposed to avoid confusion with a botanical variety (*see* Variety).
Cuneate: wedge-shaped; triangular and tapering to a point at the base.
Cupola: dome-like structure.
Cutaneous: of, pertaining to or affecting the skin.
Cuticle: waxy covering on the surface of stems and leaves that acts to prevent desiccation in terrestrial plants.
Cutin: complex fatty or waxy substance found on the surface of certain seeds or leaves, often making them impermeable to water.

Cutting: detached portion of stem or other plant part which, when rooted, produces a whole plant.
Cyme: an irregular umbellate inflorescence in which the primary axis bears a single terminal flower that develops first.

D.B.H.: diameter at breast height; generally accepted standard for measuring trees at 137 cm above the ground.
Deciduous: detaching or falling off very early; usually in reference to leaves, leaf tips or the sepals and petals of most flowers after expansion.
Decurrent: continued downwards to the stem and attached to the stem, forming a wing-like appendage.
Decussate: arranged along the stem in pairs, each pair at right angles to the pair immediately above or below, as in leaves.
Dehiscence: splitting or opening in a regular manner to let pollen or spores escape through a valve, slit, cap or other opening.
Dehiscent dry fruit: mature fruit that has a dry pericarp that opens to let seeds escape.
Dentate: toothed; having triangular teeth that are perpendicular to the margin.
Denticulate: finely dentate.
Dichogamy: male and female organs mature on the same plant at different times, ensuring natural cross-pollination.
Dicotyledonous: having two seed leaves.
Digitate: divided into distinct lobes in a radiate manner.
Dioecious: species with staminate and pistillate flowers on separate individuals, unisexual (staminate or pistillate).
Discolorous: leaves in which the two surfaces are different in colour.
Distal: opposite the point of attachment; apical; away from the axis.
Divaricate: (of a branch) coming off the stem almost at a right angle.
Dormant: physiological condition with no active growth due to temperature or drought.
Dorsal: appertaining to the back.
Double-worked plant: a plant that has been grafted twice, usually to overcome incompatibility with an interstock between the scion and rootstock.
Drupe: a fleshy indehiscent fruit having a hard endocarp and a single seed; sometimes having more than one encased seed.
Druse: star-shaped crystal.
Dulcis: sweet, agreeable.

Ecotype: a race that is adapted to a particular environment.
Ellipsoid: three-dimensional body whose plane sections are all either ellipses or circles.
Elliptic: oblong with the ends equally or almost equally rounded.
Emarginate: notched at the apex, as a petal or leaf.
Emasculated: removal of immature staminate flower structures (anthers) to prevent self-pollination.
Endocarp: inner layer of a pericarp.
Endosperm: in angiosperms, an embryonic nutritive tissue formed during double fertilization by the fusion of a sperm with the polar nuclei; which is triploid ($3n$).
Entire: smooth, without teeth or indentations; applied to margins, edges.
Eophyll: first leaf above the cotyledons.
Epicalyx: an involucre of bracts below the flower.
Epicarp: outer layer of the pericarp or matured ovary.
Epicotyl: portion of the embryo or seedling above the cotyledons.
Epidermis: outer layer of cells.
Epigeal: growing on or close to the ground.
Epigeal germination: emergence of cotyledons above the surface of the ground.
Epigynous: growing on the summit of the ovary, or apparently so.
Epipetalous: a flower in which the stamens are connected to the petals.
Ester: chemical compound formed between an acid and alcohol.
Etiolate: elongated due to lack of chlorophyll.
Etiolation: elongation, discoloration and poor plant growth due to the lack of chlorophyll.
Evergreen: plants with live leaves persisting through one or more winter seasons.
Exfoliate: peeling bark from a branch or trunk.
Exocarp: outermost layer of the fruit wall (pericarp).
Exoderm: outer layer of one or more layers of thickness in the cortex of some roots.
Exserted: projecting beyond, stamens exceeding the corolla.

Fat: ester of fatty acid and glycerol (or another alcohol) found in plants and animals; in liquid form, called oil.
Filament: stalk-like portion of a stamen, supporting the anther.
Filiform: thread-like, slender.
Fissure bark: furrowed and ridged, or splitting lengthwise.
Florets: applied to the separate flowers of inflorescences.
Flower: angiosperm reproductive structure composed of calyx (sepals), petals, stamens and pistil.
Foliaceous: leaf-like.
Foliole: leaflet.
Follicle: dry, one-celled fruit with a single placenta and splitting along the opposite edge.
Free: separate, not joined together or with other organs.
Funiculus (funicle): stalk of an embryo or seed.

Gamopetalous: having the petals fused around the base.
Genotype: an individual's hereditary constitution, with or without phenotypic expression of the one or more characters it underlies. It interacts with the environment to produce the phenotype.
Geographic race: a race native to a geographic area.
Geographic variation: The phenotypic differences among native trees growing in different portions of a species' range. If the differences are largely genetic rather than environmental, the variation is usually specified as racial, ecotypic or clinal.
Glabrescent: smooth.
Glabrous: having no hairs, bristles or stalked glands.
Gland: a secretory structure on the surface in a depression, protuberance or appendage on the surface of an organ that secretes a usually sticky fluid; any structure resembling such a gland.
Gland of salt: hydatode that excretes water with a high salt and mineral proportion.
Glaucous: surface with a fine white substance (bloom) that will rub off.
Globose: globe-shaped, spherical.
Glochids: the fine hair-like spines found in the areoles of many cacti.
Glomerule: small, compact cluster.
Glutinous: sticky, gummy, having the quality of glue.
Graft: a finished plant that comes from joining a scion and a rootstock.

Grafting: uniting parts of separate individuals, such as an aerial portion (scion) that is joined with a rootstock, and a union forms allowing/re-establishing vascular continuity and growth.

Graft incompatibility: inability of the stock and scion to form or maintain a union that will allow growth.

Graft union: the junction where the rootstock and scion come together (fuse).

Gummosis: any of various viscous substances that are exuded by certain plants and trees, then dry into water-soluble, non-crystalline, brittle solids.

Gutation: process by which water passes from inside the leaf and is deposited on the outer surface.

Gynoecious [plants]: plants that bear pistillate flowers only.

Gynoecium: whorl or group of carpels in the centre or at the top of the flower; all the carpels in a flower.

Gynomonoecious [plants]: plants that bear both pistillate and perfect (hermaphroditic) flowers.

Gynophore: stalk of the pistil.

Halophyte: plant with the capability to grow in saline habitats.

Hapaxanthic: a palm stem that exhibits determinate growth that dies after flowering and fruiting.

Heteromorphic: having different forms at different periods of the life cycle.

Heterosis: increased vigour or other superior qualities arising from the crossbreeding of genetically different plants.

Heterostyly: flower in which styles and stamens are of different heights relative to each other to ensure cross-pollination. *See* Heterotristyly for explanation of tristyly and distyly.

Heterotristyly (tristyly): flower in which the stigma and stamens are at different heights relative to each other. In tristyly stamens and stigma are the same length, or stamens are longer than stigma or stigma longer than stamens. (In distyly flowers have stamens longer than stigma or stigma longer than stamens.)

Hirsutus: with long soft hairs.

Hispid: harshly or bristly hairy.

Hydathode: structure that secretes water; found in the margins of leaves.

Hypanthium: floral tube formed by the fusion of the basal portions of the sepals, petals and stamens from which the rest of the floral parts emanate.

Hypocotyl: portion of the axis of a plant embryo below the point of attachment of the cotyledons; forms the base of the shoot and the root.

Hypogeal: underground, subterranean.

Hypogeal germination: emergence of cotyledons below the surface of the ground.

Hypogynous: situated on the receptacle beneath the ovary and free from it and from the calyx; having the petals and stamens so situated.

Imbricate: applied to leaves or to the parts of the flower when they overlap each other in a regular arrangement.

Imparipinnate: a compound leaf with a terminal pinna.

Imperfect flower: unisexual flower; flower lacking either male or female parts.

Impressed: having sunken veins as viewed from the upper leaf surface.

Inarching: *see* Approach graft.

Incised: intermediate between toothed (dentate or serrate) and lobed, being a sharply inward cut leaf (the inward cuts are called incisions).

Incompatible graft: plants whose parts will not form a permanent union when grafted together.

Incompatibility: a failure or partial failure in some process of grafting or fertilization. For example, pollen tube growth may be deficient even though the egg and sperm cells are potentially functional.

Incomplete flower: flower lacking at least one of the four basic parts: pistils, sepals, stamens or petals.

Incumbent: describing cotyledons lying with the back of one against the radicle.

Indehiscent: not opening naturally when ripe.

Indumentum: general term for the hairy or scaly covering of plants.

Induplicate: palms in which the leaflets or segments are folded upward forming a ‘V’.

Inferior ovary: one with the flower parts growing from above; one that is adnate to the calyx.

Inflorescence: any complete flower cluster including branches and bracts; clusters separated by leaves are separate inflorescences.

Infusion: liquid derived from seeping or soaking (leaves, bark, roots, etc.); extraction of soluble properties or ingredients.

Integument: natural covering, such as skin, shell or rind; also tegument.

Intercalary: meristem situated between the apex and the base.

Internode: the portion of a stem between two nodes.

Interstock: an intermediate plant part, most often a stem piece that is compatible with both the scion and the rootstock. Used in cases where the scion and rootstock are not directly compatible with each other or where additional dwarfing and cold or disease resistance is desired.

Involucre: a number of bracts subtending a flower cluster, umbel or the like.

Irregular: flowers in which the parts of the calyx or corolla are dissimilar in size or shape; or the flower cannot be divided into two equal halves in a vertical plane.

Jugate: yoked.

Juvenile: organ or tissue that is not fully developed; a plant that is unable to produce flowers in contrast with a mature plant which is capable of flowering and is able to reproduce. Plants in the juvenile state may have different morphological features from mature plants.

Lacunae: small spaces.

Lamina: blade or expanded portion of a leaf.

Lanate: having woolly hair.

Lanceolate: lance-shaped, longer than wide, widest below the middle, tapering toward the apex, or both apex and base; resembling a lance head.

Laticifer: cell or series of longitudinal cells that contain a specific fluid called latex.

Leaf primordium: lateral outgrowth from the apical meristem that develops into a leaf.

Leaf scar: mark left on a twig when a leaf falls.

Leaflet: single segment (blade) of a compound leaf.

Legume: member of the *Fabaceae* (*Leguminosae*), the pulse family, with a dry, dehiscent fruit formed from one carpel and having two longitudinal lines of dehiscence.

Lens: biconvex-lens-shaped.
Lenticel: corky spot on the surface of a twig; sometimes persists on the bark of a branch to admit air into the interior.
Lignotuber: woody underground stem.
Ligule: strap-shaped corolla, as in the rayflowers of *Asteraceae*; a thin, often scarious (scar-like) projection from the summit of the sheath in grasses.
Linear: narrow and elongated with parallel or nearly parallel edges.
Liners: rooted shoots used for propagation.
Lobe: segment of a leaf between indentations that do not extend to the midrib or base of the leaf.
Locule: compartment or cavity of an ovary, anther or fruit.
Loculicidal: dehiscing lengthwise, dividing each loculus into two parts.
Loculus: cell of a carpel in which the seed is located; cell of an anther in which the pollen is located.

Marcottage: *see* Air layering.
Mature: organ or tissue that is fully developed, for example, ripe; a plant that is able to produce flowers (reproduce). *See* Juvenile.
Medium plane: plane that divides the seed into two equal parts.
Mericarp: portion of fruit that seemingly matured as a separate fruit.
Mesocarp: fleshy part of the wall of a succulent fruit; the middle layer of the pericarp in a drupe.
Mesomorphic: soft and with little fibrous tissue, but not succulent.
Microphyllous: having small leaves that are usually hard and narrow.
Micropyle: opening in integument at apex of ovule.
Midrib: central or main vein of a leaf or leaf-like part.
Monocotyledonous: having one seed leaf.
Monoecious: having stamens and pistils in separate flowers on the same plant.
Monotypic: having only one representative.
Morphology: study of the form and structure of whole plants, organs, tissues or cells.
Mucilage: any of various gummy secretions or gelatinous substances.
Mucronate: terminating in sharp point.
Mycorrhiza: symbiotic association of fungus and root.

Naked flower: having no perianth.
Nectary: gland that secretes nectar.
Needle: narrow, usually stiff leaf, as in pines, firs and hemlocks.
Nervation: arrangement of veins, as in a leaf; venation.
Node: the narrow region on a stem where a leaf or leaves are or were attached.
Nucellus: maternal tissue surrounding the ovule.
Nut: dry, hard, indehiscent, one-celled and one-seeded fruit; usually resulting from a compound ovary.

Obconic: conical with the apex downwards.
Oblong: elongate in form with sides parallel or nearly parallel, the ends blunted and not tapering; wider than long.
Obovate: ovate with a narrow end at the base.
Obtuse: blunt point or rounded at the end, the angle of the point greater than 90°.
Ontogeny: development of an individual organism.
Open pollination: natural pollination effected by wind or insects, and not directly influenced by humans.
Opposite: leaves or branches growing in pairs, one on each side of the axis and 180° from each other.
Orbicular: circular in outline.
Ovate: egg-shaped in outline with the wider half below the middle.
Ovoid: three-dimensional structure having the shape of an egg with the broader half below the middle.

Palmate: radiately arranged, ribbed or lobed, as in the fingers of a hand.
Palminerved: having lobes radiating from a common point.
Panicle: a compound raceme; an inflorescence in which the lateral branches arising from the peduncle produce flower-bearing branches instead of single flowers.
Papilla(ae): a minute nipple-shaped projection.
Pari: prefix meaning equal.
Parietal: on the sides or wall of the carpels.
Paripinnate: having a pair of leaflets at the apex.
Parthenocarpy: production of fruit without viable seeds, as in bananas and some grapes; may be induced artificially.
Parthenogenesis: type of reproduction in which females produce offspring from unfertilized eggs; a type of apomixis.
Patch budding: is done on plants with thick bark while the plants are actively growing; a rectangular piece of bark is removed from the rootstock and covered with a bud and a piece of bark from the scion.
Pedicel: the secondary stalks of a compound inflorescence bearing individual flowers.
Peduncle: main flower stalk of a compound inflorescence, supporting either a cluster of flowers or the only flower of a single-flowered inflorescence.
Peltate: having the stalk of a leaf attached to the lower surface of the blade somewhere within the margin, rather than on the margin.
Pendulous: drooping or hanging loosely.
Pentamerous: grouped in fives.
Perennial: plant that lives for more than 2 years.
Perfect: flowers having both functional stamens and pistils.
Perianth: calyx and corolla collectively, or the calyx alone if the corolla is absent.
Pericarp: walls of a ripe ovule or fruit; its layers may be fused into one, or separated or divisible into epicarp, mesocarp and endocarp.
Periclinal: parallel to the surface.
Pericycle: a cylinder of cells that lies just inside the endodermis forming a cylinder around vascular tissues in many roots and stems.
Perigynous: when the sepals, petals and stamens are carried up around the ovary but not attached to it.
Persistent: remaining attached past the expected time for dropping.
Petal: one of the parts of the corolla, the inner set of the perianth; may be separate or united to another petal.
Petaloid: sepal having colour and texture resembling petals.
Petiole: leaf stalk; sometimes absent.
Petiolule: compound leaves, the stalk of a leaflet.
Phellogen: sheet-like meristem that produces cork.
Phenology: the relation between periodic plant development (such as leaf development, flowering, root growth) and seasonal climatic changes (such as temperature, moisture availability or daylength).
Phenotype: the plant or character as described, or degree of expression of a character; the product of the interaction of the genes of an organism (genotype) with the environment.
Photoperiodism: response (e.g. flowering, germination) of organisms to the relative length of the daily periods of light and darkness.

Phyllode: expanded flattened petiole resembling and having the function of a leaf.
Phylogeny: the evolutionary relationships among organs and taxa.
Phylotaxy: arrangement of leaf order.
Pilose: covered with hair, especially soft hair.
Pinnate: compound leaf, having lobes or blades of a leaf arranged along the sides of a common axis; also applies to major lateral veins of a leaf.
Pinnule: foliole of second or third order.
Piscicidal: poisonous to fish.
Pistil: the female organ of a flower, collectively ovary, style and stigma (gynoecium) consisting of a single carpel or two or more fused carpels.
Pistillate: with pistils and not stamens; may apply to individual flowers or inflorescences or to plants of a dioecious species in angiosperms; female.
Pit: hard endocarp that encloses the seed of a drupe.
Placenta: ovule-bearing part of the ovary and seed-bearing surface in the fruit.
Placentation: method of attachment of the seeds within the ovary.
Plagiotropic: attracted to one side.
Pleonanthy: a palm stem that grows indeterminately, producing flowers on specialized axillary branch systems.
Plumule: shoot of the embryo.
Pneumatophores: erect exposed roots that arise from underground root system.
Pod: any dry, dehiscent fruit.
Polarity: structural and/or physiological difference established in the plant, embryo, organ, tissue, cell; often in reference to direction.
Pollarded: cut back nearly to the trunk to produce a dense mass of branches.
Pollen: male spore-like structures produced by anthers in flowers and by male cones.
Pollen grain: small structure of higher plants that contains haploid male nuclei (gametes) and is surrounded by a double wall, the exina and intina; transported from the anther of the stamen to the stigma or stigmatic portion of the pistil, a process called pollination.
Pollen sac: locus in the anther that contains the pollen grains.
Pollen tube: microscopic tube that grows down the stigma from the pollen grain; through it the sperm cells are deposited into the embryo sac.
Pollination: process by which pollen is transferred from the anther where it is produced, to the stigma of a flower.
Pollinium: mass of pollen grains.
Polymorphic: having, assuming or passing through many or various forms or stages; polymorphous.
Polysome: ribosome associated with protein syntheses.
Pome: fruit in which the floral cup forms a thick outer fleshy layer and has a papery inner pericarp layer (endocarp) forming a multiseeded core (e.g. apple, pear).
Precocious: developing early, flowers appear before leaves.
Propagule: a plant part, such as a bud, tuber, root or shoot, used to propagate an individual vegetatively.
Prophyll: a leaf-like bract that covers the inflorescence during development.
Protandry: the termination of the shedding of pollen of a plant or flower prior to receptivity on the same plant or flower (proterandrous).
Protogyny: the termination of stigma receptivity prior to the maturation of pollen on the same plant or flower (proterogynous).
Provenance: the original geographic source of seed, pollen or propagules.
Pruinose: having a whitish dust on the surface.
Pruning: removal of unwanted parts of a plant.
Pseudocarp: fruit that develops not only from the ripened ovary, or ovaries, but from non-ovarian tissue as well.
Puberulent: minutely pubescent.
Pubescent: covered with fine, short, soft hairs.
Pulvinule: pulvinus at the base of a petiole.
Pulvinus: swelling at the base of the petiole related to leaf movement.
Punctate: spotted with coloured or translucent dots or depressions, usually due to glands.
Pyrene: hard or stony endocarp; nutlet.
Pyriform: pear-shaped.
Pyxidium: a seed capsule with a top that comes off as the seeds are released.

Race: a population within a species that has similar characteristics but is distinct from other populations, usually interbreeding.
Raceme: an inflorescence in which the single flowers are borne on pedicels arranged singly along the sides of a flower–shoot axis.
Rachilla (pl. rachillae): the rachis of the spikelet in palms, grasses and sedges. In palms the branches of the inflorescence that bear flowers on the terminal segements.
Rachis: main axis of a spike or of a pinnately compound leaf, excluding the petiole.
Radial symmetry: when cut through the centre along any plane, produces similar halves.
Radicle: portion of the embryo below the cotyledons that will form the roots, more properly called the caudicle.
Ramet: an individual member of a clone.
Raphide: sharp-pointed, sometimes barbed, crystals of calcium oxalate, often present in aroids and palms, sometimes acrid.
Receptacle: portion of the axis of a flower stalk on which the flower is borne.
Receptivity: the condition of the pistillate flower that permits effective pollination.
Reduplicate: palms in which the leaflets or segments are folded downward forming an inverted 'V'.
Reflexed: abruptly turned or bent backwards.
Refracted: bent sharply backwards.
Regular flower: all flower parts radially symmetrical of similar size and shape.
Reniform: kidney-shaped in outline.
Reparius: growing on the banks of streams or lakes.
Reticulate: having the veins or nerves arranged in a net-like pattern.
Retrorse: bent abruptly backwards and downwards.
Revolute: leaves where the margins are rolled backwards towards the midrib.
Rhizome: underground stem usually growing horizontally.
Rhizosphere: soil surrounding the root.
Rhombic: four-margined leaf that is diamond-shaped, having three prominent tips, two on the side and one at the top.
Rimose: having many fissures.
Rootstock: the portion of a grafted or budded plant that provides the root system; may include a length of stem.
Rosette: a crown of prostrate leaves radiating at the base of a plant.
Rugose: rough and wrinkled; applied to leaves on which the reticulate venation is very prominent underneath.
Russetting [of fruit skin]: reddish-brown discoloration.

Saccate: pouched or bag-shaped.
Sagittate: shaped like an arrowhead.
Samara: indehiscent, one-seeded winged fruit (e.g. maple, ash).
Samaroid: having the shape of the samara.
Sarcotesta: fleshy testa.
Scabrous: rough or harsh to the touch due to minute stiff hairs or other projections.
Scale: reduced leaves that are usually sessile and seldom green; sometimes epidermal outgrowths, if disc-like or flattened.
Scape: long leafless stem that finishes in a flower or inflorescence.
Scion: part of plant with three or four buds inserted into a stalk for grafting, often a shoot that is grafted onto the rootstock of another plant.
Sclerous: hardened or toughened.
Seedcoat: outer protective layer of a seed that develops from the integument of the ovule; testa.
Senescence: ageing, a progression of irreversible change in a living organism, eventually leading to death.
Sepal: one of the parts of a calyx or outer set of flower parts; may be separate or united to another sepal.
Septate: divided by a septum or septa.
Septum: dividing wall or membrane in a plant, ovary or fruit.
Sericeous: covered with silky down.
Serotinous: late in occurring, developing and flowering.
Serrate: having sharp, saw-like teeth pointed upwards or forwards.
Serrulate: finely or minutely serrate.
Sessile: without a stalk.
Sessile leaf: leaf that has no petiole.
Setiform: bristle-like.
Sheath: tubular structure surrounding an organ or part, such as the basal part of a leaf; the circle of scales around the base of pine needles.
Shield budding: *see* T-budding.
Shrub: woody plant less than tree size, frequently with several branches at or near the base.
Silique: dry, dehiscent, elongated fruit formed from a superior ovary of two carpels, with two parietal placentas, and divided into two loci by a false septum between the placentas; occurs in plants of the family *Cruciferae*.
Simple fruit: fruit that ripens from a single ovary.
Sincarpica flower: flower with its carpels fused.
Sinus: cleft or recess between two lobes of an expanded organ such as a leaf.
Spadix: spike with a thickened, fleshy axis.
Spathe: large bract at the base of a spadix, that encloses the spadix (at least initially) as a sheath.
Spatulate: shaped like a spatula (spoon-shaped); somewhat widened towards a rounded end.
Spicate: having spikes.
Spike: type of inflorescence having sessile flowers on a long common axis.
Stamen: sporophyll within the flower; in angiosperms, the floral organ that bears pollen.
Staminate: having pollen-bearing stamens only, on individual plants of a dioecious species or flowers and inflorescences; male.
Staminode: an aborted or rudimentary stamen in which the anther remains reduced and sterile.
Sterility: absence or defectiveness of pollen, eggs, embryo or endosperm, which prevents sexual reproduction. *See* Incompatibility.
Stigma: pollen-receptive part of a pistil, often enlarged, usually at the tip of the style.
Stipe: stalk of a pistil; not the pedicel; stalk under elevated glands.
Stipitate: having a stipe or borne on a stipe.
Stipule: one of a pair of lateral appendages at the base of a leaf petiole.
Stock or rootstock: the root-bearing plant or plant part.
Stolon: large, indeterminate, underground stem that produces roots at intervals capable of giving rise to a new plant.
Stone: drupe.
Stool: cluster of shoots or stems springing up from a base or root.
Striate: having longitudinal lines, such as bark.
Style: narrow upper part of ovary that supports the stigma.
Sub: prefix signifying almost, less than completely, somewhat, under.
Subbacate: partly pulpy (bacate means completely pulpy like a berry).
Sub-basal: related to, situated at, or forming the base.
Suberin: complex of fatty substances present in the wall of cork tissue that waterproofs it and makes it resistant to decay.
Suberize: convert to corky tissue.
Suckers: many stems arising from the base of a tree or shrub and gradually spreading the diameter of its basal area.
Sulcate: with narrow, deep grooves on the stem.
Superior ovary: ovary with the flower parts growing from below it.
Sympodial: an axis made up of multiple bases.
Syncarpous: having the carpels of the gynoecium united in a compound ovary.
Synpetalous: without petals.

Taxon (pl. taxa): a formal category of taxonomy, e.g. family, genus, species.
Taxonomy: classification of organisms, including identification and nomenclature until recently based upon morphological characters.
T-budding: when a single mature bud is inserted into a T-shaped incision in the rootstock (also known as shield budding).
Tepal: perianth member or segment; term used for perianth parts undifferentiated into distinct sepals and petals.
Terete: circular in cross-section.
Terminal bud: apex of the leaf is at the tip end opposite the petiole.
Testa: outer covering of the seed; the seedcoat.
Tetramerous: relating to groups of four.
Thorn: hard, sharp-pointed stem.
Tomentose: having dense soft, fine, matted, short hairs.
Toothed: the condition of a margin broken into small projecting segments, either serrations, dentations or crenations.
Topworking: cutting back the branches and top of an established tree or mature plant and then budded or grafted with new scions.
Torus: the part on which the divisions of a flower or fruit are seated.
Training: orientation of a plant in space, often combined with pruning and tying.
Trichome: hair, bristle, scale or other such outgrowth of the epidermis.
Trigonous: three-angled.
Truncate: having an apex or base that is almost or quite straight across, if cut off.
Tuber: underground stem in which carbohydrates are stored.
Tuff: cluster of short-stalked flowers, leaves, etc., growing from a common point.
Turbinate: top-shaped; a solid having a tapering base and a broad, rounded apex.

Umbel: inflorescence having the flower stalks or pedicels, nearly equal in length, spread from a common centre.
Understock: rootstock.
Unguiculate: having a small hook.
Union: the point where the scion and rootstock are joined.

Valvate: meeting without overlapping, as the parts of certain buds; opening by valves, as certain capsules and anthers.
Valve: one of the segments into which a capsule dehisces; flap or lid-like part of certain anthers.
Variety: a taxonomic subdivision of a species based on minor characteristics and often an exclusive geographic range. *See* Cultivar for a distinction between botanical variety and cultivated variety (cultivar).
Vegetative: referring to non-reproductive structures or growth.
Vegetative (asexual) propagation: propagation of a plant by asexual means (budding, dividing, grafting, rooting and air layering) when the resulting members of the clone (ramets) are identical with those of the original plant (ortet). Propagating by apomictic seed or somatic embryos is a means of vegetative propagation. *See* Asexual reproduction.
Vestigial: of or pertaining to a degenerate or imperfectly developed organ or structure having little or no utility, but which in an earlier stage of the individual or in preceding organisms performed a useful function.
Villous: densely covered with soft, fine, unmatted, relatively long hairs.
Viscid: sticky.
Viviparous: seeds germinate on the parent plant.

Whip graft: uses scions and rootstocks in grafting of the same diameter, often pencil thin.
Whorl: a ring of three or more structures (leaves, stems, etc.) in a circle, not spiralled.
Wildling: a wild plant transplanted to a cultivated area.
Wing: membrane; or thin, dry expansion or appendage of a seed or fruit.

The Glossary is based, in part, on:

Hemsley, W.B. (1877) *Handbook of Hardy Trees, Shrubs, and Herbaceous Plants*. Longman, Green and Co., London.
Snyder, E.B. (1972) *Glossary for Forest Tree Improvement Workers.* Southern Forest Experiment Station, United States Department of Agriculture (USDA). Available at: http://www.sfws.auburn.edu/sfnmc/class/glossary.html (accessed 8 November 2006).
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A

ACTINIDIACEAE

Actinidia deliciosa kiwifruit

Introduction

The kiwifruit of international commerce are large-fruited selections of *Actinidia chinensis* Planch. and *Actinidia deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson, *Actinidiaceae*. Kiwifruit are among the most recently domesticated of all fruit plants: *A. chinensis* has been cultivated commercially for little more than 20 years, *A. deliciosa* for about 70 years. The common name 'kiwifruit' is itself very recent, being devised in 1959 originally for the fruit of *A. deliciosa* but now being increasingly applied to fruit of other *Actinidia* species, such as *Actinidia arguta* (Sieb. et Zucc.) Planch. ex Miq., the 'hardy' kiwifruit or 'baby kiwi'. Kiwifruit has completely replaced the older name of 'Chinese gooseberry'. In China, 'mihoutao' (monkey peach) is used for all *Actinidia* species, but as *A. chinensis* and *A. deliciosa* are by far the most important economically of the various *Actinidia* species in China, they are often simply referred to together as mihoutao. More explicitly, the two species are sometimes referred to together as zhonghua (Chinese) mihoutao.

Although relative newcomers to the fruit bowl, kiwifruit have found ready acceptance among consumers. Externally, kiwifruit are distinctly different from other fruit. Once cut open, they are strikingly beautiful with a strong radiating pattern of lighter-coloured rays interspersed by several rows of small dark brown-black seeds. The core is creamy white and the outer flesh is a bright green or a sharp yellow. It is thus not surprising that kiwifruit are often used for food decoration rather than just being eaten. The fruit flavours are distinctive but very different in yellow and in green kiwifruit and appeal to largely different sectors of the consuming public. Ripe fruit of *A. arguta* can have a superb, aromatic flavour.

History and origins

Fruit of different *Actinidia* species have been collected from the wild for many centuries but widespread cultivation was first attempted only during the last 100 years. *Actinidia arguta* was being grown in gardens in Europe and North America during the last decades of the 19th century but its commercial potential has yet to be realized. *Actinidia deliciosa* was first grown in orchards in New Zealand in the 1920s, and cultivation of *A. chinensis* started half a century later.

Seed and plants of *A. deliciosa* were sent from China to Europe and to the USA from 1898 onwards, but establishment of the plants was restricted by their climatic requirements, the need for both male and female plants for fruiting, and by the onset of World War I. Seed of *A. deliciosa* also went to New Zealand in 1904 and there the circumstances were better and the plants prospered. The first small orchard was fruiting by the early 1930s but cultivation remained for many years on a very small scale with just enough fruit being produced for the New Zealand market. Exports, starting in 1953, were at first considered as a means of absorbing surplus fruit that could not be sold locally. Promotion and acceptance of kiwifruit on the export markets resulted in much better returns to growers from the mid-1960s so that production expanded rapidly and by 1976 exports of kiwifruit from New Zealand exceeded local consumption. The subsequent development of the New Zealand kiwifruit industry was the development of an industry geared towards export. Growers in other countries were encouraged to start growing kiwifruit and they used the cultivars first developed in New Zealand. These cultivars were all of *A. deliciosa* and so it was the hairy skinned kiwifruit with green flesh that became known to consumers throughout the world.

Domestication of *A. chinensis* is even more recent. The first experimental plantings of this species were established in China in 1957. Subsequently, a survey was made of wild kiwifruit resources in China and many superior genotypes of both *A. chinensis* and *A. deliciosa* were selected for further evaluation. These became the basis for most commercial plantings in China. Seed of *A. chinensis* were imported into New Zealand in 1977. The populations raised from these seed are probably the first plants of *A. chinensis* to have been grown outside of China, and are certainly the first such plants known to have survived. Since then seed of *A. chinensis* or budwood of superior selections have been introduced into many different countries.

World production

Kiwifruit are still a minor crop compared to other fruit such as apples, bananas, grapes or citrus. Production of kiwifruit amounts to perhaps 0.2% of total world production of fruit. In only a few countries are kiwifruit an important crop and in New Zealand they are uniquely important, now being the single most valuable horticultural export.

Actinidia chinensis and *A. deliciosa* are widespread in China and appreciable quantities of fruit (100,000–150,000 t) are collected from the wild each year. About two-thirds of this is of *A. chinensis*, one-third of *A. deliciosa* and, in addition, there are much smaller quantities of fruit of other *Actinidia* species. Harvesting of wild fruit often involves pulling vines down out of trees and this, together with general deforestation, means that the natural resource is under serious threat. However, kiwifruit collected from the wild are often very small or are otherwise of poor quality and they are becoming less important as commercial cultivation increases in China.

In 2002, the total area throughout the world planted in kiwifruit was about 120,000 ha. China had 60,000 ha of kiwifruit orchards, Italy 20,000 ha, New Zealand 12,000 ha, Chile 8000 ha and all other countries (mainly Greece, France, Japan and the USA in decreasing importance) a total of about 20,000 ha. Considering only cultivated kiwifruit, in 2002, total world production was 1,350,000 t: China produced 350,000 t, about the same as Italy, New Zealand 250,000 t and Chile 150,000 t, so together, these four countries accounted for over 80% of world commercial kiwifruit production.

Approximately 7.5% of current commercial production would be of cultivars of *A. chinensis* (almost entirely from China and New Zealand) and the remainder of *A. deliciosa*, of which about 80% would be of 'Hayward'. This cultivar still dominates international trade but cultivars of *A. chinensis*, especially 'Hort16A', are rapidly becoming more important.

Actinidia arguta remains potentially important but at present world plantings amount to only 100–200 ha.

Uses

Kiwifruit are produced primarily for fresh consumption, either scooped out with a spoon or peeled. Fruit of *A. arguta* are much smaller, about the size of a grape, and can be readily eaten whole. For all kiwifruit, the premium product is the fresh fruit, particularly if these can be stored for extended periods while still retaining quality attributes such as flavour.

Processing usually results in major changes to the colour, aroma, taste and texture of kiwifruit and most processed products lack the appeal of fresh kiwifruit. In China, fruit of *A. chinensis* are often preferred for processing because they are sweeter and because their fruit flesh has a clear yellow colour whereas the chlorophyll-based green of *A. deliciosa* fruit changes to a 'dismal' brown on processing. Increased production of yellow-fleshed kiwifruit in countries such as New Zealand may provide the raw material for more successful processed kiwifruit products.

Processing of kiwifruit is more important in China than in other producing countries, partly because its storage facilities and transport systems are still being developed. Even so, most fruit are eaten fresh, and only 20–30% of the Chinese kiwifruit production is processed into a variety of products such as fruit juices, either natural or clarified, juice concentrates, jams, fruit preserved either whole or sliced in syrup, dried fruit, soft drinks and wine and spirits.

Processing is even less important outside of China. The other three major producers of kiwifruit, Italy, New Zealand and Chile, are dependent on export of fresh fruit. New Zealand has a particularly small home market and 85–90% of kiwifruit produced each year are exported as fresh fruit. Chile and Italy each export about 75% of the kiwifruit they produce. Processing in these countries is still largely an attempt to make use of the significant quantities of fruit that do not meet export standards. Successful processing will probably require identification of specific compounds or combinations of compounds that bestow valuable nutritional or textural advantages on processed products.

Health benefits

Kiwifruit are among the most valuable nutritionally of all readily available fruit. Most published information is for *A. deliciosa* 'Hayward' (Table A.1) but the composition of *A. chinensis* 'Hort16A' is similar.

Kiwifruit are a good source of potassium and have a high potassium:sodium ratio. They are also a useful source of magnesium but other minerals are not sufficient to make a significant contribution to the diet.

They contain about 2–3% dietary fibre owing to pectins, oligosaccharides and polysaccharides that are not broken down and absorbed in the small intestine. A 100 g serving of kiwifruit will supply about 10% of recommended daily requirements.

Depending on the individual, kiwifruit can be a strong laxative, both as bulking agents and for stimulation of motility. Fresh kiwifruit, kiwifruit juice or dried products are often used to maintain regularity in bowel movement, especially for older or sedentary people. There is a huge demand throughout the Western world for natural laxative products and the laxative content of kiwifruit may well prove to be, next to their high vitamin C, their single most valuable attribute contributing to health.

Kiwifruit are outstanding for their vitamin C content. 'Hayward' kiwifruit when harvested contain about 85 mg ascorbate/100 g fresh weight and very little of this is lost on storage or ripening. Fruit stored for 6 months at 0°C and then ripened will still contain at least 90% of the vitamin C present in the fruit at harvest. Two medium-sized 'Hayward' kiwifruit, even after prolonged storage, can therefore easily satisfy recommended daily requirements (USA) for vitamin C, which range from 30 mg for a child to 120 mg for a lactating mother. 'Hayward', however, contains only relatively modest amounts of vitamin C compared to many other kiwifruit cultivars: *A. chinensis* 'Hort16A' usually contains 20–30% more vitamin C than 'Hayward' and many commonly grown kiwifruit cultivars in China contain at least twice as much. Fruit of other

Table A.1. Composition of *A. deliciosa* 'Hayward' kiwifruit (100 g fresh weight edible portion).

Proximate	g
Water	80–85
Protein	1
Lipid	0.5
Carbohydrate	15
Energy (kJ)	250
Minerals	**mg**
Calcium	40
Copper	0.16
Iron	0.4
Magnesium	25
Phosphorus	30
Potassium	300
Sodium	5
Vitamins	**mg**
B1 (thiamine)	0.02
B2 (riboflavine)	0.02
B3 (niacin)	0.5
C (ascorbate)	85
E (tocopherol)	1.6
Folate (mg)	38

Actinidia species can contain much more vitamin C, up to 1% fresh weight.

Kiwifruit, however, also have some potential disadvantages such as high oxalate content and allergenic activity. 'Hayward' kiwifruit contain appreciable amounts of oxalate but these are insufficient to cause a nutritional problem, assuming normal consumption. Nevertheless, eating some processed kiwifruit products such as nectars, dried slices or fruit 'leathers' can cause irritation of the mucous membranes of the mouth which is due, at least in part, to mechanical irritation of the membranes by oxalate raphides.

Kiwifruit also contain allergens that can cause allergic responses in susceptible consumers, possibly 2–3% of the total population. The risk should not be exaggerated: a higher proportion of the population in some countries show some adverse reactions to apples, among the most common of all fruit. Fortunately, extreme allergic responses to kiwifruit are not frequent.

'Hayward' kiwifruit contain large amounts of the highly active proteolytic enzyme actinidin (E.C. 3.4.22.14). Actinidin has been implicated in both the laxative and the allergenic properties of kiwifruit but the enzyme activity does not appear to be a major health hazard for most people. Actinidin can cause problems if fresh fruit are incorporated into gelatine-based jellies or are mixed with dairy products.

The anticancer and antimutagenic potential of the fruit are now being studied. The antioxidant capacity of kiwifruit likewise requires more study.

Botany

TAXONOMY AND NOMENCLATURE Kiwifruit belong to the genus *Actinidia* Lindl., an Asian genus of some 70 species. The defining characteristics of the genus are:

- all members of the genus are climbers or scramblers;
- all species are dioecious;
- the ovary of female flowers is formed by fusion of the lower parts of numerous carpels but the upper parts of the carpels remain free forming a distinctive circle of radiating styles;
- the fruit are botanically berries with many seeds embedded in a fleshy pericarp.

The familiar green and hairy kiwifruit belongs to *A. deliciosa*. Until recently, *A. deliciosa* was treated as a variety of *A. chinensis* and was raised to species status only in 1984: prior to that date, most references in the literature to *A. chinensis* actually refer to what is now known as *A. deliciosa*.

MORPHOLOGY Kiwifruit are vigorous vines which, in the wild, can grow to the tops of trees, 5–6 m high. Cultivated plants are tightly controlled into a single trunk, usually about 1.8 m high. The main branches form a permanent framework and the younger shoots are replaced every 2 or 3 years. Shoots of the current season come from axillary buds on canes produced in the previous season. Canes with lateral and second-order lateral shoots are the typical fruiting units of kiwifruit vines.

The canopy of a typical orchard vine has a leaf surface area of 30–40 m^2 made up of 4000–5000 leaves. Mature leaves are large, up to 20 cm in diameter, and the lower leaf surface has a thick felting of stellate hairs. Vines are deciduous and the over-wintering buds of *A. chinensis* and of *A. deliciosa* are characteristically different. In *A. chinensis*, the bud base is small, and the bud is relatively exposed, being protected only by bud scales; in *A. deliciosa*, the bud base is large and protruding and the bud is almost completely submerged in the bark.

Flowers are borne either singly (as in most female cultivars) or in small inflorescences of five to seven flowers (as in most male cultivars). In general, vines do not flower until 3 or 4 years old, but *A. chinensis* is noticeably more precocious than *A. deliciosa*. Flowers are borne in leaf axils towards the base of flowering shoots, never terminally. Pistillate flowers are generally larger than staminate flowers. Flowers are cup-shaped, facing downwards, with five or more petals which are white on opening but within a few days become a rather dirty golden. The gynoecium is surrounded by whorls of stamens with bright yellow anthers (almost black in *A. arguta*). Both pistillate and staminate flowers have a distinct odour. Flowering occurs about 2 months after budbreak: flowers are differentiated in spring and weather conditions during this period can have a marked effect on flower number and development. Female flowers remain receptive for about 4 days after opening.

The fruit is a berry with many small seeds embedded in the juicy flesh (about 250 in a 12 g fruit of *A. arguta*, at least 500 in an average-sized 'Hort16A', more than 1000 in a 'Hayward' fruit) (see Plate 5). Fruit shape and hairiness vary greatly but fruit of *A. chinensis* are usually covered with soft, downy hairs which are often shed early in fruit development; those of *A. deliciosa* have persistent, long, hard, bristle-like hairs which are only partially removed during grading and packing. Fruit of most commercial cultivars have an elongated ovoidal shape, are the size of a large hen's egg and weigh, on average, 80–110 g.

The tough hairy skin of fruit of *A. deliciosa* is certainly unpalatable, while that of *A. chinensis* fruit may not be as hairy but is still unpalatable and would not normally be eaten. Consumption of these kiwifruit requires a knife and a spoon. Some *Actinidia* species, such as *A. arguta* and *Actinidia kolomikta* (Maxim. et Rupr.) Maxim., have fruit with smooth, hairless, edible skins. They are 'snack' fruit, readily eaten without creating a mess.

The bright green colour of the fruit flesh of *A. deliciosa* and some cultivars of *A. chinensis* is due to chlorophyll which is largely retained during fruit maturation, storage and ripening. In most *A. chinensis* cultivars, such as 'Hort16A' and 'Jinfeng', the fruit flesh is yellowish green to yellow owing to partial or complete loss of the chlorophyll. 'Hongyang' (also *A. chinensis*) is even more striking as the flesh around the seeds is red, making a cross-section of the fruit most attractive.

REPRODUCTIVE BIOLOGY Every female kiwifruit flower normally sets to form a fruit. There is little subsequent fruit drop so crop load is largely determined by the number of flowers. Flower numbers are often limiting and much of vine management is aimed at ensuring that sufficient flowering wood of the desired type is retained at pruning.

All *Actinidia* species are functionally dioecious: flowers of pistillate kiwifruit may look perfect but the pollen produced is non-viable; staminate plants produce viable pollen but have only a vestigial ovary and poorly developed styles. Dioecism is not absolute and different states have been identified: male, inconstant male, hermaphrodite, inconstant female, female and neuter. Gradients of male or female sterility are also found. Among the most easily noticed variants are fruiting males which carry both staminate flowers and bisexual flowers which have small ovaries, a few ovules and limited stylar development: these can produce small fruit.

Most taxa within *Actinidia* are diploid, $x = 29$, an unusually high number possibly indicating ancient polyploidy, but some are tetraploid ($4x$), hexaploid ($6x$) or octaploid ($8x$). There may also be intrataxon variation in ploidy: for example, most plants so far studied of *A. chinensis* are diploid but plants from a restricted part of the total geographic range of the species are tetraploid. These ploidy races cannot be distinguished morphologically and the only consistent difference so far noticed is that tetraploid genotypes of *A. chinensis* flower about 2 weeks later than diploid genotypes. Most important *A. chinensis* cultivars in China are tetraploid but 'Hort16A' is diploid. All cultivars of *A. deliciosa* are hexaploid, $2n = 6x = 174$. Most cultivars of *A. arguta* are tetraploid, $2n = 4x = 116$, but several, known as 'Issai' are hexaploid.

Dioecism and ploidy variation have important practical consequences. A kiwifruit orchard must contain both male and female plants for transfer of pollen and seed set. Each kiwifruit that is of commercial size contains many seeds and there is a strong correlation between seed number and fruit size. Efficiency of pollen transfer is one of the most important factors in determining crop yield. In commercial orchards, about 10% of the canopy area is allocated to male vines set out in a regular array to ensure that male and female flowers are in close proximity. Male vines must coincide in flowering with female vines, they should have an extended flowering period and they should carry heavy flower loads producing large amounts of viable pollen capable of setting seed. Most pollen transfer is effected by honeybees which are brought into the orchard as female vines start flowering. Kiwifruit flowers are not particularly attractive to bees and many aspects of orchard layout and management are designed to keep bees working, thereby ensuring good pollination. Mechanical pollination, using pollen collected from male vines, is sometimes used to supplement natural pollination.

Variation in ploidy level had no practical significance when only cultivars of *A. deliciosa* were grown. However, the cultivars of *A. chinensis* now grown are diploid or tetraploid. To ensure fertilization and continued seed growth, female vines and their pollinators must flower at the same time and should preferably be at the same ploidy level. Nevertheless, ploidy levels may not always be critical as *A. deliciosa* pollen, which had been collected and stored, has been successfully used for mechanical pollination of diploid 'Hort16A'.

FRUIT GROWTH AND DEVELOPMENT Fruit of small-fruited *Actinidia* species, such as *A. arguta*, can reach 80% of their final size after less than 6 weeks growth and can be harvested only 100–110 days after pollination, whereas those of *A. chinensis* and *A. deliciosa* are typically harvested 180–210 days after pollination, depending on cultivar and climate. During development of the ovary into the mature fruit, linear measurements increase six- to tenfold and fresh weight and volume increase several hundredfold. About two-thirds of this increase in volume or in weight occurs in the first 10 weeks after pollination and kiwifruit growth shows the double sigmoidal curve typical of many fruit: a period of very rapid growth for the first 8 weeks (a period during which fruit of 'Hort16A' can increase by 1.6 g/day), a subsequent 3 weeks of slower growth, followed by a second period of more rapid growth. Cell division in the inner and outer pericarp ceases after the first 3 or 4 weeks and subsequent growth is almost entirely due to cell enlargement.

The chemical composition of the fruit changes during growth and maturation. Total solids increase over much of the growing season but the proportion of carbohydrates present as starch or as soluble sugars changes. Starch at its highest can account for half the total dry weight of the fruit but about 140 days after pollination, starch begins to decrease and there is an increase in soluble solids owing to conversion of the starch and to translocation of sugars from the rest of the vine.

During later stages of fruit growth in *A. deliciosa*, the internal appearance of the fruit changes little apart from seeds changing colour and the loss of starch and softening of the tissues making the fruit seem juicier and greener. Fruit of many *A. chinensis* cultivars are green during initial growth and development but during fruit maturation chlorophyll is lost so that the fruit flesh becomes yellow.

CLIMATIC REQUIREMENTS Wild *A. chinensis* and *A. deliciosa* occur mostly on steep hills and mountain slopes. They grow in relatively damp and sheltered areas and are seldom found where there is little shade or moisture or where they are exposed to strong winds. Young plants in particular do best in shade but sun is required for fruiting. Kiwifruit are abundant in gullies, under the tree canopy or on forest edges where they can scramble up through the trees. Winter temperatures can fall well below 0°C but there is need for a long frost-free period and abundant rain during the growing season. These conditions indicate the ideal conditions for successful growth and cropping of kiwifruit, climatic conditions that are generally restricted to between latitudes 25° and 45°. Kiwifruit can be grown extraordinarily well under the temperate conditions in the Bay of Plenty, New Zealand, but they are by no means restricted to such conditions and can be successfully cropped under more rigorous conditions, in California, Chile or southern Italy, if the vine management techniques first devised for New Zealand are modified.

Actinidia species differ in their climatic requirements, as indicated by their natural distributions in China. *Actinidia chinensis* is found mainly to the east, *A. deliciosa* more inland in colder regions and where both species occur in the same area, they are separated vertically, with *A. deliciosa* at the higher, colder altitudes. Therefore *A. chinensis* is likely to be more susceptible to winter cold and to spring frosts, especially as it breaks bud and flowers about a month ahead of *A. deliciosa*. Kiwifruit are temperate plants requiring a period of winter chilling for adequate budbreak and flowering. Sufficient winter chilling condenses the period of budbreak, budbreak is more uniform, there are more flowers and a condensed flowering period which should reduce fruit to fruit variation in growth and maturity. Inadequate winter chilling can be a serious problem in areas with relatively mild winters but cool springs.

Sprays of dormancy-breaking chemicals such as hydrogen cyanamide can then be applied. Winters can, however, be too cold. In such places, species such as *A. arguta* will grow and crop even if mid-winter temperatures drop to −30°C, conditions that other kiwifruit will seldom survive. This is not surprising as *A. arguta* occurs naturally at latitudes much further to the north or at much higher altitudes in the south where *A. chinensis* and *A. deliciosa* are common.

Kiwifruit are susceptible to spring and autumn frosts. They flower about 2 months after budbreak and fruit are ready for harvest 5–6 months after flowering. A frost-free growing period of 7–8 months is required.

Kiwifruit vines have very large leaves and very high rates of water conductivity and transpiration. Transpiration rates can reach 80–100 l/day. During the growing season, vines need 800–1200 mm of water evenly distributed. Vines are prone to water stress on windy days or hot sunny days and this can result in reduced fruit growth. If water is limiting during early fruit growth, any reduction in fruit size is irreversible.

A characteristic feature of kiwifruit orchards in New Zealand is the shelterbelts. New Zealand is particularly windy but inadequate shelter is a major limitation to successful kiwifruit cultivation in many parts of the world. Young vigorous shoots that eventually form fruiting canes in the following season are easily blown out in spring and windrub of developing fruit is a major cause for rejection at grading. Establishment of young vines can also be affected by wind. However, there must be a compromise: shelter may be required but living shelterbelts compete with vines for water and nutrients and excessive shading can affect vine growth and flower evocation.

Hail can cause severe damage to young shoots and leaves or fruit. Hail nets are used in some regions.

Kiwifruit may appear to be demanding in their climatic requirements but these are largely the conditions for which cultivars were originally selected in New Zealand. These cultivars may not be well adjusted to other climatic conditions but likewise cultivars selected under more extreme conditions in continental China may not be well suited to New Zealand or other temperate countries. Management practices may have to be modified to particular environments.

Horticulture

PROPAGATION Kiwifruit propagation is easily achieved by micropropagation, by rooted cuttings or, occasionally, by root cuttings. Such plants are clonal. Many are also produced by grafting onto seedling rootstocks. Under good growing conditions the method of propagation has no important effects on vine vigour or productivity although it might be expected that plants grafted onto seedling rootstocks would be more variable. Very little use has so far been made of the few clonal rootstocks that have been selected.

Mature plants can also be readily reworked. This allows rapid conversion of an established orchard to a new, more profitable cultivar or replacement of males by better pollinators. In New Zealand, many mature 'Hayward' orchards have been converted to 'Hort16A' by decapitating the plants and grafting onto the stumps. The existing root systems allow rapid development of the new canopy with good commercial yields of the new fruit being achieved in the second or third year after grafting. Such plants usually consist of a seedling rootstock (*A. deliciosa*), an interstock of 'Hayward' (also *A. deliciosa*) and a canopy of 'Hort16A' (*A. chinensis*).

SUPPORT STRUCTURES Kiwifruit vines are large and individual plants can carry 100 kg of fruit. Vines are not self-supporting and they require support structures that are strong and can last for 50 years or more. It is false economy to skimp on support structures. Fruiting canes must be firmly held in position so that they are not blown out or the fruit damaged by windrub. Two main types of support structure are used: the pergola maintains fruiting canes in a plane about 1.8 m above the ground; with T-bars, the structure of the vine is essentially similar with fruiting arms held in a fixed position but hanging towards the ground. T-bar systems are somewhat cheaper and easier to manage but pergolas give higher yields of good quality fruit as these are less susceptible to wind damage or to sunburn. Pergolas are more common for 'Hort16A' whose fruit have thinner skins and are consequently more easily damaged. Generally there are 400–500 plants/ha.

TRAINING AND PRUNING The aim is to establish:

- a well-organized framework of permanent branches;
- a balance between vegetative growth and fruit production;
- a canopy that intercepts light efficiently but is open enough to allow sufficient light through for flower evocation and fruit quality;
- a canopy open enough to allow ready access by bees and to reduce the incidence of diseases such as *Botrytis* but not so open or uneven that wind can cause fruit damage;
- a canopy that is easily managed and harvested and keeps vines to their allocated spaces;
- a canopy that allows the ready production of fruit of the size and quality required by the market.

Flowers are produced only on shoots of the current season and usually only on shoots growing from 1-year-old wood. Fruiting canes should therefore be replaced on a regular 2- or 3-year cycle. New canes should be evenly spaced and at winter pruning sufficient new wood should be left to provide the appropriate fruit load – in Italy, about 15–20 winter buds/m^2 canopy are recommended for 'Hayward'. The number of winter buds retained at winter pruning can be modified with experience: observations over several seasons will indicate the likely percentage budbreak, the number of shoots that will carry flowers, and the number of flowers per flowering shoot. Higher crop loads can reduce average fruit size, but returns are usually better for larger fruit. Much new vegetative growth is removed during summer to ensure that, while replacement canes are retained, the canopy does not become too dense or tangled. The amount of summer pruning will depend on the climate and cultivar as well as the need to protect fruit from sunburn. With 'Hayward', typically 60% of the above-ground mass of the vine is removed in prunings, leaves and fruit each season.

Individual cultivars respond differently to management. 'Hayward' is one of the least precocious and tends to carry lighter crops and selection of new fruiting wood is therefore important. Differences in phenology are also important. 'Hort16A', when grown under the same climatic conditions as 'Hayward', breaks bud and flowers a month earlier. It is particularly vigorous, especially when grafted onto mature rootstocks, and vegetative growth continues about a month later in the season with considerable production of secondary shoots. Canes developing late in the season are less productive than those that grew earlier and also tend to flower later with the fruit maturing later. However, very vigorous canes from early in the season are also not ideal. Management techniques devised for 'Hayward' cannot be simply transferred to other cultivars.

Yields vary greatly according to country and cultivar. New Zealand orchards produce about 25 t of 'Hayward' fruit per canopy ha which equates to about 6000 trays of export quality fruit. 'Hort16A' under the same conditions typically produces higher yields, 10,000 to 12,000 trays/ha, because of its growth habit and because it is more floriferous. The size of 'Hort16A' fruit is routinely increased by use of biostimulants such as Benefit®PZ. This combination of higher yields and large fruit sizes has made 'Hort16A' more profitable for growers.

Male plants are usually pruned rigorously immediately after flowering so that their vigorous growth does not shade out neighbouring female plants.

THINNING If required, thinning is carried out immediately after fruit set with removal of lateral or misshapen fruit and then any surplus fruit. If too many winter canes have been laid down, the weaker canes can be removed.

FERTILIZATION Considerable amounts of nutrients are removed from orchards but the need for fertilizers should be determined by leaf or soil analysis. Nitrogen deficiency can cause marked reductions in vegetative growth and yields whereas excesses are believed to affect fruit quality and storage. Potassium and calcium also affect fruit quality. In some areas, iron deficiency is common. There has been little work to determine relative requirements of different cultivars or at different crop loads.

MAIN DISEASES AND PESTS Similar types of pests occur on kiwifruit in the countries in which they are grown and all tend to be generalists affecting a broad range of plants. Armoured scales are generally the most serious but although the species involved are cosmopolitan, the abundance of a particular species varies according to country. The other main group of pests, the leafrollers, tend to be specific to each country and are therefore a quarantine problem as well as damaging the fruit. Nematodes are a problem in some countries.

Kiwifruit are also susceptible to bacterial and fungal diseases. *Pseudomonas* species cause bacterial canker, bacterial necrosis and, potentially most serious, bacterial blossom blight. *Sclerotinia* can also affect fruit on the vine but the other serious fungal diseases are those that develop while the fruit is in storage (mainly *Botrytis cinerea*) or after the fruit is taken from storage (e.g. *Botryosphaeria dothidea*).

When kiwifruit were domesticated, they were freed of many of the pests and diseases to which they are prone in China. However, as plantings have increased so too have the problems. Fortunately, the number of pests on kiwifruit is still fairly limited and they can be well controlled by integrated pest management systems. Organic production is realistic.

MATURITY INDICES, HANDLING AND POSTHARVEST STORAGE Kiwifruit harvested prematurely have a poor colour, an inadequate flavour when ripened, and a shortened storage life. The criteria used to decide when to harvest depends on the cultivar or species. In *A. deliciosa*, there are no useful visible indications of maturity, but the rapid increase in soluble sugars at the final stages of fruit growth is a useful indicator of physiological maturity. Fruit harvested at a soluble solids content (SSC) of 6.2–6.5% will store well and be acceptable when ripened. Dry matter is also used as a maturity index. On the basis of measurements such as SSC and firmness, 'Hort16A' fruit reach physiological maturity about 1 month ahead of those of 'Hayward', but they are not harvested until about the same time as 'Hayward' because they are promoted for their yellow flesh colour. Loss of chlorophyll is very slow once 'Hort16A' fruit are picked and in storage, so they must remain on the vine until the flesh has a hue angle of 103° or less. At this stage, firmness may be only 4–5 kgf (as compared to about 7 kgf for 'Hayward') and SSC more than 10%. Fruit of *A. arguta* ripen unevenly on the vine and are therefore harvested when they reach a dry matter (DM) threshold (approximately 20% DM) and about 1% of fruit on the vine are soft. Fruit harvested earlier are firmer, and are therefore easier to handle, but do not store as well. Fruit harvested too late are unmanageably soft and susceptible to mechanical injury.

Once maturity has been reached, the whole crop is normally harvested. Although fruit are still firm, they must be handled gently. At harvest, 'Hort16A' fruit are softer than those of 'Hayward' and they are more vulnerable to damage, especially because they have the added problem of the sharp 'beak' at the distal end of the fruit. The fruit are not cooled immediately but left at ambient for several days as this curing helps reduce the incidence of *Botrytis* stem end rot.

When harvested sufficiently mature, kiwifruit can be stored for very long periods. 'Hayward' is exceptional and can be stored for up to 6 months in air under refrigeration and the fruit will still be acceptable. Controlled atmosphere storage can extend the storage life even further. However, there can be a loss of flavour on long-term storage. Other cultivars of *A. deliciosa* tend to store less well. Cultivars of *A. chinensis* generally have relatively short storage lives and 'Hort16A' is one of the better ones with an expected storage life of 12–16 weeks. Kiwifruit are stored at or close to 0°C. They are very firm at harvest and soften in store. There is a period of very rapid softening down to about 1 kgf and then a slow and gradual softening. Excessive softening, low temperature disorders such as physiological pitting and low temperature breakdown, shrivelling from water loss and fungal pitting or stem end rots all mark the end of storage life in different cultivars. Low temperature disorders can be avoided by storage at higher temperatures but then the fruit soften more quickly. They are very sensitive to ethylene and fruit softening in coolstore is accelerated if even low levels are present. Shelf life is 3–10 days depending on the preceding storage period. Fruit of *A. arguta* are more delicate than fruit of other commercial kiwifruit species and their storage life is correspondingly shorter, at most 10–12 weeks.

MAIN CULTIVARS AND BREEDING In most countries with commercial kiwifruit orchards, 'Hayward' (*A. deliciosa*) is the only fruiting cultivar grown and it has become the kiwifruit in the marketplace (Table A.2). Thus 'Hayward' currently

Table A.2. Most important kiwifruit cultivars, 2002.

Cultivar	Area (ha)[a]	Main growing districts
Actinidia deliciosa		
'Hayward'	64,400	In all countries growing kiwifruit, including China
'Qinmei'	17,480	Mainly in Shaanxi, Guizhou and Henan, China
'Miliang No. 1'	5,500	Guizhou, Henan and Fujian, China
'Jinkui'	2,340	Hubei and Fujian, China
'Bruno'	2,000	Zhejiang, China
Actinidia chinensis		
'Kuimi'	3,080	Jiangxi, China
'Jinfeng'	2,720	Zhejiang and Jiangxi, China
'Zaoxian'	2,330	Jiangxi and Zhejiang, China
'Hongyan'	2,180	Sichuan, China
'Hort16A'	2,000	New Zealand
All others	12,120	China

[a] Areas include the 10% of orchard canopy allocated to accompanying pollinators.

accounts for about 75% of world kiwifruit production, 97.5% of kiwifruit production outside of China. It was originally selected because its fruit are large, have a good flavour and can be stored for extended periods while still remaining acceptable to consumers. The relative flowering times of 'Hayward' and its pollinators can vary according to climate so, although 'Hayward' is grown in many different countries, the accompanying males grown may vary from country to country.

The situation in China is very different. 'Hayward' is grown but, although it is the second most widely planted kiwifruit cultivar in China, it accounts for only 13% of the total area planted in kiwifruit. 'Hayward' and the eight other most common cultivars account for only 80% of total plantings. There is a strong preference for cultivars selected locally and most are largely restricted to one or two, usually contiguous, provinces. Thus 'Qinmei' (*A. deliciosa*) comprises about 30% of all kiwifruit plantings in China but is predominantly confined to Shaanxi, the province in which it was selected. The Chinese kiwifruit industry will probably consolidate on fewer cultivars of more consistent fruit quality.

The many kiwifruit cultivars in China are selections from the wild. 'Hayward' and 'Bruno' (also from New Zealand) were selections from small seedling populations only one or two generations removed from the wild. Only one successful cultivar, 'Hort16A', has so far resulted from deliberate breeding programmes. With its distinctive appearance, its golden-yellow flesh, and its very different, sweeter, 'subtropical' flavour, 'Hort16A', commercialized under the name ZESPRI™ GOLD Kiwifruit is perceived as giving the New Zealand kiwifruit industry a competitive advantage. It is the first cultivar of *A. chinensis* to be traded internationally and its success is likely to encourage the development of competitive cultivars, either some of the existing Chinese cultivars or cultivars specifically bred for the purpose. Ross Ferguson

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ADOXACEAE

Viburnum spp. viburnums

The genus *Viburnum*, *Adoxaceae* (formerly *Caprifoliaceae*), comprises more than 200 species throughout the northern hemisphere, primarily Asia and North America, and many produce copious amounts of fleshy fruit. Many are used as ornamental plants in the landscape as they can have highly scented, attractive, showy flowers and masses of variously coloured fruit borne on attractive plants that may have deciduous or evergreen foliage. Some are extremely good food sources and none are known to be toxic, although some will cause nausea if large quantities of raw fruit are consumed. At various times, several similar species have been given the name highbush cranberry and they are commonly harvested from the wild and consumed.

Several similar edible *Viburnum* species with tart, red fruit have been given the name highbush cranberry. They are commonly harvested from the wild. Thus, *Viburnum opulus*, *Viburnum edule* and *Viburnum trilobum* are now considered to be subspecies of *V. opulus* (*V. opulus opulus*, *V. opulus edule*, *V. opulus americanum* formerly *V. trilobum*). *Viburnum opulus* will be used here as the general term. In addition to *V. opulus*, many other *Viburnum* species are considered edible. The highbush cranberry species are native to the northern hemisphere but have been scattered throughout the temperate regions of the world due to their highly ornamental characteristics. While generally a woody shrub 2–3 m tall, at the northern, very cold edges of its range it may not get any taller then 0.3 m and in ideal circumstances it may reach 5 m. Highbush cranberry is adapted to a wide range of soils but is most productive on moist, reasonably fertile soils.

In the spring, the flowers bloom on large, showy, cymes.

The individual flowers are small and white but a cyme may contain hundreds of flowers. The flowers are insect pollinated and can be fragrant. Flowering takes place in the spring and the fruit develop over the summer, finally ripening in late summer and autumn. The fruit are most typically a bright red colour, or yellowish, and individually are 0.8–1 cm in diameter. The fruit of *V. opulus opulus* are usually described as astringent, whereas the fruit of *V. opulus americanum*, while tart, are considered to have a very good flavour. Since the fruit is very tart, much like a cranberry, it is seldom eaten raw; rather it is often blended with sugar in processed jelly or sauce type products.

For commercial production in managed stands, plants should be established 2–3 m apart within rows. Irrigation is important for plant establishment and for maximum fruit yield and quality. Nitrogen fertilization will also be important for best production and plant health. No chemicals are approved for weed, insect or disease control. When grown in their native range, diseases should cause minimal problems if the plants are healthy, however, bacterial leaf spot (*Pseudomonas viburni*), powdery mildew (*Sphaerotheca macularis*) and shoot blight (*Botrytis cinerea*) have been reported as potential problems. Occasionally aphids are reported as a problem. In the early 1900s, improved cultivars with larger fruit, greater production and better fruit quality were released, these include 'Hahs', 'Andrews', 'Wentworth', 'Manitou Pembina' (syn. 'Manitou') and 'Phillips'. Nearly all fruit that is now consumed is harvested from wild stands, with locally important industries selling to speciality markets.

In Native American culture, the fruit were prized for food and the roots, bark, twigs and fruit were used to treat various maladies including use as a cold remedy, pulmonary aid, cough medicine and throat aid, antidiarrhoeal, cathartic and others.

Chad E. Finn

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ANACARDIACEAE

Anacardium occidentale cashew

Cashew, *Anacardium occidentale* L. (*Anacardiaceae*), is one of the important edible nuts that is consumed worldwide. Common names include: in Arabic habb al-biladhir; in Bengali hijlibadam, hijuli; in Chinese yao guo and yao guo shu; in French acajou a pommes, noix-cajou, noix d'acajou, pomme d'acajou; in Hindi kaaju; in Malay gajus, jambu golok and jambu mede; in Nepali kaaju; in Portuguese caju and cajueiro; in Spanish anacardo, maranon, casho; in Swahili mbibo and mkanju; in Tamil mindiri; and in Thai mamuang, yaruang. The Vavilovian South American centre VIII (Brazil–Paraguay) is considered the centre of origin.

Prior to the Portuguese colonization of Brazil, indigenous Indians consumed both the nut and the enlarged pedicel (receptacle), which is referred to as the 'cashew apple'. Juice squeezed from the cashew apples was fermented to produce wine. The Brazilian Indians roasted nuts over a fire thus burning off the toxic outer covering and the Portuguese colonizers copied this method. The trees are now often found growing wild on the drier sandy soils in the central plains of Brazil and are cultivated in many parts of the Amazon rainforest. By 1750, the cashew was widely distributed throughout tropical America. The cashew trees were planted as a backyard tree, partly for shade and established beyond their indigenous coastal distribution.

The Portuguese introduced cashew trees to India in the 18th century, where they were initially grown for producing wine and brandy and later introduced to other Asian countries. The Portuguese also exported the seeds to their colonies in East Africa in the late 18th century where they quickly became naturalized and grew wild along the Mozambique coast. From there they were introduced and naturalized in other East African countries such as Kenya and Tanzania. Soon, the African people started selling the wild harvested nuts to Portuguese traders, who in turn sold them to merchants in India for processing.

Cashews have spread widely in the Indian Ocean region and have become naturalized in seashore habitats. The trees were planted in all suitable areas of tropical India, and in the 1950s quite large orchards were planted, chiefly in the Indian state of Kerala. Trade in cashew nuts started at the beginning of the 20th century and grew particularly fast in the 1930s, being dominated mainly by Indian production. Since the 1960s, there has been rapid growth in the industry, particularly in India, Madagascar and Mozambique.

World production and yield

Cashew now grows all along the sea coasts in tropical regions starting from southern America to the West Indies, west and east Africa and India. India is the largest producer of raw cashew nut in the world (Fig. A.1). In India, the state of Kerala is the largest producer, processor and exporter of raw nuts. Other cashew-growing Indian states are Andhra Pradesh, Orissa, Goa, Karnataka, Maharashtra, Tamil Nadu and west Bengal. However, in the later part of the 20th century, other countries such as Brazil, Vietnam, Tanzania, Mozambique, Guinea Bissau, Nigeria and Indonesia also started developing cashew plantations.

Global trade in raw cashews now takes place from over 24 countries. In north-eastern Brazil, cashew is grown in the states of Ceara, Piaui and Rio Grande do Norte which together account for 90% of Brazil's cashew production. The northern province of Nampula is the major contributor to cashew production in Mozambique. In Tanzania, cashews are grown in the Mtwara, Lindi, Ruvuma, Tanga and coastal regions. In Kenya, cashew is grown in the narrow coastal belt covering the districts of Kilifi, Kwale and Lamu.

India, Brazil, Mozambique, Tanzania and Kenya together

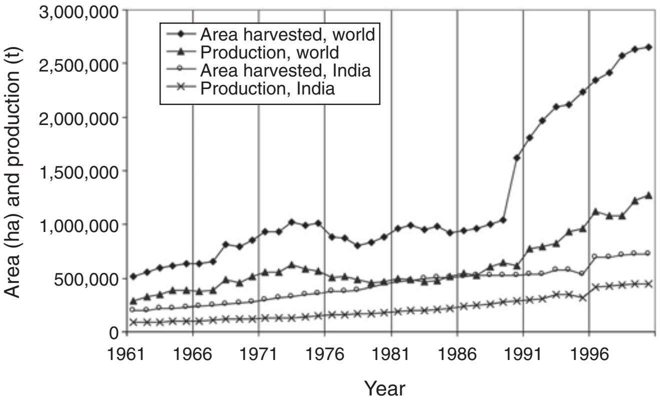

Fig. A.1. Cashew production and area harvested in the world and India.

contribute more than 80% of the total raw nut production in the world. While the area planted has increased in many of the countries over the past three decades, production has stagnated which resulted in a huge drop in productivity between 1975 and 1987. Vietnam in the past few years has gained ground as a significant producer of raw nuts and exporter of cashew kernels to the international market.

Uses and nutrient composition

The true fruit of the tree is the cashew nut that consists of a double shell containing a caustic phenolic resin in honeycomb-like cells, enclosing the edible kidney-shaped kernel. An interesting feature of the cashew is that the nut develops first and when it is full-grown but not yet ripe, the peduncle (receptacle) fills out and becomes plump, fleshy, pear-shaped or rhomboid-to-ovate, 5 to 12 cm in length. The fruit has a waxy, yellow, red or red-and-yellow skin and spongy, fibrous, very juicy, astringent, acid to subacid, yellow pulp. This swollen receptacle is the 'cashew apple'. In Brazil, the cashew apple is sold fresh and the juice is widely available. However in India the apple is not widely used.

Cashew kernels have the highest protein content among tree nuts (19.5%). This protein content matches soybean and is higher than peanut. All the essential amino acids are present. Its crude fibre is low and it has a high lipid content (46%). The lipids composition is halfway between peanut and olive oil and the oil contains all the fat-soluble vitamins. The ratio of saturated to unsaturated fatty acids is 4:1, close to the ideal 5:1. Cashews, with about 45 g of fat/100 g serving (at least a quarter of which are monosaturates) and a particularly high carbohydrate content for a nut at about 30 g/100 g portion, provides 553 calories/100 g intake (Table A.3). The kernels are also very high in magnesium, having only slightly less than almonds.

The cashew apple is used either for juice or preserved in syrup (candied). The fresh apples are very astringent due to their high tannin content, and are much more palatable if first processed to remove the bitter taste. This can be accomplished either by steaming under pressure (pressure cooked) for 10–15 min, or boiling in salty water for 15 min. The apples are then pressed to remove excess moisture and boiled in cane sugar syrup for 2 h. Finally they are sun dried, or placed in an electric food drier. Cashew apples are also canned in syrup, used to prepare chutneys and fruit pastes, and because of the high pectin content, readily set when making jams.

Table A.3. Proximate fruit composition of cashew apple and nut which has an edible flesh to fruit ratio of 87% (Source: USDA, 2003; Leung *et al.*, 1972).

Proximate	Apple (g/100g)	Nut (g/100g)
Water	85.4	5.2
Energy (kcal)	53	553
(kJ)		2314
Protein	0.8	18.2
Lipid (fat)	0.4	43.9
Carbohydrate	13.1	30.2
Fibre	0.4	3.3
Ash	0.3	2.54
Minerals	mg	mg
Calcium	7	37
Iron	0.6	6.7
Magnesium		292
Phosphorus	18	593
Potassium	124	660
Sodium	7	12
Vitamins	mg	mg
Ascorbic acid	198	0.5
Thiamine	0.02	0.42
Riboflavin	0.01	0.06
Niacin	0.5	1.06
Vitamin A	50 IU	0

The juice can also be extracted and strained, after which gelatin is added. The tannins in the juice bind to the gelatin and form a precipitate, which can then be removed by filtering. Sugar can then be added to taste. The juice readily ferments and is used in various countries to prepare wines and distilled liquors (e.g. Brazil, Guatemala, West Africa, India, Sri Lanka and the Philippines).

The cashew tree is used for reforestation, to prevent desertification, and as a roadside buffer tree. Cashew was first planted in India in order to prevent erosion on the coast. The wood from the tree is used for carpentry, firewood and charcoal. The tree exudes a gum called *cashawa* that can be used in varnishes or in place of gum arabic. Cashew bark has about 9% tannin, which is used in tanning leather.

The bark and leaves of the tree are used medicinally, the cashew nut has international appeal and market value, and even the shell around the nut is used medicinally. Cashew apple juice, without removal of tannin, is prescribed as a remedy for sore throat and chronic dysentery in Cuba and Brazil. Fresh or distilled, it is a potent diuretic and is said to possess sudorific properties. The brandy is applied as a liniment to relieve the pain of rheumatism and neuralgia.

In 16th-century Brazil, cashew apples and their juice were taken by Europeans to treat fever, to sweeten breath and to 'conserve the stomach'. The indigenous tribes had used parts of the cashew tree, the nut and apples for centuries. The Tikuna tribe in northwest Amazonia use the 'apple' juice for influenza and for warts. In traditional medicine, the fruit juice is used against diarrhoea. The shell oil (cardol) is used to heal foot wounds. The decoction of bark and leaves is used against diarrhoea and abdominal pains, inflammation and diabetes. Scientific tests have shown that sodium anacardate destroys certain snake venoms as well as tetanus and diphtheria toxins, and the vegetative form of anaerobic bacteria. Modern medicine uses cardol for its vesicant properties, as a dye for skin pigmentation, as respiratory and circulatory analeptic and as an antagonist of barbiturics.

Cashew apple contains calcium, phosphorus, iron and vitamin C (ascorbic acid) and is regarded as having skin conditioning activity due to its proteins and mucilage. Extracts are used in body care products, as coadjutant in the treatment of premature ageing and to remineralize the skin. It is also a good scalp conditioner and tonic, often used in shampoos, lotions and scalp creams.

The cashew nutshell liquid (CNSL) is used as a protective agent, in such products as varnishes and cements, and ink is extracted from the shell. This CNSL oil is composed of anacardic acid (71.7%), cardol (18.7%), cardanol (4.7%), a novel phenol (2.7%) and two unknown minor ingredients (2.2%). Each of the phenolic constituents contains monoene, diene and triene cardanols. Anacardic acids, 2-methylcardols and cardols in fruit have been found to exhibit tyrosinase inhibitory activity.

Industrially, CNSL has been used for many years as a component in the manufacture of friction dusts. The dual phenolic/alkenyl nature of CNSL makes it an ideal natural raw material for the synthesis of water-resistant resins and polymers.

The sap from the bark provides indelible ink. When the trunks of the trees are tapped, a milky juice exudes, which is white when fresh, but turns black on exposure, and, in India, is used as varnish. It stains cotton or linen deep black upon exposure to air. A tar prepared from the pericarp is used in tarring woodwork and boats to protect them from the ravages of insects, and the gum from the stems is employed by bookbinders to insure the bindings from destruction by worms and book-pests.

Botany

TAXONOMY AND NOMENCLATURE The *Anacardiaceae* includes 76 genera with over 600 species including *Spondias mombin* (hog plum), *Mangifera indica* (mango), *Pistacia vera* (pistachio nut), *Semecarpus anacardium* (Indian marking nut tree), *Metopium toxiferum*, *Comocladia dodonaea*, *Schinus molle* (Peruvian pepper tree) and *Toxicodendron vernicifluum* (lacquer tree). About 25 genera contain poisonous species. The synonyms for cashew, *A. occidentale* L. are *Acajuba occidentalis* Gaertn. and *Cassuvium pomiferum* Lam.

DESCRIPTION Under ideal tropical conditions the cashew is an attractive, erect, 7–15 m evergreen tree, with smooth brown bark, and a dense symmetrical, spreading canopy. Branching occurs very low on the trunk, with the lowest limbs often touching the ground where they can take root. More usual, where conditions are less than optimal, the tree grows to no more than 5–7 m and can develop an ill-defined trunk and a sprawling, straggly growth habit. Such trees are of less ornamental value to the landscape, though the colourful fruit remains an attractive feature. Where soil conditions permit (e.g. deep sandy loams), the tree develops a pronounced taproot. Cashews rapidly develop an extensive system of lateral roots that reach far beyond the edge of the canopy.

The simple smooth leaves occur mainly in terminal clusters and are arranged alternately on the stem on a short petiole with prominent veins. Each leaf is 10–20 cm long and 5–10 cm wide, oblong–oval or obovate (Fig. A.2). The mature leaves are green and leathery with young leaves ranging in colour from golden to red and pliable.

Cashew flowers are borne in 10–20 cm terminal panicles and consist predominantly of staminate flowers and some perfect (hermaphroditic) flowers. There are no pistillate flowers. Individual flowers are sweet-smelling, small with usually five yellowish-green petals, each about 1.5 cm long.

The true fruit is a kidney shaped nut consisting of a double-walled shell. The shell has an outer thick exocarp, and an inner hard endocarp separated by a resinous, cellular mesocarp and encloses the edible kernel. The nut is green at first, but becomes a greyish brown as it develops. As the nut approaches maturity, the pedince (receptacle) becomes swollen and fleshy, forming a 5–12 cm yellow or red, juicy, pear-shaped pseudo-fruit.

ECOLOGY AND CLIMATIC REQUIREMENTS Cashew grows best in a warm, moist, tropical climate with a well-defined dry season of 4–5 months during the reproductive phase, followed by a wet season of 4–5 months (1000–2000 mm rainfall). Cashew requires an equable environment with a maximum temperature of 34°C and a minimum of 20°C. Damage occurs to young trees or flowers below the minimum temperature of 7°C and above the maximum of 45°C. Prolonged cool

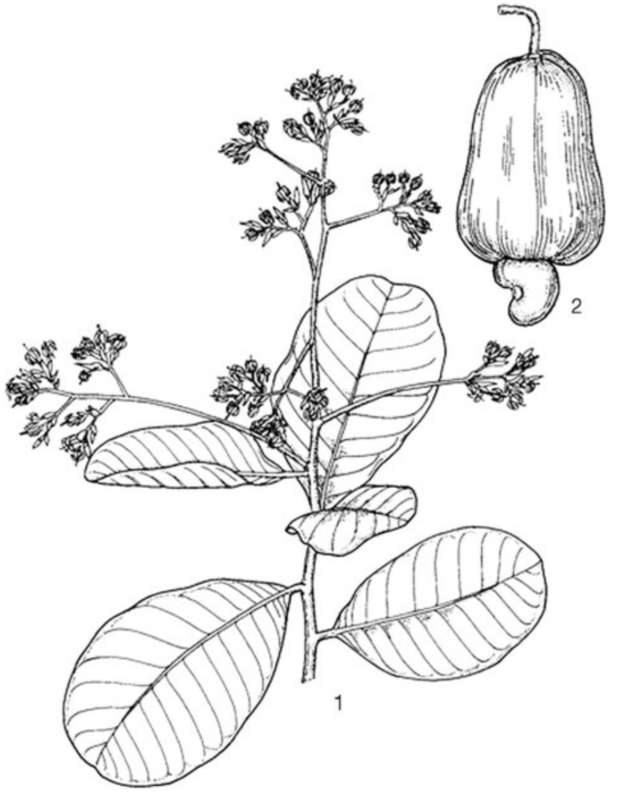

Fig. A.2. Leaf, flower and fruit of *Anacardium occidentale* (Source: Verheij and Coronel, 1992).

temperatures will damage mature trees, though such trees can survive temperatures of about 0°C for a short time. The optimum sunshine is 1285 h (9 h/day) in the flowering/fruit set period. It is grown at altitudes from sea level to 700 m and thrives well between 27°N and 28°S latitudes. Most of the regions where it is an economically important crop are between 15°S and 15°N. It grows usually unirrigated but responds to summer irrigation. Cashew flourishes in the hot, dry tropics along sea coasts.

Cashew is often grown on marginal soils and also on wasteland mostly unsuitable for other economic crops. The tree requires good drainage, friable soils and can tolerate a wide pH range and even salt injury. It is found along sandy sea coasts, fairly steep laterite slopes or rolling land with shallow top soils in India; alluvial soils in Sri Lanka; ferruginous soils in East and West Africa, Brazil and Madagascar; and volcanic soils in the Philippines, Indonesia and the Fiji Islands. The most fertile soils for cashew are virgin forest soils.

Cashew is known as a 'poor man's crop' and is good for smallholders because it will grow with minimal fertility. Under these unfavourable conditions it produces a harvest, although a low one. Many cashew groves are intercropped with coconut or annual crops.

REPRODUCTIVE BIOLOGY Fruit are produced after 3 years, during which lower branches and suckers are removed. Full production is attained by the tenth year and a tree continues to bear until it is about 30 years old. Cashew flowering is unaffected by daylength. In a seasonally dry climate, flowers are produced immediately after the rainy season. In tropical climates, that have wet and dry periods throughout the year, flowering can occur at any time.

Cashew is an andromonecious (polygamomonecious) plant with staminate and hermaphroditic flowers intermixed on the same panicle. On the same tree, the hermaphroditic or perfect flowers are bigger in size than the staminate or male flowers. The flowers produced early in the panicle are mostly male. Perfect flowers are generally produced about 1 month after the first flowers are produced in the panicle.

The petals turn from white or creamy white to pink and become recurved as the flower fully opens. The stigma is immediately receptive, however, pollen release occurs later, thereby permitting an opportunity for cross-fertilization. On opening, flowers are receptive to pollen for only a day. The presence of scented flowers and sticky pollen is circumstantial evidence of an important role for insect pollinators. Studies to date have implicated both wind and a variety of insects as pollinating agents, but there is no information on their relative importance. Beehives are placed in or near the orchard to improve the yield. The flowering period is 2–3 months in length (during the dry season), with the fruit appearing 2 months later.

FRUIT GROWTH AND DEVELOPMENT The fruit is unusual in that the kidney-shaped nut, the true fruit, is borne on a greatly enlarged, fleshy receptacle. This structure, the cashew apple, is about 5 cm in diameter and 7–10 cm in length. At maturity, approximately 2–3 months after flowering, the fruit turns bright yellow or red. Flowers and fruit at various stages of development are often present on the same panicle.

Horticulture

PROPAGATION Cashew can be propagated by seed, air layers and softwood grafts. Seeds germinate in 7–10 days. Since it is a cross-pollinated crop, vegetative propagation is recommended to obtain true progeny. Mother trees having the following characteristics are selected: (i) good health, vigorous growth and intensive branching habit with panicles having a high percentage of hermaphroditic flowers; (ii) trees 15–25 years of age; and (iii) nuts of medium size and weight (5–8 g/nut) with an average annual yield of 15 kg nuts, and 7–8 nuts per panicle. Different methods of grafting such as epicotyl grafting, softwood grafting, veneer grafting, side grafting and patch budding have been tried in cashew with varying degrees of success. Softwood grafting is the best for commercial multiplication of cashew. Softwood grafts can be prepared almost throughout the year with a mean graft success of about 60–70%. Higher success is achieved during the monsoon season. The softwood grafts are ready for transplanting in 5–6 months after grafting. A successful micro-grafting technique has been developed using *in vitro* germinated seedlings as rootstocks and axenic shoot cultures from shoot-tip and nodal cultures as micro-scions. Approach grafting, as well as layering, are most successful if carried out just prior to the pre-flowering flush of growth. Whip grafting may be more successful if it is done immediately after the fruit has ripened. Budding should be done about 1 month after flowering begins.

Cuttings are sometimes difficult to root, although ringing the cutting 40 days prior to removal from the parent plant has sometimes improved rooting. Cuttings are taken from 1–2-year-old shoots whose stems are still light-coloured and somewhat flexible. Field establishment of air layers is poor.

CULTIVATION Planting is done in pits of 60 × 60 × 60 cm during June–July. Seeds are either sown *in situ* or seedlings raised in polybags are transplanted at the onset of the monsoon. Initial close planting at 3, 4, 5 m apart, results in early shading of the soil surface, suppresses weeds, conserves soil and moisture and provides high initial yield per unit area, but requires thinning to the final spacings of 8, 9, 10 m at 5 or 6 years when canopies and root systems are intermingled with those of neighbouring trees. Recommended spacing is 10 × 10 m, thinned to 20 × 20 m after about 10 years, with maximum planting of 250 trees/ha. Once established, the field needs little care. Intercropping may be done for the first few years, with cotton, groundnut or yams. Proper staking of the plants is required to avoid lodging resulting from wind during the initial years of planting.

TRAINING AND PRUNING Sprouts coming from the rootstock portion of the graft should be removed frequently during the first year of planting. Initial training and pruning of young cashew plants during the first 3–4 years is essential for providing proper shape. Thereafter, little or no pruning is necessary. The plants should be allowed to grow by maintaining a single stem up to 0.75–1.00 m from ground level. This can be achieved by removing the side shoots or side branches gradually as the plants start growing from the second year of planting. Weak and crossed branches can also be removed. Initial training and pruning of cashew plants facilitate easy cultural operations such as terrace making, weeding, fertilizer application, nut collection and plant protection. The flower panicles that emerge from grafted plants during the first and second year of planting should also be removed (deblossoming) in order to allow the plant to continue to grow. The plants are allowed to flower and fruit only from the third year onwards.

In older cashew plantations, removal of dried or dead wood, crossed branches, and water shoots should be attended to at least once in 2–3 years. This allows proper growth of the canopy and receipt of adequate sunlight on all the branches. Pruning of cashew plants should be done during May/June in the northern hemisphere.

Topworking is used to rejuvenate unproductive and mature trees from 5 to 20 years of age. The unproductive trees are cut at a height of 0.75–1.00 m from ground level in May–September. Sprouts emerge in 30–45 days and new, 20–25-day-old shoots should be grafted with scions of high-yielding cultivars using the softwood grafting technique. To ensure at least six or seven successful grafts, 10–15 grafts are performed on the new shoots of every tree. The best season for grafting is July–November. Thinning of the extra shoots arising from the stumps should be done to obtain better growth of the grafts. Sprouts below the graft joint should be removed. The top-worked trees start fruiting from the second year. A major disadvantage is the loss of trees due to stem borer attack.

Cashew plantations are usually kept well weeded for ease of harvesting and to prevent competition for water and nutrients. In some areas, the cleared ground also acts as a firebreak.

NUTRITION On sandy soils, laterite soils and on sloping land with heavy rainfall, fertilizer is applied in a circular trench 25 cm wide and 15 cm deep, at a distance of 1.5 m from the trunk. On red loamy soils with low rainfall, the fertilizer should be incorporated into the soil in a band 1.5 m wide, at a distance of 1.5 m (inner edge) to 3 m (outer edge) round each tree.

Cashews respond well to fertilizer, but there are no specific recommendations and the following are suggested. For mature trees an annual total of 15–20 kg of fertilizer is applied, splitting the applications into thirds: one is applied at panicle emergence, another as the fruit approach maturity and a final application in August. A fertilizer dose of 750 g N, 325 g P_2O_5 and 750 g K_2O per plant is recommended for cashew. Apply one-fifth of the dose after the completion of the first year, two-fifths of the dose during the second year and thus reaching full dose from the fifth year onwards.

IRRIGATION Cashew trees are generally grown under rain-fed conditions. During summer, it is advisable to provide irrigation of 200 l/plant at fortnightly intervals. Cashew will not withstand water logging and proper drainage is essential. The use of black polyethylene sheet for mulching and fortnightly irrigation increased fruit retention.

HARVESTING AND POSTHARVEST HANDLING The colour of the nut changes from brownish green at fruit set to light green when the apple is one-quarter grown and turns grey thereafter, irrespective of cultivar. The nuts are harvested at this grey stage to avoid collecting immature nuts. The mature fruit fall to the ground as the 'apple' dries. In wet weather, fruit are gathered each day and then dried for 1–3 days. Harvesting of raw nuts is done either by collection after natural drop, after thrashing the tree with a stick or by tree shaking. The nuts are dried in the sun on bamboo mats, being turned for several days until they rattle in the shell. Care is taken to avoid overheating of the nuts. Overheating can lead to breakage of the shell liquid structure and the leakage of caustic oil to the kernel.

Mechanical shelling has been unsuccessful, so hand labour is required. Cashews are usually roasted in the shell (to make it brittle) and then cracked, the nuts removed and vacuum packed. In India, part of the nuts are harvested from wild trees by people who augment their meagre income from other crops grown on poor land. Kernels are extracted by people skilled in breaking open the shells with wooden hammers without breaking the kernels. Nuts are separated from the fleshy pedicel and receptacle, the seedcoat removed by hand and the nuts dried. Fresh green nuts from Africa and the islands off southern India are shipped to processing plants in western India.

Processing of cashew is complicated and costly when done on a large scale because of the caustic oil, CNSL. The traditional method of processing the nuts is to roast them over a fire in a perforated pan to burn off the CNSL. The nuts swell and release the CNSL, which drips through holes of the pan into the fire. This causes an abundance of thick irritating smoke. Next the nuts are tumbled in ashes or sawdust to absorb the rest of the CNSL. Shells are then removed by hand. The kernels processed this way are of low quality and used mostly for local consumption. For export-quality kernels a large infrastructure including machinery, factories and personnel is needed. A hot-oil bath is used to remove the CNSL.

The nuts are graded according to size and colour. Mini-processing factories process 500–1500 kg of raw nuts/day and employ 25–200 people/t of processed cashew. Humans are better at separating the nut from the shell than machines and kernel breakage is less at the mini-factories.

One of the biggest costs is stockpiling cashew to keep the mini-factories operating. The cashew-harvesting season is only about 2 months long. To keep the plant operating for 200 days/year, the smallest plants need to store about 100 t of raw cashew.

PESTS AND DISEASES *Helopeltis anacardii* is a sap-sucking insect that can cause flower damage and is the major insect pest in South-east Asia, India and East Africa. A severe attack will result in up to 80% of branches being damaged. *Helopeltis anacardii* usually appears with the emergence of new flushes and panicles and the symptoms are drying of the inflorescence and dieback of shoots. Pesticide is sprayed three times, first with the emergence of new vegetative flushes in October–November, second at the commencement of panicle emergence in December–January and the third at completion of flowering/initiation of fruit set in January–February.

The green ant (*Oecophylla smaragdina*), the meat ant (*Iridomyrmex sanguineus*), mantis (*Orthoderinae* sp. and *Mantidae* sp.), predatory bugs (*Geocoris australis*) and spiders (*Oxyopes* sp.) significantly reduce the numbers of *Heliopeltis* spp. Green ants were the most abundant predatory species in cashew plantations. Green ants also significantly reduce the numbers of several other cashew insect pests such as the fruit spotting bug (*Amblypelta lutescens*), the mango tip borer (*Penicillaria jocosatrix*) and the leaf roller (*Anigraea ochrobasis*). Other insect pests include borers, thrips, mealy bugs, weevils, caterpillars and leaf miners.

Cashew stem and root borer (*Plocaederus ferrugineus*) is a serious pest, which is capable of destroying the cashew tree. Main symptoms of attack are yellowing of leaves, drying of twigs, presence of holes at the base of the stem with exuding sap and frass. To reduce the spread of infestation, it is essential to remove the dead trees and trees in an advanced stage of infestation at least every 6 months. Anthracnose (*Colletotrichum gloeosporioides*) is prevalent in cashew plantations during the rainy season. The main symptom is the appearance of white patches on branches followed by drying of twigs from the tip. The affected parts are chiselled out and Bordeaux paste is applied.

Powdery mildew (*Oidium* sp.) kills the flowers and can have a devastating effect on cashew tree yields. Powdery mildew is a significant problem in East Africa. Powdery mildew likes cool, humid conditions and succulent plant growth. It does not tolerate high temperatures or high ultraviolet light concentrations. It can reproduce in 48 hours, releasing millions of spores into the atmosphere. To improve cashew yields in powdery mildew areas without using chemicals, pruning suckers on lower branches to let in more sunlight can help. These tend to be highly infected by powdery mildew and a source of spores for future infection.

Other diseases of cashew include dieback, damping off and anthracnose. Anthracnose is caused by the fungus *C. gloeosporioides* and, under wet conditions, can cause almost total crop failure. It also affects other tropical fruit trees such as mango and citrus.

Pesticide-free plantations would reduce costs and prevent health hazards and environmental damage. Encouraging an ecosystem conducive to beneficial organisms, especially ants, which prey on cashew pests would be one strategy. The nectaries (pits which secrete nectar) on cashew trees apparently attract ants to places where the trees are susceptible to pest damage (especially the young leaves, developing inflorescences and young fruit). The nectaries also attract spiders and predatory and parasitic wasps. All of these insects then prey upon the cashew insect pests. The number of nectaries increases as the tree becomes larger, and therefore more ant species are found in older trees. In younger plantings, it may be advisable to encourage a more diversified habitat to attract more ants. Creating desirable habitats for ants and other beneficial insects is done by mixed plantings, having brush and grass understories, and leaving dead wood and flat stones in the area.

CULTIVARS AND BREEDING Until recently, cashew breeding in many countries has been limited to a selection programme, attempting to find what is best from local material and foreign introductions. For commercial production, clonal propagation of superior genotypes must be the basis for the industry. A number of hybridization programmes are being carried out to select superior genotypes. Hybridization between local and introduced material aims to combine complementary qualities from parents with contrasting characteristics, taking care to prevent inbreeding depression by avoiding parents with a common ancestry. The seed produced is germinated and grafted onto a mature seedling rootstock to be appraised. Objectives include hypersensitivity to powdery mildew, bud vigour and kernel quality. The selected plants are multiplied by budding or grafting for trials. The plants are appraised over 3 consecutive crop years for growth and vegetative habit, *Helopeltis* tolerance, powdery mildew resistance (with and without chemical control) and yield in terms of nut weight, number and quality.

In India more than 35 cultivars of cashew are available that have been recommended for use in different states where cashew is grown. In Kerala, new cultiars released include 'Raghav', 'Damodar', 'Priyanka' and 'Amrutha'. The older cultivars are 'Anakkayam 1' and 'Madakatthara 1'. In Tamil Nadu 'VRI12' and 'VRI13' are popular cultivars. The dwarf-precocious cashew clones 'CCP06', 'CCP09', 'CCP1001', 'EMBRAPA50' and 'EMBRAPA51' represent popular cultivars in Brazil.

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Buchanania lanzan chironji

Chironji, *Buchanania lanzan* Spreng. (*Anacardiaceae*), is endemic in the dry deciduous tropical forests of India. The common names are: in Bengali chironji; in English narrow-leaved buchanania, cheraunji nut tree, chirauli nut, chirauli nut tree, chironji nut, cuddapa almond and cuddapah almond; in Hindi it is known as achaar, baruda, char (fruit), chironji (cheronjee) and priyala; in Kannada as charpoppu; in Malayalam as mungapper; in Nepalese as acar and ciraaunji; in Oriya as charu; in Sanskrit as char, priyalam and rajadana; in Tamil as morala; in Telugu as morichettu and saara chettu; in Burma as lambo; and in Thai as mamuang hua maeng wan and mamuang maeng wan (Porcher, 2005). The fruit of *Buchanania arborescens* (Blume) Blume, found from the Philippines through South and South-east Asia to northern Australia, is also eaten. In English, it is known as little gooseberry tree and in Tagalog as balinghasai and the fruit are 0.7–1 cm long with a thin pulp.

World production and yield

Fallen ripe fruit are collected, however sometimes the tree is cut down. This destruction has made the species vulnerable to over-exploitation. Yields of chironji are from 1 to 5 kg/tree with an average weight of 0.27 g (Rai, 1982; Chadhar and Sharma, 1997). In central India, 1500 t of fruit are collected from the wild annually.

Uses and nutritional composition

The fruit are considered as one of India's most delicious wild fruit. The seeds are also eaten and are regarded as a substitute for almonds. The fruit is used in sweets and bakery/confectionery products. The seed contains about 59% fat, 12% starch and up to 22% protein (Table A.4). In many parts of India, *Buchanania* oil is used as a substitute to olive oil and for almond oil in medicinal preparations and confectioneries. From the seeds a traditional dish 'Chironji Ki Burfi' is prepared. It is considered very beneficial for newly wed couples. The bark yields a tannin up to 13% of dry weight. The wood is only used for firewood. The leaves are used as fodder for sheep, goat and cattle. It is a host of the Kusumi lac insect. Chironji is also regarded as a valuable herb.

The tree also has numerous medicinal uses. In the different systems of medicine in India, the chironji roots, leaves, fruit, seeds and gum are used. An extract of the root is used as an expectorant, for biliousness and for blood diseases. The leaf juice is used for digestive complaints, as an expectorant, aphrodisiac and purgative. The seed oil is used to treat skin diseases and to remove face blemishes. The oil is also applied externally on glandular swellings of the neck alone and in combination with other herbal oils. *Buchanania* gum is used internally in treatment of intercostal pain and diarrhoea. The oil is useful for coating tablets for its delayed release.

Botany

TAXONOMY AND NOMENCLATURE The synonym is *Buchanania angustifolia* Roxb. The genus has about 20 species that are distributed in tropical Asia, Australia and the Pacific Islands.

Table A.4. Proximate kernel composition per 100 g of *Buchanania lanzan.*

Proximate	%
Water	3.0
Energy (kcal)	656
Protein	19.0–21.6
Lipid (fat)	59.1
Carbohydrate	12.1
Fibre	3.8
Minerals	**mg**
Calcium	279
Iron	8.5
Phosphorus	528
Vitamins	**mg**
Ascorbic acid	5.0
Thiamine	0.69
Riboflavin	0.53
Niacin	1.5

DESCRIPTION This evergreen, moderate sized tree (15 m) has a straight, cylindrical trunk and tomentose branches. The bark is rough and dark grey or black, fissured with prominent squares, 1.25–1.75 cm thick and reddish inside. The leaves are broadly oblong with a rounded base, 8–20 cm by 4–12.5 cm. The small, greenish-white flowers (0.6 cm in diameter) are axillary and on 5–15 cm long terminal panicles. The calyx is three to five lobed, 1 mm long and the four or five petals are 3 mm long. The ten stamens are inserted at the base of the fleshy disc. The ovary has five to six free carpels, inside the disc, although only one carpel is fertile. The black fruit is a drupe 1–1.5 cm in diameter.

ECOLOGY AND CLIMATIC REQUIREMENTS It is a common tree in dry open deciduous forests with a monsoonal climate to 500 m. The tree grows most commonly on yellow sandy-loam soils.

REPRODUCTIVE BIOLOGY Flowering occurs from January to March and the harvest season is from April to June.

Horticulture

The seeds are tolerant to desiccation and chilling. The seeds show 95–100% survival up to 90 days at all storage temperatures with gradual loss in germination on or after 280 days of storage. The seeds have a hard seedcoat that lowers germination. Root cutting can be successfully used for propagation. A tissue culture technique for the rapid clonal multiplication has been developed.

No known cultivars have been selected. Wide variation occurs in fruit size, fruit per panicle, panicles per tree, total soluble solids and fruit yield per tree (Munde *et al.*, 2004).

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Mangifera indica mango

Mango, *Mangifera indica* L. (*Anacardiaceae*), has been cultivated for millennia and is one of the premier fruit grown and consumed throughout the world. There are numerous common names including: mango in English and Spanish; mampelam, ampelam and mangga in Malay; mangga, paho and mango in Philippino; thayet and tharyetthi in Myanmarese; svaay in Cambodian; mwàngx in Laotian; mamuang in Thai; xoài in Vietnamese; pauh, ampelam and mangga in Indonesian; mangot, mangue and manguier in French; and mango and mangueira in Portuguese.

Native to Asia, the centre of origin is thought to be in the region of north-eastern India and Myanmar, however, it was distributed throughout South-east Asia and the Malay Archipelago at least 1500 years ago and to parts of Africa about 1000 years ago (Smith *et al.*, 1992). Wild mango is reported throughout these areas and China and Sri Lanka. Thus mango was distributed in ancient times throughout all of tropical and subtropical Asia, and northern and eastern Africa. Mango was later distributed to the New World during the exploration and colonization of the New World from the 15th to the 18th centuries by the Portuguese, Spanish, British and French. Feral mango populations are now found in parts of West

Africa, Mexico and Central and South America (Smith *et al.*, 1992). Today mango is grown on various commercial scales throughout the warm to cool subtropical and tropical areas of the world (Martin *et al.*, 1987).

World production and yield

There is an estimated 3.7 million ha of mangos worldwide (FAOSTAT, 2005a, b). Mango production in 2004 was estimated at 26.6 million t, ranked seventh in worldwide fruit production behind banana, grape, oranges, apple, coconut and plantain. The top ten mango-producing countries based on area of production include India, China, Thailand, Mexico, Indonesia, the Philippines, Nigeria, Pakistan, Guinea and Brazil. The top five largest mango-exporting countries are Mexico, India, Brazil, Peru and the Philippines with exports worldwide valued at US$560.4 million. The top five mango-importing countries are the USA, the Netherlands, the United Arab Emirates, Saudi Arabia and Bangladesh with imports valued at US$703.9 million.

Fruit are available year-round depending upon production location and cultivar. Production per ha varies greatly with average yields of 2–6 t/ha being common in some regions and with highest yields reported to be 10–30 t/ha (Verheij and Coronel, 1992). Average yields for productive orchards range from 22 to 25 t/ha (Nakasone and Paull, 1998).

Uses and nutritional composition

Mango is commonly eaten fresh and depending upon the cultivar may be consumed at an immature (unripe, green peel) stage or when fully ripe. In addition, the pulp may be cooked, dried, preserved, frozen or powdered. Mango pulp may be incorporated into beverages, desserts, ice cream, sorbets, preserves, jellies, fruit salads, chutneys, pickles, canned in syrup, pureed and dried.

Mangos are a rich source of vitamins A and C (Table A.5) and have recently been found to be high in anti-cancer antioxidants and phenols. Historically there have been many reported medicinal uses of the sap (latex), flowers, seeds and leaves for use as astringents, treating diarrhoea, haemorrhages, fever, hypertension and haemorrhoids.

Table A.5. Composition of mango per 100 g edible portion (Source: Morton, 1987; Verheij and Coronel, 1992; USDA, 2005).

Proximate	g
Energy (kJ)	225–350
Protein	0.30–0.8
Fat	0.10–0.27
Carbohydrate	13.2–20.0
Fibre	0.60–1.80
Ash	0.50
Moisture	78–85
Minerals	**mg**
Calcium	9.0–25.0
Potassium	156.0
Phosphorus	10.0–15.0
Iron	0.10–0.20
Magnesium	9.00
Vitamins	**mg**
Thiamine	0.058
Riboflavin	0.057
Niacin	0.584
Vitamin C	14–62
Vitamin E	1.12
Vitamin A (IU)	765

Botany

TAXONOMY AND NOMENCLATURE The genus *Mangifera* is one of 73 genera belonging to the *Anacardiaceae* (Bompard and Schnell, 1997). However, the taxonomy of *Mangifera* remains in flux with over 60 species found in South and South-east Asia. The genus *Mangifera* has been divided into two subgenera, *Limus* sp., which are quiet distinct from the common mango and may be ancestral to the mango, and the subgenera *Mangifera*. The subgenus, *Mangifera* is further divided into five sections based on differing floral, seed and anatomical attributes with *M. indica* belonging to Section *Mangifera* Ding Hou. This section is further divided into three groups based on floral structures and organ number variation with *M. indica* belonging to a group with five species characterized by tetra- and pentamerous flowers. Two main centres of domestication of mango are recognized, India with monoembryonic cultivars and Asia, which includes Indonesia, the Philippines and parts of Vietnam, Thailand and Myanmar, with polyembryonic seeds.

The major mango species in cultivation is *M. indica*, however *Mangifera foetida* (horse mango), *Mangifera odorata* (kuini), *Mangifera caesia* (binjai), *Mangifera langenifera* (lanjur or langoot) and *Mangifera zylanica* are cultivated or gathered commercially on a small scale in various parts of South-east Asia (Yaacob and Subhadrabandhu, 1995; Bompard and Schnell, 1997). Two broad types of mango are recognized, Indian and Indo-Chinese (Crane *et al.*, 1997). Indian types have monoembryonic seeds, are usually highly coloured, and tend to be susceptible to anthracnose (*Colletotrichum gloeosporioides*). Indo-Chinese types have polyembryonic seeds, usually are green to light green to yellow at maturity, and tend to be more resistant to anthracnose.

There are a number of mango relatives with edible fruit including cashew (*Anacardium occidentale*), anacardier géant (*Anacardium giganteum*), maprang (*Bouea gandaria*), Kaffir plum (*Harpephyllum caffrum*), bembé (*Lannea acida*), ambarella (*Spondias cytherea*), yellow mombin (*Spondias mombin*), purple mombin (*Spondias purpurea*) and imbu (*Spondias tuberose*) (Martin *et al.*, 1987).

DESCRIPTION Mango trees may grow to 45 m in height with a broad canopy up to 38 m in width. In deep soils the taproot may extend downwards to 6 m and the lateral fibrous root system may extend well beyond the canopy drip-line. Immature leaves are reddish brown and soft. Mature leaves are green, simple, spirally arranged, lanceolate to oblong, 8–40 cm long by 2–10 cm wide, and coriaceous (Fig. A.3). Flowers are borne on green, yellow or pinkish-coloured large terminal or axillary panicles up to 60 cm in length. Each panicle may possess 300–6000 individual flowers (Iyer and Degani, 1997). There are two flower types on each panicle, hermaphroditic

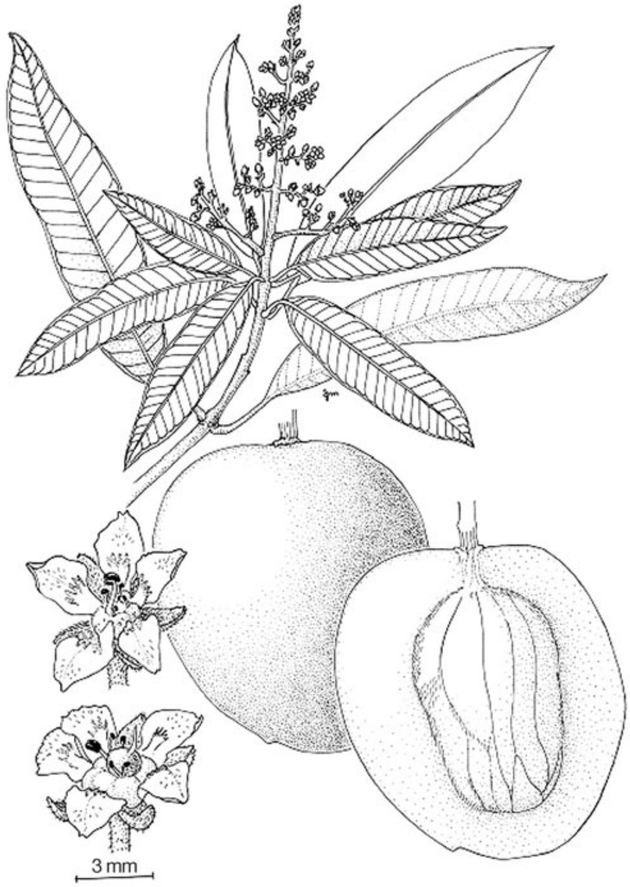

Fig. A.3. Leaf, flower and fruit of *Mangifera indica* (Source: Nakasone and Paull, 1998).

(perfect) and staminate (male). Flowers are small, greenish yellow to reddish pink, calyx five-lobed and five petals. Hermaphroditic flowers have one simple pistil with one functional stamen and four staminodes; staminate flowers have no ovary, usually one functional stamen and four staminodes. Fruit an oblong, reniform to oblate, fleshy drupe, 6–30 cm long, 100–2300 g, with or without a pronounced beak; fruit are solitary or in clusters (Martin *et al.*, 1987; Yaacob and Subhadrabandhu, 1995). Fruit possess one seed enclosed in a stony endocarp; seeds may have one (monoembryonic types) or multiple (polyembryonic) embryos. The waxy, smooth peel is somewhat leathery and ranges in colour at maturity from green to light green with ground colour or blushes of one or more shades of yellow, orange, red or purple alone or more commonly in combination. The pulp of immature fruit is hard and white to light yellow, at maturity the pulp may be more or less fibrous, soft, juicy and light yellow to orange. Fruit may emit a mild to strong aroma and the flesh from ripe fruit is sweet with a mild to strong flavour; fibre content varies. Fruit possess one monoembryonic or polyembryonic seed.

ECOLOGY AND CLIMATIC REQUIREMENTS There are two main ecological types of mango – those that evolved in the warm subtropical climate of India and those that evolved in the hot, humid, lowland tropical areas of South-east Asia. Mango trees may be grown in a wide range of climates, however, highest production of quality fruit occurs in those areas with a distinctive non-freezing cool period and/or an extended dry period (at least 3 months) prior to flowering, hot temperatures (30–33°C) during fruit development, and access to water (ideally from irrigation and not rainfall) from flowering to harvest (Davenport and Núñez-Elisea, 1997; Whiley and Schaffer, 1997).

Mango trees are adapted to a wide range of soil types including various sandy, loamy, clayey, and rocky soils (Yaacob and Subhadrabandhu, 1995). Mango trees produce best under full sunlight exposure; constant shading reduces or delays flower-bud formation. There does not appear to be any effect of photoperiod on mango flowering. Peel colour development is dependent upon light exposure. Mango trees are only moderately freeze tolerant with young trees damaged or killed at temperatures below −1.1°C to −1.7°C and mature trees damaged or killed at or below −3.9°C to −6.0°C (Snow, 1963; Campbell *et al.*, 1977). The minimum temperature for vegetative growth is about 15°C with optimum growing temperatures ranging from 24°C to about 30°C (Schaffer *et al.*, 1994). In contrast, the base temperature for panicle growth appears to be around 12.5°C. Soil temperatures at 12°C have been found to limit plant growth. Low temperatures (4.4°C–15°C) during flowering may result in abnormal flowers and reduced pollen viability and fruit set (Schaffer *et al.*, 1994; Whiley and Schaffer, 1997). In contrast, high temperatures (33–36°C) during pollen meiosis result in reduced pollen viability.

Mangos are tolerant to periodic and repeated flooding and this appears to be dependent upon development of hypertrophied lenticels along the trunk. Mango trees are very drought tolerant due to their laticifer cells (resin canals), osmotic adjustment of leaves, their deep and extensive root system, and coriaceous leaves. However, drought during fruit set and development may result in reduced yields and fruit size. Mango trees are intolerant of saline soil and water which causes necrosis of leaf margins and tips, defoliation, stem dieback and tree death. However, there is some variability in the saline tolerance of various cultivars.

Windy conditions during flowering and fruit development may cause fruit drop and reduce fruit quality through scarring. Mango trees are moderately tolerant of constant winds, however, substantial yield increases have been reported after orchard trees were protected from prevailing winds by man-made or natural windbreaks. This was attributed to improved fruit set, less physical damage to leaves and fruit and reduced disease incidence. Mature mango trees are moderately wind tolerant although large trees are susceptible to toppling, major limb and trunk damage, and uprooting due to typhoons or hurricanes (Crane *et al.*, 1993).

REPRODUCTIVE BIOLOGY The mango inflorescence bears functionally male and bisexual flowers (termed polgamy) with the ratio of functionally male to bisexual flowers varying by genetic predisposition of the cultivar, temperatures during floral morphogenesis (low temperatures reduce the proportion of bisexual flowers) and endogenous growth regulators (Davenport and Núñez-Elisea, 1997). Most mango cultivars are self-fertile but benefit from cross-pollination (Martin *et al.*, 1987). Flowers open in the morning and anthesis is generally completed by noon; receptivity of the flowers usually lasts up to about 72 h (Iyer and Degani, 1997). Fruit set varies with genetic predisposition of the cultivar for self-incompatibility, weather conditions during and immediately after flowering, and opportunity for cross-pollination. In general, fruit set from self-pollination ranges from 0 to 1.7% whereas from cross-pollination from 6.4 to 23.4% (Nakasone and Paull, 1998).

Mango flowers may be pollinated by flies, bees, thrips and other insects, with flies probably the most important. Some fruit set may occur due to wind pollination. There are two types of mangos: polyembryonic, forming seed with several adventitious embryos arising from nucellar tissue; and monoembryonic, forming seed with a single zygotic embryo.

In order to flower profusely, mango trees require mature, resting, terminals (stems) and a quiescent period induced by either cool non-freezing temperatures (8–15°C night/< 20°C day) and/or dry conditions (Davenport and Núñez-Elisea, 1997). Furthermore, the conditions during flowering (induction) after shoot initiation also influence the balance between putative floral (possibly cytokinins) and anti-floral (possibly gibberellins) endogenously produced compounds. Exposure of shoots initiated to grow during cool temperatures result in reproductive growth, in contrast exposure of shoots initiated to grow during cool temperatures but then immediately exposed to warm temperatures (25°C night/30°C day) may produce vegetative growth or mixed (reproductive/vegetative) growth.

Numerous techniques have been developed for inducing or enhancing mango flowering, however, not all of them work on all cultivars, climates and soils. Traditional methods to induce mango flowering include cincturing the trunk or branches, root pruning, smudging and applications of saline materials. More recently, foliar applications of ethylene-releasing compounds, potassium nitrate and paclobutrazol have proved to be efficacious on more cultivars and under a wider range of environmental conditions. Paclobutrazol may also be applied as a soil drench.

FRUIT DEVELOPMENT Time from flowering to fruit maturity takes 3–6 months depending upon cultivar and temperatures (Martin *et al.*, 1987). Mango fruit growth follows a typical sigmoidal pattern with the seed developing first followed by a final rapid increase in mesocarp (pulp) as fruit near maturity.

Horticulture

PROPAGATION Mango may be propagated by seed, grafting, budding, marcottage, rooted cuttings and tissue culture. Polyembryonic cultivars may be propagated by seed but grafting or budding is now more common. Monoembryonic cultivars must be propagated vegetatively; most commonly by budding or grafting. Flowering and fruiting take 6–10 years from seed and 3–5 years from grafting depending upon genetic predisposition of the cultivar, environmental conditions and culture.

ROOTSTOCKS In general, polyembryonic mangos are used as rootstocks because of their uniformity. Various rootstocks have been selected for their tolerance to soil conditions such as high pH and calcareous soils ('No. 13–1', 'Turpentine') or reduced tree vigour ('Olour', 'Vellai Colamban', 'Saber') (Iyer and Degani, 1997; Morton, 1987). Other polyembryonic rootstocks include 'Madu' in Indonesia, 'Kaew' in Thailand and 'Kensington Pride' in Australia (Verheij and Coronel, 1992).

PRUNING AND TRAINING The tree spacing selected depends upon climate, cultivar, soil type and depth, horticultural expertise and economics. Plant spacings vary widely and may range from 4 to 12 m in-row and 6 to 15 m between rows.

Pruning recommendations vary with production region, cultivar, climate, soil type, inherent vigour of the cultivar, available technology and labour, and tradition. In general, trees planted in more closely spaced orchards require initial tree training to establish two to four main scaffold limbs and the basic tree shape. Maintenance pruning to remove dead and damaged limbs, water sprouts, limit tree size and maintain production is generally recommended for immediately after harvest and may consist of hand pruning (thinning-out entire shoots and/or branches), tipping shoots back, and/or mechanical hedging and topping. Intensive hand pruning to remove non-flowering shoots after fruit set, followed by removal of fruiting stems after harvest, may limit tree size and reduce biennial bearing in some cultivars. Paclobutrazol has been used to reduce flushing and tree growth successfully in various mango regions of the world; however, the success of this practice varies by cultivar and environmental conditions (Crane *et al.*, 1997).

NUTRITION AND FERTILIZATION Fertilizer practices are based on research, observation and experience and should include the application of all essential elements. A wide range of nutrient rates and formulations is recommended depending upon the region, cultivar, soil type and availability of fertilizer materials. Furthermore, standard leaf nutrient levels vary with production region and deficiency symptoms and leaf sampling procedures have been described previously (Samra and Arora, 1997). General recommendations for young trees are about 100–200 g of an NPK (nitrogen, phosphorus, potassium) material applied two to four times per year with rates increasing and frequency decreasing as trees mature (1.0–2.0 kg/tree/application) (Crane *et al.*, 1997; Samra and Arora, 1997). Similarly, secondary (magnesium, sulphur) and minor element (zinc, manganese, iron, boron) fertilization varies widely based on local environmental conditions and inherent genetics of the cultivar grown.

Irrigation practices vary widely depending upon soil type, depth to water table, availability of water, water quality, available technology and cost, plant spacing and climate (Crane *et al.*, 1997). In general, newly planted trees should be planted during the rainy season or irrigated until established (Crane *et al.*, 1997). The necessity of irrigation for mature trees varies with climate, soil type, cultivar and tree phenology. In some areas, irrigating from flowering to near harvest is beneficial.

DISEASES, PESTS AND WEEDS There are numerous disease and insect pests of mango. Important diseases of mango include anthracnose (*C. gloeosporioides*), powdery mildew

(*Oidium mangiferae*) and bacterial black spot (*Xanthomonas campestris* pv. *mangiferaeindicae*) (Dodd *et al.*, 1997; Ploetz and Prakash, 1997; Ploetz, 2003). Other major diseases in some production regions include mango malformation (caused by a number of closely related *Fusarium* spp.) which affects panicle formation and fruit set, pink disease (*Erythricium salmonicolor*) which kills trees by colonizing the vascular and cambial tissues, and black spot (*Alternaria alternata*) which is primarily a postharvest fruit problem.

Every mango production area has a unique pest complex and numerous insect pests attack leaves, flowers, fruit, shoots and the trunk of mango and their importance varies with production region. Various mango hopper species (e.g. *Idioscopus clypealis*, *Idioscopus niveosparsus*) are of major importance in South-east Asia and attack the mango inflorescence and flowers. Numerous Lepidoptera species (e.g. *Chlumetia transversa*, *Eupithecia* sp., various Noctuidae) and several flower thrips (*Frankliniella bispinosa*, *Frankliniella kelliae*) attack mango flowers reducing fruit set and crop yields. Some fruit flies of the Tephritidae are major mango fruit pests including species from the genera *Anastrepha*, *Bactocera*, *Dacus* and *Ceratitis*. Other important insect pests include fruit piercing moths (*Eudocima fullonia*, *Eudocima maternal*, *Eudocima salaminia*), various midges (e.g. *Erosomya mangiferae*, *Erosomya indica*), the mango seed weevil (*Sternochetus mangiferae*), mango seed borer (*Deanolis sublimbalis*), various mites (e.g. *Oligonychus* sp., *Aceria mangiferae*), scales (e.g. *Aulacaspis tubercularis*, *Philephedra tuberculosa*, *Ceroplastes pseudoceriferus*) and mealy bugs (*Rastrococcus invadens*, *Rastrococcus spinosus*) (Peña and Mohyuddin, 1997; Waite, 2002).

POSTHARVEST HANDLING AND STORAGE The recommended stage of fruit maturity for harvest depends upon the end use of the fruit (e.g. green-crunchy or soft-ripe), the distance and time to markets, available storage conditions and any required quarantine treatments. For example, 'Khieo Sawoey' is harvested at the immature, green stage and consumed as a green-crunchy fruit. In contrast the recommended stage of maturity for harvesting 'Nom Doc Mai' for eating ripe is about 100–102 days from bloom in Thailand and the Philippines (Yaacob and Subhadrabandhu, 1995). Typically 'Tommy Atkins' and 'Keitt' mangos may be harvested at early or late maturity depending upon the distance to markets within the USA.

Mangos are picked by hand or with the help of various picking poles with bags or hooks. In general, fruit destined for export markets are pre-cooled, washed and sometimes treated with fungicide to reduce postharvest decay, waxed to reduce water loss, quarantine treated to kill fruit fly larvae and eggs, and then graded by appearance and size, packed, stored and shipped (Johnson *et al.*, 1997). Fruit sold in local, regional and national markets may or may not be extensively graded and treated prior to marketing. Mature mangos may also be gassed with ethylene prior to marketing to synchronize fruit ripening and colour development.

The phytosanitary requirements for exporting mangos varies by country and ranges from no restrictions to entry into a country to certification that fruit were grown in a fruit-fly free area and/or postharvest disinfested in some specific manner (Johnson *et al.*, 1997). Quarantine treatments for fruit fly disinfestations include various hot water treatments, vapour heat, hot air and irradiation. Mango storage temperatures vary by cultivar and stage of fruit maturity. Safe storage temperatures for a 2–3 week period may range from 8 to 21°C and 85 to 90% relative humidity (McGregor, 1987; Morton, 1987; Johnson *et al.*, 1997).

MAIN CULTIVARS AND BREEDING Mango is genetically heterogeneous resulting in seedling progeny with a very wide range of growth habits and fruit characteristics (Smith *et al.*, 1992). There are hundreds (perhaps more than a thousand) of mango cultivars and formal and informal selection from seedling populations has occurred for millennia throughout India and South-east Asia and more recently throughout the tropics and subtropics of the western hemisphere. There are over 25 field germplasm banks throughout the tropics and subtropics with responsibility for the conservation of *M. indica* and its relatives. Many of them house named mango cultivars, land races, selections and relatives of mango. Currently there are formal breeding or selection programmes in Asia (e.g. Malaysia, Indonesia, India, Pakistan, Taiwan), Central and South America (e.g. Brazil) and North America (e.g. Mexico, USA/Florida). Mango breeding or selection criteria include regular bearing, low to moderate vigour, disease and insect resistance, freedom from physiological disorders, increased fruitfulness and storability to name a few. Selection criteria for rootstocks included polyembrony, dwarfing, tolerance to adverse edaphic conditions (e.g. high pH, flooding) and scion compatibility (Iyer and Degani, 1997). In addition, *Mangifera* relatives possess various characteristics such as disease resistance, adaptation to stressful edaphic conditions (e.g. flooding), dwarfing, and free-stone fruit that in the future may be utilized successfully to improve cultivated mango (Litz and Lavi, 1997).

Major cultivars vary in every production area and most were selected from chance seedlings. Literally hundreds of mango cultivars are grown in India with 'Alphonso', 'Alampur Baneshan', 'Paheri' and 'Neelum' just to name a few. In Thailand cultivars are divided into those eaten unripe (called starch or crispy mango) and those eaten ripe: crispy cultivars include 'Khieo Sawoey' and 'Rad' and ripe-eating cultivars include 'Okrong', 'Nam Dok Mai', 'Nang Klangwan' and 'Thong Dam' (Yaacob and Subhadrabandhu, 1995). In the Philippines, 'Carabao' and 'Pico' are predominant cultivars. Major cultivars in the western hemisphere include 'Manila' and 'Altaulfo' (both from Mexico), 'Bourbon', 'Extrema' and 'Coraçao de Boi' (all from Brazil), 'Kensington Pride' (Australia), 'Tommy Atkins', 'Keitt', 'Kent' and 'Haden' (all originally from Florida but now the major export mango cultivars used in the export trade from Mexico and Latin America) (Knight, 1997). Jonathan H. Crane

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Pistacia vera pistachio

The pistachio, *Pistacia vera* L. (*Anacardiaceae*), is native to western Asia and Asia Minor, where it is still found growing wild in numerous hot, dry locations in Lebanon, Palestine, Syria, Iran, Iraq, India, Southern Europe and the desert countries of Asia and Africa. Several species are referred to as pistachios, but the name is generally reserved for the edible nut of commerce. The common names are variants on the Persian name pistaa: in Arabic it is fustuq, in French pistache, in German pistazie, Hindi pistaa, Italian pistacchio, Spanish pistacio and Portuguese pistácio or pistácia.

Pistachio was introduced to Europe at the beginning of the Christian era. The first pistachio introductions to the USA were by the US Department of Agriculture (USDA) plant exploration service in 1890. California introductions were first planted at the Plant Introduction Station in Chico in the Northern Sacramento Valley in 1904. Commercial pistachio production differs markedly between the more intensive new world production practices, primarily in California and the traditional, less intensive, non-irrigated production practices followed in the old world, Iran, Turkey and Syria.

A related species *Pistacia lentiscus* L. yields a mastic that is used in incense, to fill teeth, as chewing gum and as a varnish. The fruit are occasionally used to make sweets or liqueurs. The *Pistacia terebinthus* yields Cyprus turpentine collected by making incisions in the trunk. The small *Pistacia palaestina* fruit are sold in Arab markets as a condiment and have a resinous taste.

World production and yield

Modern world pistachio production is divided between the new and the old world. Iran is the world's leading producing country, followed by California, Turkey, Syria, Greece and Italy (Table A.6). Greece and Italy both produce less than 1% of the world's total production. Plantings have increased sharply in the three major producing areas, Iran, California and Turkey. Since 1985 pistachio production has been initiated in China, Argentina, Australia and South Africa. However, production in these countries has not reached commercially competitive levels. Average yield per tree ranges from 2 to 22.5 kg/year. World yields in 2000 varied from 500 kg/ha to 3037 kg/ha with a world average of 1117 kg/ha (Kaska, 2002). Yields per hectare have increased in all growing areas over the last 20 years.

Pistachios display three physiological conditions that decrease commercial yields. The first is alternate bearing, an annual cycling of high and low crops as a result of premature fruit bud abscission. The second is blanking, the failure of the embryo to develop, resulting in an empty nutshell. The third is non-splitting, the failure of the fully developed nutshell to split, resulting in a filled but unopened nut. These all appear to be related to crop load and are therefore probably ultimately related to carbohydrate competition. Thus far, little is known about the specific mechanism of each, though the correlation with crop load is apparent in each case.

Uses and nutritional composition

The primary use of pistachio nuts is eating out of hand, fresh in season, dried, and dried and roasted, with or without salt, or flavoured with spices and condiments. 'Red' pistachios are roasted and salted and then coloured with a red vegetable dye to cover blemishes. Nutritionally, pistachios are superior relative to other tree nuts and peanuts as they are lower in calories and fat, and higher in potassium, carbohydrates and protein (Table A.7). Secondary nut uses are in baked goods, nougat candies, sausages, pâtés and as a flavouring for ice cream, in ground or powdered form. In the countries where pistachios are traditionally grown, the uses are more varied than in the Western countries. The outer husk is used in India for dying and tanning. The nuts are used for a number of folk remedies such as for abdominal pains, abscesses, bruises and dysentery.

A limited amount of pistachio oil is produced for eating and cosmetic purposes. The amount of oil may increase as world nut production increases. The nut has 55% of a non-drying oil that is predominantly 23.3 g/100 g monounsaturated and 13.46 g/100 g polyunsaturated, and only 5.4 g/100 g saturated (USDA, 2006).

Table A.6. World's major pistachio producers (in millions of kilos) 2002–2004 (Source: FAO, 2004).

	Production (millions of kilos)			
Year of production	Iran	California, USA	Turkey	Syria
2002	300	137	40	40
2003	310	54	50	50
2004	305	158	85	50

Table A.7. Proximate composition for raw pistachio nut per 100 g with the nut being 53% of the nut in shell (Source: USDA, 2006).

Proximate	%
Water	3.97
Energy (kcal)	557
Protein	20.61
Lipid (fat)	44.44
Carbohydrate	27.97
Fibre	10.3
Ash	3.02
Minerals	**mg**
Calcium	107
Iron	4.15
Magnesium	121
Phosphorus	490
Potassium	1025
Sodium	1
Vitamins	**mg**
Ascorbic acid	5.0
Thiamine	0.87
Riboflavin	0.16
Niacin	1.3
Vitamin A	553 IU

Botany

TAXONOMY AND NOMENCLATURE The synonyms of *Pistacia vera* L. are *P. nigricans* Crantz, *P. officinarum* Ait., *P. reticulata* Willd. and *P. terebinthus* Mill. The pistachio of commerce is the only edible species among the 11 species of small trees in the genus *Pistacia*; all are characterized by their ability to exude turpentine or mastic.

DESCRIPTION The tree can grow to 7.5–12 m and sometimes with several twisted trunks. The rough bark is grey. The pinnate leaves (three, sometimes five) are dark green above and paler below and vary from ovoid to oblong-ovoid. When young the leaves are sometimes pubescent. Each leaf at a node subtends a single axillary bud. Most of these lateral axillary buds differentiate into inflorescence primordia and produce a nut-bearing rachis in the following year, on 1-year-old wood. One or two axillary buds do occur distally of the node on new growth. This dioecious plant's panicle has 13 primary branches, each bearing one terminal and 5–19 lateral flowers (Plate 6). The small apetalous brownish-green flowers have up to five sepals. The male flowers have five short stamens and the female flower has a single tricarpellate, superior ovary (Plate 7). The pedicelled fruit is a single-seeded oval-shaped drupe (2–2.5 cm long). A semi-dry greenish exocarp and mesocarp surrounds a hard smooth endocarp and this begins to separate as the fruit begins to mature (Plate 8). The endocarp dehisces (splits) longitudinally at the apex after the seed has reached maturity and maximum size. The exocarp changes from green to red at maturity. The seed has a papery seedcoat and two greenish-yellow cotyledons.

ECOLOGY AND CLIMATIC REQUIREMENTS The tree is classified as a phreatophyte, having an extensive root system that allows the tree to mine the soil deeply for water and nutrients. This author has observed pistachio rootstocks at 9 m in 10-year-old trees. Pistachios are adapted to survive long periods of drought.

Areas suitable for pistachio production have long, hot, dry summers and moderate winters. Pistachios grow best in areas with 2200–2800 heat units calculated as follows.

$$\text{Heat units} = \left\{\frac{\text{mean monthly Tmax} + \text{mean monthly Tmin}}{2}\right\} \times \text{number of days (April–October)}$$

Generally, pistachios should not be planted above 750 m where summer heat is usually insufficient for complete kernel development. Elevations of 60–250 m above sea level have proven ideal in the central Californian valleys. In Iran, major production occurs at 1200 m on a desert plateau. High humidity through the growing season promotes foliar fungal diseases that subsequently overwinter on both male and female trees and reinoculate the tree the following season.

Pistachios can be successfully grown on a number of soil types. In California, the sandy loams of the southwest San Joaquin Valley high in lime and boron have produced the best yields. In areas with shallow hardpan soils, tree size and productivity are limited. The tree grows best on well-drained soils and is intolerant of saturated conditions. It appears to tolerate alkalinity and salinity well. Trees grown in soils with soil water extracts up 8 dS/m produce well.

REPRODUCTIVE BIOLOGY The tree can have a long juvenile period, typically bearing few nuts before 5 years. Full bearing is achieved between 8 and 10 years of age when irrigated, later if not. Pistachios require at least 750 h of winter chilling at temperatures below 7.5°C to produce good, even, timely budbreak, normal inflorescence development, good fruit set and normal vegetative growth. When cumulative hours below 7.5°C have fallen to 670, as they did in California in 1977/78, the bloom and foliation was irregular and delayed, the leaves were deformed and the yields reduced. Varieties vary in their chilling requirement from 600 to 1050 h below 7.5°C.

This deciduous tree loses its leaves in the autumn and remains dormant through the winter. The lateral axillary inflorescence buds on 1-year-old wood begin to swell in late March. Within the first 2 weeks of April, the 100–300 flowers per paniculate rachis are pollinated and set. The tree is dioecious and a ratio of one staminate tree to eight pistillate trees is often used. The female flower is apetalous (no petals) and has no nectaries and does not attract bees. The flowers are wind pollinated and late spring rains, frosts and strong desiccating winds interfere with pollination.

ALTERNATE BEARING As the trees age, they develop an alternate bearing pattern with increasingly large and small crops. Though the specific mechanism of this phenomenon has not been defined, evidence suggests that it is a problem of carbohydrate competition, perhaps mediated by growth regulator signals. During the period of nut fill in July, the fruit buds distal to fruit clusters die and abscise. The heavier the currently borne crop, the greater the subtending bud abscission. Thus, following a heavy crop year, an individual branch may bear no fruit. Attempts to alleviate the cycle by nutritional and growth regulator sprays have not been successful. However, some success in damping the swing has been achieved with rejuvenation pruning of older trees. Currently, pruning appears to be the only method available to mitigate alternate bearing. Alternate bearing has not been demonstrated as harmful to the tree and may therefore simply be a marketing problem. Alternate bearing is not unique to pistachio trees. Several types of fruit trees show alternate bearing, however, only pistachios appear to possess the phenomenon of premature bud abscission.

FRUIT DEVELOPMENT Fruit set typically follows successful pollination. After fruit set and through April and May the endocarp, but not the seed, enlarges. The endocarp is soft and vulnerable to insect attack and premature splitting that appears to be a result of rain. In June the endocarp hardens, and from late June through to early August the seed enlarges until it fills the shell. Through late August and September the nut ripens, the radial suture around the endocarp long circumference splits, the exocarp and mesocarp hull degrades, and abscission of the individual nut from the rachis starts.

Shoot growth is simultaneous with shell growth. Growth begins in late April and concludes in late May. The new extension growth produces pinnately compound leaves with lateral inflorescence buds in the axils and, generally, a single apical vegetative bud. The buds differentiate throughout April, May and June, become quiescent in July, August and September, and resume differentiation in October. Sometimes there is an additional flush of shoot growth in late June. This growth produces primarily vegetative lateral buds as opposed to the inflorescence buds produced by the spring flush. In August, leaves distal to heavy fruit clusters often display a marked depletion and senescence. Most leaves drop by the end of November and the tree remains dormant through to the following March.

NUT BLANKS The growth of the pericarp before the seed has implications for both blank nut production and shell splitting. Blank nuts result when there is fruit set and ovary growth, but the embryo fails to grow, leaving the nutshell empty or blank. Blanking can occur during two different phases of pistachio nut development, nut setting and nut filling. It can be affected by crop load and production practices.

The first empty shells (blanks) are produced as a result of events that occur at the time of fruit set. This can occur if pollination occurs but fertilization fails either because pollen tubes do not complete growth to the ovule, or the ovule is not viable when the pollen tubes do arrive. The stimulus from pollination and/or pollen tube growth is sufficient to induce fruit set and parthenocarpy. Parthenocarpy is common in fruit that have many seeds rather than in single-seeded fruit such as the pistachio. Boron leaf levels below 120 ppm dry weight (August leaf sample) are associated with an increased percentage of blank nuts at harvest.

Blanks may also develop in July during kernel enlargement, when a certain percentage of the fertilized embryos fail to enlarge to fill the shell. Thinning a cluster prior to nut growth results in a higher percentage of filled nuts on the thinned cluster. However, the thinned and unthinned clusters have virtually the same absolute number of filled nuts, though the thinned clusters may have slightly larger nuts. This has been demonstrated on a whole-tree scale with pruning experiments.

ENDOCARP (SHELL) SPLITTING The edible pistachio, unlike the species used for rootstocks, is characterized by splitting of the endocarp at maturity. Splitting begins about the end of July, at least 1 month before fruit maturity, and continues through mid-September, progressing simultaneously with seed maturation. Final seed maturity is indicated by separation of the hull (exocarp and mesocarp) from the endocarp shell. The exocarp changes at this time from green to red and is the most obvious indicator of endocarp splitting.

Pistachio nuts may split along the longitudinal ridges of the shell and at the tip of the shell. Splitting can occur in any combination of one or both of the longitudinal ridges, with or without the tip splitting, or at the tip alone. Investigation of the anatomical structure of the longitudinal and tip split regions indicates that these parts of the shell differ from one another structurally suggesting that different mechanisms may be involved in shell separation at each site.

There is an inverse relationship between tree crop load, the percentage of nuts with split shells and the percentage of blank nuts. As crop load increases, the percentage of nuts with split shells decreases and the percentage of blank nuts decreases. Thus, in ‘heavy’ crop years the marketable crop is decreased by non and splits, and in ‘light’ crop years it is decreased by blanks.

Horticulture

PROPAGATION Both male and female trees are propagated via standard T-budding, and much less frequently by grafting. When planting a new pistachio orchard, rootstocks are planted in February or March and budded in late June, July or early August. Budding is usually done in early summer when the scion buds are mature, and the bark on the rootstock is slipping and active. Red leaves on the newest rootstock growth is a good indicator that the rootstock bark is slipping. Generally, trees between 0.7 and 1.5 cm are best for T-budding, chip budding and saddle grafts.

Pistachio rootstocks are produced from seeds germinated in January, transplanted to 0.5 m pots or plastic sleeves when they are approximately 0.25 m tall and moved outside in April. The rootstock seedlings are grown outside in the nursery for 4–12 months and planted, unbudded, 8–16 months from germination. Planting date is primarily a function of the date of latest historical frost in spring as the young rootstocks are not tolerant to temperatures below freezing. It is possible to transplant bare root nursery stock, but because bare rooted trees are very sensitive to drying, this is not a common practice.

ROOTSTOCKS In Iran, California and other pistachio-growing areas in world, the nut-producing species *P. vera* is grown on seedling rootstocks of different *Pistacia* species or interspecific hybrids. In California five rootstocks have been used by the California pistachio industry, three different *Pistacia* species and two interspecific hybrids. The rootstocks are *P. terebinthus*, *Pistacia atlantica* and *Pistacia integerrima* and two hybrids with *P. atlantica* and *P. integerrima* parentage (Table A.8). *P. integerrima* is now the standard rootstock due to its *Verticillium dahliae* resistance. In other pistachio-producing countries, the rootstocks are considerably more varied as the rootstock seed are often selected from unsplit edible nuts culled from the pistachio processing lines.

PRUNING AND TRAINING The tree has an upright growth habit characterized by a strong apical dominance and a lack of lateral vegetative buds in older trees. As the trees mature, their strong apical dominance becomes more marked. These characteristics have strong implications for young tree training, mature tree pruning and rejuvenation of fruiting wood in older trees.

Depending upon rootstock, the pistachio trees have low to moderate vigour and require 5–7 years of growth before significant fruiting occurs. For rootstocks, three *Pistacia* species, *P. terebinthus*, *P. atlantica*, *P. integerrima*, and one interspecific hybrid, UCB I, have been planted in California. Of these, *P. terebinthus* has the least, and *P. atlantica* × *P. integerrima* the greatest, vigour.

When irrigated, pistachios are generally trained for the first 5 years after budding. This training is primarily done in the dormant season though if the scion is on a vigorous rootstock, and the climate is hot enough, summer tipping for training can also be done. The cuts are primarily heading or tipping cuts. The goal is to produce a tree with two to five primary scaffolds that is amenable to mechanical harvest. After 5 years of age annual dormant pruning is done to maintain a tree small enough for mechanical harvest and to produce good annual crops. Mature tree pruning is almost entirely thinning cuts as heading cuts decrease the potential buds and do not

Table A.8. Characteristics of pistachio rootstocks from most * to least ****.

Rootstock	Cold tolerance	Disease resistance		Vigour	Early yield	Nutritional efficiency		
		Armillaria	*Verticillium*			Zn	B	Cu
P. terebinthus	*	*	****	**	***		**	
P. atlantica	**	****	****	**	***	**	***	**
P. integerrima	****	***	*	*	**	***		***
P. atlantica × *P. integerrima* PGII	***	***	****	*	**	*	**	*
P. atlantica × *P. integerrima* UCB I	***	*	*	*	*	***	***	***

produce branching due to the strong apical dominance. This is generally done by hand when the trees are dormant.

Mechanical pruning is being adopted in the California pistachio industry. Research within the past 15 years has demonstrated moderate pruning into 1–2-year-old wood by mechanical side hedging, though non-selective, does not decrease yield. Mechanical topping does decrease yield, but the lower cost of mechanical topping compensates for the loss in yield. Severe mechanical pruning, primarily topping, can mitigate alternate bearing by producing a strongly vegetative growth flush that gives a better balance of vegetative and fruiting buds in the subsequent years.

NUTRITION AND FERTILIZATION For pistachio, leaf analysis is more useful in diagnosing mineral deficiencies and toxicities than is soil analysis. Leaf samples are taken from current season's growth on non-bearing shoots in mid-August (see Table A.9), after the seed of the current crop has fully filled the endocarp but before the endocarp has split. Pistachios are relatively free of macronutrient deficiencies, nitrogen being the only macronutrient that is occasionally deficient. The trees are more susceptible to zinc, copper and boron micronutrient deficiencies. The last, boron, is particularly prevalent if the tree is on a rootstock with *P. integerrima* parentage. Boron, in excess can also produce a toxicity that is visible but rarely growth limiting.

Zinc deficiency symptoms appear early in the season, especially if the deficiency is severe. Terminal leaves are small, chlorotic (i.e. yellow) and appear in tufts, giving rise to the term 'little-leaf disease'. In highly deficient cases, terminal dieback sometimes occurs. Leaves and nuts are markedly reddish.

The boron requirement in pistachio is the highest known for any tree crop. Boron deficiency in pistachios manifests at 60 ppm in the leaf tissue as a failure to set fruit, later, at 120 ppm or less, it manifests as thickened, twisted and strapped leaves.

The symptoms of copper deficiency typically appear in midsummer, commencing with leaf scorch near the shoot tip and progressing to defoliation. Immature terminal leaves have tip burn and are somewhat heart-shaped. Slight shrivelling of the shoots occurs and small dark lesions appear on the shoot near the tip. Terminal dieback subsequently occurs in late summer. Some shoot terminals curl downward, resembling a shepherd's crook. Kernels are often badly shrivelled.

Table A.9. Critical and suggested levels for August leaf samples.

Element	Critical value	Suggested range
Nitrogen (N) (%)	2.3	2.5–2.9
Phosphorus (P) (%)	0.14	0.14–0.17
Potassium (K) (%)	1.8	2.0–2.2
Calcium (Ca) (%)	1.3	1.3–4.0
Magnesium (Mg) (%)	0.6	0.6–1.2
Chlorine (Cl) (%)	–	0.1–0.3
Manganese (Mn) (ppm)	30	30–80
Boron (Bo) (ppm)	90	120–250
Zinc (Zn) (ppm)	7	10–15
Copper (Cu) (ppm)	4	6–10

Chloride and sodium toxicities are not common except in the most saline situations. Interestingly, boron toxicity manifests as a marginal leaf burn much more commonly than visible sodium or chloride damage.

IRRIGATION Since pistachios are phreatophytes and drought tolerant, they can survive harsh climates without irrigation. Also, the stomata on their leaves, located only on the abaxial surface are somewhat less sensitive to desiccating conditions than stomata on many other trees. For economic production, adequate irrigation is necessary as it has a significant impact on young tree development, soil-borne and aerial diseases, crop yield and quality (both current and subsequent years) and tree growth. Profitable mature pistachio orchards have crop coefficients, Kc, ranging from 0.07 to 1.19 through the growing season. The crop coefficient is the fraction of water lost from a crop relative to reference evapotranspiration. Pistachio can use as much as 220 l of water per tree/day during at the hottest part of the season. The more efficient drip and microsprinkler irrigation systems are most often used in modern pistachio orchards. Irrigation research has focused on controlled deficit irrigation; manipulating water delivery to maximize the current crop year's yield and nut quality as well as the shoot growth that produces the crop in the subsequent season, while decreasing the total amount of water applied.

POSTHARVEST HANDLING AND STORAGE Pistachios are harvested by hand cluster removal, knocking or mechanical trunk shaking onto a catching frame. Because of the high moisture content, 40–50% on a fresh weight basis, fragility of their ripe hulls, and open shells within, pistachios are susceptible to mechanical injury and contamination if they drop to the orchard floor. *Aspergillus flavus*, the fungus that produces the carcinogen aflatoxin, is present in wet orchard soils and has the potential to infest pistachios that contact the soil.

Mechanical pistachio harvesters consist of two separate, self-propelled units about 7.5 m in length. One unit contains a shaker head that is clamped onto the tree trunk about 0.6 m above the ground. Most mechanical harvesters can do 0.4 ha (containing 112 female trees)/h. All Western pistachio production is mechanically harvested while hand harvesting is done in Iran, Turkey and Syria.

Shell staining can be greatly increased during postharvest transport and storage, particularly if high levels of hull damage were sustained during harvest, as damaged hulls greatly impede air flow through a bed of nuts. Shell staining generally increases with increased temperatures and increased holding times. Nuts will show damage after 8 h at 40°C, 24 hours at 30°C and 40 h at 25°C.

Previously, most processors used a single-stage drying process using air at 60–71°C for 10–14 h, to achieve 4–6% wet basis moisture. Conditions of drying were dictated by the initial moisture content of the nuts and the ambient relative humidity. Drying of pistachios is now generally a two-stage process. The hulled nuts are initially dried to 12–13% moisture in a column dryer designed for grain drying or a continuous belt dryer. This requires about 3 h at temperatures below 82°C to prevent shells from splitting so widely the nut drops out. A rotating drum dryer, at the same temperatures, can also be used for this first stage of drying. In the second stage the nuts are transferred to flat-bottomed grain bins where they are further dried to 4–6% moisture with unheated, forced air, or air heated to less than 49°C. This second stage of drying requires 24–48 h. The nuts can then be stored in these bins until needed. Smaller operations may use bin dryers for single-stage drying. The desired 4–6% moisture can be produced by 8 h at 60–66°C.

Sun drying and ambient air drying may be used in small operations. Drying in the sun requires 3–4 days, with protective covering to prevent predation by birds and rodents. Drying nuts in bins with ambient air requires 3 days if ambient temperatures and relative humidity are sufficient. Nut depth in the bin should not exceed 1.4 m and air should be circulating at 0.35 m/s. The major disadvantage to this method is the potential for fungal growth during the early stage of drying.

Once dried to 4–6% moisture, but before further processing, nuts can be held at 20°C and 65–70% relative humidity for up to 1 year. Temperatures between 0 and 10°C are recommended for long-term storage (> 1 year). Pistachios are less subject to rancidity and have a longer storage potential than almonds, pecans or walnuts. Low oxygen atmospheres (< 0.5%) aid in flavour quality maintenance. In storage, this is done by reducing the oxygen level and in packages by vacuum packaging or by flushing with nitrogen to exclude oxygen.

Insects in stored pistachios can be controlled by fumigation with phosphine. Alternatively, insecticidal controlled atmospheres and irradiation can be used. Storage of nuts in 0.5% oxygen and 10% carbon dioxide kills all instars of stored product pests after 2–5 days at 27°C. Temperatures near 0°C or between 40 and 50°C are also effective. After fumigation the use of insect-proof packaging is essential to prevent reinfestation.

Size and appearance are the most important components of pistachio quality. Defects that result in downgrading can be external, the shell, and internal, the kernel. External shell defects include total or partial non-splitting, adhering hull material, stained shells and damage by other means, including deformity and bird damage. Internal kernel defects include damage from insects and fungal pathogens, small immature kernels, rancidity and decay. Size, designated by the number of nuts per ounce (28 g) is also an important quality attribute.

Grower payout is calculated from the fresh weight of pistachios delivered to the processing plant, corrected for the weight of foreign material removed prior to hulling. Prior to hulling, a grading sample is drawn from each delivery. This sample is processed individually, the fresh:dry weight ratio calculated, and third party inspected for the percentage by weight of split nuts, non-split nuts, blank nuts, nuts with adhering hulls, light and dark stain, and other defects. Correction factors for these defects, and for hulling and drying, are applied to the corrected delivery weight to calculate grower price. The major components in determining return to the grower are weight delivered, and the percentages by weight of the filled split, filled non-split and blank nuts.

DISEASES, PESTS AND WEEDS Three foliar fungal diseases have been identified as the most destructive to pistachios. They are *Botrytis* blossom and shoot blight, caused by *Botrytis cinerea* Pers.Fr., *Botryosphaeria dothidea* and *Alternaria* late blight, caused by *Alternaria alternata*. These diseases as well as other minor diseases have been reported in other countries and in California, Arizona and Texas where pistachios are grown. Summaries of the most important diseases with diagnostic symptoms and signs of each disease and of sporadic diseases recorded on pistachios are given in Tables A.10 and A.11.

Pistachios are susceptible to a number of insect pests. The most damaging feed on the young and mature fruit and destroy nut quality. Virtually none harms the tree or destroys their host. Among the insect pest of pistachios are *Phytocoris*, a genus of hemipteran insects, two species of unarmoured scale in the family *Coccida*, the European fruit lecanium, *Parthenolecanium corni* (Bouch,), and the closely related frosted scale, *P. pruinosum* (Coq), the mireds, *Neurocolpus longirostrus* Knight (Miridae), and *Calocoris norvegicus* (Gmelin) and lygus (*Lygus hesperus*). Species of *Pentatomidae*, most notably the red shouldered stink bug (*Thyanta pallidovirens*), Uhler's and Say's stink bugs (*Chlorochroa uhleri* and *C. sayi*), the flat green stink bug (*Acrosternum hilare*), and some species of *Coreidae*, the leaf-footed bugs (*Leptoglossus clypealis* and *Leptoglossus occidentalis*) have produced fruit damage. Navel orange worm (*Amyelois transitella*) and the oblique banded leaf roller are more recent pests. Virtually all insect pest control is chemical. Thus far biological control has not been well developed for modern commercial pistachio production.

MAIN CULTIVARS AND BREEDING The diversity of scion cultivars grown in Iran and the paucity of the same in the West is another major difference between the modern, Western, Californian pistachio industry and the traditional Eastern pistachio industry. The male and female scion cultivars in both industries are *P. vera*. The Iranian, Turkish and Syrian industries have multiple local cultivars, often with different names, generated by feral trees and isolated producers.

As molecular techniques become more sophisticated the relationships among the diverse cultivars of the eastern industries is being determined. Currently, 'Montaz', 'Ohadi', 'Agah' and 'Kalehgouchi' are the major Iranian cultivars. 'Uzun', 'Krimizi' and 'Siirt' are among the major Turkish cultivars. California is a virtual monoculture with single female and male scions: the female 'Kerman' and the male 'Peters'. This reliance on a single, vegetatively propagated, female scion is a potentially devastating situation for the Californian industry if bud borne viruses appear. Louise Ferguson

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Table A.10. The most important diseases of pistachio (*P. vera*).

Common name	Fungal pathogen	Main symptoms and signs of disease
Botryosphaeria panicle and shoot blight	*Botryosphaeria dothidea*	Panicle, leaf, shoot and bud blight; black angular or circular lesions on green fruit and immature leaves; large black lesions on fruit; large brown lesions on mature leaves with light beige margins
Verticillium wilt	*Verticillium dahliae*	After sectioning, shoots show discoloured xylem tissues very characteristic for trees infected by *V. dahliae*; shoot wilting of certain portions of trees; and defoliation and sudden death of trees
Alternaria late blight	*Alternaria alternata*	Small black spots on leaves or necrotic large areas with sporulation in the centre; leaf blight; black lesions surrounded by red-coloured halo on epicarp of fruit; fruit blight
Botrytis blossom and shoot blight	*Botrytis cinerea*	Blossom and shoot blight; cankers initiated from male inflorescences common on '02–16' and '02–18' cultivars; blight and flagging of tender shoots of both male and female trees

Table A.11. Sporadic pistachio diseases recorded in California between 1985 and 1995.

Common name	Fungal pathogen	Main symptoms and signs	Year recorded
Phomopsis blight	*Phomopsis* sp.	Shoot and leaf wilting (flagging)	1985
Sclerotinia blight	*Sclerotinia sclerotiorum*	Shoot and leaf wilting and blight (flagging)	1985
Root and crown rots	*Phytophthora* sp.	Black lesions on the crown of scion but not extending into the rootstocks	1989
	Armillaria mellea	Decay of roots; white mycelial plaques and distinct black rhizomorphs	1990
Nut moulds	*Aspergillus niger*	Soft water-soaked hull covered with black sporulation on the surface touching the shell	1995
	Penicillium expansum and other *Penicillium* spp.	Disintegration of hull covered with bluish, greenish powdery sporulation. Greenish, bluish sporulation leading to soft disintegration of the hulls	1995

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Sclerocarya birrea marula

Marula, *Sclerocarya birrea* (A.Rich.) Hochs. (*Anacardiaceae*), is one of a select group of outstanding dryland African fruit trees. Much valued throughout a range encompassing over 30 countries extending at its widest some 8000 km, the species has been assigned names in numerous languages (Hall *et al.*, 2002). The best known of these are marula in southern Africa, sakoa in Madagascar, mngongo in East Africa, nobiga in Burkina Faso and neighbouring countries, birr (hence birrea) in Senegal and homeid in Sudan.

World production and yield

Considerable year-to-year fruit crop variation occurs between individual trees of *S. birrea*. Crops of over 0.5 t fresh fruit in a year have often been reported but are not generally representative. For a typical population, an estimated average annual crop of 60–90 kg fresh weight/tree (2000–3000 fruit) is more realistic (Lewis, 1987; Shackleton, 2002).

Products using the fruit flesh as initial raw material are internationally and regionally (mainly South Africa) marketed on a small scale. Currently, only a minute fraction (under 2500 t) of the potential annual fruit crop is used for this and the workforce involved is small (less than 1000 jobs, many seasonal). Liqueur, distinctive for the flavour imparted by *S. birrea* pulp, has been exported from South Africa for around 20 years while fruit juice, jams and chutneys are cottage-industry products in South Africa, Namibia and Botswana. Commercial interest in the oil is constrained by the difficulty of separating kernels from the endocarp and the small kernel weight per fruit (1.5% of fruit fresh weight; *c.*10% of whole endocarp). Nevertheless, the high oil quality is prompting efforts to overcome these complications and pilot initiatives have led to internationally marketed cosmetic products containing the oil.

Uses and nutritional composition

The fruit is a drupe, with a fleshy, edible mesocarp enclosing a hard endocarp containing 2–3 seeds rich in a useful oil. Archaeological evidence indicates that the fruit have been exploited in South Africa for over 10,000 years (Wynberg *et al.*, 2002), and in West Africa for over 1000 years (Neumann *et al.*, 1998). In the first half of the 20th century analyses revealed the suitability of the oil for soap making and the high vitamin C content of the flesh (Shone, 1979). Serious commercial initiatives are recent, however – since about 1980.

In the diversity of useful roles *S. birrea* has few rivals, but it is the nutritional value and famine food significance of the fruit flesh and kernels that has brought the tree special cultural status. Other significant uses are as utility timber, as livestock feed (fruit and foliage) and medicinal (Teichman, 1983; Hall, 2002). Fruit are important and the vitamin C-rich beer from them (Weinert *et al.*, 1990) is a regular rural market commodity. Both the pulp and the kernels have been nutritionally evaluated.

Reported values for proximate fractions (of dry weight) of the fruit pulp are: carbohydrate (68–85%); protein (3–7%); fat (1–10%); fibre (6–10%); ash (2–9%). Vitamin C concentration (mg/100 g fresh weight) is high in the skin (150–200), flesh (150–400) and juice (100–200). The kernel is rich in energy (2700 kJ/100 g), phosphorus (700–1900 mg/100 g) and potassium (500–700 mg/100 g). Fresh weight compositional values are given in Table A.12. Crude fat accounts for 55–65% of the dry weight and protein accounts for 20–35%. The dominant fatty acid is the unsaturated oleic acid (64–75% of total fatty acid content). A saturated acid, palmitic, contributes a further 11–18%. The main kernel amino acids are glutamic acid (180–270 mg/g of protein) and arginine (140–160 mg/g of protein). Lysine (18–24 mg/g of protein) and phenylalanine (48 mg/g of protein) contents are low. The oil is poor as a source of vitamin E but noteworthy for its favourable saturated:unsaturated fatty acid ratio and oxidative stability.

Botany

TAXONOMY AND NOMENCLATURE *Sclerocarya* is a genus of two species in the *Anacardiaceae* (Sapindales, Eurosid II clade – Soltis *et al.*, 2000; Judd *et al.*, 2002), referred to the tribe *Spondiadeae*. The other member of the genus, the Kenya endemic *Sclerocarya gillettii*, is the nearest relative. Collectively, however, the African/Madagascan *Spondiadeae* (*c.*50 species, currently in ten genera) invite taxonomic reassessment (Wannan and Quinn, 1991; Schatz, 2001).

Three subspecies of *S. birrea* (syn. *Poupartia birrea*) are recognized: subsp. *birrea*, from Senegal to Ethiopia and south to Tanzania; subsp. *caffra*, from Tanzania to South Africa and Madagascar; and subsp. *multifoliolata* endemic to Tanzania. The subspecies are separated on inflorescence and leaflet characters. Consideration here is at specific rather than subspecific level. The concentration of *Sclerocarya* and related genera in Africa suggests an African origin, apparently south of the equator. Northward migration of subsp. *birrea* could have been via an arid corridor near the Indian Ocean coast in the late Miocene/early Pliocene, with later spread westward.

Table A.12. Proximate fruit composition per 100g of *Sclerocarpa birrea* flesh and nut on a fresh weight basis.

Proximate	Flesh (%)	Nut (%)
Water	85	4
Energy (kJ)	225	2703
Protein	0.5	28.3
Lipid (fat)	57.3	0.4
Carbohydrate	12	3.7
Fibre	1.2	2.9
Ash	0.9	3.8
Minerals	mg	mg
Calcium	20.1	118
Iron	0.5	4.87
Magnesium	25.3	462
Phosphorus	11.5	808
Potassium	317	601
Sodium	2.24	3.81
Vitamins	mg	mg
Ascorbic acid	194	–
Thiamine	0.03	0.42
Riboflavin	0.02	0.12
Niacin	0.27	0.72

DESCRIPTION This deciduous tree usually reaches 9–12 m in height, occasionally more, with a taproot and widespreading lateral roots. At maturity the crown is rounded, but spreads impressively in very old individuals. In full leaf, the foliage is fairly dense and concentrated at the ends of stout branchlets. On old trees the bark of the trunk is rough, with roundish reddish-brown scales initially exposing light patches after shedding. The bark of young trees and shoots is smoother and paler. The leaves are alternate and imparipinnate, mostly with (depending on subspecies) 6–18 opposite, glabrous oblong to ovate, usually entire, leaflets 2–9 cm long.

With infrequent exceptions, the species is dioecious (Teichman, 1982). The male inflorescences, which arise in the axils of new or recently shed leaves, are racemes carrying several small groups of reddish flowers. The female inflorescence is reduced to a spike of one to four reddish flowers. The flowers are pentamerous, with short sepals and petals *c.*5 mm long. In each male flower there are 15–25 stamens around 3 mm long, surrounding a fleshy disc. Each female flower contains a subglobular ovary encircled by a disc with 15–25 staminodes around it. The ovary is of two to three cells, each with a single ovule. Three short lateral styles terminate in capitate stigmas. The drupe, 3–4 cm in diameter when ripe, is covered by a thick, tough exocarp, beneath which is a fibrous, fleshy mesocarp adhering to a very hard, obovoid endocarp. Each of two to three compartments within the endocarp contains a flattened seed 15–20 mm long.

ECOLOGY AND CLIMATIC REQUIREMENTS North of the equator, *S. birrea* occurs across Africa from Senegal on the Atlantic seaboard (17°W) to inland Eritrea and Ethiopia. Further south, in eastern Africa, the species reaches the Indian Ocean coast at 40°E, in Kenya. In northern Madagascar the eastern limit is 50°E. The latitudinal range is from 17°15'N (Aqr Mountains, Niger) to 31°S (Port Shepstone, South Africa). It is absent from the equatorial humid forest region. Outside the natural range the most important introduction has been to Israel for development as a potential horticultural crop (Mizrahi and Nerd, 1996), and it is widely thought that presence in Madagascar has also arisen from introduction in the distant past.

Sclerocarya birrea is mostly recorded from elevations below 1700 m, and associated with mean annual temperature > 19°C. South of the Tropic of Capricorn some populations experience occasional frost. In the natural range of the species the rainfall regime is strongly seasonal, with mean annual totals typically 500–1250 mm, 4–7 months having > 50 mm mean precipitation. Most occurrences are on deep, well drained, sandy or loamy soil, but heavier soils free of waterlogging support thriving populations in parts of southern Africa.

Sclerocarya birrea is typically a woody species of wooded grassland, parkland or grassland and individuals tend to be well separated and with full crown exposure. Natural populations are sparse, published assessments for areas of 1 ha or larger indicating numbers of individuals ⩾ 5 cm diameter to be well below five per ha (Nghitoolwa *et al.*, 2003). Selective elimination of male individuals for fuel or utility wood has modified gender ratios in favour of females in some areas. There is no regional consistency in the commonly associated woody species in the southern part of the range, but north of the equator *Acacia seyal*, *Balanites aegyptiaca*, *Commiphora africana* and *Tamarindus indica* often occur with *S. birrea*.

REPRODUCTIVE BIOLOGY Fruiting apparently starts in wild trees at an age of 7 to 10 years. Fruit are produced in quantity by an age of 15 to 20 years but the yield increases as the trees grow, to an age of well over 100 years (Shackleton *et al.*, 2002). Flowering is a dry season event, with fruit being dispersed as the succeeding rainy season starts. The flowers are small and entomophilous, producing little fragrance but a fair quantity of nectar attractive to bees, the main pollinator. Fully developed flowers open between dawn and midday. In the male flowers the anthers dehisce sequentially over 24–36 h, the pollen grains remaining viable for at least 12 h and often for more than 48 h. In the female flowers the stigmatic surfaces are receptive when the flowers open and remain so for up to 72 h. Secretion of nectar ceases on fertilization. The main natural disperser is the elephant, which swallows the fruit and transports them considerable distances. Today, however, cattle and humans are more important.

The anthesis to fruit maturity is 2–5 months, depending on temperature and plant moisture status. In years with a good crop, mature fruit fall over a 1–3 month period.

Horticulture

PROPAGATION Propagating *S. birrea* from seed is possible but effectively restricted to research and demonstration situations. There is little justification for inclusion in nursery-raised plants for distribution to farmers because the gender of individuals usually remains in doubt for 8–10 years and 50% will be male. There is some tradition of vegetative propagation using thick cuttings, which retain the gender of the source individual (Wynberg *et al.*, 2002) but success with conventional cuttings has been low. Given the dioecious character, grafting (Soloviev *et al.*, 2004) has received attention for combining known female scions with robust juvenile rootstocks but this, too, has proved difficult and remains at an exploratory stage. Recent experimental work using *Agrobacterium tumefaciens* suggests possible future use and vegetative multiplication of genetically transformed *S. birrea* (Mollel and Goyvaerts, 2004).

CULTIVATION When nursery seedlings of *S. birrea* are raised, the unit sown is the cleaned whole endocarp (200–500/kg, varying with locality), even though the two to three true seeds within contribute only 10% of the weight of this. A soaking treatment (24–48 h) is applied to loosen the caps closing the germination apertures, so they are pushed aside by pressure from the germinating seed. The first seeds are likely to germinate in 4 days but others will take longer. Over 4 weeks, seedlings should have developed from at least 80% of the endocarps. A medium of coarse sand enriched with manure is used, with a regime of watering twice daily. If root pruning or re-potting is undertaken, shade should be provided for the next 2 days. In the continuously warm West African environment, most seedlings should be 30–40 cm tall and ready for outplanting after 11 weeks. In the southern part of the range, winter sowing should be avoided and the nursery period is longer (up to 6 months).

POSTHARVEST HANDLING AND STORAGE *Sclerocarya birrea* has the unusual characteristic of dropping the mature fruit in a green state to complete the ripening process and turn yellow on the ground over the next few days. No systematic storage arrangements for fresh fruit are in general use but experimental investigations have indicated that satisfactory storage for 16 days is possible at 4°C (Weinert *et al.*, 1990). Local processing for beer is the dominant use and generally undertaken at or close to the parent trees. The fruit selected for processing are those at the appropriate ripening stage (slightly green). These are collected together in a shaded place to further ripen to a creamy yellow colour and are then processed. If commercial enterprises are supplied, fresh fruit are collected from source or delivered by middlemen. Where interest is in the kernel as a reserve dietary item, there is a tradition of storing whole endocarps in bulk off the ground. This approach preserves the quality of the kernels, which have a short shelf life once extracted.

MAIN PESTS Fruit pests include a beetle (*Carpophilus hemipterus*), a moth (*Cryptophlebia leucotreta*) and a fly (*Ceratitis cosyra*). *Sclerocarya birrea* is infected by several loranthaceous mistletoes among which *Erianthemum dregei* and *Pedistylis galpinii* are strongly associated with the tree in South Africa (Dzerefos *et al.*, 2003) but this impact has not been quantified.

MAIN CULTIVARS AND BREEDING A chromosome number of 2n = 26 has been reported for Mozambique plants (Paiva and Leitao, 1989). In southern Africa, through efforts to find a population including individuals yielding fruit as large as 100 g fresh weight with high juice, sugar and vitamin C content, superior wild trees have been identified in various locations. Some of these are under consideration for registration as cultivars (Wynberg *et al.*, 2002). On a wider front, variation is being assessed through regional and national multilocational provenance trials in eastern and southern Africa. Exploratory genetic studies have centred largely on germplasm of southern and East African origin. A possibility that historical events have modified a basic pattern of geographic variation has emerged but needs confirmation through more comprehensive sampling.

John B. Hall

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Semecarpus spp. marking trees and tar tree

The genus *Semecarpus* L. (*Anacardiaceae*) consists of about 50 species from Indo-China–Malaysia, Micronesia and the Solomon Islands. The young fruit have a tarry resin which when mixed with lime water or alum is used as a marking ink and dye. The resin from all parts of these trees frequently causes dermatitis due to phenolics and catechol. The nut of a number of the species are edible as is the fruit (swollen pedicel) when ripe.

Five species have fruit and nuts that are consumed. *Semecarpus anacardium* L. (synonyms *Semecarpus latifolia* Pers., *Anacardium latifolium* Lam., *Anacardium officinarum* Gaertner and *Anacardium orientale* Auct.) is known as the Indian marking nut tree, oriental cashew nut, bhilawa, kidney bean of Malacca and ostindischer tintenbaum (German). This medium-sized tree (15 m tall) has simple oblong to ovate-shaped alternate leathery leaves (20–60 cm long) that have hairs on the underside. The small greenish-yellow flower occurs on a panicle. The ripe, sweetish black fruit (2.5 cm long), which is the swollen pedicel, and the roasted nut are eaten. Young fruit are pickled in salt and vinegar. The pericarp of the fruit yields the black tarry juice known as bhilawan oil which when mixed with lime water yields an ink. The juice or oil is insoluble in water but soluble in alcohol, and has been used as an indigenous medicine for treatment of warts and piles.

Semecarpus australiensis Engl. is called ganyawu, tar tree and marking nut. This Australian native cashew is a well-known food source for aboriginal people of rainforest areas of north-eastern Queensland and the Northern Territory. The seed after processing can be eaten. The processed seeds (nuts) are tasty. The fleshy orange or red fruit can be eaten after baking.

The fruit of *Semecarpus cassuvium* Roxb. and *Semecarpus longifolius* Blume and the nut of *Semecarpus atra* (Forster) Vieill. are also reported to be eaten, with precautions. Robert E. Paull

Spondias cytherea ambarella

Ambarella, *Spondias cythera* Sonn. (*Anacardiaceae*), is from the Indo-Malaysian region to Tahiti and has been spread throughout the tropics. It is known as ambarella, Otaheite apple, wi or vi or evi-apple and greater hog plum in English, also as Tahitian quince or apple, Polynesian plum and golden apple. In Malaysia and Indonesia, it is known as kedondong; in

Thailand as ma kok farang; in Cambodia as mokak; in Vietnam as coc, pomme de cythere; in Costa Rica as juplon; in Colombia as hobo de racimos; in Venezuela as jobo de la India and mango jobo; in Brazil as caya – manga; in the Philippines heri, in Burma gway; and in Laos kook hvaan.

Three related species from South-east Asia have edible fruit. *Spondias acida* Bl. from the western Indo-Malayan area has acid fruit. *Spondias novoguineensis* Kostermans from New Guinea to the Solomon Islands is semi-cultivated and frequently confused with *S. cythera*. *Spondias pinnata* (Keonig ex. Linn. F) Kurz. is from Burma, India and Thailand and is cultivated for its edible fruit.

World production

Ambarella has been introduced from Melanesia through Polynesia to all tropical areas. Fruit are sold on the markets in Vietnam, Laos, Cambodia, Gabon and Zanzibar. It is cultivated in Queensland, Australia, Pacific Islands, Cuba, Haiti, Dominican Republic, Central America, Venezuela and from Puerto Rico to Trinidad in the West Indies (Morton, 1987).

Uses and nutritional composition

The pulpy flesh is eaten fresh when still firm and crisp, and also when ripe when the flesh is soft. When firm, the flesh is still crisp and juicy, and subacid with a pineapple-like fragrance and flavour. The green fruit is used for salads, curries, pickles and juices. Ripe fruit are also stewed and used for jams, jellies, juice and canned. As the fruit ripens, the skin and flesh turn golden yellow or orange. If soft, the aroma is musky and flesh is difficult to slice due to the tough fibres extending from the seed. The fruit's vitamin C content is reported at 36 mg/100 g and it is a good source of iron (Table A.13). Impact aroma volatiles include ethyl(S)(+) 2-methyl butyrate, ethyl isovalerate, ethyl propionate, ethyl butyrate, linalol and trans-pinocarveol (Fraga and Rezende, 2001). Young leaves are eaten raw or steamed as a vegetable with salted fish.

The fruit, leaves and bark have been reported to have medicinal value for the treatment of sores, wounds and burns. The bark is used mixed with other species to treat diarrhoea. The light-brown wood has a low density and has little timber value, though is has been used for canoes in the Society Islands. The gum has a high viscosity with galactose as the main component.

Table A.13. Proximate fruit composition per 100 g of *Spondias cytherea* (Source: Leung *et al.*, 1972).

Proximate	%
Edible portion	70
Water	86.9
Energy (kcal)	46
Protein	0.2
Lipid	0.1
Carbohydrate	12.4
Fibre	1.1
Ash	0.4
Minerals	**mg**
Calcium	56
Iron	0.3
Magnesium	–
Phosphorus	67
Potassium	95
Sodium	1
Vitamins	**mg**
Ascorbic acid	36
Thiamine	0.05
Riboflavin	0.2
Niacin	1.4
Vitamin A	205 IU

Botany

TAXONOMY AND NOMENCLATURE The synonym for *S. cytherea* Sonnerat is *Spondias dulcis* Soland Ex. Forst.

DESCRIPTION The rapidly growing tree can reach 10–18 m and is upright and symmetrical with a rounded crown. The bark is a light greyish brown and nearly smooth, often with four to five small buttresses. The leaves are pinnate (20–60 cm long) composed of 9–25 pairs of glossy, elliptic or obovate-oblong leaflets (6.25–10 cm long) on a short petiole (Fig. A.4). The whitish flowers are small and inconspicuous and are borne in large terminal panicles (50 cm long) appearing before the leaves. In each panicle, male, female and perfect flowers occur on short pedicels (1–4 mm). The calyx lobes are triangular (0.5 mm) and the petals (2.5 × 1 cm) are ovate-oblong. The fruit (up to 0.45 kg) are borne on long peduncles in bunches of a dozen or more and have tough thin skin that is often russetted. The fruit is an ellipsoid or globose drupe (4–10 × 3–8 cm) and changes from bright green to bright orange on ripening. The tough endocarp has irregular spiny and fibrous protuberances and contains one to five flat seeds.

ECOLOGY AND CLIMATIC REQUIREMENTS The tree grows well in the warm subtropics and tropics and grows up to 700 m in the tropics. Shaded trees produce little fruit and full exposure to sun is necessary. The branches are easily broken by strong winds and require a sheltered location. The tree is drought tolerant and may briefly lose its leaves under stress. Ambarella grows on all well-drained soils.

REPRODUCTIVE BIOLOGY The tree grows rapidly and flowers and bears fruit in 4 years. In the humid tropics, the tree produces more or less continuously. Vegetative flushing and flowering occur together. In areas with a dry season, flowering occurs on trees that are nearly leafless from lack of soil moisture. Subtropical conditions lead to flowering in spring. The dwarf selection flowers and produces fruit all year around. Fruit bats may assist in seed dispersal.

FRUIT DEVELOPMENT The fruit takes 6–8 months to mature.

Horticulture

PROPAGATION Often the tree is propagated from seeds that germinate in 1 month. Some seeds are polyembryonic.

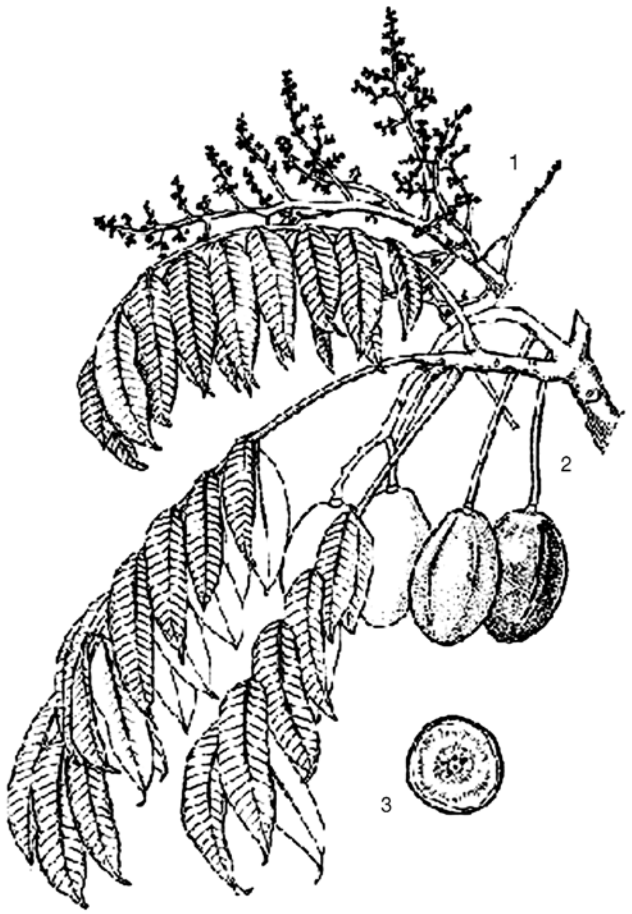

Fig. A.4. Leaf, flower and fruit of *Spondias cytherea* (Source: Verheij and Coronel, 1992).

Vegetative propagation is possible by hardwood cuttings and air layering, while grafting or shield budding on *Spondias* rootstocks is also used. Seedlings and grafted trees are more vigorous and may fruit in 4 years while budded trees and cuttings have less vigour. Tree spacing varies from 7.5 to 12 m.

ROOTSTOCKS It can be grafted on to its own rootstock. In India, *S. pinnata* Kurz. is used.

PRUNING AND TRAINING Fruit pruning within the panicle increases the size of the remaining fruit (Andall and Baldeo, 2000).

DISEASES, PESTS AND WEEDS The larvae of a beetle attacks the leaves in Indonesia, while in Costa Rica the bark is eaten by a wasp that causes necrosis. In the Caribbean, a disease called gummosis results in debarking of the stem and subsequent death of the tree and also black spots on the fruit. No major diseases are reported. Weeds are only problematic in the very young stages of growth and can be managed manually or with herbicides.

MAIN CULTIVARS AND BREEDING There are selections, but no recognized cultivars. Large variations in fruit quality (fruit acidity and spiny seeds) have been reported. Recently in Grenada, attempts have been made to cross the usual ambarella with the dwarf type that grows to a height of 3 m and produces fruit of about 65 g weight in about 12 months.

Reginald Andall and Robert E. Paull

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Spondias mombin yellow mombin

Yellow mombin, *Spondias mombin* L. (*Anacardiaceae*), is in the same family as cashew, mango and pistachio. The fruit, also known as the tropical plum, has several regional names: in English it is hog plum or yellow mombin in North America and the Caribbean islands; thorny hog plum in Malaysia; Ashanti plum in Ghana; in Latin America the Spanish names are caimito, ciruela agria, jobo, jobo jacote, ciruela de monte, ciruela amarilla, obo and uvo; in French Guiana the name is prunier mombin; and in Brazil it is called taperebá, cajá or cajá-mirim.

Spondias mombin is the most economically significant species within the genus that occurs in Brazil. No commercial orchards occur in Brazil and all fruit is collected from wild plants. The fruit is attracting attention not only to meet local market needs in the region of occurrence, but also from other parts of the country where it is highly appreciated and commercialized as frozen pulp. The frozen pulp is one of the most prized pulps in Brazilian markets and the price remains high even during the harvest season. According to pulp manufacturers, purchasers may even request a supply of yellow mombin pulp as a condition for buying other pulps.

The major limitation for the cultivation is the height of the tree – up to 30 m – and the lack of cultivars that can be recommended for commercial orchards.

World production and yield

The species is found throughout tropical America and in the tropical regions of Africa and Asia. In Brazil, the trees are found either isolated or in groups, in forests, grasslands and pastures, as well as in backyards of the north and north-east states. The plant is native to moist lowland forests from southern Mexico to Peru and Brazil. It is grown commercially to a limited extent. In Brazil, all fruit is obtained from native plants. The plant produces once a year, and harvest season varies according to climate conditions, usually between early December and late February. Adult trees in Mexico produce over 100 kg/year.

Uses and nutritional composition

The fruit is a drupe, with a thin layer of yellow, translucent, fleshy, juicy, sweet-sour and very aromatic mesocarp surrounding a bulky endocarp. In Brazil, the ripe fruit is eaten fresh, the edible portion being the exocarp and mesocarp, which together may represent as much as 81% of the fresh weight (Table A.14). Extracted pulp is frozen and sold as such to restaurants, hotels and snack bars to make juice. It is also used in ice cream and jam. In other Latin American countries, it is stewed with sugar and made into jam and the green fruit can be pickled. The fruit has a good supply of ascorbic acid (Table A.15). The major volatile components are ethyl acetate, ethyl butynate, ethyl hexanoate, hexyl butynate and linalool.

Table A.14. Characterization of ripe *Spondias mombin* L. fruit, Fortaleza, Ceara, Brazil, 2000 (Source: adapted from Filgueiras *et al.*, 2000).

Characteristics	Average figures
Fruit weight (g)	19.92
Pulp + exocarp (%)	81.65
Endocarp (%)	18.34
Length (mm)	43.10
Diameter (mm)	32.20
Soluble solids (%)	11.56
Titratable acidity (% citric acid)	1.03
Soluble solids/titratable acidity ratio	11.23
pH	3.17
Soluble sugars (%)	8.41
Reducing sugars (%)	7.65
Starch (%)	52
Total pectin (%)	28
Soluble pectin (%)	7
Pectin fractions in alcohol insoluble solids	
High methoxylation (%)	10.30
Low methoxylation (%)	2.11
Protopectin (%)	2.21
Pectin methylesterase (UAE)[a]	36.231
Polygalacturonase (UAE)	18.32
Total vitamin C (mg/100g)	36.86
Water-soluble phenolics (%)	12
Methanol-soluble phenolics (%)	11
50% Methanol-soluble phenolics (%)	14

[a]UAE, units of enzyme activity.

Table A.15. Proximate analysis of ripe *Spondias mombin* L. edible pulp per 100 g (Source: Leung and Flores, 1961; Morton, 1987).

Proximate	g
Moisture	73–89
Energy (kcal)	22–48
Protein	1.3–1.4
Fat	0.1–0.6
Total carbohydrate	8.7–10.0
Fibre	1.2
Ash	0.65
Minerals	**mg**
Calcium	31
Iron	2.8
Phosphorus	31
Vitamins	**mg**
Ascorbic acid	28–46
Thiamine	0.095
Riboflavin	0.05
Niacin	0.5
Vitamin A	71 IU

The yellow to yellowish-brown light and flexible wood of *S. mombin* is used to some extent for woodcraft, the bark and leaves contain ellagitannins with therapeutical properties. Like other *Spondias*, the tannin in the bark is used for tanning and dyeing. An exuded gum is used as glue, and the young leaves can be eaten as a cooked vegetable.

A decoction of the bark serves as an emetic substance, a remedy for diarrhoea, dysentery, haemorrhoids, gonorrhoea and leucorrhoea. The powdered bark and dried leaves are applied to wounds. A tea made from flowers and leaves is recommended to relieve stomach aches, biliousness, urethritis, cystitis and eye and throat inflammation.

Tannins with antiviral activity against the viruses Herpes Simplex type 1 and Coxsackie B2 were isolated from the alcohol extracts of leaves and branches of *S. mombin*. In Nigeria there are reports of the antimicrobial potential of leaf extracts being comparable to those of ampicillin and gentamycin, as well as its use by traditional medical practitioners in the treatment of various nervous diseases (Abo *et al.*, 1999). A decoction of leaves is traditionally used in the Venezuelan Amazon to treat malaria.

Botany

TAXONOMY AND NOMENCLATURE The genus *Spondias* was created by Linnaeus in 1753, with *S. mombin* L. as the only species. Later, this genus was expanded to include *Spondias purpurea* L., *Spondias cytherea* Sonn. and *Spondias pinnata* (L.f.) Kurz. The genus *Spondias* now has 18 species, of which nine species occur in Asia and Oceania (Pacific Ocean), and nine in the neotropics, including a species introduced from Asia and a new species, called *Spondias testudinis* Mitch. and Daly, found in the south-west Amazon.

DESCRIPTION Yellow mombin is a woody fruit tree of tropical climates, still under domestication. It is an erect, tall tree (up to 30 m) ramified at the top, with deciduous leaves; a trunk covered with thick, rough bark bearing, in young trees, many blunt-pointed spines or knobs up to 2 cm long; and a wide, attractive and impressive canopy in the flowering or fruiting seasons. The most variable characteristics are: division of the leaves – simple, pinnate or bipinnate; margins of the leaflets – entire or crenate; intra-marginal leaf vein – present or absent; inflorescence – precocious or not, terminal and composite or lateral and almost simple; number of carpels – from one to four or five; and endocarp shape and structure.

The whitish flowers usually occur in terminal pyramidal panicles from 20 to 60 cm long. Male, female and hermaphroditic flowers are found in inflorescences of the same plant. The flower has a calyx about 5 mm wide; a round receptacle 1–4 mm long; five sepals; five petals; ten stamens, five of which are inserted in a disc and alternate with the petals and five epipetalous. The number of flowers per panicle may reach as high as 2000 (Plate 9), and the number of fruit per cluster is highly variable both within and among plants.

The ovoid to oblong fruit hang in branched terminal clusters of a dozen or more (Plate 10). Each fruit is 3–4 cm long and up to 2.5 cm wide, golden yellow with a thin, tough skin. The medium-yellow translucent pulp is very juicy and fibrous. The somewhat musky acid flesh clings to the white fibrous or 'corky' stone.

ECOLOGY AND CLIMATIC REQUIREMENTS The species occur in Asia, Oceania and tropical America, and the centres of diversity are the Atlantic Forest and West Amazon in the State of Acre, Brazil, and the adjoining areas of Peru and Bolivia. In Brazil, the trees are found either isolated or in groups, in the moist topical forests of the Amazon, and the Atlantic Forest. In the humid zones of the north-east Atlantic states, it is found mainly along the coast and lowland. The trees are found in the wild, maintained or in domestic yards.

It is adapted to grow in humid and arid areas and even in warm subtropical areas with no frost. It does not grow satisfactorily above 1000 m. In tropical America, the tree grows in areas with average annual rainfall between 1000 and 2000 mm, even though there is usually a dry season of up to 5 months. The soil types in these areas are oxisols, ultisols and inceptisols with a pH from as low as 5.0 to above 7.0. The species tolerates soils with a moderately low nutrient status.

REPRODUCTIVE BIOLOGY The reproductive system is polygamous-dioic or monoic and self-incompatible. The yellow mombin tree bears hermaphroditic and strongly protandrous flowers, that is the ovary has not fully developed before pollen release. This sequence leads to cross-pollination and the undesirable variability found in orchards propagated from seed.

Flower panicles emerge after new vegetative growth which occurs following rain. In Costa Rica, the tree blooms in November/December and again in March while in Jamaica flowering occurs in April, May and June. In the north-east of Brazil it blooms only once, in the dry season, usually in August/September and fruit ripen in the rainy season (January/February).

In Mexico, trees start to produce fruit by the age of 5 years.

FRUIT DEVELOPMENT Fruit growth is sigmoid and it takes 3–4 months to develop from anthesis. Maturation starts around 80 days after anthesis and the fruit abscise when fully ripe. Ripening is associated with a decline in skin chlorophyll and acidity and increase in carotenoids and soluble solids (Costa *et al.*, 1998). Changes in acidity and soluble solids are more pronounced during the last 15 days of maturation. Fruit ripen over 4 days from the light green maturity stage.

Horticulture

PROPAGATION AND ROOTSTOCKS Yellow mombin are propagated by seeds, or asexually by cuttings, grafting or *in vitro*. The fruit endocarp or stone, contains from none to five seeds in each locule and germination is low and slow. Physical and chemical scarification of seeds increases germination percentage. High variation is found in seed-propagated trees in height, architecture and shape of canopy, physical-chemical characteristics of fruit and leaves, length of the juvenile phase, and variation in phenological phases.

Vegetative propagation can be done using cuttings from stem or roots, air layering and grafting. Cleft and side-cleft grafts onto rootstocks of *Spondias tuberosa*, *S. cytherea* or *S. mombin* are used. A high percentage of these grafts are formed within 60 days of grafting.

PRUNING AND TRAINING Grafted plants have high growth rates with single-stem trunks that tend to form a high canopy, branching at the top like seed-propagated trees. Pruning and training are required during the first year to reduce height and develop a more ramified canopy.

NUTRITION AND FERTILIZATION Fertilizer requirements have not yet been determined experimentally and adaptations of recommendations for other perennial fruit trees that grow in similar conditions are used. Campbell and Sauls (1991) suggest that under Florida conditions fertilizer should be applied every 2–3 months during the first year, beginning with 100 g and increasing to 450 g of 6–6–6–3 or similar analysis. Thereafter, three to four applications per year are sufficient, in amounts proportional to the increasing size of the tree, roughly a 450 g application/year of tree age. Bearing trees can receive 8–3–9–5 or similar analysis fertilizer at the same rates three to four times a year.

POSTHARVEST HANDLING AND STORAGE Fruit are harvested after the start of chlorophyll breakdown, when the fruit turns from light green to yellow. If harvested before this turning stage the fruit will soften and change colour, but there will be little changes in acidity, soluble solids and starch contents and the final quality will be poor.

Harvested fruit are transported in 20 kg containers to retail stores. It is also displayed in polystyrene trays containing around 200–300 g fruit wrapped with usually 12 μm polyvinylchloride (PVC) plastic film.

Storage life at 23–25°C is about 4 days for fruit at the light-green stage and less than 2 days for ripe fruit. Under refrigeration at 9–10°C the storage life can be increased to 10 days. At low temperature the fruit develops chilling injury.

PESTS AND DISEASES Commercial cultivation is still not significant and only the major pests and diseases have been recorded. The economic importance of these pests and diseases is unknown. In some cases, pests or pathogens only attack parts of the plant, causing superficial damage.

Fruit flies (*Anastrepha* spp.) attack the fruit and do reach a level of economic loss in low density planting. The leaves are attacked by the sauva ant (*Atta*) and by *Stiphra robusta* Leitão. The terminal branches are attacked by larvae and the seeds and endocarps are damaged by weevils.

The major pathogens include *Glomerella cingulata*, which causes anthracnose in leaves, inflorescences and fruit. *Sphaceloma spondiadis* causes round rough-textured lesions on leaflets and fruit characterized by cream-coloured centres and light brown borders. *Botryosphaeria rhodina* causes resinosis, with the development of dark cankers that are sometimes cracked, and abundant gum exudation, and when the lesion surrounds the trunk or branch it causes yellowing, wilting or death of the branch or the whole plant. Cercosporiosis disease caused by *Mycosphaerella mombin* affects the leaves and begins with small, round pit spots that become darker and coalesce, causing yellowing and leaflet fall. Nematodes (*Meloidogyne* spp.) attack both adult plants and plantlets. The wood is easily attacked by termites.

MAIN CULTIVARS AND BREEDING There are no reports of clones or varieties of superior quality that might be recommended for cultivation. EMBRAPA Tropical Agroindustry in Brazil is evaluating the behaviour of a number of clones with promising results. Heloisa Almeida Cunha Filgueiras and Francisco Xavier de Souza

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Spondias purpurea red mombin

The red mombin, *Spondias purpurea* L. (*Anacardiaceae*), is an aromatic fruit, highly valued for local people in the tropics since old times. The species is probably native to southern Mexico and Central America, where wild populations are still found. Early Spanish navigators took the red mombin to the Philippines. In Jalisco (Mexico) during the 19th century, red mombin was one of the most important fruit crops. Nowadays, fruit can be readily found in local markets. In Ecuador, it is commercialized and found in some supermarkets of the big cities.

The most widespread vernacular name in South America and Philippines is ciruelo, although in Central America and Mexico it is also widely known as jocote, and in some parts of South America as ovo. Many orthographic and phonetic variants of these common names have been recorded.

World production

The red mombin is the most cultivated species in the genus *Spondias*. It has been cultivated widely throughout the neotropics, from central Mexico and the West Indies, to Peru and Brazil. It is naturalized in the Antilles from cultivation, including the Bahamas, and has also been cultivated in Florida, USA (Popenoe, 1979). There are no data for world production. In Ecuador, yields of more than 4500 t/year were reported within the period 1987 and 1990–1992. In an Ecuadorean Andean dry area, the average yield ranged between 2250 to 5000 kg/ha from dry season varieties (Macía and Barfod, 2000).

Uses and nutritional composition

The tree is commonly planted as a living fence. The ripe red mombin fruit are mainly eaten fresh, but sometimes are harvested green and eaten with salt as a snack. In Mexico, ripe fruit are sometimes boiled in water with or without salt and only eaten dried afterwards. In Florida, dried slices of ripe fruit have been occasionally commercialized. The soft exocarp is easily injured and so the mesocarp is processed into marmalade, juice, wine and liquor. The pulp is used as a flavouring for ice cream.

The fruit of red mombin have a good calorific density (Table A.16) due to the high concentration of total carbohydrates (19.1%). Fructose, glucose and sucrose together account for 65% of the total soluble solids. It is a moderate source of potassium and starch, and a good source of vitamin C (Koziol and Macía, 1998). The main flavour compound is 2-hexenal.

Table A.16. Chemical composition of red mombin (*Spondis purpurea*) per 100 g (Source: Koziol and Macía, 1998).

		Range	Average
Proximate		g	g
Moisture		65.0–87.0	77.6
Food energy (kcal)		61–86	74
Protein		0.1–1.0	0.7
Fat		0.03–0.8	0.2
Total carbohydrates		16.0–22.3	19.1
Fibre		0.2–0.7	0.5
Minerals (ash)		0.3–1.1	0.7
Minerals		mg	mg
Calcium		6–25	17
Iron		0.09–1.22	0.72
Phosphorus		32–56	42
Sodium		2–9	6
Potassium		230–270	250
Zinc		–	20
Vitamins		mg	mg
Ascorbic acid		26–73	49
Thiamine		0.033–0.110	0.084
Riboflavin		0.014–0.080	0.040
Niacin		0.4–1.8	1.0
Carotene c		0.004–0.225	0.119
Pulp composition	units		
pH	%		3.29
Total soluble solids	g		18
Starch	g		2.47
Pectins	g		0.22
Fructose	g		2.53
Glucose	g		2.00
Reducing sugars	g		8.08
Sucrose	g	5.97–7.21	6.59
Citric acid	mg		30
Malic acid	mg		110
Oxalic acid	mg		30
Tartaric acid	mg		20

Botany

TAXONOMY AND NOMENCLATURE *Spondias* is a pantropical genus composed of approximately 18 species, with the centre of diversity in South-east Asia. In tropical America, there are nine species. Some of the species (*Spondias dulcis* and *Spondias mombin*) have been introduced throughout the tropics to the drier areas in Africa, Asia and the South Pacific for their edible fruit. *Spondias purpurea* is a well-defined and taxonomically separate species (Barfod, 1987). No taxonomic treatment is available of the varieties nor of the species' genetic diversity.

DESCRIPTION *Spondias purpurea* is a small deciduous tree, 3–15 m high, with grey and usually smooth bark. A rather thick and transparent exudate exudes from cuts and bruises. The imparipinnate leaves are 6–28 cm long and 5–27-foliolate with a 15–20 cm rachis. The leaflets are usually 3–6 cm long and 1–2.5 cm wide, elliptic to oblanceolate. The axillary inflorescences are 1–10 cm long, few-flowered, usually produced at older and defoliate nodes. The petals are usually red to purple, 2.5–3.5 mm long at anthesis. The fruit is a drupe, which is oblong to obovoid or subglobose 1.5–4.5 cm long and 1–3.5 cm wide. When ripe, the fruit is usually red but sometimes yellowish or orange. The mesocarp is fleshy and juicy, and the endocarp is 1.5–3.5 cm long.

ECOLOGY AND CLIMATIC REQUIREMENTS Natural populations of red mombin in Mexico and Central America are found in both dry and wet areas, including a wide range of semi-deciduous forests. It has been cultivated from 0 to 2000 m elevation with an average annual precipitation varying from 300 to 1800 mm. The tree is able to grow normally on rocky substrates, slopes or different soil types including those of little agricultural value due to a wide physiological and anatomical plasticity (Pimenta-Barrios and Ramírez-Hernández, 2003). A mycorrizal symbiosis can be associated with the root and this favours plant growth by promoting phosphorus absorption.

REPRODUCTIVE BIOLOGY Flowering time varies with climate, but usually occurs during the dry season when trees are defoliated or just as the young new leaves emerge. New vegetative shoots are produced and may constitute the major part of the potentially flower-bearing ramets. In areas with more year-round precipitation, flowering may occur nearly all year round. In dry areas, depending upon the tree's phenology, flowering can be controlled by carefully planned irrigation (Macía and Barfod, 2000). If trees are treated with 12% urea to induce defoliation, flowering is advanced by 30–40 days (Almaguer-Vargas *et al.*, 1991). There is no information on pollination.

FRUIT DEVELOPMENT The fruit develop parthenocarpically and take about 115 days from anthesis to the start of ripening (De Melo and Pereira, 2001). The new vegetative shoots and the fruit mature at the same time. Fruit usually ripen during the dry season, so that a high number of hours of exposure to full sunlight produces more sugars and hence better fruit quality. Fruit harvested at the skin-breaker stage (Plate 11) do not develop the characteristic full red colour and the fruit after harvest need to be sorted by colour (Plate 12). The best storage temperature is about 15°C for a maximum of 10 days. Harvested fruit held at 25°C ripen in 3–5 days (Manzano, 1998).

Horticulture

PROPAGATION Since the tree only infrequently produces viable seeds (Juliano, 1932), propagation is by vegetative cuttings. After the harvest, when the leaves have been shed and flowering has just started, cuttings 1–2.5 m long are obtained from the best clones. The cuttings are left in the shade for about a week and then planted 3–7 m apart, at a depth of 30–40 cm. The soil is irrigated after transplanting to stimulate rooting. Grafting on other rootstocks such as *Spondias pinnata* is possible. In Mexico and Ecuador, pruning is mainly done to keep the trees short and to facilitate harvesting from the ground. No fertilization requirements have been reported.

DISEASES, PESTS AND WEEDS No important diseases and pests have been recorded. Fruit flies may cause serious damage to ripe fruit. In dry areas just before flowering, the branches are cleaned to remove epiphytes. In Ecuador orchards have been fumigated by smoke from fires along the margins of the orchard, but occasionally chemical insecticides have been used. Weeding is necessary one or two times a year in dry areas while three or four times a year in wet regions.

MAIN CULTIVARS AND BREEDING There are two main groups of non-commercial varieties: dry-season and wet-season red mombins. Fruit of the first variety are smaller, albeit sweeter and slightly less acidic than those of the second variety (Macía, 1997). The fruit of the first variety are 2.7–3.9 cm long by 1.9–3 cm wide, compared to the larger fruit of the second variety, which are 3.1–4.5 cm long by 2.4–3.5 cm wide. Often cultivars bear the name of the area of origin or fruit characteristics. Dry-season mombin varieties include 'Tronador', 'Crillo', 'Nica', 'Morado', and 'Rojo Ácido', while the wet-season mombins are 'Corona', 'Petapa' and 'Cabeza de loro' (Leon and Shaw, 1990).

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Tapirira guianensis wild mombin

Wild mombin, *Tapirira guianensis* Aublet. (*Anacardiaceae*), is a tropical species found from Mexico south to Amazonia, to Peru and Bolivia and Paraguay. In Brazil, it is found on the

Atlantic coast from Rio in the south to Ceara and Amapa in the north, and into parts of Guyana, Venezuela, Colombia and Panama. Common names include tapiriri, tapirirá, cedro-y, cupiúva, fruta de pombo, guapiruva, pau pombo, peito de pomba and jobo in Brazil; duka and waramia in Guyana; weti-oedoe and ook doka in southern Mexico; piojo and caobina in Honduras; isaparitsi, huira caspi and huira caspi colorado in Peru; fresno, cedrillo and cedro macho in Colombia; cedrillo and capuli in Ecuador; and jobillo and cedro nogal in Venezuela. In English it is wild mombin and white mombin, and in French gommier viande biche, mombin sauvage and tapirier de la Guyane.

Uses and nutritional composition

The fruit is edible and can be dried.

Botany

TAXONOMY AND NOMENCLATURE The genus *Tapirira* is pantropical with about 15 species that are found in Asia, Africa and the Americas. Only one species has edible fruit *T. guianensis* Aublet and its synonym is *T. miryantha* Tr. and Pl.

DESCRIPTION The tree can reach 30 m in primary forests but under poor conditions is much less. The trunk has some buttresses and the bark is clear grey with some reddish brown, smooth when young becoming irregular with sinuous cracks. The sapwood is white and exudes a resin that has a sweet balsamic odour. The leaves are alternate without stipules with a variable number of leaflets (5–15). The leaflets are oblong (10 × 3.5 cm). The inflorescence is a long terminal panicle, covered with very small yellowish-white hermaphroditic or more often unisexual flowers. The five oblong petals are 2 mm long. The ovoid ovary (1.5 mm) has one ovary with five disjoined styles (0.3 mm). The fruit is a small drupe (10 × 8 mm) with a smooth yellow skin that turns black upon ripening. The edible mesocarp encloses one seed.

ECOLOGY AND CLIMATIC REQUIREMENTS The tree is found in the dry plains of Brazil in the low ground forests as a small tree. In moist forest areas it can reach 35 m height and 70 m diameter. It can be found from 50 to 900 m in elevation. The tree prefers deep, well-drained soils.

REPRODUCTIVE BIOLOGY In Honduras, flowering is observed from April to June and fruit mature 5 months later from August to September.

Horticulture

The seeds are recalcitrant and need to be planted soon after removal from the fruit. Insects and disease have not been reported.

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ANNONACEAE

Annona cherimola cherimoya

Cherimoya, *Annona cherimola* P. Mill. (*Annonaceae*), is a subtropical fruit with white, delicate, sweet flesh containing many large seeds. It is thought to have originated in the highland Andes' valleys between Peru and Ecuador at 1500–2000 m. Its antiquity is attested to by ancient artefacts shaped in the form of the fruit in Peru. Distribution through Central America and Mexico probably occurred at an early date as it has become naturalized in the cool highland areas. Distribution continued from Mexico to the Caribbean islands, then to the African coast and the Mediterranean. Introduction to Africa and the Far East is attributed to early Spanish navigators. *Annona cherimola* is known as cherimoya, chirimoya (Spanish), cherimolier (French), anona (Mexico) and noina ostrelia (Thailand).

World production and yield

The cherimoya is considered the best of the annonas and is cultivated in subtropical regions and in the tropical highlands. In most areas, it is grown as a backyard tree or as part of a subsistence farming system at appropriate elevations. Commercial production occurs in Spain, Bolivia, Chile, Peru and New Zealand. World production in 1998 was estimated at about 100,000 t (Van Damme and Scheldeman, 1999). Spain had 3600 ha that yielded 35,000 t, Peru 1800 ha and 15,000 t and Chile 1200 ha and 12,000 t. Experience has shown that the Californian coastal regions are more conducive to cherimoya production, having higher relative humidity (70–80%) in spring and summer than the interior valleys where the relative humidity can drop to 40% and below during the hotter part of the day during summer.

Uses and nutritional composition

Cherimoya is most often consumed as a dessert fruit eaten out of the hand, or scooped with a spoon. It can be served in fruit salads, sorbets, custards and pies. The fruit is high in calories and fibre. Cherimoya is a fair to good source of niacin and vitamin C (Table A.17). The seeds of the annonas are toxic.

Botany

TAXONOMY AND NOMENCLATURE The genus *Annona* is the most important in the *Annonaceae*, since among its 100 or more species, seven species and one hybrid are grown commercially. The *Annonaceae* (130 genera, 250 spp.) are considered a 'primitive' member of the *Magnoliidae*. *Annona cherimola* is closely related to *Annona glabra* and *Annona reticulata*, both morphologically and allozymes (Samuel *et al.*, 1991).

DESCRIPTION The tree is erect but low branched and somewhat shrubby or spreading, ranging from 5 to 9 m in height with young branchlets that are rusty-hairy. The leaves are briefly deciduous (just before spring flowering), alternate, two-ranked, with minutely hairy petioles 6–12.5 mm long; ovate to elliptic or ovate lanceolate, short blunt-pointed at the apex; slightly hairy on the upper surface, velvety on the underside; 7.5–15 cm long, 3.8–8.9 cm wide. New buds

Table A.17. Proximate fruit composition of cherimoya which has an edible flesh to fruit ratio of 65% (Source: Wenkam, 1990).

Proximate	%
Water	68.7
Energy (kcal)	110
(kJ)	460
Protein	1.54
Lipid (fat)	0.13
Carbohydrate	28.95
Fibre	–
Ash	0.67
Minerals	**mg**
Calcium	9
Iron	0.25
Magnesium	–
Phosphorus	24
Potassium	–
Sodium	–
Vitamins	**mg**
Ascorbic acid	12.2
Thiamine	0.11
Riboflavin	0.11
Niacin	1.0
Vitamin A	–

cannot sprout until the leaves have shed as the leaf bases grow over the axillary buds as in sweetsop.

Flowers are fragrant, solitary or in groups of two or three, on short hairy stalks along the branches, having three outer, greenish, fleshy, oblong, down petals to 3 cm long and three smaller, pinkish inner petals. A compound fruit, the cherimoya is conical or somewhat heart-shaped, 10–20 cm long and up to 10 cm in width, weighing on average 150–500 g but extra large specimens may weight 2.7 kg or more (see Fig. A.5 in entry for *Annona muricata*). The skin, thin or thick, may be smooth with fingerprint-like markings or covered with conical or rounded protuberances. The fruit is easily broken or cut open, exposing the snow-white, juicy flesh, of pleasing aroma and subacid flavour, and containing numerous hard, brown or black, bean-like, glossy seeds, 1.25–2 cm long.

ECOLOGY AND CLIMATIC REQUIREMENTS Cherimoya is capable of growing in a wide range of soil types from sandy soil to clay loams. Higher yields occur on well-drained sandy to sandy loam soils. Drainage is essential to avoid root rot diseases, hence the interest in *A. glabra* as a rootstock related to its tolerance of wet soils.

Cherimoya benefits from uniform soil moisture for good production with extremes of moisture lowering production. Rainfall and high humidity during peak flowering season greatly enhance fruit production by preventing desiccation of stigmas, prolonging their receptive period and increasing fruit set and early fruit growth.

Temperature is the limiting factor, with frost killing young trees, but older trees show some tolerance. Cherimoya (7–18°C, mean minimum) is more tolerant to low temperatures than the least tolerant soursop (15–25°C mean minimum). Cherimoya requires chilling periods and does not do as well under lowland conditions (George and Nissen, 1987b) and benefits from dry periods. Cherimoya is susceptible to high temperatures with a growing temperature of 21–30°C (George and Nissen, 1986b). Poor pollination is a frequent problem and occurs under high temperature (30°C) and low humidity (30% relative humidity (RH)). Lower temperature (25°C) and high humidity (80% RH) greatly improves pollination. Hand pollination is recommended for cherimoya to achieve more uniform fruit shape. No photoperiod responses have been reported.

The softwood of the trees makes them susceptible to wind damage and limb breakage. Tree shaking may also be partially responsible for collar rot organism penetration. The fruit skin is easily damaged by rubbing and exposure to drying winds (Marler *et al.*, 1994). Productivity can be improved by windbreaks and under-tree sprinkling to raise the RH above 60%.

REPRODUCTIVE BIOLOGY The flowers are hermaphrodite and are produced singly or in small clusters on the current season's growth, although flowers arising from old wood are common. New flowers continue to appear towards the apex of the shoot as flowers produced earlier at the basal portions mature.

Reducing irrigation in late winter to force cherimoya trees into dormancy for 1–2 months in spring is recommended in California to induce flowering. Cherimoya generally requires 27–35 days for flower bud development from initiation to anthesis. Differences in floral behaviour in the various areas may be attributed to both genetic variability and climatic differences. Flowering can extend from 3 to 6 months or even longer, with heavy peaks. Two major flowering periods occur after periods of vegetative flushes with the second peak coinciding with the onset of monsoon in India.

The flowers exhibit both dichogomy and a protogynous nature. This poses a serious problem in obtaining high yields. Cherimoya flowers are receptive, opening around 7–9 a.m. and when pollen is shed at 3–4 p.m. if the relative humidity is above 80% and temperature >22°C. The flower shows synchrony with that of sweetsop and this together with complementary functional sexes favours cross-pollination leading to natural hybridization. This is attested to by the frequent appearance of hybrid seedlings under the trees of sweetsop and cherimoya when grown in close proximity. Nitidulid beetles (*Carpophilus* and *Uroporus* spp.) are the important pollinators of annona flowers with wind and self-pollination being low (1.5%).

Pollen grains appearing early in a flowering season have thick walls, are high in starch, germinate poorly, and give poor fruit set (Saavedra, 1997). Pollen of later flowers show a high proportion of individual pollen grains without starch grains that germinate well. Hand pollination is frequently practised to ensure pollination and good fruit shape. Pollen must be collected in the evening from fully open flowers, when the sacs have turned from white to cream. The flowers are held in a paper bag, not a closed container, and should discharge that afternoon. The flowers are shaken over a shallow tray or paper to collect the pollen, which is transferred to a small container and held in the refrigerator for use the next morning. Pollen from 20–30 flowers can give enough pollen to pollinate 50–60 flowers. Hand pollination has shown some variable results and is less successful on very humid, overcast days and on young vigorous trees. About 150 flowers can be pollinated in an hour and a success rate of 80–100% can be achieved.

FRUIT DEVELOPMENT Fruit growth shows the typical sigmoidal curve with maturation occurring in 16–24 weeks depending upon growing conditions. Low humidity (<60% RH) and temperature (<13°C) near fruit maturity can increase the severity of fruit skin russetting as well as delaying fruit maturation.

Fruit is harvested when fully mature and firm. The skin colour changes as the fruit approaches maturity. Skin of immature cherimoya is greyish green but turns to yellow-green at maturity. Determining harvest time by dating floral anthesis is impractical as flowering occurs over many months. If a rigid hand pollination protocol is used with removal of naturally pollinated fruit, days from anthesis can be used.

Horticulture

PROPAGATION *Annona* spp. are usually propagated by seed. A rapid loss of seed viability occurs (6 months) and seeds should be planted as soon as possible after removal from the fruit (George and Nissen, 1987c). Seeds can take up to 30 days to germinate and gibberellic acid (10,000 ppm) can significantly increase germination and enhance seedling growth. Seedlings require at least 3–4 years to bear fruit (Sanewski, 1991).

Clonal propagation by cuttings, layering, inarching, grafting and budding have been tried. Inconsistent results are obtained with cherimoya when 1-year cuttings are treated with rooting hormones. Cherimoya is not easily propagated by air layering (less than 5% success). A modification where the new shoot is clamped and only the shoot tip is exposed is successful. Inarching of *A. cherimola* to *A. reticulata* rootstock has been successful with only *A. glabra* giving less than 70% success. Although inarching has given good results, it is time consuming and costly for large-scale propagation (George and Nissen, 1987c). Grafting is superior to budding in percentage takes and subsequent growth, with side whip graft and cleft graft techniques giving the best results (Duarte *et al.*, 1974). The branches should be defoliated 1–2 weeks before scion-wood is cut to induce bud swelling. T-budding and chip budding methods are successful.

ROOTSTOCKS There are considerable graft incompatibilities among *Annona* and *Rollinia* species and types. Cherimoya has been found to be a vigorous rootstock for ‘Pink’s Mammoth’ (atemoya) (Sanewski, 1991). This is complicated by cultivar differences in compatibility with common rootstocks. Cherimoya has been successfully grafted onto *A. retriculata* and *Annona squamosa* rootstocks.

PRUNING AND TRAINING Training of trees should begin in the nursery and pruning should continue after transplanting. It is desirable to train the tree to a single trunk up to a height of about 90 cm and then headed back to produce lateral branches. The lateral branches should be spaced 15–25 cm above each other and be allowed to grow in different directions to develop a good scaffold. After about 2 m, they could be left to natural growth. Pruning is carried out when the trees are dormant and in heavy trees involves removal of lower limbs touching the ground and branches in the centre that may be rubbing against each other. The objective is to allow sunlight access to the centre of the tree (George and Nissen, 1986a).

All lateral buds can have up to two vegetative buds and three flower buds (Schroeder, 1992). The lateral buds of cherimoya are normally ‘buried’ (subpetiolar) in the base of the swollen leaf petiole. Leaf shed must occur prior to the elongation of ‘buried’ buds (George and Nissen, 1987a). Removal of leaves mechanically by stripping or chemically with urea or ethephon releases these buds. Adventitious buds can arise at any point on a trunk.

NUTRITION AND FERTILIZATION The *Annona* spp. have an indeterminate growth habit (axillary flowering) and applying nitrogen in somewhat excessive amounts does not interfere greatly with floral initiation, as is the case with plants having determinate growth habit.

POSTHARVEST HANDLING AND STORAGE Fruit size, shape and skin colour along with the absence of defects and decay are used in grading fruit. Fruit are very susceptible to mechanical injury. Sugar levels can vary from 14 to 18%, with moderate acid levels. Mature fruit are firm that become very soft during ripening. Skin changes in colour from dark to light green or a greenish yellow and is associated with an increased surface smoothness. Fruit are harvested when mature and allowed to ripen during marketing and retailing.

There are no US or international standards. Fruit is usually packed in a single-layer pack in a fibreboard carton with foam sleeves or paper wrapping to avoid bruising. There are two carton sizes, 4 and 8 kg, with 12 or 24 fruit per carton, respectively. Fruit weight varies from 250 to 600 g. The fruit needs to be pre-cooled as soon as possible after harvest to about 12–15°C; room cooling or forced air is most often used. Fruit are stored at 10–13°C and 90–95% RH for 2–3 weeks; if held at 20°C fruit last only 3–4 days. Storage is limited by skin darkening, dessication and disease associated with chilling injury. Ripe soft fruit can be held at 0–5°C. However, fruit that is not fully ripe is chilling sensitive especially below 10°C, the extent of injury depending upon duration. Symptoms include skin darkening and a failure to fully soften and to develop full flavour.

Controlled-atmosphere storage in 5% oxygen for 30 days at 10°C leads to fruit that ripen in 11 days after removal to air storage at 20°C, versus 3 days for fruit held in 20% oxygen. The addition of carbon dioxide at 3% or 6% can also extend storage life beyond just air storage. Oxygen levels less than 1% lead to fruit having an off-flavour.

DISEASES, PESTS AND WEEDS Black canker (*Phomopsis anonacearum*) and diplodia rot (*Botryodiplodia theobromae*) occur mostly on neglected trees and cause similar symptoms of purplish to black lesions resulting in mummified fruit (Table A.18). Marginal leaf scorch is also caused by *P. anonacearum* and *B. theobromae* and causes twig dieback. Diplodia rot has darker internal discoloration and deeper, more extensive corky rot in fruit. *Cylindrocladium* fruit and

Table A.18. Major diseases of cherimoya.

Common name	Organism	Parts affected and symptoms	Country/region
Anthracnose	*Colletotrichum gloeosporioides (Glomerella)*	Flowers, fruit, leaves, dieback, seedling damping off	Universal
Armillaria root rot	*Armillaria leuteobubalina*	Roots, base of trees, decline	Australia
Bacterial wilt	*Pseudomonas solanacearum*	Tree wilt	Australia
Black canker (diplodia rot)	*Botryodiplodia theobromae*	Leaf scorch, twig dieback	Australia
Black canker	*Phomopsis anonacearum*	Leaf scorch, twig dieback	Australia
Fruit rot	*Glioclacium roseum*	Fruit	India
Purple blotch	*Phytophthora palmivora*	Spots on immature fruit, fruit drop, twig dieback	Australia
Rust fungus	*Phakopsora cherimoliae*	Leaves	Florida

leaf spot is caused by a soil-borne fungus, *Cylindrocladium colhounii*. It can cause almost total loss of fruit during years of persistent heavy rains. Symptoms begin with small dark spots, primarily on the shoulders of the fruit, that spread along the sides, enlarge, become dry and crack. Infection is skin-deep but fruit becomes unmarketable.

Some insect pests occur in numerous growing areas (Table A.19). One of the most serious insect pests in Trinidad is the cerconota moth (*Cerconota anonella*) that lays its eggs on young fruit. The emerging larvae tunnel into the pulp, causing blackened, necrotic areas. It is common to find every fruit larger than 7.5 cm infested. Bagging the fruit is sometimes done. This moth has been reported in the American tropics as far south as Brazil and is a major limiting factor in Surinam.

The bephrata wasp (*Bephrata maculicollis*) is widely distributed throughout the Caribbean and Mexico, Central and northern South America. This wasp is considered to be the most important pest in Florida (Campbell, 1985). The larvae infest the seeds and cause damage to the pulp as they bore through the flesh to emerge when the fruit matures. The thecla moth (*Thecla ortygnus*) is widespread through parts of the Caribbean and in the American tropics but it is not considered to be as serious as the cerconota moth and bephrata wasp. Primary damage is done to the flowers. The larvae feed on flower parts such as the perianth, stamen and stigmas with the flowers failing to set fruit.

Mature green annonaceous fruit have been shown to be rarely infested by the Mediterranean fruit fly (*Ceratitis capitata*) and oriental fruit fly (*Dacus dorsalis*); but are found on occasions in tree-ripened fruit. In Australia, the Queensland fruit fly (*Dacus tryoni*) infests ripening atemoya fruit. 'African Pride' appears more susceptible than 'Pink's Mammoth'. Use of bait sprays and field sanitation are recommended measures to minimize fruit fly infestation (Smith, 1991). Fruit bagging also provides protection.

Mealy bugs and various species of scale insects are found universally and usually become a serious pest on neglected trees. The former is reported to be a major pest on marketable fruit in some areas of Australia (Sanewski, 1991). Red spider mites can become a serious problem in dry areas or during dry seasons. Heavy infestations have been observed on soursop flowers and leaves in the Tecoman area of Mexico during the prevailing dry period with trees showing heavy flower drop.

Problem weeds especially grass and twining weeds should be controlled before planting by cultivation and herbicides. Young trees should to be protected from weed competition by hand weeding, mulching or contact herbicides. The shallow root system limits the use of cultivation under the tree. A translocated herbicide may be needed for perennial weeds and is applied as a spot spray.

MAIN CULTIVARS AND BREEDING The chromosome number of *A. cherimola* is $2n = 14$. Existing commercial cultivars show considerable variation in growth, fruit set, fruit size and quality. No single cultivar has all the desirable characteristics. The length of the juvenile period varies with earliest production occurring in 2 years and full production in 5–6 years. This juvenile period is extremely variable with scions on seedling rootstocks. The seedling rootstocks are derived from extremely heterogenous openly pollinated seeds; hence it is difficult to fix

Table A.19. Major insect pests of cherimoya.

Common name	Organism	Parts affected	Country/region
Banana spotting	*Amblypelta lutescens*	Young fruit	Queensland
Bephrata wasp (soursop wasp)	*Bephrata maculicollis*	Fruit	Mexico, Americas, Trinidad, Surinam
Caribbean fruit fly	*Anastrepha suspensa*	Fruit	Caribbean, Mexico
Cerconota moth (soursop moth)	*Cerconota anonella*	Fruit	Americans, Trinidad, Surinam
Citrus mealy bug	*Planocuccus citri*	Fruit	Queensland
Coconut scale	*Aspidiotus destructor*, other genera and species	Leaves, stem	Caribbean
Mealy bug	*Dysmicoccus*	Stem, leaves	Universal
Potato leaf hopper	*Empoasca fabae*	Leaves	Caribbean
Queensland fruit fly	*Dacus tryoni*	Fruit	Australia
Red spider mite	Several genera, species	Leaves, flowers	American tropics
Scale insects	*Saissetia coffeae*	Leaves, stem	Universal
Southern stink bug	*Nezara viridula*	Fruit	Caribbean
Thecla moth	*Thecla ortygnus*	Flower, young fruit	Americas, Caribbean
Wasp	*Bephratelloides paraguayensis*	Fruit	Americas, Barbados

specific characters in a short period. Breeding programmes have focused on selections from seedling populations. Early maturity, better fruit appearance, and in the subtropics greater cold tolerance are the most frequent objectives.

Cherimoya has very few named clonal cultivars (Table A.20). Most of the plantings have been of seedlings. In California, some old cultivars of cherimoya include ‘McPherson’, ‘Deliciosa’ and ‘Bays’. Considerable work in Peru has been done on the development of cultivars that are not known elsewhere. Chile, Spain and New Zealand grow the cherimoya as it is more tolerant to cold temperatures with more successful self-pollination than the atemoya. New Zealand’s principal cultivars are ‘Reretai’, ‘Burton’s Wonder’, and ‘Burton’s Favorite’. Chilean cultivars ‘Bronceada’ and ‘Concha Lisa’ have performed well in Australia; ‘Bronceada’ possesses a postharvest cold-storage life of 3 weeks. In Spain, ‘Fino de Jete’ and ‘Campa’ are the most extensively cultivated due to their superior yield and quality (Pascual *et al.*, 1993). Isozyme studies indicated that these two cultivars showed identical banding patterns for 15 enzymes, indicating that they may be the same cultivar. A cluster analysis of isozyme patterns showed that Spanish cherimoya cultivars were distinctly different from cultivars in California (Pascual *et al.*, 1993) and atemoya (Ellstrand and Lee, 1987).

In order to develop cultivars adapted to cooler environments, Australia has concentrated on self-progenies and interspecific crosses of *A. cherimola* with *A. reticulata* and *Annona diversifolia*. Progenies of *A. cherimola* × *A. reticulata* are late maturing, showing flowering and fruiting characteristics of *A. reticulata* that flower in the autumn and mature fruit in late spring. Four promising selections possessing most of the fruit qualities of commercial cultivars have been established in various areas for further evaluation (George *et al.*, 1992). Robert E. Paull

Table A.20. Selected cultivars of cherimoya.

Name	Origin
‘Andrews’	Australia
‘Bays’	USA – California
‘Booth’	USA – California
‘Bronceada’	Chile
‘Burton’s Wonder’	New Zealand
‘Campa’	Spain
‘Concha Lisa’	Chile
‘Cristalino’	Spain
‘E-8’	Ecuador
‘Fino de Jete’	Spain
‘Kempsey’	Australia
‘Libby’	USA – California
‘Lisa’	USA – California
‘Mossman’	Australia
‘Negrito’	Spain
‘Reretai’	New Zealand
‘White’	USA – California

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Annona muricata soursop

Soursop, *Annona muricata* L. (*Annonaceae*), is the most tropical member of the genus and produces the largest fruit in the family and is the only one lending itself to preserving and processing. It was distributed very early to the warm lowlands of eastern and western Africa, Asia and to south-east China.

It is called soursop in English and guanabana in most Spanish-speaking countries. French-speaking areas of West Indies and West Africa call it corossol, corossol epineux or cachiman epineux. It is known as guayabano, guayabana (the Philippines); catoche (Venezuela); nangka belanda, zuurzak, sirsak (Indonesia); thurian-khaak, noina (Thailand); mundla (India); fruta de conde, araticum do grande, graviola, jaca do Para (Brazil); guanaba (El Salvador); nona sri kaya, durian belanda, durian maki (Malaysia); zapote de viejas, cabeza de negro (Mexico); huanaba (Guatemala); anona de puntitas, anona de broquel (Argentina); sinini (Bolivia); and sorsaka, zuurzak (the Netherlands).

World production and yield

This small, evergreen and quick-growing tree is commonly found on subsistence farms in South-east Asia and the Pacific islands. It is grown extensively in Mexico from Culiacan to Chiapas, and from Veracruz to the Yucatan Penninsula in the Gulf region. Orchards as large as 20 ha occur. In many other areas in the world, soursop remains cultivated as a backyard tree planted along the roads, in house yards, in mixed planting and wastelands.

It is a highly nutritious fruit crop. The harvesting season is similar in most areas, differing only in range. Mean monthly soursop production in Hawaii shows a year-round production with two peaks. Soursop yields in Hawaii from trees grown in a marginal field have shown approximately 43 kg/tree on 4-year-old trees increasing up to 83 kg/tree on 6-year-old trees. At Paramaribo, Surinam, soursop yields of 54 kg/tree at 278 trees/ha are reported. No world production, export and import figures are available. Commercial plantings are mostly limited to the Philippines, the Caribbean and South America. Soursop pulp is available commercially from South America.

Uses and nutritional composition

Fruit are harvested when fully mature, firm, yellowish green with spines set apart. The ripe fruit are usually consumed fresh as a dessert or snack item. This fruit has the greatest processing potential of the annonas because of the excellent flavour of the pulp and high recovery from the large fruit. At processing plants soursop fruit is stored on racks in the shade and inspected daily. All fruit found to yield to finger pressure are removed for processing. Slightly immature fruit will ripen but such fruit lack the full flavour and aroma, and nectars prepared from such purée have a flat taste. The fragile skin of the fruit, irregular shape and softness limit machine processing and the fruit has to be hand peeled and cored. Pulp recovery percentages ranged from 62 to 85.5% (Paull, 1982). Differences in recovery percentages are due to differences in equipment, extraction methods, cultivar and cultural practices, including environmental influences. The number of seeds per fruit also influences pulp recovery.

Soursop pulp is viscous and requires dilution, the pH is adjusted to 3.7 by addition of citric acid and sugar to 15% to create a desirable balance between acidity, sweetness and flavour in the diluted nectar. Unsweetened and sweetened soursop pulp processed below 93°C show no changes in organoleptic properties, though freeze preservation produces a higher quality product. Enriched pulp, sweetened or unsweetened, can be processed and stored frozen for use in various products or reconstituted directly by the consumer. Purée and juice concentrates can be used to prepare iced soursop drink or mixed with other juices, or made into sherbets and gelatin dishes. The juice, with the addition of sugar, makes an excellent ice cream or sherbet for making a refreshing drink. 'Champola' made with strained pulp, milk and sugar is a famous fruit drink in Havana, Cuba. In the Dutch East Indies, the juice mixed with wine or brandy is a popular drink. The fruit also makes excellent preserve, jam or jelly. In Malaysia, the delicate flavour of soursop is popular for flavouring ice cream and puddings. In the Philippines, young soursop fruit with seeds that are still soft may be used as a vegetable and cooked with coconut milk. Mature but hard fruit may be made into sweets.

The edible portion of the soursop fruit is an excellent source of vitamins B and C, and a fair to poor source of calcium and phosphorus (Table A.21). The predominant organic acids in the fruit are acetic, lactic and malic acids with some quantities of citric and oxalic acids. Soursop is a good source of potassium, riboflavin and niacin.

The soursop has some medicinal uses. A decoction of young shoots and leaves is a remedy for gall bladder infection, coughs, diarrhoea, dysentery and indigestion. Mashed leaves are used as a poultice to alleviate eczema and rheumatism. The seeds, like those of other members of the genus, contain a toxic alkaloid. The flowers are antispasmodic. The ripe fruit prevents scurvy while the unripe fruit may be used for dysentery and has astringent properties. The tree can also be used in landscapes.

Botany

DESCRIPTION The soursop is a small, evergreen, slender and upright or low-branching and bushy tree, growing to heights of 4.5–9 m and becomes straggly and untidy with age. The leaves are alternate, smooth, dark green and glossy above, dull and paler below, obovate to elliptic, 7–20 cm long. When crushed, the leaves will emit a strong odour.

Flowers are solitary, 2.5–4 cm long with three thick, fleshy

Table A.21. Proximate fruit composition of soursop in 100 g edible portion (Source: Wenkam, 1990).

Proximate	%
Edible flesh	34
Seed/skin	34
Water	80.1
Energy (kcal)	71
(kJ)	247
Protein	0.69
Lipid (fat)	0.39
Carbohydrate	18.23
Fibre	0.95
Ash	0.58
Minerals	**mg**
Calcium	9
Iron	0.82
Magnesium	22
Phosphorus	29
Potassium	20
Sodium	22
Vitamins	**mg**
Ascorbic acid	16.4
Thiamine	0.07
Riboflavin	0.12
Niacin	1.52
Vitamin A	0

petals and three close-set, pale yellow inner petals alternating with three fleshy, slightly spreading, yellow-green outer petals. The flower has a peculiar smell. The flowers are hermaphrodite and are often produced singly or in small clusters on old wood.

The fruit, a syncarp, is broadly ovoid or ellipsoid and usually irregularly shaped or curved due to improper carpel development (Fig. A.5). Fruit are nearly always longer than they are wide. Fruit size varies from < 0.45 kg to > 4.5 kg, largely dependent upon the extent of pollination and fertilization. A normal fruit is generally heart-shaped to oval, but if there is poor pollination, unfertilized ovules fail to develop and the resulting fruit assumes distorted irregular shapes and is usually undersized. The skin is dark green with many recurved, soft spines 0.5–1.3 cm apart. There is often a constriction like a fault on the side of the fruit, where the skin has not swollen and the spines are much closer together. The fruit stalk is about 3–8 cm long and woody. The ripe pulp, which adheres to the skin but is easily separated into segments (which were the separate ovaries), is juicy, creamy white with a cottony texture and contains many black seeds about 2 cm long. The pulp has an agreeable subacid flavour with a distinct aroma.

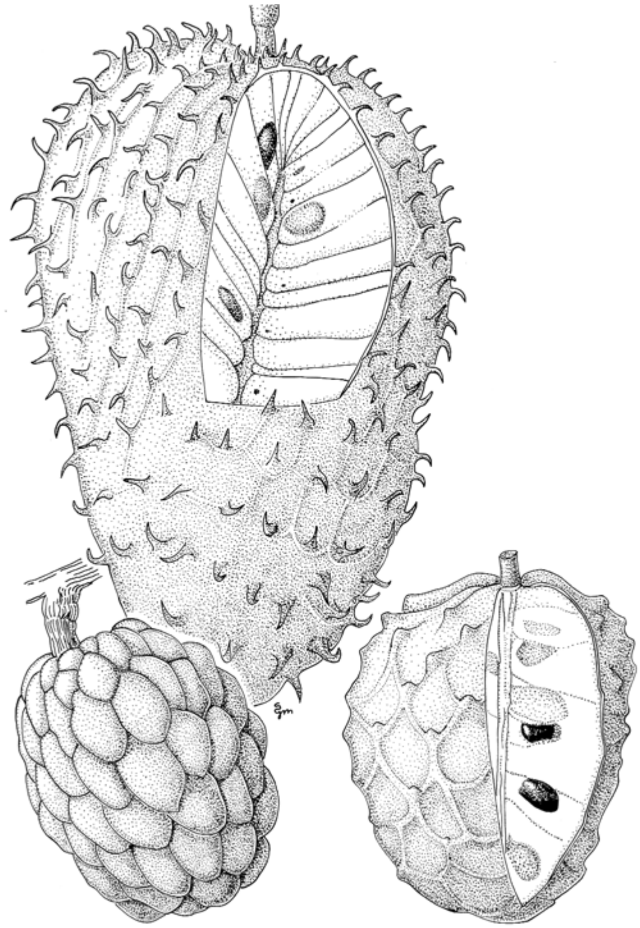

Fig. A.5. Annona fruit – soursop (top), sweetsop (bottom left) and cherimoya (bottom right) (Source: Nakasone and Paull, 1998).

ECOLOGY AND CLIMATIC REQUIREMENTS Soursops are capable of growing in a wide range of soil types from sandy to clay loams provided that the soil has good drainage. The tree is commonly grown on slightly acid soils with optimum pH at 5–6.5. It also grows on the porous, oolitic limestone of south Florida and the Bahamas. Higher and more consistent yields are obtained on trees grown on well-drained sandy to sandy loam soils. Waterlogging is a major cause of floral abscission and root rot such as bacterial wilt caused by *Pseudomonas* spp. Soursop cannot tolerate standing water for any length of time but can tolerate dry soil conditions.

The tree thrives in the warm and humid tropics below 1000 m and is very susceptible to cold. In mountainous areas (15°–25°C mean minimum) the tree produces very few fruit. Frost kills young trees, but older trees show some tolerance. Defoliation and an interruption of fruiting occur when the temperature drops to near freezing. Poor pollination is a frequent problem and occurs at high temperature (30°C) and low humidity (30% relative humidity (RH)), even with hand pollination. Lower temperature (25°C) and high humidity (80% RH) greatly improves pollination.

The softwood of the trees makes them susceptible to wind damage and limb breakage. Fruit productivity is improved by the provision of windbreaks.

REPRODUCTIVE BIOLOGY *Annona* species generally require 27–35 days for flower bud development from initiation to anthesis. Flowering can extend from 3 to 6 months or even longer, with heavy peaks. The soursop produces fruit throughout the year but peak production in most areas comes during summer and early autumn, sometimes with a secondary peak during early spring. Two major flowering periods occur after periods of vegetative flushes with the second peak coinciding with the onset of monsoon in India (Kumar *et al.*, 1977). Defoliation of *A. muricata* manually or by using ethephon spray promotes lateral branch growth and induces additional flower formation near the apex of the branches. No photoperiod responses have been reported.

The flowers exhibit both dichogomy and a protogynous nature. Soursop floral anthesis takes place mostly between noon and 8 p.m. and 4 a.m.–8 a.m., with pollen release occurring between 4 a.m. and 8 a.m. Flower opening and pollen dehiscence are not synchronous and thus very low self-pollination occurs. Cross-pollination may take place early in the morning because at anthesis the flower usually emits a fragrance that attracts insects. In order to increase yield, hand pollination has become an important aspect of cultivation practices in some areas.

Nitidulid beetles (*Carpophilus* and *Uroporus* spp.) are the important pollinators of *Annona* flowers with wind and self-pollination being low (1.5%). Also studies have shown that these beetles breed rapidly in rotting fruit media and that populations of these beetles are increased by maintaining the rotting fruit attractant (Thakur and Singh, 1964).

FRUIT DEVELOPMENT Fruit growth shows the typical sigmoidal curve with maturation occurring in 16–24 weeks. Low humidity (< 60% RH) and temperature (< 13°C) near fruit maturity can increase the severity of fruit skin russetting as well as delaying fruit maturation.

Horticulture

PROPAGATION The soursop are usually propagated by seed. There is a rapid loss of seed viability (6 months) after harvest and seeds should be planted as soon as possible after removal from the fruit. Fresh seeds can take up to 30 days to germinate with about 85–90% germination. Propagation by cuttings or air layering has not been very successful. Hypocotyl explants of soursop are suitable for *in vitro* culture with good rooting but poor shoot induction (Rasai *et al.*, 1995).

Transplanting should be done at the beginning of the wet season if there are seasonal dry periods and no irrigation facilities. Plants should have attained a height of 30–46 cm at transplanting time with the union of grafted or budded plants placed 15 cm or so above the ground. Trees should be irrigated as soon as possible after transplanting. Soursop trials in Hawaii showed that the spacing should be 4.6 × 6 m without affecting growth or interfering with cultural practices.

ROOTSTOCKS Atemoya is not compatible with soursop as rootstock (Sanewski, 1991). In Florida, soursop has been grafted on 1-year-old seedlings of sugar apple and pond apple, the latter rootstock being tolerant to flooding.

IRRIGATION The annonas are grown in many areas without irrigation when rainfall is well distributed. Except for pond apple (*Annona glabra*), soursop can stand periods of drought and prefer rather dry conditions. Water stress should be prevented during flowering, fruit set and fruit development as fruit are more sensitive than leaves. Soursop has a shallow fibrous root system and may benefit from mulching.

PRUNING AND TRAINING The soursop usually produces a symmetrically conical tree and is well adapted to the central leader system. An alternative is to develop a mushroom-shaped tree that is topped at 1.8–2.4 m. The fruit in this system is borne on the lateral branches and hangs down for ease of harvesting. When properly trained, little pruning is required except to thin out poorly placed and weak branches. To contain trees within a certain space allocation and height limitation the longest branches extending horizontally and vertically may be pruned annually, preferably immediately after harvest. Very severe pruning reduces subsequent fruiting.

NUTRITION AND FERTILIZATION Observations in Hawaii and Mexico indicate that it is desirable to provide 1.3 kg of a triple-15 fertilizer formulation during the first year of production, split into two applications. In Hawaii, the first increment should be given around February for the primary crop in July and the second increment applied in August for the December–January secondary crop. Each year thereafter, up to approximately the sixth-bearing year, the total amount can be increased by approximately 0.45 kg/tree/year. In the Philippines, the application of 100–150 g ammonium sulphate a month after planting and an equal amount 6 months after or at the end of the rainy season is recommended. The quantity is increased every year until the trees start to bear fruit, at which time, about 250–300 g complete fertilizer, high in nitrogen and potassium, is used. A full-grown tree may need at least 500 g complete fertilizer per application.

POSTHARVEST HANDLING AND STORAGE High temperature can cause premature fruit ripening and fermentation of the fruit. Fruit is harvested when fully mature and firm. The skin colour changes as the fruit approaches maturity. The immature soursop is dark green and shiny, losing its sheen and becoming slightly yellowish green with spines set apart at maturity. Soursop respiration begins to increase within a day after harvest and reaches its peak at the sixth to eighth day. Ethylene production is initiated approximately 48 h after initiation of respiration rise and reaches its peak at about the same time as the respiration peak reaches a plateau (Paull, 1982). Total soluble solids increases from around 10–16% during the first 3 days of ripening. The major titratable acids are malic and citric acids. After day 5 to 6, titratable acidity, ethylene production and total phenols decline, changes that produce a bland flavour and even a slightly objectionable odour. The optimum edible stage is at days 6 and 7, which coincide with ethylene production (Paull, 1982).

Fruit is hand harvested and put into lug boxes or baskets. In large soursop orchards mechanical harvesting aids are feasible and accelerate handling. Harvested fruit should be handled with care to prevent bruising of the skin. Firm fruit are held after harvest for 4–7 days at room temperature before softening begins; optimum quality processing occurring 5 and 6 days later (Paull *et al.*, 1983). The skin of ripening soursop gradually turns dark brown to black, but the flesh is unspoiled. Storage below 15°C causes chilling injuries and a failure to develop full flavour. At lower temperatures, skin discoloration rapidly occurs.

DISEASES, PESTS AND WEEDS A number of diseases have been reported in the literature (Table A.22). Anthracnose caused by *Colletotrichum gloeosporioides* (*Glomerella cingulata*) is the most serious on soursop, particularly in areas of high rainfall and atmospheric humidity and during the wet season in dry areas (Alvarez-Garcia, 1949; Dhingra *et al.*, 1980). This disease causes twig dieback, defoliation, dropping of flowers and fruit. On mature fruit the infection causes black lesions.

Black canker (*Phomopsis anonacearum*) and diplodia rot (*Botryodiplodia theobromae*) occur mostly on neglected trees and cause similar symptoms of purplish to black lesions resulting in mummified fruit. Marginal leaf scorch is also caused by *P. anonacearum* and *B. theobromae* and causes twig dieback. Diplodia rot has darker internal discoloration and deeper, more extensive corky rot in fruit. Cylindrocladium fruit and leaf spot is caused by a soil-borne fungus, *Cylindrocladium colhounii*. It can cause almost total loss of fruit during years of persistent heavy rains. Symptoms begin with small dark spots on the shoulders of the fruit that spread along the sides, enlarge, become dry and crack. Infection is skin-deep but fruit becomes unmarketable.

Some insect pests occur in numerous growing areas (Table A.23). One of the most serious insects in Trinidad is the cerconota moth (*Cerconota anonella*) that lays its eggs on young fruit. The emerging larvae tunnel into the pulp, causing blackened, necrotic areas. It is not uncommon to find every fruit larger than 7.5 cm infested. Bagging the fruit is sometimes done. This moth has been reported in the American tropics as far south as Brazil and is a major limiting factor in Surinam.

The bephrata wasp (*Bephrata maculicollis*) is widely distributed throughout the Caribbean and Mexico, Central and northern South America. This wasp is considered to be the most important pest in Florida (Campbell, 1985). The larvae infest the seeds and cause damage to the pulp as they bore through the flesh to emerge when the fruit matures. The thecla moth (*Thecla ortygnus*) is widespread through parts of the Caribbean and in the American tropics but it is not considered to be as serious as the cerconota moth and the bephrata wasp. Primary damage is done to the flowers. The larvae feed on flower parts such as the perianth, stamen and stigmas with the flowers failing to set fruit.

Mature green annonaceous fruit are rarely infested by the Mediterranean fruit fly (*Ceratitis capitata*) and oriental fruit fly (*Dacus dorsalis*), but these are found on occasion in tree-ripened fruit.

Mealy bugs and various species of scale insects are found universally and usually become a serious pest on neglected trees. Red spider mites can become a serious problem in dry

Table A.22. Major diseases of soursop.

Common name	Organism	Parts affectedand symptoms	Country/region
Anthracnose	*Colletotrichum gloeosporioides (Glomerella)*	Flowers, fruit, leaves, dieback, seedling damping off	Universal
Armillaria root rot	*Armillaria leuteobubalina*	Roots, base of trees, decline	Australia
Bacterial wilt	*Pseudomonas solanacearum*	Tree wilt	Australia
Black canker (diplodia rot)	*Botryodiplodia theobromae*	Leaf scorch, twig dieback	Australia, Brazil
Black canker	*Phomopsis anonacearum*	Leaf scorch, twig dieback	Australia
Purple blotch	*Phytophthora palmivora*	Spots on immature fruit, fruit drop, twig dieback	Australia
Rust fungus	*Phakospora cherimoliae*	Leaves	Florida
Fruit rot	*Gliocladium roseum*	Fruit	India
Rhizopus rot	*Rhizopus stolonifer*	Fruit	Brazil
White spot	*Cercospora* sp.	Leaves	Colombia

Table A.23. Major insect pests of soursop.

Common name	Organism	Parts affected	Country/region
Bephrata wasp (soursop wasp)	*Bephrata maculicollis*	Fruit	Mexico, Americas, Trinidad, Surinam
Wasp	*Bephratelloides paraguayensis*	Fruit	Americas, Barbados
Cerconota moth (soursop moth)	*Cerconota anonella*	Fruit	Americas, Trinidad, Surinam
Thecla moth	*Thecla ortygnus*	Flower, young fruit	Americas, Caribbean
Banana spotting	*Amblypelta lutescens*	Young fruit	Queensland
Mealy bug	*Dysmicoccus*	Stem, leaves	Universal
Citrus mealy bug	*Planococcus citri*	Fruit	Queensland
Southern stink bug	*Nezara viridula*	Fruit	Caribbean
Caribbean fruit fly	*Anastrepha suspensa*	Fruit	Caribbean, Mexico
Queensland fruit fly	*Dacus tryoni*	Fruit	Australia
Potato leaf hopper	*Empoasca fabae*	Leaves	Caribbean
Red spider mite	Several genera, species	Leaves, flowers	American tropics
Scale insects	*Saissetia coffeae*	Leaves, stem	Universal
Coconut scale	*Aspidiotus destructor*, other genera and species	Leaves, stem	Caribbean

areas or during dry seasons. Heavy infestations have been observed on soursop flowers and leaves in the Tecoman area of Mexico during the prevailing dry period with trees showing heavy flower drop.

Problem weeds especially grasses and twining weeds should be controlled before planting. The shallow root system limits the use of cultivation under the tree.

MAIN CULTIVARS AND BREEDING A desirable hybrid would be between the cherimoya and soursop. This would combine the larger fruit size and acidity of the soursop and the sweetness, flavour and texture of cherimoya. Attempts to cross the soursop with cherimoya, ilama, bullock's heart or sweetsop have not been successful and may reflect considerable genetic distance of soursop from the other species (Samuel *et al.*, 1991). Breeding programmes have focused on selections from seedling populations. Early maturity, greater yield, better fruit appearance, and in the subtropics greater cold tolerance are the most frequent breeding objectives. In Indonesia and the Philippines, two distinct soursop forms exist, that of the sour- and the sweet-fruited with the sweet-fruited having fewer seeds than the sour-fruited. The sweet 'Sirsak Ratu' from Java occurs in a few regions only, whereas the sour type is more common (Yaacob and Subhadrabandhu, 1995).

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Annona senegalensis wild soursop

This very popular African *Annona* (*Annona senegalensis* Pers., *Annonaceae*) is widespread in tropical semiarid and sub-humid areas, often growing in savannah regions. It occurs from the Nile River area to the Transvaal and Zululand in South Africa. It is common as a single understorey shrub in wooded savannah areas. *Annona senegalensis* is among the popular shrubs and trees browsed by Fulani pastoralists' cattle in central Nigeria (Bayer, 1990). The common names include wildesuikerappel in Afrikaans, giishta and yebere lib in Amharic, gishta and gishta gaba in Arabic, wild custard apple and wild soursop in English, annone and pomme cannelle du senegal in French, and numerous local African names. Morton (1987) gives mavulu, mugosa, mbokwe, makulo and mlamote in Kenya; mtopetope and mchekwa in Zanzibar and Pemba; mabengeya, elipo, obwolo and ovolo in Uganda; aboboma, batanz, bangoora and bullimbuga in Ghana; mposa, muroro and mponjela in Malawi; dilolo, iolo and malolo in Angola; sougni, mete, dangan, sounsoun, tangasou, dougour, ianouri, ndong and anigli in West Africa.

Uses and nutritional composition

The ripe fruit's edible white pulp has a pleasant, pineapple-like taste. The leaves are sometimes used as vegetables, while the flowers serve as a spice for various meals. A yellow or brown dye and an insecticide are obtained from the bark. The bark is also used for treating guinea worms and other worms, diarrhoea, gastroenteritis, snakebite, toothache and respiratory infections (Fatope *et al.*, 1996; Alawa *et al.*, 2003). The leaves are used for treating pneumonia and as a tonic to promote general well-being. The roots are used for stomach ache, venereal diseases, chest colds and dizziness. Various plant parts are combined for treating dermatological diseases and ophthalmic disorders. *Annona senegalensis* is shown to be therapeutically effective against *Trypanosoma brucei brucei* in mice, which agrees with the claims of some practitioners of traditional medicine that it is effective against trypanosomiasis in man (Igweh and Onabanjo, 1989; Sahpaz *et al.*, 1994; Freiburghaus *et al.*, 1996).

The edible fleshy pulp contains many seeds, which are particularly eaten in northern Nigeria. About 11 fatty acids have been identified in the seeds of *A. senegalensis* of which oleic, gondoic, palmitic and stearic acids predominate (Wélé *et al.*, 2004). Terpinen-4-ol is the major volatile component.

Botany

DESCRIPTION This shrub or small tree is 2–6 m tall, taller under favourable conditions. The bark is smooth to rough, silvery grey or grey-brown, with leaf scars; the slash is pale pink (Isawumi, 1993). Young branches have dense, brown, yellow or grey hairs that are lost later. The leaves (6–18.5 × 2.5–11.5 cm) are simple, alternate, oblong to ovate or elliptical, with eight to ten pairs of prominent lateral nerves. They are green to bluish green with almost no hairs on top, but often with brownish hairs on the underside. The solitary or groups of two to four flowers are up to 3 cm in diameter, on 2 cm long stalks. The flowers arise in leaf axils. The three ovate sepals are free and smaller than the petals. There are six fleshy cream to yellow petals in two whorls that are greenish outside, creamy or crimson inside. The inner whorl of the petals curve over the stamens and ovary. The stamens are 1.7–2.5 mm long. As with other *Annona* spp., the fleshy ovoid to globose fruit (2.5–5 × 2.5–4 cm) is formed from many fused carpels. The unripe fruit is green, turning yellow to orange on ripening, with the outline of the carpels forming a coloured network. The edible fleshy pulp contains numerous oblong orange-brown seeds.

TAXONOMY AND NOMENCLATURE There are many synonyms for this species including *Annona arenaria* Thonn. ex Schum., *Annona chrysophylla* Boj., *Annona porpetac* Bail., *Annona senegalensis* Pers. var. *chrysophylla* Boj., *Annona senegalensis* Pers. var. *latifolia* Olive, and *Annona senegalensis* var. *porpetac* (Bail.) Diels.

ECOLOGY AND CLIMATIC REQUIREMENTS Richardson *et al.* (2004) described the *Annonaceae* as a pantropically distributed family found predominantly in rainforests, so they are megathermal taxa. However, *A. senegalensis* grows best in low and mid-elevation tropical climates as a deciduous shrub. It may grow in drier areas as long as the roots have continuous access to water. The species occurs along riverbanks, on fallow land, in swamp forests and at the coast, often as a single plant in the understorey of savannah woodlands. It is found from coastal areas to 2400 m. The major habitat, according to Isawumi (1993), is the savannah, although it is identified by Salami (2001) as one of the common tree species now found in the tropical rainforest belt of Nigeria. The mean annual temperature is from 17–30°C and mean annual rainfall of 700–2500 mm. It is very sensitive to frost. The tree is found on diverse soil types and does well on sandy loam soils.

REPRODUCTIVE BIOLOGY The tree starts bearing fruit in 3 years. Along the coast of Tanzania, it flowers from December through to February (Mbuya *et al.*, 1994). Flowering occurs earlier from October to December elsewhere. The period of defoliation is generally brief, and leaf flushing, flowering and fruiting occur mostly in the dry season (Devineau, 1999). The fruit matures during January to March, sometimes extending to April. Poor pollination leads to misshaped fruit. Hand pollination can improve the shape and yield. As the fruit ripens, there is a tendency for cracking to occur.

Horticulture

CULTURE Propagation is normally by seed and root suckers. Scarification of the seed improves germination. The trees coppice well after felling and are readily pruned to a desired shape. Young plants do not compete well with weeds and need to be protected from fire and browsing animals.

DISEASES, PESTS AND WEEDS As with other annonas, anthracnose caused by *Colletotrichum gloeosporioides* is a major problem on leaves, flowers and fruit. On the leaf, it causes small, light green spots, dark spots on the flowers and shedding and fruit mummification. Victor N. Enujiugha

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Annona squamosa sweetsop

Sweetsop (*Annona squamosa* L., *Annonaceae*) is a small tropical tree originating in the New World tropics, probably in the Caribbean region. This species is the most widely grown *Annona* spp. in the tropical regions of the Americas, Africa, Asia and the Pacific. Sweetsop is also named sugar apple and has many other regional names, such as custard apple (India), anon (Spanish), ata (Portuguese), noi-na (Thailand), atis (Philippines) and fan-li-chi (Taiwan).

World production and yield

Sweetsop is the most widely grown *Annona* species. The fruit is frequently found in village markets but has not shown much potential for large commercial cultivation due to the small fruit size, frequent cracking at maturity and poor shelf life. The perishable nature and supply shortages make marketing localized or air shipment essential. However, sweetsop is intensively cultivated in Taiwan. In the last 5 years, the average annual production of sweetsop in Taiwan was 50,005 t from a total harvested area of 4978 ha. More than 80% of the production is in Taitung county of southern Taiwan.

Fruit is usually harvested from July to October, and can be extended to March if summer pruning is conducted. Taiwan's peak of production occurs between July and March. In India (Poona), the peak of production occurs later between August to November, and in Thailand, Florida and the Caribbean between July and September.

Uses and nutritional composition

Sweetsop is a good source of carbohydrate, potassium, calcium, phosphorus and ascorbic acid (Table A.24). The fruit is usually consumed fresh and also can be used to make juices, shakes and ice creams. There are folk medicinal applications of sweetsop. The stems, leaves and seeds of sweetsop contain the toxic aporphine alkaloids (anonaine) (Bhakuni *et al.*, 1972). In tropical America, a leaf decoction is used as a cold remedy while a bark decoction is used to stop diarrhoea. Sweetsop juice is also able to resolve diarrhoea in children (Enweani *et al.*, 1998). The root is used in the treatment of dysentery and the ground seed powder has insecticidal properties. The bark extracts have been shown to have an anti-tumour effect in the laboratory (Hopp *et al.*, 1996).

Botany

TAXONOMY AND NOMENCLATURE The *Annonaceae*, or custard apple family, comprises about 120 genera and more than 2000 species (Leboeuf *et al.*, 1982). The genus *Annona* is the most economically important one, containing *c.*120

Table A.24. Proximate sweetsop fruit compositions per 100 g (USDA, 2002).

Proximate	%
Water	73.32
Energy (kcal)	94
(kJ)	393
Protein	2.06
Lipid (fat)	0.29
Carbohydrate	23.64
Fibre	4.40
Ash	0.78
Minerals	**mg**
Calcium	24
Iron	0.6
Magnesium	21
Phosphorus	32
Potassium	247
Sodium	9
Vitamins	**mg**
Ascorbic acid	363
Thiamine	0.111
Riboflavin	0.113
Niacin	0.883
Vitamin E	0.590
Panthothenic acid	0.226
Vitamin B6	0.200
Vitamin A	6 IU

species. Three major commercial species throughout the world are: the cherimoya (*Annona cherimola*), sweetsop (*A. squamosa*) and atemoya (a hybrid of *A. cherimola* and *A. squamosa*). The sweetsop species name '*squamosa*' refers to the knobbly appearance of the fruit. The chromosome number of *A. squamosa* is $2n = 14$.

DESCRIPTION The sweetsop tree is normally smaller than the cherimoya, attaining heights of 3–6 m with slender branches. The leaves are oblong-lanceolate, 10–15 cm long and 3–5 cm wide, alternately arranged on short petioles and narrower than those of the cherimoya (Fig. A.6). Young leaves are slightly hairy. The sweetsop is semi-deciduous in growth habit and most leaves are shed before new shoots appear. The flowers of sweetsop are hermaphrodite and exhibit a protogynous dichogamy nature. Flowers are axillary, pendant, single or in clusters of two to five on leafy shoots. The flower is 2–4 cm long and contains three degenerated sepals and six petals. The six petals are arranged into two whorls with three each and the petals of the inner whorl are degenerated into small scales or completely disappear. The multiple pistils grow on the conical receptacle, in the centre of the flower with a number of stamens at the periphery. The compound fruit is nearly heart-shaped, 6–10 cm in diameter (see Fig. A.5 in entry for *Annona muricata*). It is yellowish green in colour but a purple-fruited variant is also known. The exterior parts of adjacent carpels (the conical segments) are not completely fused and these rounded protuberances separate frequently, exposing the white flesh upon ripening. Many of the conical segments contain a single black or dark-brown seed. There are 30–40 seeds in an average fruit.

ECOLOGY AND CLIMATIC REQUIREMENTS The sweetsop is probably the most drought tolerant *Annona* species as it grows and produces poorly where rains are frequent. Sweetsop does very well in the drier north of Malaysia than in the south which has year-round high moisture.

Temperature is a limiting factor, with frost killing young trees, but older trees show some tolerance. Sweetsop does not require a period of low temperature to flower and does well under lowland conditions and dry periods. Seedlings have high photosynthesis activity at 30°C and show vigorous shoot growth (Higuchi *et al.*, 1998). Poor pollination is a frequent problem under high temperatures (> 30°C) and low humidity (< 60% relative humidity (RH)), even with hand pollination. Lower temperature (25°C) and higher humidity (80% RH) greatly improves pollination. However, very high RH (> 95%) may reduce the stigma receptivity (Marler *et al.*, 1994) and affect anther dehiscence. Hence, high humidity but no rain during blooming is advantageous.

Fig. A.6. Leaf and flower of *Annona squamosa* also showing buried axillary bud (Source: Nakasone and Paull, 1998).

Light penetration to the base of vigorous trees with a dense canopy in a closely spaced orchard can be extremely low and can reduce fruit set. Pruning practices and spacing need to be adjusted to increase light penetration. No photoperiod responses have been reported.

The softwood makes the trees susceptible to wind damage and limb breakage. Tree shaking may also be partially responsible for penetration by collar rot organisms. The fruit skin is easily damaged by rubbing and exposure to drying winds (Marler *et al.*, 1994). Productivity is improved by windbreaks and overhead misting to raise the RH above 60%. Under-tree sprinklers and efficient irrigation scheduling are also helpful. The tree is sensitive to salinity stress (Marler and Zozor, 1996). Trees grown in tropical coastal areas may be damaged by wind-borne salt that can be alleviated by the use of windbreaks and overhead sprinklers.

Sweetsop is capable of growing in a wide range of soil types, from sandy soil to clay loams. However, the tree is shallow-rooted and waterlogging can lead to root rot. Flooding of sweetsop seedlings and rootstocks greatly reduces growth and photosynthetic rate (Núñez-Elisea *et al.*, 1999). High yields occur on well-drained sandy to sandy loam soils. The optimal soil pH for sweetsop is 6.0–6.5.

REPRODUCTIVE BIOLOGY The flowers of sweetsop are hermaphrodite and are produced singly or in small clusters on the current season's growth. Flower initiation begins at the basal end of the growing branch (Lo, 1987). New flowers continue to appear towards the apex of the shoot as flowers produced earlier at the basal portion mature.

The period from floral bud initiation to anthesis is highly variable. Differences in floral behaviour can be attributed to both genetic variability and climatic differences. Flowering can be extended from 3 to 6 months or longer, with heavy peaks. Two major flowering periods occur after periods of vegetative flush with the second peak coinciding with the onset of monsoon in India (Kumar *et al.*, 1977).

The flowers exhibit a protogynous dichogamy nature that limits self-pollination and cross-pollination can increase fruit set. Nitidulid beetles (*Carpophilus* spp. and some others) are the important pollinators (George *et al.*, 1992) with wind and self-pollination being low. Pollen grains appearing early in a flowering season have lower germination rates than pollen from late flowers (Yang, 1988). The pollen is usually shed in loosely bound tetrads; individual grains are also observed. Pollen grains deposited on the stigma surface only germinate during the female phase and are inhibited at or after anther dehiscence. Once the pollen germinates, there appears to be no apparent barrier to the growth of compatible pollen tubes towards the embryo sac (Vithanage, 1984). Artificial pollination is frequently practised to ensure pollination and good fruit shape. Hand pollination is normally carried out before 8 a.m. every week using a small brush. Pollen can be collected in the morning between 5 and 8 a.m. from fully open flowers, when the sacs have turned from white to cream. The collected pollen is used to pollinate half-open flowers whose pistils are already receptive. Hand pollination has shown some variable results and is less successful under non-favourable climatic conditions and on young vigorous trees.

Hand pollination in commercial orchards is tedious, time consuming and a costly practice. Attempts have been made to use growth regulators, with considerable variation in the results obtained. Treatments with naphthalene acetic acid (NAA), benzyladenine (BA) and gibberellic acid-3 (GA_3) at 25–250 ppm can induce fruit set with high variation among treatments. Most of the fruit induced are seedless and are smaller, with lower flavour and less fruit splitting than occurs in seedy fruit that result from pollination (Yang, 1988).

FRUIT DEVELOPMENT Fruit growth shows a double sigmoidal curve with maturation occurring in 14–18 weeks depending upon cultivars and growing conditions. Fruit is harvested when fully mature and firm. Low humidity (< 60% RH) and temperature (< 13°C) near fruit maturity can increase the severity of fruit skin russetting as well as delaying fruit maturation.

Horticulture

PROPAGATION Sweetsop is usually propagated by seeds. The recalcitrant seeds should be planted as soon as possible after removal from the fruit. Seeds from fruit having a rest of about 1 week after harvest are better than those directly taken from the harvested fruit. Seeds can take up to 20–30 days to germinate and germination is increased by soaking seeds for 3–4 days.

Inarching of *A. squamosa* to *Annona reticulata* rootstock has had up to 70% success rate. Nevertheless, inarching is time consuming and costly for large-scale propagation (George and Nissen, 1987). Grafting and budding have a similar success rate. The branches should be defoliated 1–2 weeks before scion wood is cut to induce bud swelling. Rooting of tip and stem cuttings has been used for some cultivars, while good success has been achieved with micropropagation. Air layering has been less successful (< 10% success rate).

Transplanting should be done at the beginning of the wet season if there are seasonal dry periods and no irrigation. In the subtropics, planting should not occur if there is a risk of frost. Plants should have attained a height of 30–45 cm at transplanting time with the union of grafted or budded plants placed 15 cm or so above the ground. Trees should be irrigated as soon as possible after transplanting, with wind and sun guards sometimes required.

The periodically pruned small sweetsop can be spaced at 3.5–4.0 × 4.5–5.0 m. In dry areas with less luxuriant growth, closer within-row spacing can be considered. A closer spacing would increase humidity and benefit the longevity of stigma receptivity. However, for the convenience of field machine operations and consistent yields, spacing can be increased to 5.0–5.5 × 6.0–6.5 m.

ROOTSTOCKS Although sweetsop is often propagated by seeds, superior cultivars can be propagated via inarching, budding and grafting to sweetsop or other *Annona* rootstocks, such as *A. cherimola* and *A. reticulata* (Sanewski, 1991). *Annona glabra* is compatible but less hardy. *Annona muricata* and *Annona palustris* are not compatible rootstocks for *A. squamosa*.

PRUNING AND TRAINING Training of trees should begin in the nursery and pruning should continue after transplanting. It is desirable to train the tree to a single trunk up to a height of about 80–90 cm and then headed back to produce lateral branches. The scaffolds should be trimmed to about 60 cm long to induce lateral branching. The tree height should be maintained at *c.*2–2.5 m with a canopy of *c.*2.5–3 m in diameter to prevent wind damage and to make it convenient for field practices. In general, pruning is carried out when the trees are dormant and involves removal of lower limbs touching the ground and branches in the centre that may be rubbing against each other. One-year-old branches are cut back to 10–15 cm to induce new growth that will be the fruiting shoots, and the pruning leaves 120–150 branches/tree.

The lateral buds of sweetsop are subpetiolar, in the base of the swollen leaf petiole (Fig. A.6). Leaf shed must occur prior to elongation of the 'buried' buds. Removal of leaves mechanically by stripping or chemically with urea or ethephon releases these buds. In Taiwan, normal pruning occurs in February/March with fruit harvest from July through to October. Pruning in January can induce flowering but it takes a longer time to induce floral development and the total flower number is less than pruning in February/March. Summer pruning of selected shoots (June–September) can lead to harvesting fruit from November to the next March (Yang, 1987). The shoots are pruned back to *c.*10 cm with two or three buds left and the leaves on the pruned shoots must be removed to release the buds.

NUTRITION AND FERTILIZATION The annonas have an indeterminate growth habit (axillary flowering) and applying nitrogen does not greatly interfere with floral initiation. However, excessive tree vigour is usually associated with reduced flowering and yields in many tree crops. In Taiwan, continued research and field observation of sweetsop nutrition (Chang, 2000) has led to greater refinements in terms of fertilizer quantity and tree age applications (Table A.25). After 8 years of age, the annual amounts of NPK (nitrogen, phosphorus, potassium) fertilizer remain the same, as the tree size is kept constant by annual pruning and by competition from adjacent trees. The annual requirements of nitrogen, phosphorus and potassium are split into three increments. The early spring application includes all the annual phosphorous application and 20% of the nitrogen and

Table A.25. A guide to annual application of nitrogen, phosphorus and potassium (NPK) for sweetsop trees of different ages in Taiwan (Source: Chang, 2000).

Tree age (years)	N (g/tree/year)	P (g/tree/year)	K (g/tree/year)
2	100–150	44	83–125
4	350–500	88	208–415
6	450–650	132	374–415
8	700–1000	175–220	580–830

potassium. In the summer application, 70% of the nitrogen is applied to stimulate vegetative growth with 40% of the potassium after summer pruning. The remainder is applied in the autumn (Chang, 2000). The use of foliar nutrient analysis has become a useful management tool in determining sweetsop fertilizer programmes (Table A.26). The most recently matured leaf, the third or fourth leaf from the apex on a non-fruiting shoot without a leaf flush is used. The best sampling time is in early December.

Black speck is a physiological disorder possibly caused by calcium deficiency. Symptoms begin with small dark spots primarily on the shoulders and waist of the fruit skin. In serious cases, the number of dark spots increases and covers the whole fruit. The damage is only limited to a thin layer of flesh tissue right under the skin but fruit has reduced market values. Spraying $Ca(NO_3)_2$ or $CaCl_2$ (0.3–0.5%) two to three times over 5–7 days when early symptoms of black speck appears, controls the symptoms (Lin, 2000).

POSTHARVEST HANDLING AND STORAGE The skin colour changes from greyish green to yellow-green as the fruit approaches maturity. Adjacent carpels near the peduncle commonly separate and radiate out at maturity, exposing the white pulp. Harvested fruit should be handled with care to prevent bruising of the skin. Harvesting immature fruit results in poor quality and a failure to ripen. Mature fruit on the tree tend to split.

The fruit is climacteric and rapidly ripens within 3–6 days after harvest. The onset of increased rates of carbon dioxide and ethylene production occur about 3 days after harvest, but the respiratory peak appears before the ethylene climacteric or both occur simultaneously. The optima storage temperature of sweetsop is between 15 and 20°C (Broughton and Tan, 1979; Vishnu Prasanna *et al.*, 2000). Fruit stored under low RH conditions ripen faster and have better taste and appearance than those stored under high RH.

DISEASES, PESTS AND WEEDS A number of diseases have been reported (Table A.27). Anthracnose caused by *Colletotrichum gloeosporioides* (*Glomerella cingulata*) is the most serious in areas of high rainfall and atmospheric humidity and during the wet season in dry areas (Dhingra *et al.*, 1980). This disease causes twig dieback, defoliation, dropping of flowers and fruit. On mature fruit the infection causes black lesions. Another severe fruit rot disease is attributed to *Gliocladium roseum* and affects 20–90% of the fruit in India. Symptoms consist of water-soaked spots that turn soft and brown.

Black canker (*Phomopsis anonacearum*) and diplodia rot (*Botryodiplodia theobromae*) occur mostly on neglected trees and cause similar symptoms of purplish to black lesions resulting in mummified fruit. Marginal leaf scorch and twig dieback can be also caused by *P. anonacearum* and *B. theobromae*. Diplodia rot has darker internal discoloration and deeper, more extensive corky rot in fruit. *Phytophthora* blight (purple blotch) caused by *Phytophthora citrophthora* and *Phytophthora nicotianae* that mostly infest fruit and leaves occurs during the wet season (Huang *et al.*, 1991). Fruit may be mummified and stay on the tree or drop, and the infected leaves show water-soaking spots that turn brown-black. Pink disease caused by *Corticium salmonicolor* mainly infests stems and causes twig dieback.

Table A.26. Tentative leaf nutrient standards for sweetsop in Taiwan, presented as a guide (Source: Anon., 1995).

	Acceptable range	
Nutrient	Sampling in May–June	Sampling in September–December
N (%)	2.75–3.25	2.60–3.10
P (%)	0.15–0.20	0.11–0.15
K (%)	1.30–1.80	0.80–1.20
Ca (%)	0.40–0.90	0.40–1.50
Mg (%)	0.30–0.50	0.30–0.50
Mn (ppm)	200–350	200–350
Fe (ppm)	40–80	40–80
Zn (ppm)	8–20	8–20
Cu (ppm)	5–40	5–40
B (ppm)	30–50	30–50

Table A.27. Major diseases of sweetsop.

Common name	Organism	Parts affected and symptoms	Country/region
Anthracnose	*Colletotrichum gloeosporioides* (*Glomerella cingulata*)	Fruit, leaves, twigs	Universal
Armillaria root rot	*Armillaria leuteobubalina*	Roots, base of tree, decline	Australia
Bacterial wilt	*Pseudomonas solanacearum*	Tree wilt	Universal
Black canker	*Phomopsis anonacearum*	Fruit, leaves	Universal
Black canker (diplodia rot)	*Botryodiplodia theobromae*	Fruit, leaves	Universal
Brown root rot	*Phellinus noxius*	Root, base of tree, decline	Taiwan
Fruit rot	*Gliocladium roseum*	Fruit	India
Phytophthora blight (purple blotch)	*Phytophthora citrophthora* and *Phytophthora nicotianae* (or *Phytophthora parasitica*)	Fruit, leaves; immature fruit may be mummified and stay on the tree or drop	Taiwan
	Phytophthora palmivora	Same effects	Australia
	P. parasitica	Same effects	India
Pink disease	*Corticium salmonicolor*	Trunk, stem, twig dieback	Taiwan
Rust fungus	*Phakopsora cherimoliae*	Leaves	Florida

Bacterial wilt is caused by *Pseudomonas solanacearum* and is characterized by rapid wilting and death of young trees and slow decline of old trees. There is a general decline of vigour and defoliation on affected limbs. Vascular discoloration of woody tissues occurs in the roots and up to the trunk at ground level. Brown root rot is caused by *Phellinus noxius* mainly infesting the roots and base of the tree and is characterized by a slow wilting and eventually results in death of the whole tree.

Some insect pests of sweetsop occur in most growing areas (Table A.28). The most serious pest is the annona seed borer (*Bephratelloides cubensis*) that is widely distributed throughout the Caribbean and Mexico, Central and northern South America and is found in Florida. This chalcidoid wasp lays its eggs on young fruit and the emerging larvae tunnel into the pulp, causing blackened, necrotic areas. Bagging the fruit is sometimes done. The annona fruit borer (*Cerconota anonella*) is another important pest in the American tropics. The atis moth borer (*Anonaepestis bengalella*) is the most serious pest of sweetsop in Taiwan.

Mealy bugs and various species of scale insects are found universally and usually become a serious pest on neglected trees. Red spider mites can become a serious problem in dry areas or during dry seasons. Yellow tea thrips (*Scirtothrips dorsalis*) can damage young shoots, flowers and fruit.

Mature green annona fruit are rarely infested by fruit flies, but are found occasionally in tree-ripened fruit. Use of bait sprays and field sanitation are recommended measures to minimize fruit fly infestation (Smith, 1991). Fruit bagging also provides protection.

Problem weeds, especially grasses and twining weeds, should be controlled before planting by cultivation and herbicides. Young trees should be protected from weed competition by hand weeding, mulching or contact herbicides. The shallow root system limits the use of cultivation under the tree. A translocated herbicide may be needed for perennial weeds and is applied as a spot spray. Nevertheless, to reduce the use of herbicides, grass cover is recommended, in which the whole field is covered with grass except the ground under canopies.

MAIN CULTIVARS AND BREEDING The origin of most cultivars is unknown. Existing commercial cultivars show considerable variation in growth, fruit set, fruit size and quality. No single cultivar has all the desirable characteristics. The length of the juvenile period varies with earliest production occurring in 2–3 years and full production in 5–6 years. This juvenile period is extremely variable with scions on seedling rootstocks. India and Taiwan have produced a few named cultivars (Table A.29). The major named cultivars of *A. squamosa* in Taiwan are ‘Ruan-zhi’, ‘Cu-lin’, ‘Da-mu’, ‘Xi-lin’ and ‘Tai-nong no. 1’. In India, commercial varieties include ‘Balanagar’, ‘Mammoth’, ‘Arka’, ‘Arka Sahan’, ‘Barbadose Seedling’, ‘Washington’, ‘Red Sitaphal’ and ‘Purandhar’. ‘Cuban Seedless’ is a seedless cultivar with medium-sized fruit developed in Cuba; another Cuban cultivar is low in fibre content. Seedling populations have been established in Taiwan to select superior lines with increased yield and improved quality. Early maturity, better fruit appearance, higher edible flesh ratio, postharvest and shipping quality and in the subtropics greater cold tolerance are the most frequent objectives. Chung Cheng Chen and Robert E. Paull

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Table A.28. Major insect pests of sweetsop.

Common name	Organism	Parts affected	Country/region
Ambrosia beetles	Many species in the Scolytidae family	Twigs, branches, trunk	Florida
Annona fruit borer	*Cerconota anonella*	Fruit	Florida, Caribbean, American tropics
Annona seed borer	*Bephratelloides cubensis*	Seeds (fruit)	Florida, Caribbean, American tropics
Atis moth borer	*Anonaepestis bengalella*	Fruit	Taiwan, Philippines, India
Fruit fly	*Dacus zonatus* Saunders	Fruit	India
Mealy bugs	*Pseudococcus maritimus* and *Pseudococcus calceolariae*, *Planococcus pacificus*, *Planococcus citri*, *Ferrisia virgata*, *Pesudococcus chiponensis*, *Pseudococcus virgatis*, *Pseudococcus lilacinus*	Stems, leaves, fruit	Florida, Taiwan, Australia, India
Red spider mite	*Oligonychus coffeae*, *Oligonychus mangiferus* and several other genera and species	Leaves, flowers	American tropics, Taiwan
Scale insects	*Aspidiotus destructor*, *Chrysomphalus ficus*, *Philephedra tuberculosa*, *Ceroplastes floridensis*	Leaves, twigs	Caribbean, Taiwan, Florida, India
Thrips	*Scirtothrips dorsalis*	Twigs, flowers, fruit	Taiwan

Table A.29. Some selected cultivars of sweetsop.

Country/region	Name
Taiwan	'Ruan-zhi', 'Cu-lin', 'Da-mu', 'Xi-lin', 'Tai-nong no. 1'
India	'Balanagar', 'Mammoth', 'Arka', 'Arka Sahan', 'Barbadose Seedling', 'Washington', 'Red Sitaphal', 'Purandhar'
Thailand	'Fai Kaew', 'Fai Krung', 'Nang Kaew', 'Nang Sir Krung', 'Nang Thong'
Florida	'Lessard', 'Kampong Mauve', 'Red Sugar', 'Cuban Seedless'
Egypt	'Abd El-Razik'

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Annona squamosa × *Annona cherimola* atemoya

Atemoya (*A. squamosa* × *A. cherimola*, *Annonaceae*) is a hybrid in the custard apple family, consisting of about 120 genera, widely distributed. All are native to the American tropics and subtropics. Some are grown as ornamentals while others are known for their edible fruit and perfume. Three major species of *Annona* are grown commercially: the cherimoya (*Annona cherimola* Miller), sugar apple (*Annona squamosa* L.) and atemoya or custard apple (*Annona* spp. hybrids) (George *et al.*, 1987). The cherimoya is indigenous to the tropical highlands of Peru and Ecuador, while the sugar apple is widely distributed throughout tropical South America (George and Nissen, 1985a, b). Most atemoya hybrids resemble cherimoya in vigour and tree habit, but exhibit flowering and fruiting characteristics intermediate to both parents.

World production

In the late 1990s, atemoya production was significant in Australia (3000 t), Israel (500 t), Florida (200 t) and Hawaii (50 t). In comparison, cherimoya production was significant in Spain (15,000 t), Bolivia (6000 t), Chile (2300 t) and Peru (400 t) while sugar apple production was significant in Thailand (75,000 t) and the Philippines (6000 t) (George and Nissen, 1992a; George *et al.*, 1997). Chile exports 1000 t of cherimoya annually. Yields of 80–150 kg/tree (15–25 t/ha) have been recorded for mature cherimoya and custard apple trees (George and Nissen, 1986a, 1992a). In Australia, the annual production of atemoya is expected to double in the next 10 years due to the planting of new, higher yielding cultivars with exceptional eating quality (George *et al.*, 1999).

Uses and nutritional composition

Atemoyas are usually consumed as dessert fruit. Because seeds of the fruit are interspersed throughout the flesh, cultivars containing few seeds are the most desirable. The perishable nature and supply shortage limits the market area or makes air shipment essential. The fruit is rich in starch when firm but increases markedly in sugar as it softens. The main sugars are glucose and fructose (80–90%). Compared with other fruit, atemoya fruit contain significant quantities of vitamin C, thiamine, potassium, magnesium and dietary fibre (Table A.30). The calorific value is high (> 300 kJ/100 g) and is almost double that of peach, orange and apple (George and Nissen, 1993).

Table A.30. Proximate fruit composition of atemoya per 100 g (Source: Leung and Flores, 1961).

Proximate	%
Edible portion	70
Water	71.5–78.7
Energy (kJ)	310–394
Protein	1.1–1.4
Lipid	0.4–0.6
Carbohydrate	18.1
Fibre	0.05–2.5
Ash	0.4–0.75
Minerals	**mg**
Calcium	17
Iron	0.3
Magnesium	32
Phosphorus	40
Potassium	250
Sodium	4.5
Vitamins	**mg**
Ascorbic acid	50
Thiamine	0.05
Riboflavin	0.07
Niacin	0.8
Vitamin A	–

Botany

TAXONOMY AND NOMENCLATURE The *Annonaceae* (120 genera) is considered a 'primitive' member of the *Magnoliidae*. The genus *Annona* is the most important in the *Annonaceae*, since among its 100 or more species, seven species and one hybrid are grown commercially. Atemoya, commonly called custard apple in Australia, is a hybrid between *A. squamosa* and *A. cherimola*. P.J. Wester of Florida produced the first hybrids in 1908 and called it the 'atemoya', by using the Brazilian name 'ate' for sweetsop and 'moya' from cherimoya. In 1927, hybrids were also developed in Poona, India. It should be noted that common names, such as custard apple, have been used with reference to many different species of *Annona*.

DESCRIPTION Cherimoya trees are 3–10 m tall whereas sugar apple is a shrub of 3–6 m. Atemoya trees are hybrids, morphologically intermediate between the above two species and vary in height from 3 to 10 m. All three species are semi-deciduous in growth habit. The tropical species, sugar apple sheds its leaves in the dry season, whereas cherimoya and custard apple from the subtropics shed their leaves in spring. Leaves are alternate, simple and entire. Vegetative buds are often subpetiolar (Fig. A.6), consequently natural leaf abscission or artificial defoliation is necessary prior to emergence of new growth flushes (George and Nissen, 1987a).

The *Annona* flower is hermaphrodite and exhibits protogynous dichogamy (George and Nissen, 1992a). The flowers are two series of three petals, and the outer series are thick and fleshy. With cherimoya and atemoya, floral buds can be initiated on 1-year and older wood but most are produced in synchronization with the current season's shoot growth (Moncur, 1988; Higuchi and Utsunomiya, 1999). *Annona* spp. generally require 27–35 days for flower bud development from initiation to anthesis. Differences in floral behaviour in the various areas may be attributed to both genetic variability and climatic differences (Kshirsagar *et al.*, 1976). Flowering can extend from 3 to 6 months, with normally between two and three peaks. For example, in Australia, atemoyas produce the first flowers during early summer with a second flowering during the late summer or early autumn.

Fruit are a pseudocarp formed by the fusion of the carpels and the receptacle into a fleshy mass. Fruit shape is highly variable ranging from spheroid to ovoid with the fruit surface covered with U-shaped areoles, which can be smooth or pointed. The white pulp is easily separable from the seeds and is very popular, especially in the Americas.

ECOLOGY AND CLIMATIC REQUIREMENTS The cherimoya is indigenous to the tropical highlands of Peru and Ecuador, while the sugar apple is widely distributed throughout tropical South America. Most hybrids resemble cherimoya in vigour and tree habit, but exhibit flowering and fruiting characteristics intermediate to both parents. All three species are now widely distributed throughout the world.

Both atemoya and cherimoya are best grown in frost-free locations as young trees are killed at −1°C and mature trees at −3°C (George and Nissen, 1985a, 1992a). Cherimoya is more cold tolerant than custard apple and can withstand a longer duration at −3°C. Sugar apple, on the other hand, is frost sensitive. In the cool subtropics, cherimoya rootstocks, because of their ability to grow at lower soil and air temperatures than sugar apple, may increase tree growth and productivity. Conversely, in warm subtropical areas, trees may be vigorous but unproductive.

Trees of atemoya are semi-deciduous and are dormant in late winter and early spring. This dormancy or rest period enables the tree to avoid frost or drought. Cherimoya appears to initiate growth at 7°C compared with 10°C for custard apple (George and Nissen, 1985a, 1987a). Budbreak of most atemoya normally occurs in late spring, after a winter dormancy. In warm areas, chemical defoliation can be used to advance budbreak by 4–6 weeks (George and Nissen, 1987a). This treatment does not work in atemoya at < 12°C because shoot growth is erratic (George and Nissen, 1986a, b). Provided insect pollinators are present and environmental conditions are conducive for set, defoliation has the potential to increase early fruit production in warm regions.

In glasshouse studies, 32°C days/27°C nights, used to simulate tropical conditions, induced strong vegetative flushing and reduced floral production in atemoya (George and Nissen, 1987b). In warm areas such as Florida, Hawaii and Queensland, strong vegetative flushing occurs in midsummer during flowering and may reduce fruit set unless trees are propagated on dwarfing rootstocks or interstocks (George and Nissen, 2002a). Under cooler conditions in Chile, California and New Zealand, trees are less vigorous.

Temperatures between 22–28°C during flowering period are ideal for fruit set in atemoya (George and Nissen, 1985a) whereas 18–28°C is more suitable for cherimoya (Saavedra, 1977). Flower opening and anther dehiscence are both advanced with increasing temperature, however at > 28°C the stigmas desiccate before the anthers dehisce (George and Nissen, 1988). In controlled-environment studies, relative humidity (RH) of > 95% and < 60% severely reduced fruit set (George and Nissen, 1988). The adverse effects of high RH appear to be due to changes in stigmatic secretions, which restrict pollen germination and pollen tube growth. At low RH, desiccation of the stigma may occur before anthers dehisce as most flowers are at the female stage in the early morning and the anthers only release pollen in the afternoon (Saavedra, 1977). Studies in Chile (Saavedra, 1977) and Egypt (Ahmed, 1936) showed that spraying flowers with water or inserting a drop of water into the flower at anthesis could increase fruit set about sixfold. Although stigmas appear to require constant, moderately high RH, a diurnal change appears to be necessary for anther sacs to split (Kshirsagar *et al.*, 1976). As flowering of *Annona* spp. occurs during summer in the subtropics, RH levels below 30% are common. Late afternoon rain or under-tree irrigation can increase fruit set perhaps by causing condensation of water droplets within the fleshy petals of the flower (George and Nissen, 1985b). In contrast, light rain or continuous daily sprinkling are detrimental possibly because they dilute the floral scents which attract pollinators.

Excessively low temperatures may retard fruit maturation while excessively high temperatures may cause premature ripening and fermentation (George and Nissen, 1985a, 1992a). As expected, cultivars appear to vary in this regard. Physiological disorders such as russetting also appear to be more prevalent when temperatures fall below 13°C (George and Nissen, 1985a).

Atemoya is capable of growing in a wide range of soil types from sandy soil to clay loams. Higher yields occur on well-drained sandy to sandy loam soils. Drainage is essential to avoid root rot diseases.

Moderate drought (ψ_L of −1.5 Mpa) has been shown to reduce shoot growth by about 20–30% and increase the number of flowers per lateral by about 40% compared with well-watered controls, due to reduced apical dominance and increased lateral branching (George and Nissen, 2002a). However, severe drought (ψ_L of −2.0 MPa) reduced flowering and fruit set by 30% in trees growing at 28°C and moderately high vapour pressure deficity (VPD) of 1.2 kPa (George and Nissen, 1988). Drought has been shown to reduce fruit size by about 10% due to reduced stomatal conductance (g_S) and carbon dioxide assimilation (George and Nissen, 1992b, 2002a). In controlled-environment glasshouses there was a continuous but decreasing decline in g_S over a range of ψ_L from −0.8 MPa to −4.0 MPa at high RH of 90% (George *et al.*, 1990), whereas at 60% RH, g_S was extremely low, irrespective of the tree water status. The stomata of atemoya are thus more sensitive to RH than ψ_L.

Overall, atemoya benefits from uniform soil moisture during the fruit development period with extremes of moisture lowering production. The adverse effects of drought on productivity can be minimized by maintaining soil water potentials (ψ_S) > −20 kPa. Bearing atemoya trees may need up to 1440 l/tree every 4 weeks during slow growth phase and from 500 to 750 l/tree every 3–5 days during flowering fruit set and fruit growth (Sanewski, 1991). Reducing irrigation in late winter to force atemoya trees into dormancy for 1 or 2 months in spring is recommended in Australia and California, respectively. The amount and frequency of irrigation must be determined by experience in any particular location and soil type. Water stress should be prevented during flowering, fruit set and fruit development, as fruit are more sensitive than leaves.

Heavy shading of vigorous trees can reduce fruit set in atemoya (Marler *et al.*, 1994). Light penetration to the base of vigorous trees with a dense canopy in a close spacing can be 2% of full sunlight and there is very little fruit set. Pruning practices and spacing need to be adjusted for this growth aspect. No photoperiod responses have been reported.

Trees are susceptible to wind damage and limb breakage. Tree shaking may also be partially responsible for penetration and infection by collar rot organisms. The fruit skin is easily damaged by rubbing and exposure to drying winds (Marler *et* *al.*, 1994). Productivity can be improved by windbreaks and under-tree sprinklers to raise the RH above 60%.

REPRODUCTIVE BIOLOGY The flowers exhibit protogynous dichogomy. Dichogamy appears to be the main factor limiting self-pollination and fruit set in *Annona* and poses a serious problem in obtaining high yields. The atemoya female parts are receptive between 4 and 8 a.m. and appear moist and sticky (Thakur and Singh, 1964). The pollen is discharged in the afternoon of the same day from 3 to 6 p.m. if the RH is above 80% and temperature > 22°C. At lower temperatures pollen is released on the afternoon of the second day. The pollen sacs turn a greyish colour as pollen is discharged. Upon opening, flowers are receptive for about 24 h. The flowering seasons of *A. squamosa* and *A. cherimola* coincide. When sweetsop pollen is shed at about 2 a.m., cherimoya flowers are receptive, opening around 7 to 9 a.m. and when cherimoya pollen is shed at 3 to 4 p.m., sweetsop flowers are receptive. This flower synchrony together with complementary functional sexes favours cross-pollination leading to natural hybridization. This is attested to by the frequent appearance of hybrid seedlings under the trees of sweetsop and cherimoya when grown in close proximity.

Beetles of the Nitidulidae family are the main insect pollinators of *Annona* flowers. Nitidulid beetles (*Carpophilus* and *Uroporus* spp.) are the important pollinators of *Annona* flowers with wind and self-pollination being low (1.5%). Fruit set of 'African Pride' atemoya increases linearly with increasing numbers of nitidulid beetles per flower (George *et al.*, 1992). Three or more beetles per flower increased fruit set to nearly 25%. Studies also showed that these beetles breed rapidly in rotting fruit media and that populations of these beetles can be increased by maintaining the rotting fruit attractant. Alternatively, fruit set may be increased by using pheromone bait stations (Pena, 2002).

Pollen early in a flowering season has thick walls, is high in starch, germinates poorly and gives poor fruit set. Pollen of later flowers shows a high proportion of individual pollen grains without starch grains that germinate well. Hand pollination can increase fruit set in excess of 40% (Schroeder, 1943) and is frequently practised, improving fruit set and fruit shape. Pollen must be collected in the evening from fully open flowers, when the sacs have turned from white to cream. The flowers are held in a paper bag, not a closed container, and should discharge that afternoon. The flowers are shaken over a shallow tray or paper to collect the pollen that is transferred to a small container and held in the refrigerator for use the next morning. Enough pollen to pollinate 50 to 60 flowers can be obtained from 20–30 flowers. Pollination is done before 7 a.m. every few days during the flowering period using a small brush or puffer. Hand pollination has shown some variable results and is less successful on very humid, overcast days and on young vigorous trees. About 150 flowers can be pollinated in an hour and a success rate of 80–100% can be achieved.

Hand pollination in commercial orchards is tedious, time consuming and a costly practice. Attempts have been made to use growth regulators, with considerable variation in the results obtained. Auxin (indole acetic acid (IAA), napththalene acetic acid (NAA)) induces growth very slowly with less fruit drop, while gibberellic acid-3 (GA_3) promotes fruit set and growth rate, however, the effects are short lived and repeated applications are needed (Yang, 1988). Applications of the two substances separately at appropriate times have produced seedless fruit between 200 and 300 g in size (Saavedra, 1977). In Japan, four sequential applications of gibberellin (GA_3, 1500 ppm) produced near seedless fruit of 300–400 g in selected cherimoya cultivars (Yonemoto *et al.*, 2000a, b). Repeated spraying is necessary to prevent fruit abscission during the first 2 months. Seedless fruit are generally smaller, with less flavour and less fruit splitting than occurs in seedy fruit that result from pollination (Yang, 1988). Spraying with GA_3 is not recommended as a general management practice for atemoya because of variable results, though it could be used in areas with poor natural pollination.

FRUIT DEVELOPMENT Fruit exhibits a two-stage growth pattern with maturation occurring 16 to 26 weeks after fruit set, depending upon species and growing conditions (George, 2000). Low humidity (< 60% RH) and temperature (< 13°C) near fruit maturity can delay fruit maturation whereas very high temperatures (> 35°C) can cause premature fruit ripening and fermentation of the fruit. In Australia, due to climatic differences between regions within the country, fruit may be harvested over a period of 8 months.

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PROPAGATION Atemoya is normally propagated by grafting (Table A.31). Varieties are very difficult to propagate by cuttings or layering. There are cultivar differences in rooting ability of atemoya, with 'African Pride' having a higher rooting response (15%) than 'Pink's Mammoth' and cherimoya (<5%). Time of cutting removal is crucial for success; cuttings taken at the end of the cool season have a higher rooting rate. Roots should occur in 8–12 weeks and are ready to pot in 16–20 weeks. Recent research has shown softwood cuttings to give a higher strike than hardwood cuttings (Nissen, personal communication, 2003).

Air layering can be used with some cultivars, though cherimoya are not propagated easily by this method. A modification where the new shoot is clamped and only the shoot tip is exposed is successful. Inarching of atemoya to *Annona reticulata* rootstock has been successful. Although

Table A.31. Rootstock and scion compatibility of atemoya (Source: Sanewski, 1991).

	Scion[a]			
Rootstock	Atemoya	Gefner	Pink's Mammoth	Page/Bradley
Atemoya	C			
Gefner		C		
Pink's Mammoth			C	
Page/Bradley				C
Annona cherimola	C		C	C?
Annona glabra	N			
Annona muricata	N			
Annona palustris	–			
Annona reticulata	N	P	P	
Annona squamosa	C	C	C	C?

[a]C, compatible; P, partially compatible; N, not compatible; –, unknown.

inarching has given good results, it is time consuming and costly for large-scale propagation.

Grafting is superior to budding in percentage takes and subsequent growth, with whip graft and cleft graft techniques giving the best results (Duarte *et al.*, 1999). The branches should be defoliated 1–2 weeks before scionwood is cut to induce bud swelling. T-budding and chip budding methods are sometimes successful. There are considerable graft incompatibilities among *Annona* and *Rollinia* spp. and types.

Transplanting is best done when the trees are dormant. In the subtropics, planting should not occur if there is a risk of frost. Plants should have attained a height of 30–46 cm at transplanting time with the union of grafted or budded plants placed 15 cm or so above the ground. Trees should be irrigated as soon as possible after transplanting, with wind and sun guards sometimes required.

In Australia and Florida, depending on rootstock, atemoya trees are planted 4–6 m apart within the row with 6–8 m between rows (Campbell, 1985). Narrower tree spacing is used for 'African Pride' on *A. squamosa* rootstock or interstock and the widest spacing is used for 'Pink's Mammoth' on *A. cherimola*. More recently, with new, exceptionally high-yielding cultivars such as 'KJ Pinks' trained onto the open Tatura system, higher planting densities have been made possible.

ROOTSTOCKS Cherimoya has been found to be a vigorous rootstock for atemoya. Atemoya is not compatible with *Annona glabra*, *Annona muricata* and *A. reticulata* as rootstocks (Sanewski, 1991) (Table A.31). This is complicated by cultivar differences in compatibility with common rootstocks. Atemoya cultivars 'Bradley' and 'Page' are compatible with custard apple rootstocks but 'Gefner' shows partial incompatibility with the same rootstock. With atemoya, George and Nissen (2002b) showed that tree size could be reduced by half using sugar apple rootstocks, but sugar apple was found to be susceptible to bacterial wilt, caused by *Pseudomonas solanacearum*, with up to 30% of trees dying within 6 years after planting. Consequently, cherimoya, which is only mildly susceptible to bacterial wilt, has been the preferred rootstock of choice in Australia.

PRUNING AND TRAINING Training of trees begins in the nursery with pruning continuing after transplanting. It is desirable to train the tree to a single trunk up to a height of about 90 cm and then headed back to produce four to six main branches or sub-leaders. These branches should be spaced 15–25 cm above each other and be allowed to grow in different directions to develop a good scaffold. After about 2 m, they could be left to natural growth. Pruning is carried out when the trees are dormant and in heavy trees involves removal of lower limbs touching the ground and branches in the centre where branches may be rubbing against each other. The objective is to allow sunlight access to the centre of the tree. More recently, with the development of exceptionally high-yielding varieties with lower tree vigour, trees are now being trained onto an open Tatura or Y trellis system. These systems allow for greater light interception and overcome the problems of deep shading with goblet-trained trees.

With atemoya, all lateral buds can have up to two vegetative buds and three flower buds. The lateral buds are normally 'buried' (subpetiolar) in the base of the swollen leaf petiole (Fig. A.6). Leaf shed must occur prior to the elongation of 'buried' buds (George and Nissen, 1987a). During spring, just prior to budbreak, removal of leaves mechanically by stripping or chemically with urea or ethephon, followed by the application of rest-breaking chemicals, can help to release these buds from dormancy (Sanewski, 1991; George *et al.*, 2002b). Dormant pruning is also normally carried out in late winter or early spring, just before budbreak. At this time, laterals are moderately pruned as George *et al.* (2001) have shown that severe stub pruning of laterals to < 20 cm long is detrimental to yield and fruit quality. This pruning strategy aims to produce one or two fruit on new season laterals. The ideal seasonal growth of laterals producing fruit is about 60 cm long and about 10 mm in diameter at the base. Annual lateral growth more than 60 cm is considered excessive for mature fruiting trees, and increases the severity of internal fruit disorders (George *et al.*, 2002b). Vigorous trees are also summer pruned, which involves shoot tipping and usually leaf stripping to force the subpetiolar buds into lateral growth concomitantly with late flowering.

NUTRITION AND FERTILIZATION The *Annonas* spp. have an indeterminate growth habit (axillary flowering) and applying nitrogen in somewhat excessive amounts does not interfere greatly with floral initiation, as is the case with plants having a determinate growth habit. However, excessive tree vigour is usually associated with reduced flowering, yield and fruit quality in many tree crops and the atemoyas are no exception (George *et al.*, 1989).

In Australia, continued research and field observations of atemoya nutrition (Sanewski, 1991; George *et al.*, 2002c) have led to greater refinements in terms of quantity of fertilizer and times of incremental applications during the annual growth and fruiting cycles. After 10 years of age, the annual amounts of nitrogen, phosphorus and potassium (NPK) remain the same, as tree size is kept relatively constant by annual pruning and competition from adjacent trees. The annual requirements of nitrogen and potassium are split into four increments (Table A.32). In the cool subtropical areas, greatest vegetative growth takes place during the warmer months from spring to autumn. Reduction in nitrogen during the winter minimizes new vegetative growth in young trees that are vulnerable to cold temperatures. This adjustment is not necessary in the warm tropics. There is one application of phosphorus per year, during the early autumn.

The use of foliar nutrient analysis has become a useful management tool in determining atemoya fertilizer programmes (Table A.33). Sampling for foliar analysis consists of obtaining the most recently matured leaf; the fourth or fifth leaf below the growing point. Sample leaves are selected from non-bearing shoots without a leaf flush, during late summer or early autumn.

The primary sink for potassium in the atemoya is the fruit, rather than the leaves and thus there is a high requirement, with deficiency likely. About 60% of the potassium requirement is applied during the fruit development period. Atemoyas also have a fairly high requirement for magnesium and calcium. Heavy vegetative growth during the fruit

Table A.32. A guide to annual application of nitrogen, phosphorus and potassium (NPK) for 'Pink's Mammoth' atemoya trees of different ages using straight fertilizers (g/tree/year) and percentage distribution of application of annual amounts (Source: Sanewski, 1991).

Tree age (years)	Urea (g/tree/year)	Superphosphate (g/tree/year)	Potassium chloride (g/tree/year)
2	400	500	360
4	860	550	930
6	1300	780	1170
8	1600	880	1500
10	1750	880	1650

Fertilizer	Early spring	Early summer	Early autumn	Late autumn
Urea (%)	20	30	40	10
Superphosphate (%)			100	
Potassium chloride (%)	10	30	40	20

Table A.33. Tentative leaf nutrient standards for atemoya in Queensland, Australia presented as a guide (Source: George *et al.*, 2002).

Nutrient	Acceptable range
Nitrogen (%)	2.4–3.2
Phosphorus (%)	0.15–0.21
Potassium (%)	1.0–1.5
Calcium (%)	1.0–1.6
Magnesium (%)	0.35–0.4
Sodium (%)	< 0.02
Chloride (%)	< 0.3
Manganese (ppm)	60–140
Copper (ppm)	10–20
Zinc (ppm)	40–70
Iron (ppm)	50–110
Boron (ppm)	18–30

development period competes for nutrients such as calcium and boron. Calcium-deficient fruit develop hard, brown, lumpy tissues around the central core. Deficiency in calcium and boron are considered as causal factors for these lumps (Cresswell and Sanewski, 1991; George *et al.*, 2002d). Applying excessive boron can be phytotoxic, especially in sandy soils. A desirable practice is to use organic fertilizers with inorganic fertilizer as a supplement to maintain a balance and to control cropping (Sanewski, 1991).

POSTHARVEST HANDLING AND STORAGE Atemoyas are harvested every 3–7 days with experienced pickers harvesting from 150 to 180 kg of fruit/h. Heart-shaped fruit are preferred with a smooth cherimoya-like skin, instead of the bumpy sweetsop skin type. Besides shape, size (200–500 g) and skin texture, the fruit should be free of blemishes and mechanical injury that can lead to skin blackening. The fruit skin colour changes from darker to lighter green and can be greenish yellow at harvest. During ripening of this climacteric fruit, the skin darkens further and splitting occurs. Harvested fruit should be handled with care to prevent bruising of the skin. This is especially important for fruit that is marketed for fresh consumption. Australian standards specify mature atemoya fruit 75 mm in diameter, firm with 'creaming' between segments on the skin. Containers are about 7 kg in size, fibreboard or polystyrene (450 × 215 × 180 mm), well ventilated and marked with 'custard apple' and the number of fruit. Foam sleeves or paper wrapping are used to minimize damage. The presence of soft fruit and even one fruit-fly-damaged fruit can lead to rejection of the consignment.

During ripening, skin splitting occurs and the skin darkens. Fruit are stored at 10–13°C and 90–95% RH. Atemoya is sensitive to chilling injury and shows skin darkening and loss of aroma and flavour. Ethylene production is high (100–300 μl/kg/h at 20°C) and ripening is accelerated by exposure to 100 ppm ethylene for 24 h. Respiration rate at 20°C is 40–460 mg carbon dioxide/kg/h.

DISEASES, PESTS AND WEEDS Black canker (*Phomopsis anonacearum*) and diplodia rot (*Botryodiplodia theobromae*) occur mostly on neglected trees and cause similar symptoms of purplish to black lesions resulting in mummified fruit (Table A.34). Marginal leaf scorch is also caused by *P. anonacearum* and *B. theobromae* and causes twig dieback. Diplodia rot has darker internal discoloration and deeper, more extensive corky rot in fruit. Fruit and leaf spot may also be caused by a soil-borne fungus, *Cylindrocladium colhounii* (Hutton, 1999) which can cause almost total loss of fruit during years of persistent heavy rains. Symptoms begin with small dark spots primarily on the shoulders of the fruit that spread along the sides, enlarge, become dry and crack. Infection is skin-deep but fruit becomes unmarketable. The control measures recommended are good orchard maintenance with heavy mulching and lower branch pruning to prevent splashing of soil during heavy rainfall (Sanewski, 1991). A new fruit spotting disease (*Pseudocercospora* spp.) has been identified in recent years (Hutton, 1999). Symptoms are small grey spots 1–5 mm in diameter. It develops under wet conditions and is spread by the wind.

Bacterial wilt of atemoya is caused by *Pseudomonas solanacearum* and is characterized by rapid wilting and death of young trees and slow decline of old trees. There is a general decline of vigour and defoliation on affected limbs. Vascular discoloration of woody tissues occurs in the roots and up to the trunk at ground level. It has caused up to 70% of tree deaths in 12 years in orchards using *A. squamosa* rootstocks in Queensland.

One of the most serious insect pests in Trinidad is the cerconota moth (*Cerconota anonella*) that lays its eggs on young fruit (Table A.35). The emerging larvae tunnel into the pulp, causing blackened, necrotic areas. It is common to find

Table A.34. Major diseases of atemoya.

Common name	Organism	Parts affected and symptoms	Country/region
Anthracnose	*Colletrotrichum gloeosporioides* (*Glomerella*)	Flowers, fruit, leaves, dieback, seedling damping off	Universal
Armillaria root rot	*Armillaria leuteobubalina*	Roots, base of trees, decline	Australia
Bacterial wilt	*Pseudomonas solanacearum*	Tree wilt	Australia
Black canker (diplodia rot)	*Botryodiplodia theobromae*	Leaf scorch, hard black lumps on surface of fruit, twig dieback	Australia
Black canker	*Phomopsis anonacearum*	Same effects	Australia
Purple blotch	*Phytophthora palmivora*	Spots on immature fruit, fruit drop, twig dieback	Australia
Cylindrocladium fruit rot	*Cylindrocladium colhounii*	Small spots and blotches on the fruit	Australia
Pseudocercospora fruit spot	*Pseudocercospora* spp.	Purplish-grey spots on the fruit	Australia
Rust fungus	*Phakopsora cherimoliae*	Leaves	Florida
Fruit rot	*Glioclacium roseum*	Fruit	India

Table A.35. Major insect pests of atemoya.

Common name	Organism	Parts affected	Country/region
Bephrata wasp (soursop wasp)	*Bephrata maculicollis*	Fruit	Mexico, Americas, Trinidad, Surinam
Wasp	*Bephratelloides paraguayensis*	Fruit	Americas, Barbados
Cerconota moth (soursop moth)	*Cerconota anonella*	Fruit	Americans, Trinidad, Surinam
Thecla moth	*Thecla ortygnus*	Flower, young fruit	Americas, Caribbean
Banana spotting	*Amblypelta lutescens*	Young fruit	Queensland
Mealy bug	*Dysmicoccus*	Stem, leaves	Universal
Citrus mealy bug	*Planocuccus citri*	Fruit	Queensland
Southern stink bug	*Nezara viridula*	Fruit	Caribbean
Caribbean fruit fly	*Anastrepha suspensa*	Fruit	Caribbean, Mexico
Queensland fruit fly	*Dacus tryoni*	Fruit	Australia
Potato leaf hopper	*Empoasca fabae*	Leaves	Caribbean
Red spider mite	Several genera, species	Leaves, flowers	American tropics
Scale insects	*Saissetia coffeae*	Leaves, stem	Universal
Coconut scale	*Aspidiotus destructor*, other genera and species	Leaves, stem	Caribbean

every fruit larger than 7.5 cm infested. Bagging the fruit is sometimes done. This moth has been reported in the American tropics as far south as Brazil and is a major limiting factor in Surinam. The bephrata wasp (*Bephrata maculicollis*) is widely distributed throughout the Caribbean and Mexico, Central and northern South America. This wasp is considered to be the most important pest in Florida (Campbell, 1985). The larvae infest the seeds and cause damage to the pulp as they bore through the flesh to emerge when the fruit matures. The thecla moth (*Thecla ortygnus*) is widespread through parts of the Caribbean and in the American tropics but it is not considered to be as serious as the cerconota moth and bephrata wasp. Primary damage is done to the flowers. The larvae feed on flower parts such as the perianth, stamen and stigmas with the flowers failing to set fruit. The banana spotting bug (*Amblypelta lutescens*) and the fruit spotting bug (*Amblypelta nitida*) are considered to be serious atemoya pests (Waite and Huwer, 1998). The banana spotting bug is reported to be confined to northern Queensland with both being found in southern Queensland. The bugs cause small black 2–10 mm spots on the shoulders of young fruit and penetrate about 1.0 cm into the fruit. The damage resembles the symptoms of diplodia rot (black canker) (Sanewski, 1991).

Mealy bugs and various species of scale insects are found universally and usually become a serious pest on neglected trees. The former is reported to be a major pest on marketable fruit in some areas of Australia (Sanewski, 1991; Smith, 1999). Red spider mites can become a serious problem in dry areas or during dry seasons.

Mature green annonaceous fruit have been shown to be rarely infested by the Mediterranean fruit fly (*Ceratitis capitata*) and oriental fruit fly (*Dacus dorsalis*), but are found on occasion in tree-ripened fruit. In Australia, the Queensland fruit fly (*Dacus tryoni*) infests ripening atemoya fruit. 'African Pride' appears more susceptible than 'Pink's Mammoth'. Use of bait sprays and field sanitation are recommended measures to minimize fruit fly infestation (Smith, 1991; Lloyd, 1999). Fruit bagging also provides protection.

Problem weeds especially grasses and twining weeds should be controlled before planting by cultivation and herbicides.

Young trees should to be protected from weed competition by hand weeding, mulching or contact herbicides. The shallow root system limits the use of cultivation under the tree. A translocated herbicide may be needed for perennial weeds and are applied as a spot spray.

MAIN CULTIVARS AND BREEDING In Australia, the earliest cultivar that was grown was 'Pink's Mammoth' which was introduced from British Guiana in the 1890s. This cultivar takes 6–7 years to begin producing commercial-size yields of fruit that are large, weighing 800 g to as large as 2 kg and is a less precocious bearer than 'African Pride', which was probably introduced into Australia from South Africa, although its origin may have been Israel. Both these cultivars have now been superseded by two new cultivars, 'Maroochy Gold', originating out of the Queensland Department of Primary Industries breeding programme, and 'KJ Pinks', a budsport of 'Pink's Mammoth' with exceptionally high fruit setting. Both these cultivars produce medium to large fruit with excellent eating characteristics. The main cultivar grown in Florida and Hawaii is 'Gefner', an Israeli cultivar; this cultivar prefers semi-tropical conditions. It produces small- to medium-sized fruit. Most minor cultivars listed in the literature have now been discarded.

Breeding and selection in atemoya (*Annona* spp. hybrids) and cherimoya (*A. cherimola*) has been much neglected. Most atemoya cultivars are hybrids of cherimoya (*A. cherimola*) and sugar apple (*A. squamosa*). However, other atemoya cultivars are of unknown genetic origin. Few new cultivars of atemoya and cherimoya have been selected in the past 20 years due to the small population of naturally occurring seedlings, and lack of a breeding programmes/strategies for these fruit. In contrast, other subtropical and tropical fruit such as mango have been intensively selected from over several hundred thousand seedlings for more than 100 years.

Wester (1913, 1915) was the first person to realize the possibilities of genetic improvement of *Annona* and initiated a breeding programme in Florida and the Philippines. However, because of the small number of progeny he evaluated, no new varieties were selected. No further breeding of atemoyas was carried out until the late 1980s when the authors initiated a breeding programme in atemoya in Australia and coincidently Zill and Medeem (personal communication, 1997) were undertaking introductions and breeding for atemoya in Florida. In Florida approximately 3000 seedling progeny, mainly interspecific crosses, have been planted out in Zill orchards near Boynton Beach. To date, none of the progeny of these crosses has produced commercial cultivars.

Many interesting species and selections have been introduced into Florida from Central America over several decades (Whitman, 1972; Popenoe, 1974; Zill, personal communication, 1997). Many of these have been used in the Florida breeding programme, and more recently in the Australian breeding programme since their recent introduction in 1998. In Spain, over the past 20 years, Dr Jose Farre (personal communication, 1997) has conducted a major cherimoya varietal introduction programme from South America.

The main characteristics being selected in atemoya are fruit symmetry, smooth skin, chilling tolerance and low seed number or seedlessness. Seedlessness is a desirable characteristic being sought in atemoya and may be achieved through various strategies. The most commonly used approach in other crops is to double the chromosomes of diploids to produce tetraploids which, in turn, are crossed back to a diploid to produce a triploid plant which is often sterile and produces seedless fruit. This technique should also work with atemoya and other *Annona* spp. which are diploids (Thakur and Singh, 1964, 1965).

In Queensland, considerable recent progress has been made in selecting new types, identifying appropriate parents and gaining an understanding of the inheritance of desirable traits in atemoya (George *et al.*, 2002c). Inter-varietal crosses have been made between the best selections of atemoya and the main commercial cultivars such as 'African Pride', 'Pink's Mammoth' and 'Hillary White' (Table A.36). Interspecific crosses have also been made between four different species: *A. cherimola* (cherimoya), *A. squamosa* (sugar apple), *A. reticulata* (bullock's heart) and *Annona diversifolia* (ilama). Some 10,000 breeding lines have been field planted since 1992.

Several cultivars have been selected in Israel (Gazit and Eistenstein, 1985). More recently, active breeding and selection programmes have been conducted in Florida and Australia (George *et al.*, 2002a). The latter programme has produced four named cultivars to date and has successfully hybridized atemoya with *A. diversifolia* and *A. reticulata* to produce red and pink skin types. There is considerable variation among seedlings.

An alternative approach to conventional breeding using mutation techniques is also being evaluated in Australia. Early results indicate that it may be feasible to produce tetraploids using colchicine applications to juvenile buds. Ten advanced selections are being trialed at six evaluation sites throughout Queensland and northern New South Wales.

The Queensland and Florida programmes have successfully developed hybrids with red skin colour and pink internal flesh. Red skin colour may be carried by either a single or double recessive gene. Fruit symmetry, flesh recovery and flavour characteristics of some crosses are excellent. To date, one advanced selection, 'Maroochy Gold', has been named.

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Table A.36. Selected cultivars of atemoya.

Name	Origin
'Maroochy Gold'	Australia
'KJ Pinks'	Australia
'Pink's Mammoth'	Australia
'African Pride'	Southern Africa
'Bradley'	USA – Florida
'Page'	USA – Florida
'Gefner'	Israel
'Kabri'	Israel
'Malalai'	Israel

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Asimina triloba pawpaw

The North American pawpaw, *Asimina triloba* (L.) Dunal, grows wild as an understorey tree or thicket-shrub in mesic hardwood forests ranging from northern Florida to southern Ontario (Canada) and as far west as eastern Nebraska. Fruit (100–1000 g) may be borne singly or in clusters, are highly nutritious, have a strong aroma and a unique flavour that resembles a combination of banana, mango and pineapple. This oblong-shaped fruit has both fresh market and processing potential.

Pawpaws have a well-established place in folklore and American history. The traditional American folk song, ‘Way down, yonder in the pawpaw patch’ was quite popular at one time and autumn hunting for pawpaw in the woods is a cherished tradition for many rural families in the eastern USA. The first report of pawpaw dates back to 1541 when followers of the Spanish explorer Hernando de Soto found Native Americans growing and eating pawpaws in the valley of the Mississippi. The Native Americans used the bark of pawpaw trees to make fishing nets. Daniel Boone and Mark Twain were reported to have been pawpaw fans. Lewis and Clark, the explorers who between 1804 and 1806 successfully crossed America from St Louis to the mouth of the Colombia River, recorded in their journal (18 September 1806) how pawpaws helped save them from starvation. Several American towns, townships, creeks and rivers were named after the pawpaw during the 19th century. Interest in pawpaw as a fruit crop was evident in the early 1900s, however, the rapid perishability of the fruit is likely to have decreased interest in pawpaw. Interest in pawpaw did grow in the years between 1950 and 1985. Recently, there has been developing interest in pawpaw as a gourmet food.

World production

Although pawpaw has great potential for commercial production, orchard plantings remain limited. Currently, most pawpaw fruit for sale are collected from wild stands in the forest. However, in a number of states in the USA small private orchards, usually less than 1 ha in size, have been planted. There are also pawpaw plantings in Italy, China, Israel, Japan, Romania, Belgium and Portugal. In the USA, pawpaw fruit and products are mainly sold at farmers' markets, directly to restaurants and via entrepreneurs on the Internet. However, at present the grower base is insufficient to establish a commercial processing industry.

Uses and nutritional composition

Pulp from fruit can be eaten fresh or processed. The flavour of the fruit can intensify as it over-ripens, as with banana, resulting in pulp that is excellent for use in cooking. The seeds and skin are generally not eaten. Local delicacies made from fruit pulp include ice cream, compote, jam, pies, custards and wine. The pawpaw fruit has a high nutritional value (Table A.37). Pawpaw and banana are similar in dietary fibre content and overall nutritive composition. The highly perishable nature of the fruit can limit the available supply.

Table A.37. Nutritional composition of pawpaw[a] per 100 g (Source: Peterson *et al.*, 1982; Jones and Layne, 1997).

Proximal analysis	g
Food energy (kcal)	80
Protein	1.2
Total fat	1.2
Carbohydrate	18.8
Dietary fibre	2.6
Vitamins	**mg**
Vitamin A RE[b]	8.6
Vitamin A Iu[s]	87
Vitamin C	18.3
Thiamine	0.01
Riboflavin	0.09
Niacin	1.1
Minerals	**mg**
Potassium	345
Calcium	63
Phosphorus	47
Magnesium	113
Iron	7
Zinc	0.9
Copper	0.5
Manganese	2.6
Essential amino acids	**mg**
Histidine	21
Isoleucine	70
Leucine	81
Lysine	60
Methionine	15
Cystine	4
Phenylalanine	51
Tyrosine	25
Threonine	46
Tryptophan	9
Valine	58

[a] Pawpaw analysis was done on pulp with skin, although the skin is not considered edible. Probably much of the dietary fibre, and possibly some of the fat, would be thrown away with the skin.
[b] RE, Retinol equivalents – these units are used in the Recommended Dietary Allowances table (National Research Council, 1989).
[c] IU, International units.

Botany

TAXONOMY AND NOMENCLATURE The pawpaw, *A. triloba*, is a member of the mostly tropical custard apple family, *Annonaceae*, which is the largest primitive family of flowering plants. This family includes several delicious tropical fruit such as the custard apple (*Annona reticulata* L.), cherimoya (*Annona cherimola* Mill.), sweetsop or sugar apple (*Annona squamosa* L.), atemoya (*A. squamosa* × *A. cherimola*) and soursop (*Annona muricata* L.). The genus *Asimina* is the only temperate-zone representative of the tropical *Annonaceae*, and includes nine species, most of which are native to the extreme south-eastern regions of Florida and Georgia. The North American native pawpaw (*A. triloba*) produces the largest fruit, has the most northerly and largest native range and the greatest commercial potential of the *Asimina* genus. Pawpaw is also a common name for papaya (*Carica papaya*), a tropical fruit in the family *Caricaceae*. The two fruits are genetically unrelated, but some pawpaws do have a papaya-like flavour.

DESCRIPTION Pawpaw is a moderately small, deciduous tree or shrub that flourishes in the deep, rich fertile soils of river-bottom lands of the forest understorey. Trees may attain 5–10 m in height and are usually found in patches, due to root suckering. In sunny locations, trees typically assume a pyramidal habit, with a straight trunk and lush, dark green, long, drooping leaves (Fig. A.7 E). Leaves occur alternately, are obovate-oblong in shape, glabrous, with a cuneate base, acute midrib, and may be 15–30 cm long and 10–15 cm wide. Vegetative and flower buds occur at different nodes on the stem, the flower buds being basipetal. Vegetative buds are narrow and pointed, and the flower buds are round and covered with a dark-brown pubescence.

The dark maroon-coloured flowers of the pawpaw are hypogynous and strongly protogynous. Flowers are pendant or nodding, with sturdy pubescent peduncles up to 4 cm long (Fig. A.7 B). The mature flowers have an outer and inner whorl of three, maroon-coloured, three-lobed petals reaching up to 5 cm in diameter (Fig. A.7 A). The inner petals are smaller and fleshier, with a nectary band at the base. The flower has a fetid aroma. Flowers have a globular androecium and a gynoecium usually composed of three to seven carpels resulting in three to seven fruited clusters; up to nine-fruited clusters have been noted (Fig. A.7 C). Flowers emerge before leaves in spring (about April in Kentucky). Pawpaw blossoms occur singly on the previous year's wood.

Pawpaw's custard apple-like fruit are berries. The fruit have an oblong shape, green skin, a pleasant but strong aroma when

Fig. A.7. (A) Mature flower with an outer and inner whorl of three maroon-coloured, three-lobed petals; (B) a mature pawpaw flower and developing cluster from an earlier flower; (C) pawpaw cluster with ripe fruit; (D) a fruit cut open lengthwise and seeds removed; and (E) a pawpaw tree showing natural pyramidal growth habit in a full sun exposure.

ripe, and intense flavour (Fig. A.7 C, D). However, flavour varies among cultivars, with some fruit displaying complex flavour profiles. Fruit from poor quality pawpaw genotypes can have a mushy texture, lack sweetness and have an overly rich flavour with turpentine or bittersweet aftertaste; many wild pawpaws have poor eating quality. Fruit from superior genotypes have a firm texture, a delicate blend of flavours, are rich but not cloying, and have no bitter aftertaste. The flavour of a pawpaw fruit can intensify when it over-ripens, as with banana, resulting in pulp that is excellent for use in cooking. The fruit are oblong-cylindrical, typically 3–15 cm long, 3–10 cm wide and weigh from 100 to 1000 g. They may be borne singly or in clusters which resemble the 'hands' of a banana plant. In the fruit, there are two rows of seeds (12–20 seeds) that are brown and bean shaped and that may be up to 3 cm long. The seeds and skin of the fruit are generally not eaten. The endosperm of the seeds contain alkaloids that are emetic and if chewed may impair mammalian digestion. Pawpaw fruit allergies have been reported in some people.

REPRODUCTIVE BIOLOGY Flowers are strongly protogynous and are predominantly self-incompatible, although the pawpaw cultivar 'Sunflower' may be self-fruitful. Pollination is by flies (Diptera) and beetles (Nitidulidae), and possibly other nocturnal insects. Seedlings normally begin to flower upon reaching about 1.8 m in height, but may not set fruit; cropping is achieved at 5–8 years of age. Grafted pawpaw trees often flower within 3 years of planting, but often fail to set fruit at that time. This may be due to inadequate pollination or inadequate canopy to support fruit development. Grafted trees usually begin reliable fruit production at 5–6 years of age.

For an individual tree, the bloom and pollination period may last from 3 to 4 weeks. There is also cultivar variation for bloom date that may be related to chilling hour requirement. As a result, harvest for an individual tree may be extended over a 3–4 week period. Thus, multiple harvests are necessary depending on fruit ripeness. Each fruit cluster develops from an individual flower, and fruit within a cluster develop and often ripen at different times (Fig. A.7 C). In cultivation, pawpaw yields per tree are often low. Yields for mature grafted trees in the seventh year can average between 2.0 and 6.5 kg/tree, depending on the cultivar. The tropical *Annonaceae* relatives of the pawpaw, such as cherimoya, sweetsop (sugar apple), soursop and atemoya also have low yields, due to low rates of natural pollination. Pawpaws in the wild often have poor fruit set due to low light levels in the understorey and pollinator limitation. Pawpaws in the wild often produce many root suckers that could potentially result in large clonal patches contributing to poor fruit set because of self-incompatibility. Fruit set can be improved by hand cross-pollination and it is likely this could be used to improve yields.

FRUIT GROWTH AND DEVELOPMENT Fruit increase in size during the course of spring and summer, ripening in late summer or early autumn. Pawpaw fruit ripening is characterized by an increase in soluble solids concentration (up to 20%), flesh softening, increased volatile production and, in some genotypes, a decline in green colour intensity of the skin. Within 3 days after harvest, ethylene and respiratory climacteric peaks are clearly evident as pawpaw fruit rapidly soften. A common practice to determine maturity is to touch each fruit to determine if it is ready to harvest; ripe softening pawpaw fruit yield to slight pressure, as ripe peaches do, and can be picked easily with a gentle tug. Thus, fruit are harvested when they have already begun ripening and have lost some firmness.

Horticulture

PROPAGATION The pawpaw produces a relatively large, flat seed with a dark brown fibrous seedcoat. Seed can be collected from fruit when the flesh is soft or over-ripe. Pawpaw has moderately recalcitrant seed that does not tolerate desiccation, and it only has a relatively short period of viability at room temperature. As little as 5 days under open-air conditions can reduce the moisture content of pawpaw seeds to 5% and result in total loss of viability. Pawpaw seed requires stratification for optimal germination. Pawpaw seeds must be stored moist at chilling temperature (5°C) to overcome embryo dormancy. Seed can be stored in moist peat moss in ziplock bags for 2–3 years at 5°C and maintain a high germination percentage. Storing pawpaw seed in a freezer (-15°C) will kill the embryo and make the seed not viable.

Stratified seed can be sown in a well-aerated potting substrate with a high sphagnum peat moss component (> 75% by volume), cation exchange capacity and water-holding capacity. Tall containers should be used to accommodate the developing taproot of seedlings. Because pawpaw has a coarse fibrous root system that is quite fragile, most commercial nurseries propagate pawpaw in containers rather than in a nursery bed. Although some commercial nurseries sell bare-root trees grown in nursery beds, we do not recommend this practice. Transplant shock is common with bare-root trees and field establishment is usually poor. Young pawpaw seedlings are sensitive to excessive ultraviolet (UV) light and can be damaged under full sun conditions. If growing seedlings outside, the plants should be kept in moderate shade their first year (we use 55% shade cloth) for maximum growth of the plant. Seedlings will grow well in whitewashed or even unshaded greenhouses. Plants in their second year of growth outside do not require shading and will grow nicely in full sun provided water is not limiting.

Chip-budding and whip-and-tongue grafting are the two most reliable means to clonally propagate pawpaw. Winter collected, dormant budwood should have its chilling requirement fulfilled. Chip budding and grafting are most successful when the seedling rootstock is at least 0.5 cm diameter and actively growing. Bud take exceeding 90% can be obtained. Clonal propagation of pawpaw by other methods such as root cuttings or softwood cuttings has been unsuccessful. Clonal propagation of pawpaw by tissue culture has been attempted using various explant sources of different physiological ages. The primary limitation in tissue culture is the inability of explants to form roots.

ROOTSTOCKS Currently, pawpaw cultivars with superior fruit characteristics are propagated by grafting and budding onto seedling rootstocks. No clonal rootstocks are available for pawpaw.

TRAINING AND PRUNING Present recommendations for pawpaw plantings are 2.4 m within rows and 3.7–4.6 m between rows. Row orientation should be north–south if possible. Shading of pawpaw in the field the first year is recommended and can be accomplished by installing translucent double-walled polyethylene 'tree-tubes' around each tree, securing them with bamboo stakes. However, trees taller than 45 cm at planting do not require shading. During warm summer temperatures (> 35°C), the tubes should be removed from the trees, otherwise foliage within tubes can became heat-stressed and desiccated. Weed control is important to limit competition and improve establishment, but there are no herbicides currently recommended for use on pawpaw. Mulching with straw or other organic material can be used to limit weed growth in the tree row. When natural rainfall is inadequate, supplemental irrigation can substantially improve tree survival rates.

Most pawpaw genotypes naturally develop a strong central leader. The growth habit is similar to that of 'Bradford' pear, a popular ornamental tree in the USA. Trees should not be headed at planting and no pruning is required in the first year. Branches can often develop narrow crotch angles in relation to the trunk. Training to more horizontal scaffold limbs increases scaffold strength and reduces limb breakage that may occur under heavy crops or during ice storms. Pruning is conducted in late winter–early spring and consists of removing low branches to a height 60–90 cm on the trunk.

THINNING Pawpaw fruit set can often be low, but some growers do practise hand thinning of fruit to increase fruit size.

FERTILIZATION Fertilization requirements have not been determined for bearing pawpaw trees. However, trees provided with water-soluble fertilizer (20N-8.6P-16.6K) plus soluble trace elements once in May, June and July during active growth have achieved 30–45 cm of shoot extension each year in Kentucky. Excellent growth has been achieved with granular ammonium nitrate fertilizer (34N-0P-0K) broadcast under pawpaw trees in early spring at 30–60 g N/tree applied before budbreak.

DISEASES AND PESTS Pawpaws have few disease problems; however, leaves can exhibit leaf spot, principally a complex of *Mycocentrospora aiminae*, *Rhopaloconidium asiminae* Ellis and Morg. and *Phyllosticta asiminae* Ellis and Kellerm. At orchards in Oregon (outside pawpaw's native range), vascular wilt-like symptoms have been observed in the spring after pawpaw trees have leafed out. The pawpaw peduncle borer (*Talponia plummeriana* Busck) is a small moth whose 5 mm-long larva burrows into the fleshy tissues of the flower causing the flower to wither and drop. The zebra swallowtail butterfly (*Eurytides marcellus*), whose larvae feed exclusively on young pawpaw foliage, will damage leaves, but this damage has been negligible in plantings. The larvae of a leafroller (*Choristoneura parallela* Robinson) may also damage flowers and leaves. Deer will not generally eat the leaves or twigs, but they will eat fruit that has dropped on the ground. Occasionally, male deer will rub their antlers on young trees, scraping off bark and occasionally breaking off branches. Japanese beetles (*Popillia japonica* Newman) occasionally feed on young foliage and can damage pawpaw trees.

Biologically active compounds known as annonaceous acetogenins have been extracted from pawpaw twigs and have potential as human medications and botanical pesticides. About 250 of these compounds have been isolated and characterized. Three of these compounds, bullatacin, bulletin and bullanin have high potencies against human cancer cells *in vitro*. Dr Jerry McLaughlin of Nature's Sunshine Products (Spanish Fork, Utah) has developed a commercial head-lice-removal shampoo from pawpaw. Botanically derived pesticides that are environmentally compatible and biologically degradable may also be obtained from pawpaw because the annonaceous acetogenins are toxic to several economically important insect species.

HANDLING AND POSTHARVEST STORAGE Pawpaw fruit soften rapidly at room temperature after harvest. At room temperature, very soft ripe fruit have a shelf life of 2–3 days while those fruit that are just beginning to soften have a shelf life of 5–7 days. Fruit that have just begun to soften can be stored for 1 month at 4°C with little change in fruit firmness and they will ripen normally when returned to room temperature. Hard immature fruit will not ripen, even if treated with ethephon. Because fruit are non-uniform in size and shape, packaging that minimizes bruising during shipping needs to be developed.

MAIN CULTIVARS AND BREEDING Efforts to domesticate the pawpaw began early in the 20th century. In 1916, a contest to find the best pawpaw was sponsored by the American Genetics Association. This contest generated much interest and the sponsors thought that with time and 'intelligent breeding' commercial quality varieties could be developed and an industry begun. However, an industry did not develop. Pawpaw enthusiasts noted that the rapid perishability of pawpaw fruit was the major factor inhibiting commercialization.

Beginning in the 20th century, elite pawpaw selections from the wild were assembled in extensive collections by various enthusiasts and scientists, including Benjamin Buckman (Farmington Illinois, c. 1900–1920), George Zimmerman (Linglestown, Pennsylvania, 1918–1941), and Orland White (Blandy Experimental Farm, Boyce, Virginia, 1926–1955). From about 1900–1960, at least 56 clones of pawpaw were selected and named. Fewer than 20 of these selections remain, with many being lost from cultivation through neglect, abandonment of collections, and loss of records necessary for identification. Since 1960, additional pawpaw cultivars have been selected from the wild or developed as a result of breeding efforts of hobbyists. More than 40 clones are currently available (Table A.38). From 1995 to 1999, Kentucky State University (KSU) and the PawPaw Foundation (PPF) established a Pawpaw Regional Variety Trial (PRVT) with 28

Table A.38. Commercially available pawpaw cultivars (Source: descriptions derived from Jones and Layne, 1997; Jones *et al.*, 1998; and unpublished data of K. Pomper)[a].

Cultivar	Description[b]
'Adam's Secret'	From Pennsylvania, large fruit, few seeds, skin remains green when ripe
'Blue Ridge'	Selected in Kentucky by Johnny Johnson; has white-fleshed fruit
'Collins'	Selected in Georgia
'Convis'	Selected from Corwin Davis orchard. Large-size fruit, yellow flesh; ripens first week of October in Michigan
'Davis'	Selected from the wild in Michigan by Corwin Davis in 1959. Introduced in 1961 from Bellevue, Michigan. Medium-size fruit, up to 12 cm long; green skin; yellow flesh; large seed; ripens first week of October in Michigan; keeps well in cold storage.
'Duckworth A'	Low-chill cultivar selected in San Mateo, Florida by Eric Duckworth, seedling of Louisiana native parent; tree with pyramidal shape
'Duckworth B'	Low-chill cultivar selected in San Mateo, Florida by Eric Duckworth, seedling of Louisiana native parent; grows no larger than a shrub
'Estil'	Selected by Nettie Estil in Frankfort, Kentucky. Large fruit, smooth-textured flesh
'Ford Amend'	Selected from wild seedling of unknown parentage by Ford Amend around 1950. Introduced from Portland, Oregon. Medium-size fruit and earlier than 'Sunflower'; ripens late September in Oregon; greenish-yellow skin; orange flesh
'G-2'	Selected from G.A. Zimmerman seed by John W. McKay, College Park, Maryland, in 1942
'Glaser'	Selected by P. Glaser of Evansville, Indiana. Medium-size fruit
'IXL'	Hybrid of 'Overleese' and 'Davis'; large fruit, yellow flesh; ripens second week of October in Michigan
'Jack's Jumbo'	Selected in California from Corwin Davis seed; large fruit

Cultivar	Description[b]
'Kirsten'	Hybrid seedling of 'Taytwo' × 'Overleese'; selected by Tom Mansell, Aliquippa, Pennsylvania
'LA Native'	From LA, blooms late in Tennessee, small fruit, somewhat frost hardy
'Little Rosie'	Selected by P. Glaser of Evansville, Indiana. Has small fruit. Reported to be an excellent pollinator
'Lynn's Favorite'	Selected from Corwin Davis orchard. Yellow fleshed, large fruit; ripens second week of October in Michigan
'M-1'	Selected from 'G-2' seed by John W. McKay, College Park, Maryland, in 1948
'Mango'	Selected from the wild in Tifton, Georgia, by Major C. Collins in 1970. Vigorous growth
'Mary Foos Johnson'	Selected from the wild in Kansas by Milo Gibson. Seedling donated to North Willamette Experimental Station, Aurora, Oregon, by Mary Foos Johnson. Large fruit; yellow skin; butter-coloured flesh; few seeds; ripens first week of October in Michigan
'Mason/WLW'	Selected from the wild in Mason, Ohio, by Ernest J. Downing in 1938
'Middletown'	Selected from the wild in Middletown, Ohio, by Ernest J. Downing in 1915. Small-size fruit
'Mitchell'	Selected from the wild in Jefferson Co., Illinois, by Joseph W. Hickman in 1979. Medium-size fruit, slightly yellow skin, golden flesh, few seeds
'NC-1'	Hybrid seedling of 'Davis' × 'Overleese'; selected by R. Douglas Campbell, Ontario, Canada, in 1976. Large fruit; few seeds; yellow skin and flesh; thin skin; early ripening, 15 September in Ontario and early September in Kentucky
'Overleese'	Selected from the wild in Rushville, Indiana, by W.B. Ward in 1950. Large fruit; few seeds; bears in clusters of three to five; ripens first week of October in Michigan and early September in Kentucky
'PA-Golden 1'	Selected as seedling from seed originating from George Slate collection by John Gordon, Amherst, New York. Early cropping. Medium-size fruit, yellow skin, golden flesh; matures late August in Kentucky and mid-September in New York
'PA-Golden 2'	Selected as seedling from seed originating from George Slate collection by John Gordon, Amherst, New York. Fruit: yellow skin, golden flesh; matures mid-September in New York
'PA-Golden 3'	Selected as seedling from seed originating from George Slate collection by John Gordon, Amherst, New York. Fruit: yellow skin, golden flesh; matures mid-September in New York
'PA-Golden 4'	Selected as seedling from seed originating from George Slate collection by John Gordon, Amherst, New York. Fruit: yellow skin, golden flesh; matures mid-September in New York
'Prolific'	Selected by Corwin Davis, Bellevue, Michigan, in mid-1980s. Large fruit; yellow flesh; ripens first week of October in Michigan
'Rebecca's Gold'	Selected from Corwin Davis seed, Bellevue, Michigan, by J.M. Riley in 1974. Medium-size fruit; kidney-shaped; yellow flesh
'Ruby Keenan'	Medium-size fruit with excellent flavour
'SAA-Overleese'	Selected from 'Overleese' seed by John Gordon, Amherst, New York, in 1982. Large fruit; rounded shape; green skin; yellow flesh; few seeds; matures in mid-October in New York
'SAA-Zimmerman'	Selected as seedling from seed originating from G.A. Zimmerman collection by John Gordon, Amherst, New York, in 1982. Large fruit; yellow skin and flesh; few seeds
'Silver Creek'	Selected from the wild in Millstedt, Illinois, by K. Schubert. Medium-size fruit
'Sue'	Selected in southern Indiana. Medium-size fruit, yellow flesh, skin yellow when ripe
'unflower'	Selected from the wild in Chanute, Kansas, by Milo Gibson in 1970. Tree reported to be self-fertile. Large fruit; yellow skin; butter-coloured flesh; few seeds; ripens early to mid-September in Kentucky and the first week of October in Michigan
'Sunglo'	Yellow skin, yellow flesh, large fruit that ripens first week of October in Michigan
'Sweet Alice'	Selected from the wild in West Virginia by Homer Jacobs of the Holden Arboretum, Mentor, Ohio, in 1934
'Taylor'	Selected from the wild in Eaton Rapids, Michigan, by Corwin Davis in 1968. Small fruit; bears up to seven fruit in a cluster; green skin; yellow flesh; ripens first week of October in Michigan
'Taytwo'	Selected from the wild in Eaton Rapids, Michigan, by Corwin Davis in 1968. Sometimes spelled 'Taytoo'. Small fruit; light-green skin; yellow flesh; ripens first week of October in Michigan
'Tollgate'	Yellow fleshed, large fruit that ripens first week of October in Michigan
'Wells'	Selected from the wild in Salem, Indiana, by David Wells in 1990. Small- to medium-size fruit; green skin; orange flesh. Ripens mid- to late September in Kentucky
'White'	Selected in Kentucky by Johnny Johnson; has white-fleshed fruit
'Wilson'	Selected from the wild on Black Mountain, Harlan Co., Kentucky, by John V. Creech in 1985. Small fruit; yellow skin; golden flesh
'Zimmerman'	Selected in New York from G.A. Zimmerman seed by George Slate

[a]Descriptions come from a wide variety of sources and most of the cultivars have not been compared for performance side by side at one geographic site.
[b]Fruit size categories of small, medium and large are < 100 g, 100–150 g and > 150 g, respectively.

clones at 13 sites across the USA. Cultivars being tested include 'Middletown', 'Mitchell', 'NC-1', 'Overleese', 'PA-Golden 1', 'Rappahannock', 'Shenandoah', 'Sunflower', 'Susquehanna', 'Taylor', 'Taytwo', 'Wells' and 'Wilson'. The other 15 clones were selections from the PPF breeding effort. Tree survival, trunk cross-sectional area, fruit size and taste, flesh-to-seed ratio, resistance to pests and diseases, and overall productivity on a year-to-year basis are among the attributes being evaluated. The pawpaw cultivars 'PA-Golden 1', 'Overleese', 'NC-1', 'Sunflower', 'Shenandoah' and 'Susquehanna' have performed well in Kentucky, have excellent fruit size and flavour, and are recommended for planting in the south-eastern USA. Complete results from the PRVT and additional regional recommendations will be available in a few years.

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Rollinia mucosa biriba

Biriba tree, *Rollinia mucosa* (Jacq.) Baill. (*Annonaceae*), is considered to have been cultivated in pre-Columbian times and is now widely grown throughout the Amazon region. It is also found in north-eastern Brazil, the Antilles and other parts of the Caribbean. The fruit is appropriate for the fresh fruit market, with prices varying according to size. The species is an excellent alternative to diversify fruit gardens and to supply the demand motivated mainly by originality of the native fruit. Moreover it is an important genetic resource for its natural genetic variability, which can be used in domestication studies, for selection of superior genotypes or as a source of genes for related species.

The species is most commonly known as biriba. Other names include biribazeiro, biriba-de-pernambuco or fruta-de-condessa (Brazil); anon (Peru); chirimoya (Ecuador); mulato (Colombia); sinon (Venezuela); anona babosa or zambo (Mexico); cachiman morveusc, cachiman coehon or cachiman montagne (Guadalupe); cachiman or anon cimamon (Puerto Rico); anonillo (Panama); candongo or anona (Dominican Republic); and wild sugar apple (English).

World production and yield

In Central Amazon, the fruit is sold per unit at open markets or by street vendors. The species is not commercially exploited, even considering its value as a food source and for income for small farmers. It is most often found in home gardens or urban yards and small farms. Fifteen-year-old trees can produce over 150 fruit/year (Souza *et al.*, 1997). During the first three harvests of trees evaluated at EMBRAPA Western Amazon Experimental Station, State of Amazon, the average production reported was about 45 fruit/tree, with a range from 35 to 55 (Sousa, 1998).

Uses and nutritional composition

Biriba has become a popular fruit due to its delicate flavour, pulp yield and fruit size which is enough for one individual.

Fruit is consumed fresh, although some in the Amazon prefer to blend it into a juice with or without milk. Fruit is 52% pulp, 42% peel and 6% seeds (Costa and Müller, 1995). The pulp is creamy, slightly acid to sweet, with total soluble solids ranging from 10 to 20% (Sousa, 1998). The fruit is regarded as being rich in vitamin C (Table A.39). The fruit and seeds contain acetogenens and alkaloids that may be anti-tumour agents and can inhibit platelet aggregations (Liaw *et al.*, 2003). The wood is hard and heavy and is used for boats, masks and boxes.

Botany

TAXONOMY AND NOMENCLATURE There are approximately 65 species in the genus *Rollinia*, but only *R. mucosa* is cultivated for its fruit. Synonyms include *Rollinia deliciosa* Saff., *Rollinia orthopetala* A. DC., *Rollinia pulchrinervis* A. DC., *Rollinia sieberi* A. DC. and *Annona mucosa* Jacq.

DESCRIPTION The tree is leafy with a round or conic canopy, requiring sufficient space for satisfactory development. During a study carried out on 80 plants conserved in a diversified collection of Amazon indigenous species genetic resources at EMBRAPA Western Amazon Experimental Station, this species was considered to have a fast initial growth, reaching a height of 3.7 m with a trunk 6.1 cm in diameter at 50 cm in its first year (Sousa and Paiva, 2000). The leaves are alternate, simple, oblong- or elliptical-oblong-shaped, 15–25 cm long and 8–11 cm wide, coriaceous, deciduous, without stipules, with a petiole 5–10 mm long. Solitary flowers are hermaphrodite and arranged on large pedicels. The fruit is a syncarp consisting of many joined carpels of pyramidal-shaped fruitlets. The ripened fruit is yellowish coloured and varies in shape, size, consistency and pericarp. The black seeds are about 1–1.5 cm long.

ECOLOGY AND CLIMATIC REQUIREMENTS The biriba tree is typically found growing in hot and humid climates. In the Municipality of Manaus, State of Amazonas, Brazil, where the species is under study, the climate is characterized by a short dry season, with an average rainfall above 60 mm during the driest months (July and August) and above 300 mm during the rainy season (January–March), annual rainfall averaging around 2700 mm. The annual average temperature for the last 10 years has been around 26°C, with temperatures during the coldest month never being below 18°C.

The tree grows better in deep soil with a high content of organic matter and good drainage, even though it tolerates poor, acid and heavy-textured soils. In the Brazilian Amazon, the tree has been planted in upland xanthic ferralsols (yellow oxisols) that have a clay texture, high acidity and high content of exchangeable aluminum. In that region, the tree also grows in lowlands subject to periodic flooding.

Table A.39. Composition of edible flesh of biriba per 100 g (Source: Morton, 1987).[a]

Proximate	%
Water	77.2
Energy (kcal)	80
Protein	2.8
Lipid (fat)	0.2
Carbohydrate	19.1
Fibre	1.3
Ash	0.7
Minerals	**mg**
Calcium	24
Iron	1.2
Phosphorus	26
Vitamins	**mg**
Ascorbic acid	33
Niacin	0.5

[a]The pulp is 52% of the total fruit weight and the total soluble solids/acidity ratio is 28.

REPRODUCTIVE DEVELOPMENT The juvenile period from seed is about 3 years. The biriba tree is among the most tropical species and flowers just once a year after leaf fall, which occurs in the Central Amazon during the low rainfall season, between June and September. In Costa Rica, flowers are observed between February and July.

FRUIT DEVELOPMENT In the state of Amazonas, fruit usually mature between October and May, and between June and November in Costa Rica. The fruit mature about 55 days from anthesis (Falcão, 1993). Fruit may be spherical to oblong-shaped, attaining 10–20 cm in length, 7–20 cm in diameter and an average weight from 200 to 1000 g. Special care must be taken in harvesting and handling to avoid fruit darkening due to mechanical injury (Fig. A.8).

Horticulture

PROPAGATION Trees are propagated either vegetatively or by seeds. Seeds should be sown as soon as they are collected from

Fig. A.8. Biriba, *Rollinia mucosa*, is a syncarp of many joined pyramidal-shaped fruitlets with soft spines that are easily damaged during harvesting and handling.

the fruit, preferably from high-yielding plants with high-quality fruit. Germination takes about 30 days with about 80% germination. The most common vegetative method is grafting. Rooted plantlets can be produced *in vitro* (Figueiredo *et al.*, 2000).

DISEASES AND PESTS *Cerconota anonnela* (Lepidopterene) larvae attack maturing fruit and cause considerable damage. A borer (*Cratosomus bombina*) burrows into the bark and trunk leading to secondary infections and branch death. White flies (*Aleurodicus cocois*) and mealy bugs (*Pseudococcus brevipes* and *Aspidiotus destructor*) are common on the leaves. Cercospora leaf spot occurs and *Glomerella cingulata* causes stem dieback and fruit rot.

MAIN CULTIVARS AND BREEDING No breeding programmes have been described. The existing variation in the trees planted from seeds offer excellent opportunities for selection for yield, size, weight, consistency and total soluble solids content. Some selections may have been made by Indians in the Upper Solimôes River region, where fruit weighing above 4 kg with a smooth pericarp are found (Clement *et al.*, 1982; Lima and Costa, 1997). These selections have been known as *biriba do Alto Solimões*. Nelcimar Reis Sousa

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APOCYNACEAE

Carissa congesta karanda

The English names of *Carissa congesta* Wight. (*Apocynaceae*), in addition to karanda, include Bengal currant and karaunda. It is known as karandan and senggaritan in Indonesia; kerenda, kerandang and berenda in Malaysia; caramba and pekunkila in the Philippines; naam daeng, manaao ho and naam khee haet in Thailand; and cay siro in Vietnam. The species is common throughout its native range of India, Sri Lanka, Myanmar and Malacca and it grows often in Thailand, Cambodia, South Vietnam and East Africa. Introduced as a hedge, it is now wild around Djakarta. The synonym is *Carissa carandas* Auct.

Uses and nutrient composition

The sourish-sweet fruit is consumed fresh when ripe and the more acid fruit is stewed with sugar (see Table A.40 for proximate fruit composition). It is also used to make beverages, pickles, curries, tarts, jellies and chutneys. The fruit exudes a gummy latex when cooked, but the red juice is clear and consumed as a cold beverage. Green fruit can be pickled.

The fruit can be used for tanning and dyeing while a paste of the pounded root serves as a fly repellent. The white or yellow wood is hard, smooth, and useful for handicrafts and utensils.

Unripe fruit are used medicinally as an astringent and ripe fruit as an antiscorbutic, and as a traditional remedy for biliousness. A leaf decoction is used in cases of intermittent fever, diarrhoea, oral inflammation and earache. The bitter root is a stomachic and vermifuge, and contains salicylic acid and cardiac glycosides. Bark, leaves and fruit contain an unnamed alkaloid.

Table A.40. Proximate fruit composition of karanda per 100 g (Source: Morton, 1987).

Proximate	g
Water	83
Energy (kcal)	75
Protein	0.39–0.66
Lipid	2.57–4.63
Carbohydrate	7.9–12.5
Fibre	0.62–1.8
Ash	0.66–0.78
Vitamins	mg
Ascorbic acid	9–11

Botany

This is a woody, straggly, climbing shrub growing 3–5 m high. It can reach the top of tall trees and numerous spreading dense branches are set with sharp, simple or forked thorns (5 cm long) that occur in pairs in the leaf axils. The evergreen leaves are opposite, oval or elliptic, 2.5–7.5 cm long, dark green, glossy and leathery on the upper surface and dull light green underneath. The tubular white, sometimes tinged with pink, fragrant flowers have five lobes that are twisted to the left. The flowers occur in terminal clusters of two to 12.

The shrub requires full sun in non-humid tropical regions. The species has some cold tolerances and can be grown up to 1800 m in the Himalayas. It can grow well on poor, rocky soils though does better on well-drained fertile soils.

It can bloom and fruit throughout the year. Trimming encourages new growth and profuse flowering. The fruit are in clusters of three to ten and can be oblong, ovoid to round, 1.25–2.5 cm long. The purplish-red, smooth skin is thin and glossy, but tough and turns dark purple to black when ripe. The juicy red to pink pulp is acid to sweet sometimes bitter with specks of latex. The flesh may enclose two to eight small flat, brown seeds.

Horticulture

Karanda is normally propagated by seed, as cuttings are not easily rooted. Young shoot cuttings can be rooted under constant mist. Grafting is possible onto seedlings. Karanda is a good rootstock for carissa (*Carissa macrocarpa*).

Karanda is often grown as a hedge and can be trimmed to encourage new growth and profuse flowering. When young the plant grows slowly, though once established, it grows more vigorously and becomes difficult to control. When kept trimmed new shoots are encouraged and it will bloom and fruit profusely. Flowers occur in terminal clusters on this new growth.

The pests and diseases of karanda are similar to those of other carissas. Twig dieback due to *Diplodia*, stem canker (*Dothiorella* spp.), green scurf (*Cephaleuros virescens*) and algal leaf spot have been noted.

Some sweet selections have been made from the considerable wide variation in seedling population. This variation in fruit quality ranges from oval, dark-purple skin, red flesh, acid fruit to round, maroon, pink-fleshed, seed subacid. Robert E. Paull

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Carissa macrocarpa Natal plum

Carissa (*Carissa macrocarpa* (Ecklon) A. DC., *Apocynaceae*) is known widely as Natal plum and amantungula in English. Other names include akamba, agamita, agam, amatungulu, agamssa and adishawel. It is native to Natal, South Africa and is now cultivated worldwide in the tropics and subtropics, although not in South-east Asia.

World production

As a native to the coastal region of Natal, it is also cultivated in the Transvaal of South Africa. It was first introduced into the USA in 1886 by the horticulturist Theodore L. Meade and again in 1903 by Dr David Fairchild. The latter seed introduction was distributed for evaluation in different climatic zones of Florida, the Gulf States and California. It was introduced into Hawaii in 1905, the Bahamas in 1913 and the Philippines in 1924. It was widely planted in Israel but rarely set fruit. It is valued as a protective hedge and the fruit is a by-product.

Uses and nutritional composition

The fruit is dark red when fully ripe and is eaten fresh when slightly soft to the touch. It has a sour taste and is eaten whole without peeling or seeding (see Table A.41 for proximate fruit composition). If halved or quartered and seeded it may be used in fruit salads, and as a topping for cakes, puddings and ice cream if cooked as a sauce or used in pies and tarts. Stewing or boiling causes the latex to leave the fruit and adhere to the pot. It can be pickled.

Botany

TAXONOMY The synonym is *Carissa grandiflora* A. DC.

DESCRIPTION This vigorous, spreading woody shrub is up to 5.5 m in height and width. All parts have a gummy white sap. The thorns (5 cm) are double-pronged and appear on all the branches. The leathery, evergreen leaves are opposite, ovate, glossy and 2.5–5 cm long. Shoots grow from the axil in a pair of small scale leaves.

Table A.41. Proximate fruit composition for Natal plum per 100 g.

Proximate	g
Water	82
Energy (kcal)	68
Protein	0.4
Lipid	0.9
Carbohydrate	16.4
Fibre	0.8
Ash	0.4
Minerals	**mg**
Calcium	11
Iron	1.3
Phosphorus	7
Vitamins	**mg**
Ascorbic acid	56
Thiamine	0.04
Riboflavin	0.06
Niacin	0.2
Vitamin A	25 IU

The white tubular flowers are 5 cm across, five-lobed, and borne singly or a few occur at the tips of the branchlets. The flowers have a sweet fragrance. Some plants bear functionally male flowers with stamens longer than the style. The stamens in functionally female flowers are the same length as the style and have no pollen.

The round, oval or oblong fruit (6.25 cm long, 4 cm across) has a gummy latex when unripe. The berries' tender, smooth skin changes from green to a bright magenta-red crimson coated with a thin, whitish wax bloom when ripe. The flesh is juicy, strawberry-coloured with a milky sap enclosing six to 16 small, thin, flat brown seeds that can be eaten.

ECOLOGY AND CLIMATIC REQUIREMENTS This subtropical to near tropical species can withstand light frost to −4°C when well established. Best growth occurs in the full sun. It grows well in many soil types and has moderate drought and salt tolerance. Well-drained soils are required, as the tree is intolerant of waterlogging.

REPRODUCTIVE BIOLOGY The plant flowers and sets fruit all year. The flowering peaks in Florida occur from May through to September. A vegetative growth phase is followed by flowering and thorn formation. The pollinators are small beetles and hawkmoths and other night-flying insects. Unproductive plants that set fruit are apparently self-infertile as they bear fruit after hand cross-pollination.

Horticulture

PROPAGATION Seeds germinate in 2 weeks and seedlings grow slowly. Air laying, ground layering and shield budding are the preferred propagation methods. Treated softwood cuttings are also used. Karanda (*Carissa congesta* Wight.) is a desirable rootstock and gives increased yields. Trimming allows shape to be maintained and a new flowering site to develop.

Seedlings begin to bear fruit in 2 years and cuttings sooner. A standard, well-balanced fertilizer is adequate. Micronutrients maybe needed on limestone soils.

DISEASES, PESTS AND WEEDS Spider mites, thrips, white flies and scale attack the young plants. A number of fungal diseases have been reported in Florida including leaf spot and green scurf caused by *Cephaleuros virescens*; leaf spot caused by *Alternaria* sp., *Botryosphaeria querquum*, *Fusarium* sp., *Gloeosporium* sp., *Phyllosticta* sp. and *Colletotrichum gloeosporioides*. Anthracnose on the fruit is also caused by *C. gloeosporioides*. Dieback caused by *Diplodia natalensis* and *Rhizoctonia solani*, and root rot from *Phytophthora parasitica* and *Pythium* sp. also occur.

MAIN CULTIVARS AND BREEDING Selections have been made in South Africa, California and Florida. These include 'Fancy', 'Torrey Pines', 'Gifford', 'Extra Sweet' and 'Frank'. Numerous landscape cultivars have been released which are compact, dwarf and less thorny.

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Couma guianensis, Couma macrocarpa, Couma utilis

Couma utilis Muell. Arg., *Couma macrocarpa* Barb. Rodr. and *Couma guianensis* Aubl. (*Apocynaceae*) are Amazonian fruit and latex species of limited economic value. The species produce a non-elastic latex that was important in the manufacture of chewing gum and is still in some demand. The origin of these species is not known with precision, though the centres of diversity are in the forests of Central and Western Amazonia (Cavalcante, 1991).

The common names for *C. utilis* Muell. Arg. are sorva or sorvinha (Brazilian Portuguese), couma (Spanish) and milk tree (English). *Couma macrocarpa* Barb. Rodr. is called cumã-açu or leche caspi (Peru), juansoco (Colombia), capirona (Spanish) and sorva grande (Portuguese). *Couma guianensis* Aubl. is commonly known as Poirier de la Guiana (French Guiana).

World production and yield

Couma latex production in Amazonia reached 66,000 t/year just after World War II, probably from the two central Amazonian *Couma* species combined, but currently production is only about 1000 t/year. This fall in the production is due in part to the predatory exploitation practices used, since the trees are cut to maximize latex extraction. A greater cause is the gradual substitution of *Couma* latex by synthetics in the chewing gum industry.

No plantations for latex or fruit production are known to exist, hence the *Couma* species are not accounted for in agricultural statistics for the Amazon basin. Fruit yield of *C. utilis* is about 30 kg/plant from 6-year-old trees.

Uses and nutritional composition

The fruit are edible and the trees are beautiful ornamentals whose potential has been unexploited to date. Occasionally the pulp of *C. utilis* is used to make ice creams, juices, sweets and creams. The composition of 100 g of pulp contains 68.7% water, 3.6% proteins, 6.9% lipids and 15.8% of other carbohydrates (Villachica *et al.*, 1996).

Couma utilis and *C. macrocarpa* produce the raw latex material for chewing gum that is mixed with latex from species of the *Sapotaceae* family, principally *Manilkara zapota* (L.) P. van Royen, the chicle. The latex of *C. utilis* is preferred, but extractors don't always maintain purity. The latex of *C. guianensis* is not used because it has a bitter flavour.

The latex is extracted from sorva trees by cutting the bark in helical grooves (similar to the technique used in rubber *Hevea brasiliensis*) and the latex exudes in abundance. After coagulation and moulding into a compact block, it is commercialized under the name 'sorva'. Cavalcante (1991) reported that the latex is used as a milk substitute to mix with coffee (which explains the common name in English), and to mix with cooked maize or banana in a local dish called 'mingau'. Some indigenous Amazonian peoples mix *Couma* latex with banana pulp to cure diarrhoea; others mix the latex with castor bean oil (*Ricinus communis* L.) as an anti-helminthic remedy. It is used by both native Amazonians and mixed-blood peasants to caulk canoes and boats, as well as for whitewashing wooden houses.

Botany

TAXONOMY AND NOMENCLATURE The genus *Couma* (*Apocynaceae*) contains 15 species in the neotropics, of which three are the most important in northern South America: *C. utilis* Muell. Arg. (synonym *Couma rigila* Muell.), *C. macrocarpa* Barb. Rodr. and *C. guianensis* Aubl.

DESCRIPTION In open areas, *C. utilis* grows to 12 m and in the forest it may reach 20 m.The bark is smooth, thick and decorated with big white to brown spots caused by lichens. When the bark is cut it exudes large amounts of white latex. The canopy is wide, with dense, dark green foliage, with abundant low branching in open areas. The inflorescence is axillary corymbose. The small flowers are hermaphrodite, gamopetalous and the corolla is pink or light purple, with five petals. The fruit are small glabrous berries (10–20 g), succulent, generally green, sometimes brown when ripe, containing many small seeds. The fruit pulp is edible, with a pleasant flavour, often reminiscent of sun-dried raisins. The fruit are harvested from the tree when they are almost ripe, and often forced to ripen with chemical treatments, and then tied into clusters of 20–25 fruit to be marketed.

Couma macrocarpa is a large tree, reaching 30–40 m in height. The trunk has thick, spongy, dark-coloured bark, decorated with clear spots created by lichens, and exudes a thick, white, viscous latex with a sweet flavour. Leaves are simple, up to 20 cm in length by 13 cm in width, the lateral nerves of up to 20 pairs are regularly parallel while the basal ones are perpendicular to the central nerve. The fruit is a round berry, 5–7 cm in diameter, with a green to brown exocarp, a fibrous, juicy pulp and several seeds.

The tree and fruit morphologies of *C. guianensis* are quite similar to *C. utilis* and *C. macrocarpa*, however the size of the *C. guianensis* tree is smaller than *C. utilis*. The leaves are equal in size to those of *C. macrocarpa* but distinct in secondary nerve patterns. The fruit of *C. guianensis* are smaller than *C. macrocarpa* and larger than *C. utilis*.

REPRODUCTIVE BIOLOGY *Couma utilis* starts flowering in 3 years in Manaus and 6 years in Belém, Brazil. In the first years, yields are low and variable. Flowering occurs in the first half of the rainy season (December–March in Manaus), followed by a shorter (or equivalent) flowering peak at the end of the rainy season (May–June/July) (Falcão *et al.*, 2003). The main pollinators are probably bees, including *Eulaema mocseryi* Friese, *Eulaema nigrita* Lepetier, *Xylocopa frontalis* Olivier, *Epicharis* sp. and *Tetrapedia* sp. Similar information does not exist for *C. guianensis* and *C. macrocarpa*.

FRUIT GROWTH AND DEVELOPMENT Fruit growth starts immediately after flowering, unless pollination is inadequate, then the flowers are immediately shed. Ripe fruit are harvested (or fall) about 103 days after fruit set. Although there are frequently two flowering peaks, there is normally only one fruit harvest per year, with peak yield in August (the mid-dry season in Manaus).

ECOLOGY The three *Couma* species are native to humid tropical climate, and are found naturally in the upland forests of Amazonia, with altitudes less than 500 m. They grow well in the acid soils that predominate in these regions. *Couma utilis* is often found in fields and second growth, but *C. guianensis* and *C. macrocarpa* are generally only found in undisturbed forests.

Horticulture

PROPAGATION Seed propagation is the only method commonly used, although side veneer grafting has been reported. The seeds are extracted from completely ripe fruit, which are recognized by the dark green coloration of the epicarp and by the soft pulp consistency. The number of seeds per fruit varies from two to 42, with an average of 12. The seeds are orthodox, tolerating drying and freezing, and can be maintained in storage by conventional methods.

Germination is fast and uniform, with emergence starting 22 days after sowing and stabilizing 10 days later, when it reaches 90%. Initially the seedlings must be protected from direct sunlight, and after 6–8 months they can be hardened off and transplanted to the field.

CULTIVATION Although tolerant of poor acid soils, an orchard should be established on good soils after ploughing, disking and correcting acidity. Planting pits should measure $50 \times 50 \times 50$ cm, be fertilized with 5–10 kg of mature manure and 200 g superphosphate, well mixed. Spacing of 7×7 m for *C. utilis* and at least 8×8 m for *C. macrocarpa* is recommended. Weeding is essential at least in the first 2 years. Manure (5–10 kg) should be applied yearly in orchards for fruit.

MAIN PESTS AND DISEASES The only pest observed attacking sorva in Brazil is a Coleoptera (*Protopulvinasia* sp.). The intensity of infestation is normally low and control measures are generally unnecessary. The fungus *Meliola* sp. (called fumagina) is the only pathogen that may limit the photosynthetic capacity of leaves, as it covers them with a powdery black fungal layer. Danival Vieira de Freitas

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Hancornia speciosa mangaba

Mangaba, *Hancornia speciosa* Gomes (*Apocynaceae*), a Brazilian indigenous fruit, is very much appreciated in the north-east region of the country. The common names in Brazil are magabeira, magabiba, mangaiba-uva and mangaba tree-de-minas. The English name is mangaba tree and in the French caoutchouc de Pernambouc. The mangaba tree predominates in the Amazon and north-east region of Brazil. It is also found in Venezuela, Colombia and Peru. The name of this fruit is derived from the tupi-guarani language, which means 'good fruit for eating'. The production of mangaba is largely from collected fruit and the tree is still not cultivated.

World production and yield

Current studies are underway in the north-east region of Brazil to quantify production and determine fruit characteristics suitable for commercial plantings. Species conservation is threatened by deforestation and the number of wild plants has declined. Brazilian annual fruit production was estimated to be 1500 t in 2002. About 80% of the production occurs in the first half of the year, with 55% concentrated between January and March, lower production occurs during August to November.

Uses and nutritional composition

The fruit is consumed fresh or as juice, compotes, jellies, liqueurs and vinegars. The mangaba fruit is industrialized in the form of frozen pulp and is used as juices and in ice cream. The pulp yield is about 86% of whole fruit. The gummy pulp is a good source of iron and vitamin C (Table A.42). The latex is used to produce rubber and utilized as a popular medicine for treatment of ulcers and tuberculosis.

Table A.42. Pulp characteristics of the ripe mangaba based on 100 g of fresh pulp (Source: Alves *et al.*, 2000).

Constituent	Average
Weight total (g)	19.8
Seeds (%)	13.2
Shell + pulp (%)	86.5
Length (mm)	33.4
Diameter (mm)	30.1
Total soluble solids (%)	16.7
Total titratable acidity (%)	1.77
Soluble solids per unit acidity	9.51
pH	3.29
Total soluble sugars (%)	13.0
Reducing sugars (%)	7.72
Starch (%)	0.52
Total pectin (%)	0.54
Soluble pectin (%)	0.24
Fractional pectin (% – in relation to ISA[a])	
High methoxlyation	10.35
Low methoxylation	1.10
Insoluble protopectin	0.29
Pectinmethylesterase (UEA[b])	498.3
Polygalacturonase (UEA)	17.3
Total vitamin C (mg/100 g)	139
Soluble phenolics in water (%)	0.29
Soluble phenolics in 100% methanol (%)	0.33
Soluble phenolics in methanol 50% (%)	0.31

[a]ISA, insoluble solids in alcohol.
[b]UEA, units of enzymatic activity.

Botany

TAXONOMY AND NOMENCLATURE The genus *Hancornia* (*Apocynaceae*) has a single species with six varieties (Monachino, 1945). The varieties are *H. speciosa* var. *speciosa*, *H. speciosa* var. *maximilliani* A. DC., *H. speciosa* var. *cuyabensis* Malme, *H. speciosa* var. *lundii* A. DC., *H. speciosa* var. *pubescens* (Nees. et Martius) Muell. Arg. and *H. speciosa* var. *gardneri* (A. DC.) Muell. Arg.

DESCRIPTION The mangaba tree is a xerophytic plant that has a semi-deciduous life cycle. The latex-producing tree is evergreen and grows 2–10 m high, rarely to 15 m in height. Canopy diameter varies from 4 to 5 m. The reddish bark is wrinkled. The branches occur as whorls on the main stem. The simple green leaves are leathery. The main roots grow deep in the soil. The inflorescence consists of one to seven white, hermaphrodite double flowers, about 6 cm long that occur terminally on the latest growth. The fruit is an ellipsoidal or round berry varying from 2.5 to 6 cm in diameter (3–51 g). The yellow exocarp is often stained with red or has red grooves. The soft, fibrous, white fleshy pulp is often both sweet and acidic, containing 2–15 or as many as 30 seeds. Seeds are 7–8 mm in diameter, disc-shaped, wrinkled and a clear chestnut brown. The poisonous latex is white and produced mainly in stem and leaves.

ECOLOGY AND CLIMATIC REQUIREMENTS For optimum development, the mangaba tree requires areas with an annual mean temperature of about 25°C and annual rainfall of 750–1500 mm. However, the plant tolerates drought and grows in the hottest periods. The mangaba tree grows better in sandy acidic soils that are poor in nutrients and organic matter, and in soils with little water retention. However, the mangaba tree can develop in deep, well-drained and sandy-loamy soil.

REPRODUCTIVE BIOLOGY Fruit production begins 5–6 years after planting, although there are reports of fruit production after 1 year. The tree has two main flowering periods. In the state of Sergipe in Brazil, flowers occur in August and February. The flowering period varies from 90 to 120 days. The flowers produce a faint odour and are open from about 4:30 p.m. to 10:00 a.m. the next day. Bees (*Euglossini*), hawkmoths (*Sphingidae*) and Ninphaelidae (*Heliconius*) are the most frequent visitors and are thought to be the main pollinators.

FRUIT GROWTH AND DEVELOPMENT The fruit begins to ripen about 112 days from anthesis.

Horticulture

PROPAGATION Propagation is from recalcitrant seeds obtained from ripe fruit. These fruit should be from selected healthy plants, with good organoleptic characteristics. Immediately after extraction, the seeds should be washed to totally eliminate the pulp, and dried under shade for 24 h and usually sown within 4 days. Care must be taken to avoid calcareous substrates, excess organic matter or overly wet conditions to avoid seedling disease. Vegetative propagation by grafting can be done on plants 50–80 cm tall. However, grafting is commercially difficult due to the very thin stems. Shoot cuttings show poor rooting response and micropropagation is being tried.

PRUNING The slow growing tree usually produces a broad canopy and many branches droop down and touch the ground during wind. The first pruning should be performed when the plant reaches 1 m in height. After fruiting, it is important to prune to remove dry, broken and diseased and insect-damaged branches.

DISEASES AND PESTS The main pest is green aphid (*Aphis gossypii*) that attacks the branch terminal leaves causing leaf rolling. Control can be achieved by bi-weekly spraying of commercial insecticides. Green cochineal (*Coccus viridis*) attacks the new branches and the inferior part of the leaves along with the main rib. Caterpillars occasionally attack and defoliate young plants. This pest is controlled by commercial pesticides. Other insects such as leaf-cutting ant (*Atta* spp.), arapuá (*Trigona spinipes*) and bugs (*Theogonis stigma*) also attack the plants.

The most serious disease is anthracnose caused by *Colletrotichum gloeosporioides* that can cause complete defoliation of young plants and dark stains on the fruit when infection occurs at flowering and fruiting. Other diseases include root rot (caused by *Cylindrocladium clavatum* and *Fusarium solani*), wet rot, damping-off or wilt (*Sclerotium rolfsii* Sacc.) and brown spot or leaf spot (*Mycosphaerella discophora* Syd. var. *macrospora*).

HANDLING AND POSTHARVEST STORAGE Since the ripe fruit is very perishable it should be harvested at the half-ripe stage. The optimum harvest is based on the change of colour from green to clear yellow. Mature green fruit are physiologically mature and are able to reach the peak of edible quality in 2–4 days. This very short postharvest life limits transport to markets and commercialization. Abscised fruit, 'natural fall', ripen in 12–24 h and must be consumed quickly and are regarded as being higher in quality.

Fruit are packed in plastic boxes immediately after harvest and shipped. Fruit have a high rate of respiration which at higher temperatures further reduces shelf life and limits marketing to 3 or 4 days. Storage temperatures of 6–9°C extend the useful postharvest life to 7–10 days when held in polyethylene films. At 6°C or lower, the fruit develop chilling injury. Storage at 8°C is recommended.

GERMPLASM, CULTIVARS AND BREEDING No select cultivars are available, though research in the area of genetic resources and improvement is promising. The Farming Research Organization at João Pessoa city in the Paraíba State (EMEPA-PB) Brazil, has 324 accessions collected from Paraíba, Pernambuco and Rio Grande do Norte states. The Federal University of Alagoas (UFAL), in partnership with the Secretariat of Agriculture, Supplies and Fishes of Alagoas (SEAP-AL), Rio Largo, has a collection with accessions collected along the coast of Alagoas state. The Agricultural Research Company (IPA) from Pernambuco State maintains on experimental station at Porto de Galinhas that has 125 accessions on 1.3 ha.

Marcelo A.G. Carnelossi and Narendra Narain

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Saba comorensis rubber vine

This forest liana, *Saba comorensis* (Boj.) Pichon (*Apocynaceae*), grows on other trees in the riparian equatorial rainforest of Africa. It is native to the Comoros, Ghana, Kenya, Malawi, Mozambique, Tanzania and Uganda. The common names are rubber vine in English and mbungo and mpira in Swahili. The fruit is commonly found in the local markets. It can be used as an ornamental for its flowers and their fragrance.

Uses and nutritional composition

The fruit pulp is edible and it makes a refreshing sour drink. The fruit does not abscise and must be harvested when it turns yellow. It has a relatively long postharvest life. The stem yields latex that is an inferior rubber. Bark decoctions are used to treat rheumatism.

Botany

TAXONOMY AND NOMENCLATURE The synonyms are *Landolphia comorensis* (Boj.) K. Schum. var. *florida* (Benth.) K. Schum. and *Saba florida* (Benth.) Bullock.

DESCRIPTION This strong forest liana grows up to 20 m long on other trees. The stem is lenticillate and exudes a white, sticky latex when cut. The ovate or elliptical leaves are 7–16 × 4–8.5 cm. The fragrant flowers are borne on many short-stalked terminal or axillary corymbs. The corolla is tubular with a yellow throat and white petals. The fruit is subglobose 4–8 cm long and 3.5–6 cm wide, greenish when young, turning orange-yellow when ripe. The yellow flesh contains numerous brown-black seeds.

ECOLOGY AND CLIMATIC REQUIREMENTS The vine is very abundant in undisturbed forests, coastal areas and around the Great Lakes region of Africa from sea level to 1250 m. It is rare in open areas. The area has a mean annual temperature around 20°C and a mean annual rainfall of 900–2000 mm. The liana grows on a variety of soil types.

REPRODUCTIVE BIOLOGY A vine will not flower every year and flowering time is not regular among populations. In Tanzania, flowers occur between February and November with fruit maturing 10 months later from December to May. The seeds are dispersed by birds and monkeys.

Horticulture

PROPAGATION The liana regenerates naturally by seed on fertile moist soils under partial or full shade. It can be propagated by cuttings and the vine can be coppiced. The seeds germinate in about 12 days with a high germination rate in excess of 90%. Robert E. Paull

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Saba senegalensis saba

This riverine liana, *Saba senegalensis* (A. DC.) Pichon (*Apocynaceae*), from western Africa is found in Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Niger, Senegal and Tanzania. The common names are liane saba or saba in French and mandinka and madd in Wolof.

Uses and nutritional composition

The fruit has a sweet-sour taste and often appears in local markets during the fruiting season (see Table A.43 for proximate fruit composition). The leaves are used in Senegal to prepare sauces and condiments as a salty appetizer. In Côte d'Ivoire, the latex is used as an adhesive for poison preparations for arrows as it hardens upon exposure. The inferior rubber produced from the latex is sometimes used to adulterate genuine rubber. The leaves are eaten to stop vomiting and bark decoctions are taken for diarrhoea and food poisoning.

Botany

TAXONOMY AND NOMENCLATURE The synonyms are *Landolphia florida* var. *senegalensis* (A. DC.) Hall. f., *Landolphia senegalensis* (A. DC.) Kotschy and Peyr., *Landolphia senegalensis* var. *glabrifolia* Hua, *Saba senegalensis* var. *glabrifolia* (Hua) Pichon, and *Vahea senegalensis* (A. DC.) Pichon.

DESCRIPTION This liana grows up to 40 m long and can often be shrub-like with a trunk up to 20 cm in diameter. The bark is rough or scaly. The opposite leaves are one-and-a-half to three times as long as wide and have a 4–14.5 mm long petiole. The flowers (3–30) occur in a cyme on a 2.5–6 cm peduncle and each flower is on a 2.5–8 mm pedicel. The corolla has a yellow throat with the tube being five to nine times as long as the calyx. The stamens are inserted 3.5–6 mm above the corolla base with 0.4–1 × 0.1 mm stamens and anthers 1–2 × 0.2–0.5 mm. The ovary is often ribbed and has about 30 ovules and a style that is 1.5–3 mm long. The fruit is 5–15 × 4–10 cm wide with a 1 mm thick wall.

Table A.43. Proximate fruit composition of saba per 100 g.

Proximate	%
Water	80
Energy (kcal)	71
Protein	0.8
Lipid	0.2
Carbohydrate	18.5
Fibre	1.3
Ash	0.5
Minerals	**mg**
Calcium	58
Iron	1.0
Phosphorus	28
Vitamins	**mg**
Ascorbic acid	48
Thiamine	15
Riboflavin	0.03
Niacin	5
Vitamin A	Trace

ECOLOGY AND CLIMATIC REQUIREMENTS The vine is commonly found in riverine areas and open woodland from sea level to 800 m.

REPRODUCTIVE BIOLOGY Flowers are produced all year-round.

Horticulture

The species grows directly from seed and can regenerate naturally. Robert E. Paull

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ARACEAE

Monstera deliciosa ceriman

The ceriman, *Monstera deliciosa* Liebm. (*Araceae*), is the only aroid grown for its compound fruit. Another English name for this vine is monstera. In Mexico and Latin America it is known as piñanona or piña anona, ceriman de México or balazo. Other names include ojal or huracán in Venezuela; hojadello in Colombia; Costilla de Adán in Peru; harpón or arpón común in Guatemala; caroal, liane percee or liane franche in Guadeloupe; siguine couleuvre in Martinique; arum du pays or arum troud in French Guiana; and banana de brejo, banana do mato or fruta de México in Portuguese. As an ornamental and as a foliage house plant, it is known as 'Mexican breadfruit', 'hurricane plant', 'Swiss-cheese plant', 'split leaf philodendron' and 'windowleaf'.

World production and yield

The species is native to the wet forest of southern Mexico, Guatemala, and parts of Costa Rica and Panama. In 1908, it was reported to be cultivated in Florida, Portugal and Algeria (Labroy, 1908). Though no longer cultivated on any scale for its fruit, it is found for sale at roadside markets in southern Florida (Fig. A.9). It has been spread around the world as an ornamental foliage plant that can be used indoors or outdoors generally climbing on some structure or tree.

Uses and nutritional composition

The fully ripe fruit pulp is served as a dessert with cream, in fruit salads or ice creams. The flavour is between pineapple and banana with sweet, lactone and coconut overtones, somewhat like piña colada. The flavour is due mainly to ethyl esters with the only terpene being linalool (Peppard, 1992). It can be stewed. Ripe fruit soluble solids are about 19% with 7–8 meq/100 g titratable acidity, oxalic acid being a major acid

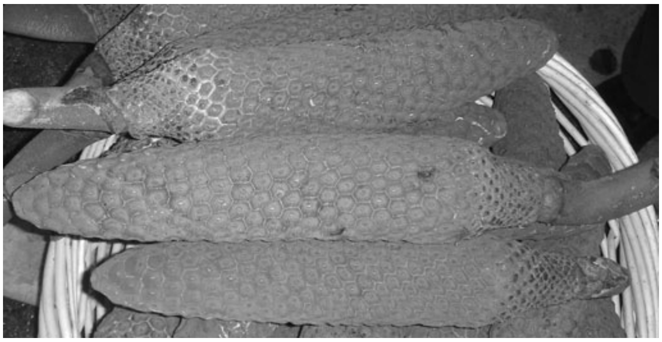

Fig. A.9. *Monstera deliciosa* fruit on sale at a roadside stall in Florida.

component (Peters and Lee, 1977). Table A.44 shows the proximate fruit composition of ceriman.

Acridity associated with the oxalic acid raphides and associated proteins occurs in the growing fruit and floral remnants and all other parts of the plant. Aerial roots have more raphides than soil-borne roots, suggesting tissue variation. Sensitive individuals suffer throat irritation, urticaria and anaphylaxis due to the acridity of the raphides. Ripe fruit lack acridity, although there are individuals that will suffer from diarrhoea or intestinal gases when eating the ripe fruit, so that small amounts should be eaten the first time. The fruit can be consumed when the rind has loosened the entire length of the fruit, otherwise only the part where the rind is loose should be eaten.

The aerial roots are used as ropes and to fashion baskets. A root and leaf infusion is taken for arthritis. A preparation of the roots is used in some places as a remedy for snake bites. The inflorescences have a high concentration of the aromatic amines, tyramine and dopamine, though these are absent from reproductive organs.

Botany

DESCRIPTION This fast-growing stout herbaceous vine up to 24 m long spreads over the ground forming mats and can climb trees. The rarely branched stems are cylindrical (6.25–7 cm thick) and rough with leaf scars producing numerous tough aerial roots normally at a node. The oval leaves are leathery on stiff, flattened petioles (up to 105 cm long). Mature leaves are up to 90 cm long and 80 cm wide, deeply cut at the margins to 23 cm strips and perforated on each side of the midrib with oblong holes of various sizes. Young leaves are heart-shaped and without holes and these are the ones used for smaller pots as indoor plants.

Table A.44. Proximate fruit composition of ceriman per 100 g (Source: Morton 1987).

Proximate	%
Water	77.9
Energy (kcal)	73.7
Proteins	1.8
Lipids	0.2
Carbohydrates	16.2
Fibre	0.57
Ash	0.85

Multiple inflorescences arise from the leaf axils on tough cylindrical stalks. The spadix is cream to tan, surrounded initially by a waxy white spathe with a pointed apex. This spadix develops into a green compound fruit (20–30 cm long by 5–8 cm wide) with a cylindrical form resembling corn on the cob. The sessile flowers have two-carpellate and two-locular gynoecia. A viscous gum-like nectar is produced near the stigma that attracts bees. The thick, hard rind of hexagonal plates (scales) cover the individual segments made up of a juicy ivory pulp. Between the individual segments are thin, black membranes. Occasionally, a pale green, pea-size seed occurs in some of the individual segments of this compound fruit. The individual fruit of the inflorescence are berries 1 cm long by 5–6 mm in diameter.

TAXONOMY AND NOMENCLATURE *Monstera deliciosa* is a member of the *Araceae* whose synonym is *Philodendron pertusum* Kunth & Bouche, a name which is still used to some degree in the ornamental foliage plant business as it is closely related to *Philodendron*. It has a close relative *Monstera adansonii* from Surinam called five-hole plant.

ECOLOGY AND CLIMATIC REQUIREMENTS This is a tropical species found all over tropical America in the hot humid forests, under 600 m altitude with a yearly rainfall above 1000 mm, where it lives under the shade of the large trees on which it climbs as an epiphytic plant. It does best in semi-shade under high moisture conditions. Under subtropical conditions, it can be grown especially as an indoor plant. The plant grows well in almost any soil that is well drained and rich in organic matter. It does not stand saline conditions.

REPRODUCTIVE BIOLOGY Suckers begin to produce fruit in 2–4 years while cuttings take 4–6 years to fruiting. Flowering and fruiting overlap as it requires 12–14 months from the opening of inflorescence to fruit maturity. Cross fertilization is required for fertilization and seed initiation.

FRUIT DEVELOPMENT Fruit development can take 12–14 months and it does not require fertilization. As the fruit matures, the rind takes on a lighter shade and progressively ripens toward the apex over 5–6 days. The portion eaten is only that for which the rind can be easily removed.

Horticulture

PROPAGATION It can be raised from seed or by tissue culture, though generally it is by stem cuttings that take very easily; these cuttings are stem pieces, 15–30 cm long with two nodes or stem tips when there is no new leaf unfolding. Suckers with or without roots can also be used. Seeds are used occasionally and they should be sown as soon as possible after removal from the fruit since they are short lived. The plant should be transplanted close to a tree trunk or a wall so that it can climb.

The harvested fruit kept at room temperature will finish their ripening in about 5–6 days and the ripe fruit can be kept in the refrigerator for a week. A pronounced ethylene and respiratory climacteric occurs during ripening concurrent to a rapid conversion of starch to sugars. The whole fruit can be ripened in a plastic wrap, paper or aluminium foil.

DISEASES, PESTS AND WEEDS Plants used as indoor ornamentals have usually pest problems while those outside normally do not. Scale insects, mites, mealy bugs and caterpillars do attack the plant. In Florida, a grasshopper can cause severe leaf losses in certain years. It is not regarded as a host to Caribbean fruit fly. Leaf spots caused by *Botriodiplodia theobromae* or *Acrosperia fluctuata* are frequent when ventilation is poor. Anthracnose, bacterial soft rot and root rot have also been reported.

MAJOR CULTIVARS AND BREEDING Ornamental variegated forms and regional selections exist.

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ARECACEAE – the Palm Family

The palm family, consisting of over 2500 species arrayed among 200 genera, is known to botanists as the *Arecaceae*, though the old name *Palmae* is still sometimes used in horticulture. Over 90% of the diversity within the family is contained within the world's tropics, and the utility of many palms in human industry at both subsistence and world-market levels makes the *Arecaceae* the third most economically important family of plants after the grasses and legumes.

Morphology, growth and development

Palms, despite their ability to reach tree-like dimensions, have more in common with lawn grasses, maize and rice than with oak trees, maples or tropical hardwoods when it comes to their basic structure and growth processes. Like the former three familiar plants, palms are monocotyledons and, as monocots, lack a vascular cambium. Palms therefore have little to no capacity for secondary growth. Once a palm stem achieves its maximum girth at a given point on the stem, it is largely incapable of increasing its stem diameter. Furthermore, the bundles of conducting tissue within the palm stem, formed during the earliest stages of stem development, must last the entire life of the palm. Palms are also not able to repair their vascular tissue if damaged. It is thus impossible to graft one part of a palm to another. However, the transport of water and nutrients throughout the leaf canopy is efficient due to numerous vascular bundles throughout the trunk. Most importantly of all, the future of a palm stem rides upon the continued health of a single actively growing apical meristem within the bud with little or no ability to regenerate itself. Very few palms have the ability to branch on their aerial stems in the normal course of their growth (Tomlinson, 1973) although occasionally an aberrant individual of an otherwise non-branching species will produce a branched head. Thus if the meristem is killed, the entire palm (if solitary) or an individual palm stem (if clustering) is doomed to eventual death.

Tomlinson (1990) describes the life of a palm as successive series of semi-discrete, but interdependent episodes or phases: seed, embryo, seedling, establishment, mature vegetative and mature reproductive. A palm requires varying horticultural treatment depending on its phase of development, and may express more or less tolerance for certain environmental variables at one given stage versus another. Failure to understand these sometimes subtle but crucial phase differences can result in damage or even death after various horticultural operations such as transplanting.

Unlike broadleaved, dicotyledonous trees, palms complete their increase in stem diameter before elongating. During this 'establishment phase', the palm is particularly sensitive to growth checks or less than optimal environmental conditions.

Since palms do not produce growth rings in their trunks, there is no absolutely reliable way to determine the age of a palm without being witness to its entire history. A palm's age can be crudely determined by counting the number of: (i) leaves in the canopy; (ii) adhering leaf bases; and (iii) leaf scars on the trunk, then observing the rate of leaf production. If the total number of leaves, bases and scars observed is divided by the estimated number of leaves produced annually, a reasonable estimate of the palm's age can be derived. Understorey palms are estimated to live for 60–100 years. Canopy palms have longer lifespans, 100 to 700 or more years (Morici, 1999).

Palm roots

Shortly after seed germination, the seedling root or radicle of a palm ceases to function and is replaced by roots produced from a specialized area of the stem called the root initiation zone. It is during the establishment phase of its growth that a young palm fully develops this initiation zone at the base of the stem. Such roots, originating from the stem, are called adventitious, in contrast to the underground root system of many dicots, which develop sequentially from a perennial seedling root. Again, unlike dicots, palm roots emerge from the stem at maximum thickness; they are incapable of secondary growth. However, they can branch to four orders, with third and fourth order roots the primary absorbing organs. Normally, root development is restricted to the subterranean portion of the trunk, but on some palms the root initiation zone extends for some distance above ground level. Most extreme in this regard are the 'stilt-root' palms of wet tropical rainforests that produce long, thick, support roots from as high as 2–3 m above the ground. A positive consequence of the adventitious root system in palms is that transplanting of mature specimens is relatively easy.

Palm stems

The stems or trunks of palms are as diverse as the palms themselves, varying in thickness, shape, surface features and habit. A sizable group of palms (the rattans) even grow as high-climbing vines into the canopies of rainforest trees. Many palm stems remain covered with the remains of old leaf bases for many years; others readily shed their dead leaves. For the first years of a palm's life, the stem consists of little more than overlapping leaf bases shielding the all-important meristem. Some palm trunks swell noticeably at the base as they develop with age; others develop conspicuous bulges further up on the stem. Most tall-growing palms eventually produce a clear trunk, usually grey or brown, sometimes green. The trunks of some palms are conspicuously spiny; these spines are sometimes the remains of fibres that occurred within the tissue of the leaf bases. The scars left behind by fallen leaves frequently create a distinctive pattern on the trunk. This may appears as rings, or, if the leaves incompletely sheath the trunk, variously shaped scars.

Palm stems vary from about 1 cm to more than 1 m in diameter. All growth in thickness is primary, that is increase in diameter precedes the completion of extension growth. Below the leaf-generating meristem, within the first one to several nodes of the apex, is a 'primary thickening meristem' that facilitates the expansion growth of the stem across those first few nodes. All maturation of the stem tissue is basipetal (downward from the apex). Once expansion growth is complete within a given segment on the developing stem, little or no additional cell division takes place in that region.

The outer surface layer on the stem may become thick walled and sclerotic due to deposition of lignin. A number of palms do produce cork cells in the outer cortex but there is no uniform, single-layered, cork cambium. Instead, the phellogen consists of tiers of meristematic cells. No lenticels or pores appear on the outer surface, but occasional passive vertical splits occur on some palm trunks.

The degree of heterogeneity in the anatomy of the palm stem figures importantly in the use to which palm trunks can be put. The densely fibrous peripheral 'sheath' external to the vascular bundles, which forms the main mechanical support of the palm stem, can be so hard as to dull cutting blades (which is why palms are often left standing when tropical forest is cleared by hand). Within the palm stem there may occur stegmata, small cells with uneven walls that contain a single silica body. These are found in association with fibres and are, in part, responsible for the hardness of this tissue.

Palms may either be single-stemmed (solitary) or multi-stemmed (clustering). The basal suckers on a clustering palm may originate very close to the parent stem or some distance from it. Both solitary and clustering forms may occur in the same genus, or even (albeit rarely) in the same species.

Dichotomous branching of the aerial stems, in which the apical meristem actually divides, is relatively rare in palms, occurring only in the genera *Hyphaene* and *Nypa*. Axillary branching from lateral meristems is typical of virtually all clustering or multi-stemmed palms.

Palm leaves

Palm leaves are amazing feats of organic engineering; they are the largest such organs in the plant kingdom. Leaf development in the palms is unique in the plant kingdom. Segments (palmate and costapalmate leaves) or pinnae (pinnately compound) originate within a continuous tissue mass rather than from separate primordial units. Two processes are involved: plication (folding) via differential growth, and segmentation (Uhl and Dransfield, 1987; Tomlinson, 1990). Many of the details of the leaf development process in palms are still not well understood.

The way in which the leaf segments (fan palms) or leaflets (feather palms) are folded around the main vein or midrib is an important feature of palm leaves that has significance in the taxonomy and identification of the major groups within the family. Palms in which the leaflets or segments are folded upward, forming a 'V', are called induplicate. Palms in which the leaflets or segments are folded downward, forming an inverted 'V', are termed reduplicate. Most of the fan palms have induplicate leaves, while the majority of the feather palms have reduplicate leaves. The best place to look to determine which type of folding characterizes a particular species is right at the point where the leaflet attaches to the rachis (feather palms) or, on fan palms, the point where the segments first split from the rest of the leaf.

All palm leaves consist of three main parts: the blade, the petiole and the leaf base. Each part has a constrained mechanical function that lends these large structures the integrity required to resist wind and other stresses.

The petiole or leaf stem functions mechanically like a tapered beam or cantilever. The extension of the petiole through the lamina of a pinnate leaf is called the rachis; in palmate leaves, the costa. The petiole can be short or long; in a few species it is apparently obsolete. The petiole of a number of palm species is toothed along the margins, ferociously so in some. Generally, the rachis continues through the central leaflet of induplicate leaves, while the blade of reduplicately folded leaves is bifid at its apex.

The leaf base is that part of the petiole that sheathes the stem. It functions mechanically as a stressed cylinder (analogous to a barrel), and supports almost all of the mechanical stresses to which the leaf is subject. It initially develops as a closed tube, but goes through considerable modification throughout the life of the palm. On many palms, the base remains attached to the trunk or stem for some time after the blade and the petiole drop off. In some cases, the pattern of leaf-base stubs is a distinctive feature of the palm's appearance. On other palms, the sheath splits near its base or disintegrates but leaves behind a mass of fibre of varying weave and consistency. The tubular leaf bases of some feather-leaved palms sheath each other so tightly around the stem that they form a conspicuous neck-like structure called a crown shaft. Often waxy and smooth, and sometimes strikingly coloured, the crown shaft can be a structure of singular beauty. Crown shaft palms are 'self-cleaning' in that the tubular leaf base forms two abscission zones, one at its base and one along the dorsal surface, that allow a leaf to fall freely after it senesces.

Palm leaf blades basically fall into three main classes: the fan palms (palmate or costapalmate leaves); the feather palms (pinnate or bipinnate leaves); and entire or bifid leaves. The fan palms are described as either palmate or costapalmate. Fan palm leaves are circular or shaped like an out-stretched hand. They are divided shallowly or deeply into a variable number of segments which are often split at the tips themselves. Palmate and costapalmate leaves are similar in appearance except for the extension of the petiole into the blade of the costapalmate leaf. This extension is sometimes referred to as the costa. Costapalmate leaves are often twisted or folded sharply along or at the tip of the costa.

Feather palm leaves consist of a series of individual leaflets arrayed along an extension of the petiole called the rachis. Pinnately-compound palm leaves are feather leaves that are only once-compound; that is, there is only a single series of leaflets. The leaflets may be numerous or few, narrow or broad, pointed at the tip or blunt and toothed. They can be regularly arranged along the rachis or attached in groups of several. Bipinnately-compound palm leaves are twice-compound; that is, the primary leaflets themselves consist of a system of smaller secondary leaflets. Bipinnately-compound leaves are very rare in the palm family, occurring in only a single tribe (*Caryoteae*) of the family.

Entire-leaved palms have neither segments nor leaflets. Instead, the leaf consists of an unsplit blade longer than it is wide. Bifid leaves are similar in general appearance to entire leaves but have two lobes in their apical portions. Bifid leaves are related structurally to pinnate leaves (and essentially represent an early development stage of a pinnately compound leaf), while entire leaves are developmentally related to palmate or costapalmate leaves. The first leaves of many palm seedlings are entire or bifid, regardless of what type of mature leaf occurs on the palm. Palms that have either entire or bifid leaves throughout their life are thus generally assumed to have retained juvenile characteristics (neotony).

Palms are apparently largely devoid of chemical defences against arthropod predators and other herbivores. Only a single palm genus (*Orania*) is known to contain compounds that are poisonous to humans. An important defence mechanism in the palm arsenal appears instead to be the impressive diversity of spiny structures that may occur on a variety of vegetative or even reproductive parts.

Reproductive morphology

The duration of time that a palm spends in its mature vegetative (sterile) phase may be a few years or many. Palms enter the mature reproductive phase of their lives at the time they produce their first inflorescence. Palms are categorized into two groups based on their reproductive behaviour. A hapaxanthic palm stem exhibits determinate growth. It grows vegetatively for a varying period of time, flowers and fruits after ceasing vegetative growth, then dies. Hapaxanthic palm stems have two possible phenological patterns: (i) a short reproductive phase during which lateral inflorescences are produced in axils of upper bract-like leaves; and (ii) a longer reproductive phase during which lateral inflorescence buds are initiated in the leaf axils but are suppressed until vegetative growth ceases, at which time they mature basipetally. In most palms, flowering axes mature acropetally (older inflorescences are lower on the plant). This type of hapaxanthy is known only in the fishtail palm tribe (*Caryoteae*). A solitary-stemmed palm that exhibits hapaxanthy is also referred to as monocarpic since the palm ceases to live after its fruit mature.

Far more common is the condition known as pleonanthy. Pleonanthic palm stems grow indeterminately; each shoot is of potentially unlimited vegetative growth and flowers are produced on specialized axillary branch systems year after year throughout the reproductive life of the palm.

Palm inflorescences are classified on the basis of where they originate relative to the crown of the palm. Suprafoliar inflorescences originate and stand above the canopy. An interfoliar inflorescence is produced from leaf axils within the canopy. An intrafoliar inflorescence is produced below the canopy of leaves (typical of most palms with crown shafts).

The individual flowers of a palm are generally quite small and inconspicuous, but are usually borne in such numbers on the inflorescence that they may be collectively showy. The inflorescences are palms are frequently quite long and much branched, but on some species they are short and spike-like. The palm inflorescence is a branch complex, made up of repeating units and their associated bracts, with up to five branch orders.

The flowers themselves are borne on terminal segments of all branch orders called rachillae (singular: rachilla). These are often very short. Each flower is subtended by a minute scale-like bract. The pedicel (flower stalk) may also bear a small bracteole. Flowers may be solitary but are usually clustered with varying complexity.

Bisexual flowers (with both stamens and carpels) are the exception. Most palms have unisexual flowers, and the plants are either monoecious (same plant) or dioecious (different plants). On monoecious palms, flowers of both sexes may be spatially segregated on the same inflorescence, but only rarely are they restricted to a single inflorescence of one sex or the other. Flowers of each sex are often functional at different times.

The simplest palm flowers are trimerous (parts in threes) with three slightly imbricate (overlapping) sepals, three slightly imbricate petals, six stamens in two whorls, and three distinct, uniovulate carpels in a superior ovary. However, there is an enormous amount of variation in flower structure throughout the family. The basic structure is actually very rare and is found in nine genera of the *Coryphoideae* (the subfamily considered to be closest to the ancestral palm group (Moore, 1973; Moore and Uhl, 1982)). The basic plan is modified in many ways via connation and/or adnation of parts, increase, reduction or loss, and by differential elongation of the receptacle (Moore and Uhl, 1973; Uhl, 1988). In many genera, the female flowers do not have very well developed sepals and petals.

The palms exhibit extraordinary diversity in pollen morphology, even within genera, and may be an indication of great antiquity for the family, since pollen morphology is often considered a fairly conservative character in plant evolution. The basic monocot morphology, that is elliptic shape, monosulcate (single germination pore), reticulate (net) exine ornamentation, occurs in at least some members of each subfamily and is very common in the *Coryphoideae* (considered the most primitive subfamily).

In contrast to the often diminutive flowers, the fruit (and seeds as well) of many palm species are fairly large and conspicuous. In fact, the largest seed of any plant known on Earth belongs to a palm, *Lodoicea maldivica*. A palm fruit consists of three layers: a thin, superficial exocarp or epicarp (outer surface); a thick and fleshy or fibrous mesocarp; and a thick and bony (or thin) endocarp (the innermost layer). The majority of palm fruit are described as drupes. A drupe is defined as a fleshy, one-seeded fruit with a thick and sclerotic endocarp that does not open or split at maturity. Palm fruit with thin endocarps qualify as berries. Palm fruit with fleshy mesocarps are generally dispersed by animals; those with a fibrous mesocarp are sometimes dispersed and may float (e.g. a coconut). A husked coconut in the supermarket has been cleaned down to the endocarp. Structural variation in palm fruit is found in size, shape, surface texture, mesocarp composition, extent of the endocarp and the number of seeds they contain. Most palm fruit are smooth, but some can be scaly, hairy, warty or prickly. For more than a few species, the display afforded by the ripe fruit is much more conspicuous than that of the flowers.

The innermost layer of the fruit wall, the endocarp, remains adherent to the seedcoat in many palm species. In particular, the endocarp of cocosoid palms (subfamily *Arecoideae*, tribe *Cocoeae*) is fused to the seedcoat. When seeds of many palm species are cleaned before sowing, usually the endocarp is at least partially retained.

The seedcoat of some species bears interesting patterns of ornamentation or sculpturing on its surface. In subfamily *Calamoideae*, the seedcoat is fleshy (sarcotesta). Most of the volume of the seed is taken up by the nutritive tissue called the endosperm that feeds the developing seedling. In most palm seeds, the endosperm is liquid early in development but becomes solid at maturity. Seeds with hollow centres, such as the coconut, are very rare. The actual embryo of a palm is quite small, and is located in a small chamber at one end of the seed.

Seed germination

The way palm seeds germinate falls into one of two categories. In palms with remote germination, the seedling axis develops at some distance from the actual seed. The first structure to emerge from the seed is called the cotyledonary petiole. It resembles, and many people mistake it for, the first seedling root. The cotyledonary petiole grows downward into the soil (sometimes very deeply) and swells at its base. From this swelling emerges the first seedling root (radicle) and seedling shoot (plumule). The actual cotyledon or seed leaf remains inside the seed functioning as an absorptive organ called the haustorium. The haustorium transfers nutrients from the endosperm to the young seedling. In palm seeds with remote germination, the radicle persists for some time and produces lateral roots. The seeds of date palms (*Phoenix* spp.) have remote germination. A number of palm species with remote germination (*Borassus*, for example) bury the seedling axis deep in the soil.

The other main class of palm seed germination is called adjacent germination. In these seeds, only a small portion of the cotyledon emerges from the seed. It appears as a swollen body abutting the seed surface and is called the 'button'. The radicle and plumule emerge from the bottom and top of the button. In palms with adjacent germination, the first seedling root or radicle is usually narrow, very short lived, and is quickly replaced by roots formed at the seedling stem base (adventitious roots). As with remote germination, a haustorium remains inside the seed absorbing food from the endosperm. Some common palms with adjacent germination include coconut (*Cocos nucifera*). In coconut, however, the first stages of germination occur in the fibrous fruit wall that adheres to the seed and cannot be observed without dehusking the nut.

Taxonomy and classification

Modern classification of the palm family began with the work of Harold E. Moore (1973), who recognized 25 natural groups of genera but without any formal taxonomic rank. Uhl and Dransfield (1987) formalized Moore's classification and summarized the wealth of information that had accumulated on each group of the palms, much of it as a result of Moore's extensive fieldwork.

Uhl and Dransfield recognized six subfamilies in the palms, each in turn divided further into tribes and, in some cases, subtribes. These are: *Coryphoideae* (three tribes), *Calamoideae* (two tribes), *Nypoideae* (only one species), *Ceroxyloideae* (three tribes), *Arecoideae* (six tribes) and *Phytelephantoideae*. These six subfamilies basically represent six major lines of evolution.

Four characters are most useful in delimiting the subfamilies: (i) whether the leaf is palmate, costapalmate or pinnate and either induplicate or reduplicate; (ii) the number of peduncular bracts on the inflorescence; (iii) the arrangement of the flowers on the rachillae; and (iv) the structure of the gynoecium (female reproductive parts).

Coryphoideae

The *Coryphoideae* is the most diverse as well as the most unspecialized ('primitive') subfamily of the palms. The leaves of *Coryphoideae* are palmate, costapalmate, rarely entire or pinnate, and induplicate. With the exception of the *Nypoideae*, all apocarpous palms (with free carpels) are in this subfamily. The flowers of *Coryphoideae* are solitary or clustered, but never in triads. Palms in this subfamily are never strictly monoecious (separate male and female flowers on the same plant). Many coryphoid palms are valued ornamentals, and the hardiest palms in the world belong to this subfamily. The date palms (*Phoenix*) belong to this subfamily as well, and the induplicate-leaved, pinnate or bipinnate tribe *Caryoteae* (the fishtail palms) is also allied with the group.

Calamoideae

The *Calamoideae*, the rattans, contain only 22 genera, but this represents a quarter of all palm species because of the sizable number of rattan species in the Asian tropics. Only four genera occur in the New World (*Raphia* occurs in both hemispheres); the subfamily is most abundant in eastern Old World tropics, often in high rainfall or swampy areas. Many of the species are conspicuously spiny. *Calamoideae* contains the only palmate-leaved palms outside of the *Coryphoideae*, but all are reduplicate, and the group includes many climbing species (the rattans). Plants are monoecious, dioecious or polygamous (bearing both unisexual and bisexual flowers) and are characterized by tubular inflorescence bracts, a dyad of bisexual or unisexual flowers as the basic flower cluster, and by the closely overlapping scales covering the ovaries and fruit. A number of genera have fleshy seedcoats (sarcotesta).

Nypoideae

This tribe consist of a single monotypic genus, *Nypa*. *Nypa fruticans* is a mangrove palm of Asia and the west Pacific and is very different from other palms. It grows from a prostrate, dichotomously branched stem and bears reduplicate, pinnate leaves and erect inflorescences with a terminal head of female flowers and branched, lateral spikes of staminate flowers. The flowers are solitary, both sexes with sepals and petals and the females are apocarpous. *Nypa* is one of the earliest recognizable palms in the fossil record, with occurrences throughout both hemispheres.

Ceroxyloideae

The *Ceroxyloideae* are mostly New World palms, but two genera occur in Madagascar, one in the Mascarene Islands and one in Australia. The subfamily is distinguished by reduplicate leaves that are regularly or irregularly pinnate, bifid or entire (the latter two only occur in *Chamaedorea*), numerous peduncular (empty) bracts on the inflorescence, and flowers arranged singly in rows (acervuli). A crown shaft is sometimes formed by the leaf sheaths. The species are bisexual, monoecious or dioecious. New evidence from DNA sequences indicates that this subfamily may be an artificial one, as has been suggested on the basis of morphological evidence.

Arecoideae

This pantropical subfamily is the largest in the palm family and contains the greatest number of horticulturally and agronomically significant species such as coconut and African oil palm. The *Arecoideae* consists of approximately 113 genera in six tribes. All are reduplicate and monoecious. The basic flower cluster of the *Arecoideae* is the triad, but it is reduced to a single flower along some portions of the rachillae in many genera.

Phytelephantoideae

This morphologically isolated subfamily comprises three genera (*Ammandra*, *Phytelephus* and *Palandra*) in north-west South America and Panama. Male flowers contain a large number of stamens and female flowers are clustered in a head-like structure. The fruit are many seeded. The hardened endosperm of the phytelephantoid palms is called tagua or vegetable ivory and is carved into figurines or fashioned into buttons. A sizable industry for the latter flourished in the early part of this century but was rendered obsolete by the plastics industry. The desire to promulgate sustainable development of rainforest products coupled with the worldwide ivory trade ban has stimulated renewed interest in tagua as a marketable commodity.

The palms are a very ancient branch of the monocotyledons, and differentiated when the continents were closer together. The present geographic distribution of the family was strongly influenced by the break up of the ancient continents, Laurasia and Gondwanaland. The earliest unequivocal occurrence of fossil palms is from the late Cretaceous (*c.*80 to 90 million years ago). The earliest fossil palm leaf remains are costapalmate, followed by pinnate, then strictly palmate. Fossil evidence suggests that the subfamilies *Coryphoideae*, *Arecoideae*, *Nypoideae* and *Calamoideae* have been distinct for more than 50 million years.

Pollination biology

The small size and fairly bland coloration of most palm flowers, as well as the copious amount of pollen produced, led early botanists to conclude that most palms were pollinated by wind. It is now known that, in fact, most palms are insect pollinated (Henderson, 1986). The large amount of pollen produced may offset predation by pollen-feeding insects (often the very same ones responsible for pollination). Beetle (particularly weevil) pollination is very common among the palms. Palms pollinated by weevils tend to mature their female flowers first (or, if the flowers are bisexual, the stigma will be receptive before the pollen is shed), have a short flowering period and tightly spaced flowers. Bee-pollinated palms typically are protandrous, have a longer period of flowering and flowers considerably separated on the rachillae. Thrips, flies and ants have also been reported to pollinate palms. Other types of animal pollination are rare, but include bats (*Calyptrogyne*) and birds (*Pritchardia*).

The ecological role of palms

Our understanding of the role that palms play in the complex ecology of tropical forests is probably very incomplete. Fleshy palm fruit are important sources of food for numerous birds, rodents and primates in the tropics. Other animals feed on the carbohydrate- and oil-rich endosperm of the seeds. Some species of parrots are completely dependent on certain palm seeds as a high-energy food source during their breeding season and may fail to breed if the supply of seed is somehow restricted. Palms provide roosting places for birds and bats, and the large leaves serve as shelter for numerous smaller animals.

Ethnobotany and economic botany of palms

Many people are surprised to learn that the palm family is third only to the grass and bean families in economic importance worldwide. *Cocos nucifera* and *Elaeis guineensis* are major cash crops throughout the world's tropics, as is the date palm (*Phoenix dactylifera*) in subtropical arid zones. Equally significant are the myriad uses to which local palms are put by indigenous human cultures wherever palms are found naturally (Balick and Beck, 1990; Schultes and Raffauf, 1990; Johnson, 1998). These include exploitation for food, oil, fibre and construction, as well as medicinal and ceremonial use.

Alan W. Meerow

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Acrocomia aculeata gru-gru palm

Gru-gru palm, macauba or mucaja *Acrocomia aculeata* (Jacq.) Lodd. (*Arecaceae*), is a single-stemmed spiny palm widely distributed in (sub)tropical America. The fruit mesocarp and seed both yield useful oils.

World production and yield

Most oil extraction from *A. aculeata* occurs at the subsistence level, but some commercial exploitation has taken place in Brazil and Paraguay. In 1980, 190 t of oil was produced in the three Brazilian states of Maranho, Ceara and Minas Gerais. One 18 g fruit yields about 2.4 g of fruit oil and 1 g of seed oil (Pesce, 1985). In 1971, Paraguay exported 7400 t of kernel oil.

Uses and nutritional composition

The oil pressed from the fruit can be utilized for cooking without refinement if extracted from very fresh fruit. It is also processed into soap. The seed (kernel) oil is sweet to the taste and has been used in the manufacture of margarine. The seed is 60% fat, 17% saturated (75% oleic and 8% linoleic acids). The fruit contains 4.6 mg of carotene/100 g and is edible. Dried seeds yield about 65% oil, and the fruit pulp, 64% (Balick, 1979). The yellow oil from the mesocarp has higher iodine content than African oil palm fruit, but the fruit hydrolizes rapidly after harvest if not extracted quickly, especially if damaged (Duke, 2001). The seed meal is used as livestock food. More details of the nutrient composition of the fruit and seed are listed in Table A.45.

Botany

TAXONOMY AND NOMENCLATURE *Acrocomia* at one time contained many more species, all of which have been reduced to synonyms of *A. aculeata* (Henderson, 1994). There is one other species in the genus, *Acrocomia hassleri* (Barb. Rodr.) Hahn, a dwarf palm of southern Brazil and adjacent Paraguay. The genus is classified in the tribe *Cocoeae* of the subfamily *Arecoideae*. Synonyms for *A. aculeata* include *Acrocomia sclerocarpa* Mart., *Acrocomia totai* Mart. and numerous others (Henderson *et al.*, 1995).

DESCRIPTION *Acrocomia aculeata* is a robust, tall-growing palm, 4–11 m in height. The grey trunk is 10–35 cm in diameter, often swollen, and armed with spines. A skirt of dead leaves sometimes persists below the crown of 10–30 greyish-green, arching leaves. The pinnate leaves are several metres long, with numerous leaflets arranged irregularly around the rachis in various planes, thus giving the leaf a plume-like appearance. The leaflets are coated with white wax on their lower surface. The once-branched spiny inflorescences emerge from the axils of the leaves. Male and female flowers are borne on the same inflorescence, the males at the tip of the rachilla and the females near the base. The one-seeded fruit are globose, 2.5–5 cm in diameter and ripen to yellowish orange.

ECOLOGY AND CLIMATIC REQUIREMENTS Gru-gru palm is widely distributed from Mexico to Argentina, Bolivia, Paraguay and the West Indies, but is not found in Peru and Ecuador. It typically occupies open woodlands and savannahs in areas with seasonal rainfall, mostly at low elevation but reaching 1200 m in the Andes of Colombia. It is believed to have been introduced to some portions of its range by human activity (Henderson *et al.*, 1995). In some areas it forms large populations. It is quite drought tolerant, and can also withstand several degrees of frost (at least some of its ecotypes). It tolerates slightly acid to slightly alkaline soils.

REPRODUCTIVE BIOLOGY Scariot *et al.* (1991) studied the reproductive biology of this species near the Brazilian capital of Brasilia. Plants flowered between August and December and ripened their fruit between March and June. The flowers are pollinated by various beetle species.

Horticulture

PROPAGATION The seed of *A. aculeata* is surrounded by a bony endocarp after the fleshy mesocarp is removed. If this is cracked or otherwise scarified, seeds germinate in 4–6 months. They are thought to be recalcitrant, and should thus be planted soon after falling from the tree.

DISEASES, PESTS AND WEEDS In some areas of its range, gru-gru nut is attacked by a stem-boring weevil, *Ryna barbirostris*, which can completely destroy the trunk. The fungus *Phaeophora acrocomiae* causes a leaf spot disease.

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Aiphanes aculeata mararay

Mararay, *Aiphanes aculeata* Willd. (*Arecaceae*), is a widespread and very spiny, Neotropical palm with edible fruit and seeds. The fruit are offered in Colombian markets, but no summary data are available.

Table A.45. Percentage composition of various fruit and seed products of *Acrocomia aculeata* (Source: Markley, 1956).

Constituent	Outer fruit wall (epicarp)	Pulp (mesocarp)	Pulp, expeller cake	Shell (endocarp)	Kernel (endosperm)	Kernel, expeller cake
Moisture (H_2O)	6.65	4.31	5.26	6.84	3.17	7.44
Lipids (oil)	3.88	27.94	6.26	2.46	66.75	7.22
Nitrogen	0.74	0.67	0.98	0.31	2.02	5.50
Protein	4.62	4.18	6.12	1.94	12.62	34.38
Crude fibre	36.00	8.82	6.83	49.69	8.60	11.65
Sugars	–	4.85	5.16	–	1.28	2.80
Ash	5.82	10.32	9.16	3.26	1.98	5.37
Potassium	2.18	2.18	2.75	1.02	1.36	1.55
Phosphorus	0.10	0.12	0.16	0.04	0.42	1.14
Calcium	0.07	0.09	0.10	0.04	0.08	0.27

Uses and nutritional composition

The epicarp and mesocarp of the fruit is rich in carotene (Balick and Gershoff, 1990). The seed is used in candies (Bernal, 1992).

Botany

TAXONOMY AND NOMENCLATURE There are about 22 species of *Aiphanes*, distributed mostly in the Andean region of South America, especially Colombia and Ecuador. Most are rainforest palms, occurring from sea level to 2800 m in elevation. The genus is classified in the tribe *Cocoeae* of subfamily *Arecoideae*. *Aiphanes aculeata* was long known as *Aiphanes caryotifolia* (Kunth) H. Wendl. Henderson *et al.* (1995) list many others. Other common names include cocos rura (Bolivia), corozo (Colombia, Ecuador) and macaguita (Venezuela).

DESCRIPTION Mararay is a solitary-stemmed, feather-leafed palm growing 4–12 m tall, with stems about 10 cm in diameter that are armed with sharp fibre spines. The 10–15 pinnate leaves bear 25–40 pairs of leaflets arranged irregularly in clusters of four to six that spread in different planes. The leaflets characteristically widen abruptly towards their tip. Petioles and leaflets bear spines similar to those of the stem. The nodding inflorescences emerge from among the leaves, subtended by a woody spathe, also armed with spines. The one-seeded fruit are globular, 1.5–2.3 cm in diameter, usually bright red, but sometime orange or white, with a juicy orange mesocarp. The bony endocarp surrounding the seed has three pores near the middle.

ECOLOGY AND CLIMATIC REQUIREMENTS Unlike most of its congeners, *A. aculeata* is a denizen of dry forest between 500 and 1500 m in Venezuela, Colombia, Peru, Bolivia and western Brazil, but absent (at least in the wild) from Ecuador.

REPRODUCTIVE BIOLOGY Bee and fly pollination has been reported for many members of the genus. Alan W. Meerow

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Allagoptera spp.

Allagoptera (*Arecaceae*) consists of four species of cocosoid palm distributed from eastern Brazil to Bolivia, Paraguay and Argentina. These species are not produced commercially.

Uses and nutritional composition

The fruit and the seeds of most *Allagoptera* spp. are edible. No information on their nutritional value is available.

Botany

TAXONOMY AND NOMENCLATURE *Allagoptera* consists of four species of cocosoid palm distributed from eastern Brazil to Bolivia, Paraguay and Argentina. It is classified in the tribe *Cocoeae* of subfamily *Arecoideae*. *Allagoptera arenaria* (Gomes) Kuntze (caxandó, coco da pria, seashore palm) is found along the Atlantic coast of Brazil from Bahia in the north to Sao Paulo in the south. It is short stemmed and mostly underground. The leaves are densely waxy on the underside. The sweet mesocarp of the fruit is eaten. *Allagoptera brevicalyx* Moraes (buri da prioa, caxandó) is endemic to Brazil. The leaflets of this species are slit at the tip and waxy grey on both surfaces. *Allagoptera campestris* is found in southern Brazil, northern Argentina and Paraguay, from 600 to 1500 m elevation. The immature fruit is edible. *Allagoptera leucocalyx* (Mart.) Kuntze has a distribution similar to that of *A. campestris.* Both the mesocarp and seeds are edible.

DESCRIPTION The stems are mostly subterranenan and short, solitary, but appearing clustered, often somewhat postrate. The stem sometimes dichotomously branches and the growing point is lower in the ground than the base of the stem. The pinnate leaves usually number four to ten and are frequently waxy, at least on the underside. Petioles are short. Narrow leaflets are clustered irregularly and radiate in different planes, and are often split at the tip. The inflorescences are spicate and emerge from among the leaves. The flowers are densely packed on a short, broad flowering branch. On the lower portion of the rachilla, flowers occur in triads of two lateral staminate flowers and a central pistillate flower. Only staminate flowers occur on the upper portion of the rachilla. The yellowish-green fruit bear one or two seeds, and are densely crowded into a club-shaped fruiting stem.

ECOLOGY AND CLIMATIC REQUIREMENTS All *Allagoptera* spp. come from seasonally dry habitats and do best on sandy soils. The more southerly occurring species are hardy to −4°C. *Allagoptera arenaria* is extremely salt tolerant. It grows on dunes or adjacent restinga vegetation on very sandy soils, often forming large colonies, from 0 to 10 m elevation. *Allagoptera brevicalyx* is restricted to Bahia and Sergipe states on coastal dunes or dry woods near the ocean, from 0 to 20 m elevation. *Allagoptera campestris* occurs in the inland cerrado vegetation from 600 to 1500 m elevation and *A. leucocalyx* is found on dry, rocky, sandy soils from 200 to 700 m elevation.

Horticulture

Allagoptera arenaria is extremely salt tolerant, and makes a fine ornamental in tropical and subtropical coastal areas. Propagation is by seed, which germinates erractically over 3–6 months. High temperature helps speed germination. All are slow-growing palms. Alan W. Meerow

Areca catechu betel nut

Betel nut, *Areca catechu* L. (*Arecaceae*), is a single-stemmed, pinnate-leafed palm cultivated extensively throughout tropical Asia and Africa for its seed, which is chewed as a breath freshener. Also the nuts are said to have stimulant properties. It is estimated that between 10 and 25% of the world's population chew betel nuts with some frequency.

World production and yield

A single betel nut palm produces two to three fruiting stems annually, each containing 150–250 fruit; larger-fruited varieties will produce fewer. One hundred fruit weigh 1.5–2.3 kg. A hectare with 1000 palms yields 450,000–750,000 fruit, which is processed down to 15–25 cwt of dried areca nuts (the seed). An average annual yield of nuts is estimated at 17.5 cwt/ha (Duke, 2001). India and Pakistan are major producers, but almost all of the production is locally consumed. In 1969 and 1970, there were reportedly 1 million ha of betel nut in production in Pakistan alone (Duke, 2001). It is also produced throughout Malaysia and the Philippines, and the latter exports a large quantity to India, as does Sri Lanka. An estimate of world production is 184,000 ha, producing 191,000 t/year (Bavappa *et al.*, 1982).

Uses and nutritional composition

Dried areca nuts are either ground into powder or sliced. Slices are typically enclosed within a leaf of betel pepper (*Piper betel*), mixed with various spices (especially cloves), some lime and sometimes tobacco. Powdered betel may be carried about in a pouch and taken like tobacco snuff. The nuts are chewed at social occasions and after meals. They sweeten the breath, especially if mixed with spices. Chewing the nuts stains saliva red and sustained use will turn the gums and teeth black. A large number of folk medicinal uses for the nuts are also recorded (Duke, 2001). Black and red dyes are also manufactured from the nuts. The fibrous mesocarp is an important industrial product used for insulation and particle board.

Almost 400 calories are contained within 100 g of fresh betel nuts, along with 6.0 g protein, 11 g fat, 70 g carbohydrates, 540 mg calcium, 63 mg phosphorus, 5.7 mg iron, 76 mg sodium, 446 mg potassium, 0.17 mg thiamine, 0.69 mg riboflavin, 0.6 mg niacin and trace amounts of vitamin C. The seeds also contain vitamin A. A number of unique alkaloids are contained within the seed, and some health authorities claim that frequent habitual use has negative health effects (Van McCrary, 1998). Arecaine and arecoline are two of these alkaloids, sometimes compared to nicotine in their stimulating, mildly intoxicating and appetite-suppressing effects. Epidemiologic studies have linked the use of betel nut to various oral cancers, though this may be more a factor of concurrent abuse of tobacco and alcohol.

Botany

TAXONOMY AND NOMENCLATURE *Areca catechu* L. is one of about 60 species of mostly small or modest-sized monoecious palms found in the understorey of Asian tropical forests. It is classified in the palm subfamily *Arecoideae*, tribe *Areceae*.

DESCRIPTION Betel nut palm is a single-stemmed palm with a slender trunk, conspicuously ringed by the scars of fallen leaves, capable of reaching 30 m in height (Fig. A.10), but often smaller, especially when grown in full sun. The sheathing leaf bases form a smooth, greyish crown shaft. The pinnate leaves are 1–1.5 m long, with several dozen obliquely toothed leaflets. The apical pinnae are fused together to form a fishtail-like shape. The branched flower stems emerge from below the crown shaft, and are roughly 1 m long. The small flowers are arranged in triad clusters of two staminate flowers flanking a slightly larger pistillate flower. The orange or red drupes are 5–6 cm long and 4–5 cm wide, varying from spherical to somewhat flattened, and contain a single seed.

ECOLOGY AND CLIMATIC REQUIREMENTS *Areca catechu* is thought to be originally native to the Malaysian peninsula, but its use has resulted in a long history of cultivation and naturalization through south and South-east Asia. It requires a warm, humid tropical climate to thrive, and is damaged at 0°C. In the tropics, elevations below 1000 m suit the palm best. It performs best with annual rainfall in excess of 500 mm, but responds favourably to irrigation in drier climates. In the wild, it is usually found at the margins of rainforest or below the

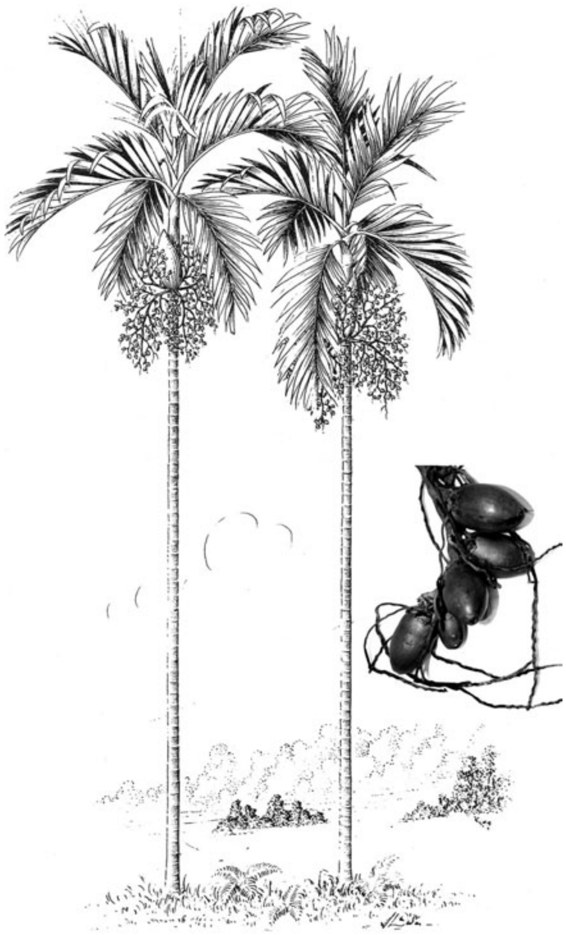

Fig. A.10. *Areca catechu* palm and insert showing fruit (with permission from Sitijati Sastrapradja from Palem Indonesia, Lembaga Biologi Nasional, 1978; fruit photograph provided by Ken Love).

canopy; in time it may penetrate the upper strata of vegetation. It colonizes secondary forest readily. The palm grows on a variety of soils, as long they have good water-holding capacity.

REPRODUCTIVE BIOLOGY *Areca catechu* is monoecious, with separate staminate and pistillate flowers borne on the same inflorescence. The palms are insect pollinated. Little is recorded in detail about the species' reproductive biology. The palms are diverse in flowering and fruiting season depending on the area in which they are grown. Palms usually begin to flower and fruit after 7 years from seed.

FRUIT DEVELOPMENT Betel nuts mature in 6–8 months after pollination of female flowers. The fruit are harvested typically when their full colour (yellow, orange or red, depending on source) is developed. Optimum fruit production usually takes 10–15 years, and the palms will generally bear heavily for 30–75 years of their life (60–100 years is the best estimate available).

Horticulture

PROPAGATION Seeds are the only means of propagation of betel nut. Ripe fruit are gathered, sun-dried for several days or in shade for a week. Seeds are sown either in rows or in groups of several dozen in pits of prepared soil. Plantain leaves are sometimes used as germination containers. Of course, the seeds may be sown in trays or other nursery containers as well, but this is seldom done in the main production areas. Seeds germinate erratically in as little as 6 weeks and upward to a year. Typically 1–2-year-old seedlings are planted into their permanent sites at a density of 1000–1500 palms/ha. Some degree of shade is generally provided by bananas or fruit trees. Betel nut is thus an important component of agroforestry systems in Asia.

NUTRITION AND FERTILIZATION Betel nut palms are tolerant of many different soils types, except very sandy soils with low water-holding capacity. A pH of 6.3–6.5 is probably ideal, though the palm tolerates acidity to at least 5.0 and alkalinity to 8.0. Year-round irrigation is essential where a marked dry season occurs. Applications of manure or inorganic NPK (nitrogen, phosphorus, potassium) fertilizers have proven beneficial (Duke, 2001).

DISEASES, PESTS AND WEEDS Koleroga disease (*Phytophthora omnivorum* var. *arecae*), which attacks the fruit, and foot rot (*Ganoderma lucidum*), which infects the base of the stem, are the two most serious diseases of betel nut palm. Innumerable other fungal blights, mostly leaf spot diseases, have been reported on *A. catechu*. *Thielaviopsis paradoxa* is an endophytic fungus that causes the stems to split lengthwise. Bacterial decline caused by *Xanthomonas vasculorum* has been reported. Several nematode species are a problem in Thailand. Insect pests include rhinoceros beetle (*Orcytes rhinoceros*), a caterpillar that feeds on the leaves (*Nephantis serinopa*) and a borer (*Arceerns fasiculatus*).

MAIN CULTIVARS AND BREEDING In some of the areas throughout its natural range and where it has been introduced, betel nut populations have been selectively propagated for various characteristics such as fruit shape and size, nut flavour and, presumably, concentration of biologically active constituents (Duke, 2001). Years of selection have resulted in those forms coming true from seed for those specific characteristics (i.e. they are likely to be homozygous for the genes promoting these traits). These selections have at times been given formal botanical rank, but are probably better considered as cultivars. 'Deliciosa' has been applied to varieties with very mildly flavoured nuts. 'Batanensis' produces shorter and thicker stems. 'Communis' has orange-red fruit.

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Arenga pinnata sugar palm

Sugar palm, *Arenga pinnata* (Wurb) Merr. (*Arecaceae*), is a solitary palm from Asia widely cultivated for its starchy pith and sugary sap which contains much higher levels of sucrose than most sugarcane varieties, as well as the industrially valuable fibre extracted from the leaf sheaths. A minor use for the palm is the extraction of the edible endosperm of partially ripened seeds for preparation as sweetmeats.

Uses and nutritional composition

Half-ripe fruit are first peeled to remove the fruit wall which contains high levels of irritating calcium oxalate crystals. The seeds are washed and the seedcoat removed. The endosperm is first soaked in lime water for a few days then boiled in sugar solution, sometimes flavoured with various spices. The juice of the ripe fruit is used as a fish poison and should never be consumed. While the stem starch and the sugary sap of *A. pinnata* has been analysed, no nutritional information on the seed is available.

Botany

TAXONOMY AND NOMENCLATURE *Arenga pinnata* is one of about 17 Asiatic species in the genus. It is classified in the tribe *Caryoteae*, which was once placed in the subfamily *Arecoideae*, but has been shown to be more closely related to the subfamily *Coryphoideae*, which consists of mostly fan-leafed palms. *Arenga saccharifera* Labill. is a synonym.

DESCRIPTION Sugar palm grows up to 15 m in height with a solitary stem up to 0.5 m in diameter (Fig. A.11). The remains of old leaf sheaths cover the stem with a dense coat of dark brown fibres and spines. The induplicate, pinnate leaves are erect, nearly 10 m long with 100 or more, dark-green leaflets with a white waxy coating on their underside. The stout

Fig. A.11. *Arenga pinnata* palm showing multiple inflorescences (with permission from Sitijati Sastrapradja from Palem Indonesia, Lembaga Biologi Nasiona, 1978).

petioles are 1.5–2 m long and covered with fibre. The leaflets are about 1 m long, 5–8 cm wide, and usually with jagged, 'fishtail' tips. Large pendent inflorescences emerge from the leaf axils sequentially from bottom to top, consisting of many long, slender rachillae drooping from a short peduncle. Typically, the flowers are arranged in a triad of two staminate flowers flanking a central pistillate flower, but unisexual inflorescences are sometimes produced, especially those developing in the upper axils. The flowers are stalkless and purple, sometimes scented. The ovoid fruit is 5–6 cm in diameter, yellow to yellowish brown with a fleshy white mesocarp that is irritating to the skin. Each contains two to three grey-brown seeds, 2.5–3.5 cm long and 2–2.5 cm wide.

ECOLOGY AND CLIMATIC REQUIREMENTS *Arenga pinnata* is thought to have originated in Indonesia but is now widely distributed through India, Sri Lanka, southern China, South-east Asia, New Guinea and Guam, from sea level to 1200 m elevation. It is a rainforest palm in its natural state, and thrives on rich, moist soil in partial shade, but is adaptable to drier areas and to full sun. Sugar palm is tolerant of temperatures below freezing but is damaged at –2°C. Specimens have been known to recover from temperatures as low as –4°C (Duke, 2001).

REPRODUCTIVE BIOLOGY The flowers of sugar palm are insect pollinated, though details are lacking in the literature. In its natural forest habitat, the fruit are dispersed by fruit bats, civets and probably other small mammals. The sugar palm is a hapaxanthic palm, and begins to decline (and eventually dies) after the uppermost inflorescences set fruit. The palm has a long period of juvenility (6–12 years), and lives for about another 15 years after flowering begins. Flowering and fruiting occurs throughout the year in the lowland tropics.

FRUIT DEVELOPMENT It takes 2 years for the fruit of *A. pinnata* to mature.

Horticulture

PROPAGATION Sugar palm is propagated from seed, which germinates in 3–12 months.

DISEASES, PESTS AND WEEDS Sugar palm is rarely troubled by pests or disease. The stem-rotting fungus *Ganoderma pseudoferreum* has been reported to affect *A. pinnata*. In South-east Asia, the rhinoceros beetle, *Orcytes rhinoceros*, has been known to feed on the foliage.

MAIN CULTIVARS AND BREEDING While some degree of regional selection has been applied to sugar palm, mostly towards reducing the juvenile period, no rigorous breeding or cultivar evaluation programme has ever been conducted.

Alan W. Meerow

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Astrocaryum aculeatum chonta palm

Chonta palm, *Astrocaryum aculeatum* G.F. Mey (*Arecaceae*), is a solitary palm widely distributed in the Amazon region, and often associated with former or present human habitation. Its edible fruit is valued locally. The fruit are sold in markets in Amazonian Colombia and Brazil.

Uses and nutritional composition

The orange, fleshy mesocrap of the fruit is consumed. The fruit contains 3.5% protein, 19.1% carbohydrate and 16.6% fat. In addition, the level of vitamin A is reported to be 50,000 IU/100 g of pulp, three times that of carrots. The oil pressed from the seed is chemically similar to coconut oil. Local people steam the fruit and eat them, or crack open the seed inside young fruit to drink the clear, sweet endosperm. Other species of *Astrocaryum* with edible fruit or seeds are listed in Table A.46. No information on their nutritional value is available. *Astrocaryum jauari* is a waterside plant, and the fruit, which drop into the watercourses along which the palms grow, are an important food source for river fish. Use of the seeds for fish food in aquaculture projects has been proposed (Borgtoft Pedersen and Balslev, 1992).

Botany

TAXONOMY AND NOMENCLATURE There are perhaps 18 species of *Astrocaryum* (Henderson *et al.*, 1995). *Astrocaryum princeps* Barb. Rodr. and *Astrocaryum tucuma* Mart. are common synonyms for *A. aculeatum*; Henderson *et al.* (1995) list others (Table A.46). The genus is classified in the tribe *Cocoeae* of subfamily *Arecoideae*.

Table A.46. Other species of *Astrocaryum* with edible fruit.

Species	Common name	Origin	Uses	Characteristics	References
Astrocaryum acaule Mart.	Espina, corozo, palmeira lú, tucumai	Guiana, Amazon	Edible pulp and nut	Stem very short and underground; five to nine leaves, leaflets 55–103 per side in irregular clusters; fruit obovoid, 2.5–3 cm long, 1.5–2 cm wide, yellow-green to orange	Fouqué, 1973; Martin *et al.*, 1987
Astrocaryum campestre Mart.	Jarivá, tucum	Brazil, Bolivia	Edible fruit	Stem short, underground; three to six leaves, leaflets 17–43 per side, in irregular clusters; fruit 3–3.5 cm long, 2–2.5 cm wide, orange or yellow-green	Fouqué, 1973
Astrocaryum chambira Burret	Chambira	Western Amazon	Edible fruit	Stem to 30 m tall; leaves 9–16, erect, to 5 m long; inflorescence solitary and erect; large, light green fruit, mesocarp fibrous	Villachica, 1996
Astrocaryum gynacanthum Mart.; Syn.: *Astrocaryum munbaca* Mart.	Coco de puerco (Colombia), cubarro (Venezuela); mumbaca	Amazon mostly east and centre, on non-inundated lowlands	Mesocarp occasionally eaten	Stems clustered, to 12 m, 3–10 cm wide; fruit obovoid 2.5–3 $\times$ 1.2–1.5 cm, densely crowded, bright orange; mesocarp orange, floury	Henderson *et al.*, 1995
Astrocaryum huaimi Mart.	Chontilla	South-western periphery of the Amazon: Peru, (Madre de Dios), eastern Bolivia to Mato Grosso in Brazil	Pulp and nut oily, edible	Spiny stem to 10 m, clustered or solitary; fruit obovoid 3–4.5 $\times$ 2–3cm, yellow to orange	Fouqué, 1973; Henderson *et al.*, 1995
Astrocaryum jauari Mart.	Jauari	North of South America, on regularly flooded sandy soils	Pulp has a flat taste; edible nut (oil)	Multiple spiny stems to 15 m; fruit ovoid 4–5 $\times$ 2.5–3 cm, greenish orange	Fouqué, 1973; Martin *et al.*, 1987
Astrocaryum macrocarpum Huber	Palmeira tucumã-assi	Brazil	Pulp	Syn. of *A. aculeatum* according to Henderson *et al.*, 1995	Martin *et al.*, 1987
Astrocaryum mexicanum Liebm. ex Mart.	Lancetilla (Honduras), chocho, chichón (Mexico)	Mexico to Central America	Inflorescence and endosperm eaten; leaves for thatching; trunks as tool handles	Stem solitary, to 8 m, 2.5–8 cm wide; fruit ellipsoid to obovoid, 4–6 cm, densely covered with short black spinules, brownish	Henderson *et al.*, 1995
Astrocaryum murumuru Mart.	Chonta (Bolivia), chuchana (Colombia, Ecuador), huicongo (Peru), murumuru, muruí (Brazil)	Amazon, periodically flooded areas, up to 900 m in eastern Andes	Mesocarp and nut occasionally eaten; leaves and stems in house construction	Spiny stem, solitary or clustered, to 15 m; fruit obovoid, 3.5–9 $\times$ 2.5–4.5 cm, brown, tomentose to scarcely to densely covered with short black spinules; mesocarp fleshy or fibrous	Henderson *et al.*, 1995; Silva, 1996
Astrocaryum princeps Barb. Rodr.	Tucumã-açú	Brazil	Pulp	Syn. of *A. aculeatum* according to Henderson *et al.*, 1995	Martin *et al.*, 1987
Astrocaryum vulgare Mart. Syn.: *Astrocaryum awarra* de Vriese, *Astrocaryum guianense* Splig. ex Mart., *Astrocaryum segregatum* Drude, *Astrocaryum tucuma* of Wallace, *Astrocaryum tucumoides* Drude	Tucuma; tucumã, tucumã do Pará, cumari, acquiere, awarra, palmier tucuman, aouara	Amazon	Juice, oil	Usually clustering, stems 410 m tall; leaves 8–16, erect, leaflets 73–120 per side, irregularly clustered; fruit globose, 4–5 cm and 3–3.7 cm wide, orange	Fouqué, 1973; Cavalcante, 1991; Henderson *et al.*, 1995; Villachica, 1996

DESCRIPTION Chonta palm is a solitary-stemmed feather palm growing 20 m or more tall. The trunk may reach 25 cm in diameter and is covered with long black spines. There are between six and 15 erect leaves extending to 6 m in length. There are 73–130 pairs of leaflets arranged in irregular clusters that spread in various planes. The inflorescence emerges from the leaves and is erect, subtended by a spiny bract. The flowering branches have only two to four female flowers at their base; the rest of the flowers are male. The globose fruit are 4–5 cm in diameter, yellow-orange or yellow-green.

ECOLOGY AND CLIMATIC REQUIREMENTS Chonta palm is widespread throughout the central and eastern Amazon of Colombia and Venezuela, Trinidad, the Guianas and Brazil, below 1000 m. It is rarely found in forests of the Amazon, but is much more common in deforested areas, and is thought to have been introduced in some parts of its range. It has little tolerance of frost.

REPRODUCTIVE BIOLOGY Consiglio and Bourne (2001) found that beetles were the most efficient pollinator of chonta palms.

Horticulture

Seeds of chonta palm can take more than a year to germinate.

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Attalea cohune cohune

Cohune, corozo, *Attalea cohune* Mart. (*Arecaceae*), is a tall-growing single-stemmed, pinnate-leafed palm native to the wet Atlantic coast lowlands from Mexico to Honduras and Belize, but cultivated as far south as northern South America. The seeds are a source of a high-quality oil.

World production and yield

No data are available. Yields are said to vary, which has prevented sustainable large-scale processing. Fruit and/or nuts are exported from Central America for soap manufacturing.

Uses and nutritional composition

The seed of the cohune palm yields a non-drying oil used in food, for lighting and soap production. The fruit are sometimes made into sweetmeats and also fed to livestock. Per 100 g, the seed contains 6.8 g protein and 52.2 g fat (Duke, 2001).

Botany

TAXONOMY AND NOMENCLATURE The cohune palm was formerly known as *Orbignya cohune* (Mart.) Dahlgren ex Stanl. Palm species formerly recognized as the separate genera *Maximiliana*, *Orbignya* and *Scheelea* have been combined with *Attalea* (Henderson *et al.*, 1995). It is classified in the tribe *Cocoeae* of subfamily *Arecoideae*. Other *Attalea* species with edible fruit or seeds are listed in Table A.47.

DESCRIPTION The cohune palm grows 16–20 m tall, producing a trunk up to 30 cm in diameter that is conspicuously ringed with old leaf scars after the persistent old leaf bases finally fall. The 15–30 leaves are as much 10 m long, and fairly erect, arching ultimately at their tip. Each leaf bears 30–50 leaflet pairs, each up to 45 cm long, rigid and dark green. The flower stems emerge from among the leaves, contained by a woody bract in bud. The branches of the staminate inflorescences are up to 15 cm long; staminate flowers have as many as 24 stamens. The fruit are borne in pendulous clusters; each fruit is 4–8 cm long, 3.3–4.5 cm wide, brown or yellow-brown and containing one to three seeds.

ECOLOGY AND CLIMATIC REQUIREMENTS The cohune palm occurs from sea level to 600 m on a variety of soil types from southern Mexico to Belize, but also sparingly in northern South America. It is most abundant in wet rainforest on rich soils, but is found in disturbed, open areas. Some populations are undoubtedly relics of cultivation. Little or no tolerance of freezing temperatures is to be expected. Wide tolerance of pH is reported (Duke, 2001).

Horticulture

PROPAGATION Cohune palm seeds remain viable for 6 months. They should be planted about 5 cm deep and kept moist. A spacing of 100 trees/ha has been recommended.

DISEASES, PESTS AND WEEDS Fruit are often parasitized by the larvae of bruchid beetles. Fungal pathogens that have been reported include *Achorella attaleae*, *Gloeosporium palmigenum* and *Poria ravenalae* (Duke, 2001).

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Table A.47. Some additional *Attalea* species with edible fruit or seeds (Source: Henderson *et al*., 1995).

Species	Synonym	Common names	Distribution and habitat	Descriptive notes	Edible product
Attalea allenii H.E. Moore		Taparin, táparo, igua, mangué	Atlantic slopes of Panama and NW Colombia; lowland rainforest below 500 m	Subterranean stems; leaves 8–15, leaflets in irregular clusters, apical leaflets partially joined along margins; fruit light brown, 6–8 cm long, 3.5–5 cm wide	Liquid endosperm is drunk; seeds eaten
Attalea amygdalina Kunth	*Attalea victoriana* Dug.	Táparo, almendrón	Colombia, dry to wet forested ravines, 1000–1600 m	Subterranean stems; leaves 10–15, leaflets two-ranked; fruit 6–9 cm long, 5 cm wide	Seeds edible; high oil content
Attalea butyracea (Mutis ex L. f.) Wess. Boer	*Scheelea butyracea* (Mutis ex L. f.) H. Karst. ex H. Wendl.; many others listed in Henderson *et al.* (1995)	Palla, jací, palama real, corozo, canambo, coquito, coyol real, shebon, yagua	Widespread from Mexico to northern South America in seasonal and wet forest as well as savannah and disturbed areas, usually below 300 m	Stem to 20 m and 25–50 cm broad; leaves 15–35, petiole and sheath spiny, leaflets two-ranked; fruit 4.5–8.5 cm long, 3–4.5 cm wide, orange, yellow or brown	Fruit and seed edible
Attalea colenda (O. F. Cook) Balslev & Henderson		Palma real	SW Colombia and western Ecuador, lowland rainforest or deciduous forest, below 900 m	Stem to 30 m, leaves 15–20, petioles long, leaflets two-ranked; fruit to 6 cm long, 3.5 cm wide, orange-brown	Oil similar to coconut and African oil palm extracted from seed commercially
Attalea exigua Drude		Catolé, indaia rasteira	Brazil, cerrado vegetation below 800 m	Subterranean stems; leaves 4–8, arched, leaflets irregularly arranged in clusters; fruit 4–6 cm long, 3–5.5 cm wide, reddish orange to dark purple	Endosperm of seed used to make confections and as a sweetener
Attalea maripa (Aubl.) Mart.	*Maximiliana maripa* (Aubl.) Drude; many others listed in Henderson *et al.* (1995)	Cusi, anajá, inajai, guichire, inayo, maripa, kukarit, inayuga, cucurito	Widespread in N South America east of the Andes in primary and secondary forest, open and disturbed areas at low elevation	Stems 3.5–20 m tall, leaves 10–22 in five distinct vertical rows on long petioles, leaflets irregularly arranged in tight clusters; fruit 4–6 cm long, 2.5–3 cm wide, brown	Seed edible

Attalea speciosa babassu

Babassu, *Attalea speciosa* Mart. ex Spreng. (*Arecaceae*), is a single-stemmed, pinnate-leafed palm native to the Amazon region. The Brazilian common name babaçu or babassu is from the Tupi-Guarani Indian language: *ba* = fruit; *açu* = large); it is known as cusi in Bolivia (Anderson *et al.*, 1991). It is an important local resource in the southern Amazon, especially in Brazil, yielding an oil comparable to coconut. Other parts of the palm are also used by local people. There has been some developmental interest in Brazil on expanding production as well as increasing oil extraction efficiency.

World production and yield

It is estimated that several hundred thousand households harvest the fruit of the babassu palm in the Brazilian state of Maranhão alone (Balick and Pinheiro, 1993). The economic value of the palm in that state was estimated at US$85 million (May, 1986), but that included all uses to which this versatile palm is put. However, most of the value resides in subsistence economies, thus an exact figure is elusive. Oil extracted from the seeds averages 90–150 kg/ha annually (it constitutes about 7% of the fresh fruit), and a minimum of 85,000 t of babassu kernel oil were extracted annually during the 1970s in Maranhão state (Pesce, 1985). During both World Wars, there was significant export of babassu oil to Europe from Brazil, a trade which all but disappeared by the 1960s (Anderson *et al.*, 1991). A shortage of coconut oil in the 1980s resurrected the export industry briefly. Most production outside of subsistence use feeds the Brazilian cosmetic industry, and 150,000 t of the oil was produced in 1985 (Balick and Pinheiro, 1993).

Uses and nutritional composition

The seed (kernel) of babassu is rich in lauric acid (60–70%), and is thus comparable to that of coconut (*Cocos nucifera*) or African oil palm kernel (*Elaeis guineensis*). Over 80% of the oil is saturated fat, about 11% monosaturated and the remainder polyunsaturated. The oil contains 19 μg of vitamin E/100 g. It does not turn rancid as quickly as other palm oils. The seed meal left over after oil extraction is often used as feed for livestock. The hard fruit husks make an excellent charcoal (Balick and Pineiro, 1993). The seeds are an important food resource for the hyacinth macaw (Munn *et al.*, 1988).

Botany

TAXONOMY AND NOMENCLATURE Babassu was long known as *Orbignya phalerata* Mart. Other synonyms include *Orbignya martiana* Barbosa Rodrigues, *Orbignya barbosiana* Burret and *Orbignya speciosa* (Martius) Barbosa Rodrigues. Palm species formerly recognized as the separate genera *Maximiliana*, *Orbignya* and *Scheelea* have been combined with *Attalea* (Henderson *et al.*, 1995).

DESCRIPTION The babassu is a single-stemmed palm, reaching to 30 m in height and a girth of 20–50 cm. The crown consists of 10–25 large, pinnate leaves that are at first sub-erect but then become arching. The apical portion of the leaf is often twisted. The petiole is short, 10–40 cm long, while the rachis extends from 5.5 to nearly 9 m in length, supporting several hundred leaflets. Each pinna is 20–185 cm long and 1–6 cm wide. The pendent inflorescences, arising from the leaf axils, are either entirely male or bisexual, and are up to 2 m long. In bud they are contained by a woody bract. Staminate inflorescences are branched into as many as 400 flower-bearing rachillae, each with 15–100 flowers. Bisexual inflorescences have slightly more branches, each with one or two (sometimes three) pistillate flowers and one to several staminate flowers that may not fully develop. The fruit is an oblong drupe, 6–13 cm long and 4–10 cm wide. The outer and middle layers are fibrous and mealy, respectively. A tough, woody inner wall (endocarp) surrounds three to six (rarely fewer, or even more rarely up to 11) ovoid seeds 3–6 cm long, with oily white endosperm.

ECOLOGY AND CLIMATIC REQUIREMENTS The babassu is widely distributed along the southern edges of the Amazon basin from the Atlantic Ocean to Bolivia, extending throughout eastern and central Amazonas and northward to Guyana and Surinam. Most populations are found south of the Amazon River. There are areas in Maranhão and Piauí states of Brazil where huge populations, as many as 10,000 palms/ha (Anderson *et al.*, 1991) can be found. These so-called 'babassu zones', with high numbers of juvenile palms (fruiting individuals are usually in the range of 100–200/ha), may be in part artefacts of human activity, as babassu palm colonizes disturbed sites very readily. These zones constitute as much as 150,000 km^2 in south-eastern Amazonas, often in the transitional areas between forest and savannah. In primary rainforest, mature reproductive palms are more scarce (*c.*50/ha) because of light limitations. Babassu palms in the forest may remain in the juvenile phase of growth for as much as 50 years (Anderson, 1983).

Babassu has fairly broad ecological tolerance. Though the babassu zones are usually on good soils with high annual rainfall, *A. speciosa* also occupies the savannahs of the Brazilian cerrado vegetation with as much as a half-year dry season (though the larger populations are always along rivers). The palm is not, however, tolerant of frequently inundated soils. Annual average rainfall of 1500–2500 mm appears optimal, and little or no tolerance of freezing temperatures is to be expected. Wide tolerance of pH is reported (Duke, 2001).

REPRODUCTIVE BIOLOGY Babassu has a consistent phenology over a wide range. Leaf emergence and flowering occurs during the local rainy season, followed approximately 9 months later by fruit ripening and leaf senescence and loss (Anderson *et al.*, 1991). In some stands, flowering occurs throughout the year.

FRUIT DEVELOPMENT Babassu palms rarely begin to fruit before 8 years under the best conditions. Fruit production increases for the next dozen years, and trees bear for upwards of 75 years.

Horticulture

PROPAGATION Research on germination of babassu seed is fairly extensive (Frazão and Pinheiro, 1985; Pinheiro, 1986;

Pinheiro and Araujo Neto, 1987a, b). The babassu seed has a type of germination known as 'remote tubular'. It germinates hypogeally (the cotyledon does not emerge from the seed). The cotyledonary petiole emerges from the seed and grows down to a depth of as much as 60 cm. The seedling stem and root thus develop deeply underground while the rest of the cotyledon (haustorium) absorbs the endosperm and enlarges within the seed and occupies the space formerly filled by the endosperm.

Fire and shade stimulate germination, and both conditions are found in the forest–savannah transition zone where the palm is often most common. An extensive adventitious root system is formed early in the life of the palm. The apical meristem remains underground for several to many years as the stem expands in diameter before elongation commences. The palm is thus able to re-grow successfully after injury. Needless to say, such a system is difficult to adapt to nursery production. Successful nursery seed germination of such palms has been accomplished in very deep containers, or even in long lengths of plastic pipe.

NUTRITION AND FERTILIZATION Babassu palms are most productive on fertile soils, which suggests that the palms will respond to fertilization. No information has been published on mineral nutrition, however. The extensive root system of the palms implies a fairly efficient mechanism of nutrient uptake.

MANAGEMENT Most management strategies for babassu involve enhancement of natural stands, rather than establishment of plantations. The numerous seedlings and stemless juveniles require thinning, which can only be accomplished by harvest for palm heart (which kills the palm) or with systemic herbicides. A combination of juvenile palms and young reproductives are retained, and older palms as well as those producing only male flowers are eliminated.

DISEASES, PESTS AND WEEDS Fruit are often parasitized by the larvae of *Pachymerus nucleorum*, a bruchid beetle, after they fall from the tree.

MAIN CULTIVARS AND BREEDING The wide ecological tolerances of babassu suggest that seed-propagated lines with specifically adapted features, as well as more productive individuals, could be isolated, but no breeding or sustained selection programmes have been initiated. Alan W. Meerow

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Bactris gasipaes peach palm

The peach palm, *Bactris gasipaes* Kunth (*Arecaceae*), is known as pupunha (Brazil), chontaduro (Columbia), pejibaye (Costa Rica) or pijuayo (Peru) and is the only domesticated palm in tropical America. It was probably first used for its wood, was fully domesticated for its starchy-oily fruit and is now most important for its heart-of-palm. The name in English and other European countries is a misnomer, as the fruit is more like a tree cassava (*Manihot esculenta* Crantz) than a juicy peach (*Prunus persica* (L.) Batsch) (Clement *et al.*, 2004). During the last two decades of the 20th century, cultivated peach palm supplanted wild harvested palms in most producing countries (except Brazil, where *Euterpe* spp. dominate) as the principal source of heart-of-palm in both Latin American (the major production and consumption region) and world markets (Mora Urpí and Gainza Echeverria, 1999). While this is a modern success story, peach palm is under-utilized for its originally important product – the fruit.

The origin of peach palm has been debated extensively and inconclusively for more than a century. Recent morpho-anatomical evidence suggested that peach palm's origin will probably be found in south-western Amazonia (Ferreira, 1999), in what is now northern Bolivia, south-eastern Peru and western Brazil. Recent allozyme evidence also pointed towards that region (Rojas-Vargas *et al.*, 1999), as does a DNA (RAPD) analysis (Rodrigues *et al.*, 2004). It now appears that two dispersions occurred from that region: one to the north-east, resulting in the Pará microcarpa landrace and undescribed intermediate populations; one to the north-west, resulting in the complex of micro-, meso- and macrocarpa landraces and undescribed populations that occupy central and western Amazonia, the rest of north-western lowland South America, and Central America up to Nicaragua (Fig. A.12). The full number and distribution of peach palm landraces remain to be determined.

Archaeological evidence on early distribution and possible origin(s) and dispersion is still fragmentary (Morcote-Rios and Bernal, 2001). The earliest records are of carbonized seeds from the lowlands of Costa Rica, dated to 2250–1650 years before present (BP) and 2190 ± 60 BP, while the earliest records in Amazonia are from Colombia, dated to 1080 ± 40 BP. No records exist for the putative region of origin nor the majority of peach palm's Amazonian distribution. None the less, archaeology will be important for confirming the hypotheses based on modern plant morphology, anatomy and genetics. A linguistic study of indigenous names of peach palm is underway and will offer further clues.

During the century immediately following European conquest, the fruit was reported to be used principally as a cooked starchy staple, or fermented to make a drink, or ground and dried into flour. The wood was important for tools and weapons because of its straight grain and durability (the modern Colombian name, chontaduro, means the 'tough palm'). Throughout western Amazonia and extending up to Costa Rica the peach palm appears to have been a staple starch crop, perhaps as important as maize (*Zea mays* L.) and cassava in much of this region. The date palm (*Phoenix dactylifera* L.) is the Old World's dry tropical domesticate with similar importance in subsistence, as was noted by the earliest European conquerors who were familiar with it from south-eastern Spain.

Peach palm's pre-Columbian importance in Central America was attested to by one of the first legal cases in the Spanish colonies (1541–1546; Patiño, 1963: 121–122). In 1540, a band of adventurers was authorized by the governor of Panama to establish a settlement in the Sixaola River valley (in what is now southern Costa Rica's Atlantic coast), where they reported that the local people depended on peach palm for

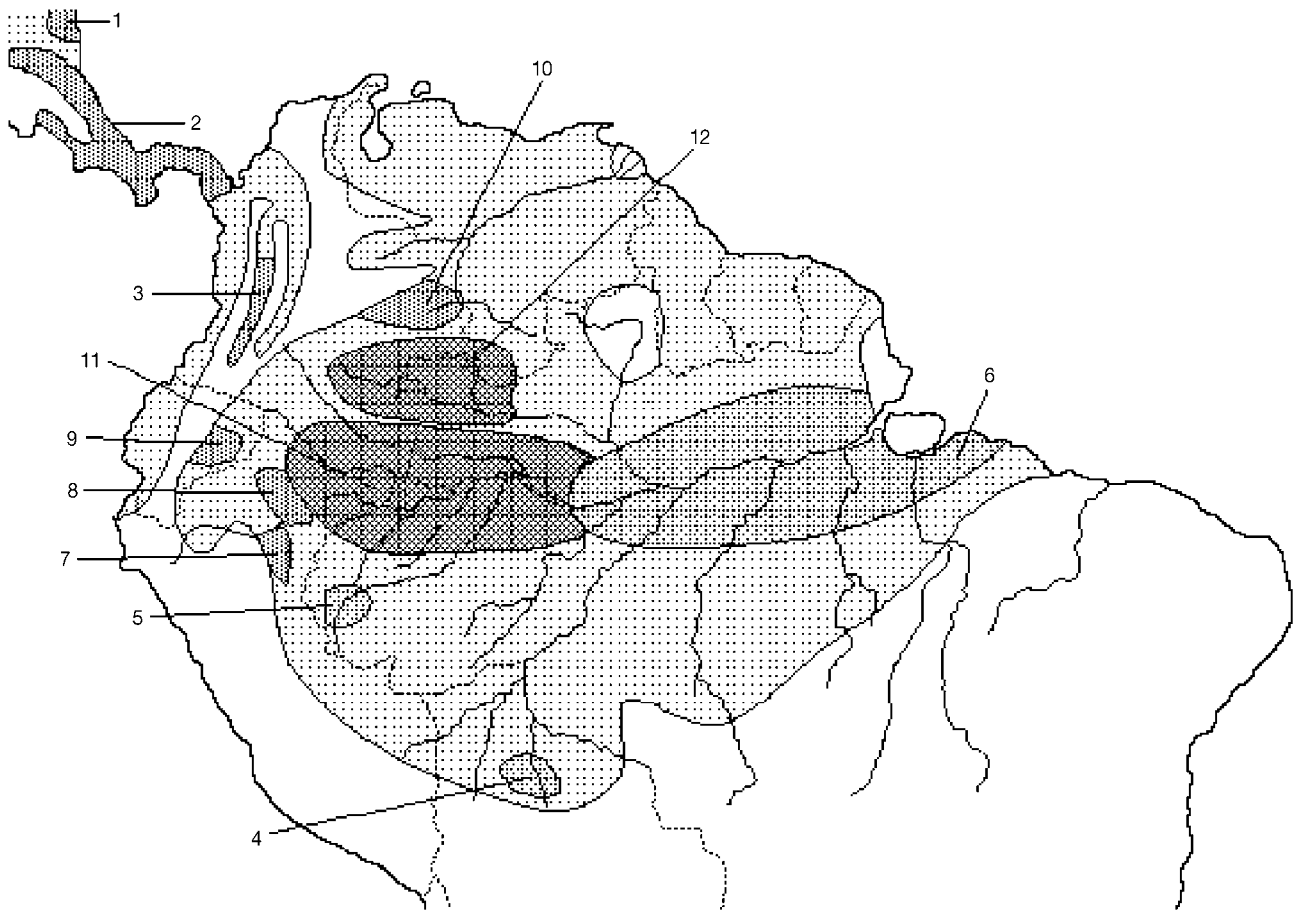

Fig. A.12. Approximate distribution of *Bactris gasipaes* var. *gasipaes* (light shading) in the lowland Neotropics, with the distribution of valid (defined by molecular characterization and morphometric data) and still-to-be-validated landraces. Occidental (Central America and north-western South America) landraces: 1. microcarpa Rama; 2. mesocarpa Utilis; 3. mesocarpa Cauca. Oriental (Amazonia) landraces: 4. microcarpa Tembé; 5. microcarpa Juruá; 6. microcarpa Pará; 7. mesocarpa Pampa Hermosa; 8. mesocarpa Tigre; 9. mesocarpa Pastaza; 10. mesocarpa Inirida; 11. macrocarpa Putumayo; 12. macrocarpa Vaupés (Source: Rodrigues *et al.*, 2004).

their subsistence. The governor of Nicaragua heard of this settlement and, considering the Sixaola valley to be part of his territory, sent an expedition to expel the Panamanian group. This second expedition included a large group of Nicaraguan natives, who relied upon maize for subsistence. When the invaders did not find enough food in the Sixaola valley, they started cutting peach palm for its heart-of-palm. This led to expanded conflict, and between 30,000 and 50,000 palms were cut in the valley to subjugate the local population and expel the original band of adventurers. The Panamanian governor prepared a detailed legal case against the Nicaraguan governor about this conflict, which was sent to Madrid and provided an enormous amount of detail about peach palm. The cut trees would have furnished about 750 t of fresh fruit each year (assuming 30,000 cut, with each yielding five or six bunches, each with 50–70 fruit (details in the legal documents)), a major subsistence contribution in a small river valley and a strong argument for its role as a staple of the subsistence diet.

North-western Amazonia, the Colombian Pacific coast (called the Chocó) and southern Central America (up to Costa Rica) is where peach palm was most important (see distribution of meso- and macrocarpa landraces in Fig. A.12). Although maize and cassava were both present, peach palm seems to have been a staple and was certainly the reason for harvest festivities. The beginning of the harvest season was celebrated by preparation of large amounts of cooked fruit, which was consumed both directly and after being transformed into a fermented drink (chicha). Depending upon the number of days of fermentation, the chicha would have been similar in potency to a low alcohol beer (3–5%) or as strong as wine (10–12%). These harvest festivities were followed, 9 months later, by a peak in births, probably due to the better nutritional status of the mothers during the harvest season (Patiño, 1992) and may be how peach palm earned its reputation as an aphrodisiac as well. The 500 years since the European conquest has seen a significant decline in peach palm's importance, to the point that it is currently an under-utilized minor crop.

World production and yield

Peach palm is still almost exclusively a Neotropical crop, with only experimental areas in Africa, Asia and Oceania. As a fruit crop, it is grown almost exclusively by smallholders in home gardens and swiddens, with a few small orchards near major consumption areas. Hence, all production data are estimates. The estimated production of the State of Amazonas, Brazil, in 2000 was 13,600 t of fresh fruit bunches; Brazilian Amazonia probably produced at least twice that amount. Colombian production was estimated at 49,000 t in 2002, divided between its Amazonian and Chocó (Pacific) lowlands. Costa Rican production was estimated at 10,500 t in 2002, divided between its Atlantic and humid Pacific lowlands, and there are probably more orchards there than in other countries (Clement *et al.*, 2004). Bolivia, Ecuador, Peru and Venezuela also produce moderate amounts of peach palm in their Amazonian lowlands, while Venezuela also produces in its Orinoco river basin lowlands and Ecuador in its Pacific coastal lowlands. French Guiana, Guyana, Nicaragua, Panama and Surinam are minor producers. Extrapolation from this scanty data set suggests that total Neotropical production is probably about 120,000 t, of which only about 50% is commercialized as fresh fruit, while the other 50% is used for subsistence, either directly or as animal feed, or is wasted (Clement *et al.*, 2004). A typical fresh bunch weighs 2–5 kg, and is worth US$0.50–1.00 at the farm gate and US$1.00–3.00 in the market, so Neotropical farmers earn about US$11 million/year from the commercialized fruit, while consumers pay about US$30 million/year to enjoy it.

In contrast, the heart-of-palm is grown in high-density (> 5000 plants/ha), high input commercial monocultures and some production statistics exist. Brazil had approximately 20,000 ha in production in 2002 and another 3000–5000 ha recently planted. Bolivia had 3000 ha in the Cochabamba region and Colombia had 1000 ha in its Chocó region. Costa Rica had 8000 ha in production in 2002, down from 12,500 in 1998 due to severe competition from Ecuador, which had 10,000 ha in production in 2002. Panama, Peru and Venezuela have minor production areas. Extrapolation from this data set suggests that the total Neotropical production area is greater than 43,000 ha. Assuming standard density (5000 plants/ha), this area yields 322.5 million hearts-of-palm/year, each weighing about 200 g, worth about US$0.25 per heart at the farm gate, so farmers earn about US$80 million. An additional 200 g of edible stem tissue is also processed from each stem, but farmers don't get paid for this. The majority of consumers buy 300 g net weight bottles or 500 g net weight cans of processed heart-of-palm, paying US$2–5 per bottle in Brazil (variation due to distances between production area and market, and perceived quality of brand name) and more in the USA and the European Union. Bottles are standard in Brazil, as consumers feel more confident of quality when they can see the hearts. The state of São Paulo, Brazil, is the largest world consumer of heart-of-palm, followed by the rest of Brazil, the European Union, the USA and other Latin American countries. Ecuador and Costa Rica are the major exporting countries of peach palm hearts; Brazil exports less than 10% of its total heart-of-palm production, which includes many more hearts of *Euterpe oleracea* Mart. than of peach palm.

Uses and nutritional composition

Today the fruit is used principally as a cooked snack, although the major-producing countries all have cookbooks with varied recipes. There is a niche market demand for dry flour, but the benefit/cost ratio of supplying this demand is generally negative, principally because of supermarket stocking strategies, and Latin American research and development institutes have not devoted enough attention to changing this ratio (Clement *et al.*, 2004). As fruit drinks gain continually greater market share among health-conscious consumers, chicha could make a comeback. The name peach palm was coined by Alexander van Humboldt and is derived from the aroma of the fermented pulp, which recalls that of fresh tree-ripened peaches. The flavour is distinctly fruity (though not peachy), rather than starchy, and is very pleasant. More food technology research and development is needed to exploit this opportunity, especially in countries that already know peach palm's flavour.

The fruit is energy rich, due both to starches and to oils, while the heart-of-palm is essentially a dietary product (Table A.48). The relative proportions of starch to oil vary inversely

Table A.48. Mean chemical composition per 100 g of peach palm fruit mesocarp[a] and of heart-of-palm[b].

	Fruit mesocarp	Heart-of-palm
Proximate	g	g
Energy (kcal)	273.5	47.6
Protein	3.3	1.5
Fat	6.0	1.3
Saturated	2.2	0.73
Monounsaturated	3.3	0.35
Polyunsaturated	0.5	0.22
Carbohydrate	34.9	5.2
Fibre	2.0	0.9
Ash	0.8	na[c]
Minerals	mg	mg
Calcium	18.9	42.4
Iron	0.59	0.23
Magnesium	17.1	3.4
Phosphorus	na	na
Potassium	240.5	193.6
Sodium	4.3	0.1
Vitamins	mg	mg
Vitamin A (carotene)	1.1	na
Vitamin C	18.7	3.2
Thiamine (vitamin B1)	0.045	na
Riboflavin (vitamin B2)	0.135	na
Niacin	0.81	na

[a] Mesocarp of three fruit.
[b] A section 9 cm long, 2 cm in diameter.
[c] na = not available.

along the domestication continuum, with wild-type fruit being rich in oils while the domesticates are rich in starches (Table A.49). Fruit protein quality is not exceptionally high, but fruit mesocarp oil is rich in monounsaturated oleic acid (Yuyama *et al.*, 2003). The fruit contain two antinutritional factors, a trypsin inhibitor and calcium oxalate crystals, which are denatured or eliminated by boiling, respectively. The heart-of-palm contains calcium oxalate crystals. The fruit chemical composition is similar to that of maize and better than that of potato or cassava on a fresh weight basis (Table A.49), which is part of the reason that peach palm offers an opportunity for enhanced food security in humid tropical areas, an opportunity that is unexploited in Africa and Asia.

Botany

TAXONOMY AND NOMENCLATURE Henderson (2000) revised *Bactris* and provided a testable hypothesis about the relationships among taxa closely related to peach palm. Seventeen different species in three genera had been considered close peach palm relatives since Ruiz and Pavon described the first wild population in 1798 as *Martinezia ciliata*; they are now all synonyms. Taxonomic controversy of this type is common in species with domesticated populations because morphological variation is enhanced during the domestication process (Clement, 1999). In the new hypothesis, all cultivated populations and landraces are now *Bactris gasipaes* Kunth var. *gasipaes* and all wild populations are now *B. gasipaes* var. *chichagui* (H. Karsten) Henderson.

A complex hierarchy of landraces was proposed on morphometric grounds. As understood here, each landrace is a meta-population composed of a variable number of closely related domesticated and always cultivated subpopulations, defined by a specific combination of morphological characteristics, a distinct geographic distribution and associated ethnohistory. The original landrace hierarchy proposal had a primary geographic division defined by the Andes, with an Oriental group in lowland northern South America and an Occidental group in lowland north-western South America northwards into Central America (Fig. A.12). Within these groups, fruit size is the primary factor to distinguish landraces into microcarpa (10–30 g), mesocarpa (30–70 g) and macrocarpa (> 70 g), since this trait was most modified by human selection. In the Oriental group, three microcarpa, five mesocarpa and two macrocarpa landraces had originally been mapped, while in the Occidental group, one microcarpa and four mesocarpa landraces had been mapped. The new genetic analysis (Rodrigues *et al.*, 2004) reduced this to three microcarpa, four mesocarpa and two macrocarpa in the Oriental group, and one microcarpa and two mesocarpa in the Occidental group (Fig. A.12). This new analysis also suggests that the Andes was not a barrier to dispersion (as originally proposed by Prance, 1984) and the Oriental/ Occidental distinction may not be important.

Table A.49. Comparison of mean chemical composition (g/100 g)[a] of peach palm (Amazonian mean and three landraces), cassava, maize, sweet potato and a set of 21 succulent Amazonian fruits.

Crop	Water	Protein	Oil	Carbohydrate	Fibre	Energy (MJ)
Peach palm[b]	45.0	3.5	27.0	19.8	3.8	1.47
Juruá landrace[c]	54.4	3.1	13.8	19.6	8.4	1.04
Solimões landrace[c]	42.7	4.1	12.0	31.2	9.3	1.20
Putumayo landrace[c]	52.6	1.9	3.5	38.0	3.2	0.85
Cassava[d]	65.2	1.0	0.4	32.8	1.0	0.55
Maize (fresh)[d]	63.5	4.1	1.3	30.3	1.0	0.54
Sweet potato[d]	67.2	0.9	0.2	29.6	1.1	0.53
Succulent fruits[c]	82.8	0.9	0.8	11.9	2.9	0.26

[a] Fresh weights; the difference between the sum of the means and 100 is due to ash content.
[b] Mora Urpí *et al.* (1997).
[c] Clement *et al.* (2004) and references therein.
[d] Leung and Flores (1961).

DESCRIPTION The peach palm is a multi-stemmed palm that may attain 20 m in height (Plate 13). Stem diameter varies from 15 to 30 cm and internode length from 2 to 30 cm, and becomes reduced with age after 5 years. The internodes are armed with numerous black, brittle spines, although spineless mutants occur and have been selected for in several areas. The stem is topped by a crown of 15–25 pinnate fronds, with the leaflets inserted at different angles. The heart-of-palm is a gourmet vegetable composed of the tender unexpanded leaves in the palm's crown. The inflorescences appear among the axils of the senescent fronds. After pollination, the bunch contains between 50 and 1000 fruit (there is a strong negative correlation between fruit size and fruit number in a bunch) and weighs 1–25 kg. Numerous factors cause premature fruit drop: poor pollination, poor plant nutrition, drought, crowding, insects and diseases. The fruit is a drupe with an humid starchy/oily mesocarp, a fibrous red, orange or yellow exocarp, and a single endocarp, with a fibrous/oily white kernel. Individual fruit of var. *gasipaes* weigh between 10 and 250 g, with means varying according to landrace, and seeds weigh between 1 and 4 g; fruit of var. *chichagui* weigh between 0.5 and 5 g and seeds weigh between 0.3 and 1 g (Plate 14).

ECOLOGY AND CLIMATIC REQUIREMENTS Wild peach palm (var. *chichagui*) occurs in transitional natural ecosystems and where natural disturbances are frequent, principally along riverbeds and in primary forest gaps, while cultivated peach palm (var. *gasipaes*) only occurs in ecosystems created by humans. Extensive natural stands of wild peach palm have not been reported (see population structure above), nor are wild palms harvested today.

Cultivated peach palm is adapted to a wide range of ecological conditions, reflecting its wide anthropogenic geographical distribution in the humid Neotropics. It is most productive on relatively deep, fertile, well-drained soils at low to middle altitudes (< 1000 m above sea level), with abundant and well-distributed rainfall (2000–5000 mm/year) and average temperatures above 24°C. It produces relatively well on low-fertility soils, including highly eroded laterites with 50% aluminium-saturated acid soils, following the slashing-and-burning of primary or secondary forest, since the burn releases calcium and magnesium that neutralize the acidity and aluminium toxicity, but fruit production decreases in the long term without additional lime and nutrient inputs. It does not tolerate waterlogged soils. It can withstand relatively short dry seasons (3–4 months) if soils are not excessively sandy, but dry seasons significantly reduce growth and yield. Symbiotic associations with vesicular-arbuscular mycorrhizae improve growth and are often essential for normal development.

The peach palm is often reputed to be rustic and well adapted to tropical soils with few nutrients (NAS, 1975). In fact, like any domesticated crop, it requires good husbandry. These contradictory observations are due to peach palm's domestication in traditional agroecosystems in the American tropics. Wild peach palm produces abundant fruit with no additional inputs on low fertility soils, but these fruit are very small, so total yield is low and export beyond the system is minimal. During the domestication process, peach palm became well adapted to scavenging nutrients after the burning of previous vegetation. In these agroecosystems, the palms are generally transplanted, arriving with a partially developed root system already inoculated with mycorrhizae. This initial advantage is complemented by its fibrous root system and its strong competitive ability to absorb nutrients (Fernandes and Sanford, 1995). The result is fast initial growth, to get the crown above competing cassava and low stature fruit trees. In traditional agroecosystems, weedy regrowth is managed at progressively lower rates until a managed fallow develops, with nutrient recycling similar to natural forests. In the initial stages of this sequence, peach palm does well, but is eventually shaded out by taller fallow trees. This sequence of events apparently supports the contention that peach palm is both rustic and well adapted to low nutrient soils, but in fact it is well adapted to compete for nutrients and light when these are available in traditional systems, and dies out as these become less available. In modern agroecosystems, peach palm requires appropriate fertilization to remain productive.

REPRODUCTIVE BIOLOGY Phenology varies both within and among countries, and the environmental events that trigger flowering are not yet clear. In central Brazilian Amazonia, the main flowering season extends from the mid-dry season (August–September) to the beginning of the rainy season (November), and fruit ripen between late December and late March. In Costa Rica's Atlantic zone, the main flowering season extends from May to July and the fruiting season from August to October; this region has a much less pronounced dry season than central Amazonia. When the dry season is less pronounced, a second flowering period may occur in plants with good nutritional status. When this happens, the harvest seasons are separated by about 6 months. Costa Rican farmers have taken advantage of micro-climatic, soil and altitudinal variability to supply their major San José market year-round, effectively exploiting phenological variability (Clement *et al.*, 2004).

Peach palm is predominantly allogamous, having separate pistillate and staminate flowers, and protogynous development (i.e. the female flowers are receptive before the male flowers shed pollen). Self-pollination is thought to be regulated by a genetic incompatibility mechanism, but there is considerable variation in self-fertility. Self-pollination may occur: (i) within the same inflorescence; (ii) between inflorescences of the same stem; or (iii) between inflorescences on different stems of the same plant. The latter event is probably much more common than the other two events, although the first event may be common at the beginning and end of the season when sufficient cross-pollen is not available.

The pollination cycle lasts 3 days in a given inflorescence. Female anthesis begins when the inflorescence bract opens in the afternoon, and unfertilized female flowers may remain receptive for up to 48 h. Late in the afternoon of the second day, female flower anthesis normally ends and male flower anthesis begins (protogyny). Male flowers release their pollen in 15–30 minutes, showering the inflorescence and visiting insects, and then the male flowers abscise. The insects then leave and search for a recently opened inflorescence, attracted by a musky scent produced by a gland on the male flowers. The reproductive biology of peach palm suggests a tight co-evolutionary history with very small curculionid beetles, thousands of which are attracted by the musk to a single inflorescence. Where peach palm has been introduced recently, the lack of these curculionid beetles may severely limit fruit set.

Wild peach palm (var. *chichagui*) occurs in small sub-populations (three to 20 plants), normally quite distant from the next such sub-population (500 m to several kilometres). This meta-population structure favours genetic drift and self-pollination within sub-populations, with consequent reduction in genetic diversity and random shifts in allele frequencies, making the genetic incompatibility mechanism very important as a way of counteracting this. However, to assure population survival, the mechanism must also allow some self-fertility. Population structure of cultivated peach palm (var. *gasipaes*) is remarkably similar to that of wild peach palm, as traditional farmers tend to have three to ten plants in their home gardens and five to 30 in their agroforestry plots (Clement *et al.*, 2004), each of which is a distinct sub-population. In these agroecosystems, human selection pressure tends to reinforce self-pollination, as fewer more-closely related plants are used to create each new sub-population, resulting in a further reduction of genetic diversity, as observed by Rodrigues *et al.* (2004). This reduction is typical of domesticated species, but a human behavioural characteristic – seed exchange – acts to enhance genetic diversity and maintain genetic viability. Neighbours exchange seed quite frequently within villages, and seeds are often taken as gifts when visiting other villages or are requested as gifts when a special tree is observed (Adin *et al.*, 2004). Seed exchange and buying seed in the market are important mechanisms for maintaining genetic diversity in any crop, but are especially important in under-utilized crops that are more likely to be threatened by or suffering genetic erosion.

FRUIT GROWTH AND DEVELOPMENT Fruit develop to maturity in 3–4 months. Inflorescences develop in sequence on the stem, so one cannot harvest all bunches on the stem at the same time. The fruiting season typically extends over a 2–4 month period (rarely more in exceptionally good years). The first harvest of the season normally yields the largest and best-quality fruit, after which fruit quality gradually deteriorates due to increasing insect damage and fungal infection, favoured both by the presence of fruit and by the gradual depletion of physiological reserves.

During the first 2 months of growth, the fruit expands in size and its composition is rich in starches and some protein. During the third month, starches are metabolized to produce oils and carotenes, and the mesocarp and exocarp gain colour. When the exocarp has 50% of its final colour, the seed is mature and the fruit can be harvested. Full flavour and colour come a week or so later, and the full flavour may be too strong for some consumers. Hence, fruit tend to be harvested and commercialized before full ripeness. After harvest, fruit deteriorate rapidly (3–7 days), so must be handled carefully and expeditiously.

Horticulture

PROPAGATION The peach palm is propagated by seed, as vegetative propagation of off-shoots is difficult and a commercial tissue culture protocol has not yet been developed. The seed is considered to be recalcitrant (i.e. it can not be dried or frozen for storage). Seeds obtained from healthy productive trees at the beginning of the harvest season have greatest germination success, better than 80% with standard practices. These practices include careful pulp removal and seed cleaning, sowing in appropriate substrates with sufficient (but not excessive) irrigation tailored to the substrate, moderate shade (75% of full sun) and frequent inspection for pests and diseases. Fresh seeds take 30–90 days to germinate, depending upon temperature and humidity, and a field-ready seedling takes another 4–6 months to produce in an organic-matter rich, well-fertilized substrate.

FIELD MANAGEMENT Planting density, plant management and fertilization vary significantly between the fruit crop and the heart-of-palm crop. The fruit crop is generally grown in agroforestry systems of varying diversity and less frequently in monoculture orchards. In the latter, spacing must be at least 5 × 5 m (400 plants/ha) or different rectangular or triangular arrangements to allow sufficient light into the orchard; wider spacings allow more intercropping during the early years. Off-shoot management is critical to reduce within-clump competition for light and nutrients, while maintaining enough off-shoots to replace the fruiting stem when this grows too tall to harvest economically (above 10 m, which is often attained in 10 years or less).

Dolomitic lime is recommended for managing soil acidity in tropical America's typically acid Oxisols and Ultisols, especially when aluminium concentration is high. During field preparation 2 t/ha is recommended and 1 t/ha at 3-year intervals for maintenance (Bovi, 1998) to provide sufficient magnesium and calcium, while making phosphorus more available. Juvenile plants require abundant nitrogen (N) and moderate phosphorus (P) (90–120 kg/ha N; 45 kg/ha P; 80–90 kg/ha K), while fruiting plants require abundant potassium (K) and nitrogen, with moderate phosphorus (140–190 kg/ha N; 90 kg/ha P; 150–180 kg/ha K). In most tropical soils micronutrient deficiencies are common, but poorly studied with peach palm. Hence, animal manure is strongly recommended and mineral fertilization can be reduced proportionately. Leguminous groundcover crops are also highly recommended, as they suppress weeds and provide organic matter and nitrogen to the system.

The heart-of-palm crop is grown in high density (> 5000 plants/ha), high input stands (standard spacing is 1 × 2 m, but numerous alternatives exist, especially when small tractors are used for maintenance). After field planting, the first harvest is obtained within 18–24 months and the clumps are maintained by periodic harvesting of the larger off-shoots – the clumps are essentially immortal if adequately fertilized and weeded. Most researchers and growers consider off-shoot management important, but the Pampa Hermosa landrace germplasm that is used in most plantations produces fewer off-shoots than Utilis landrace germplasm, for example, and thus requires less management on average. Dolomitic lime should be applied as above. The perennially juvenile plants require abundant nitrogen (200–250 kg/ha N) and moderate levels of other macronutrients (20–40 kg/ha P; 100–120 kg/ha K). Harvesting leaves 90% of the biomass to mulch the field and many agroindustries compost the other 9% for use in the nursery or return it to the field, all of which makes the crop very sustainable. Both organic and conventional (mineral fertilizer, but almost no pesticides) heart-of-palm are available, although little research has been published on the organic alternative to date.

MAIN DISEASES AND PESTS *Erwinia* bacteria can be a problem where drainage is poor or shade intense in heart-of-palm stands. Anthracnose (*Colletotrichum*) fungal attack indicates inadequate phosphorus fertilization. Poor nursery management allows damping-off (*Fusarium*) and other fungal diseases to become important. Poor plant nutrition leads to increasing fungal attacks on fruit during the season, but these tend not to reach critical levels. Hence, as in other minor crops, most peach palm diseases can be managed with appropriate fertilization and field practices, and no pesticides are normally used.

Beetles (Coleoptera) may be locally important fruit or seed pests, but only in the Colombian Pacific have they seriously affected fruit yields. A seed-boring beetle has occasionally been reported in the south-west Amazon. Foliage mites (*Retracus* spp.) are indicative of poor plant nutrition and occasionally require chemical control on fruiting plants, but not in heart-of-palm orchards, where rapid growth and harvest keep their populations under control. Gophers (ground squirrels), pigs, rabbits and rats are pests in some areas, and all can be controlled with fencing or poison baits.

POSTHARVEST HANDLING AND STORAGE Fruit from spineless peach palm is typically collected by climbing the stem and lowering the fruit bunches to the ground with a rope or dropping them into a net. Most peach palms have spiny stems, however, and these are very difficult to climb. Hence, farmers use poles with a hook or curved knife at the end, with which they dislodge or cut the fruit bunch and catch it with a net or foam cushion. Harvesting from the ground is faster and safer than climbing the stem to collect fruit, but it causes more damage to the fruit. Both methods are expensive in man-hours and help explain why many bunches don't get to market during the peak harvest season, when bunch prices are depressed by excess supply. In Brazilian Amazonia, a 10 m tall tree requires three men (or adolescent boys) to harvest a bunch: one man to manage the pole and dislodge the bunch; two men to manage the net or cushion. At twice the national minimum wage (the most common agricultural labour rate in the region – the minimum is R$240 = US$81/month, January 2004), this can cost US$0.45, equivalent to 90% of the farm gate price of a fresh bunch (Clement, 2000). Needless to say, height growth is a major problem in growing peach palm for fruit and the reason that tall stems are cut to make room for younger off-shoots.

Fresh fruit are very perishable, due to its chemical composition (Table A.48). A ripe fresh bunch can be maintained in good condition without refrigeration for only 4–6 days if kept in the shade and well ventilated. With refrigeration (20°C, 70% relative humidity) and waxing, storage can be extended to 8 days, but few merchants have the necessary capital and facilities. Shelf life of fresh fruit can be extended by collecting well-developed fruit that are just starting to change from green to their final colour, and this is now standard practice throughout the region. Frozen, dried or canned fruit can be conserved for months, but with the consequent loss of final flavour and colour.

In practice, no commercial ventures have survived by industrially processing the fruit. Only Costa Rica had successfully developed the technology, and during the 1980s several small processing and commercialization businesses had fair success. During the late 1980s and 1990s, farmers discovered the advantages of planting where phenology offered them a market window (see 'Fruit growth and development' above) and fresh fruit are now available year-round. This drove the processing businesses to ruin, since their product was perceived to be of inferior quality and was more expensive (Clement *et al.*, 2004).

Fresh fruit are commonly sold by the bunch, or they are minimally processed and packaged, especially in Costa Rica. The processing involves only removal of fruit from the bunch, washing, waxing (by the more capitalized communities), sorting and classifying, and packaging in net bags of specified weight. Cooked fruit is handled like fresh fruit. In all other countries, fruit are sold at market in bunches or as cooked fruit.

If fruit are destined for flour, they should be processed on the day of harvest or the following day. Processing involves: cooking the entire bunch to facilitate removal of the fruit, denature potential toxins and improve starch quality; cutting the whole fruit into small pieces; removing the seeds and drying the pulp and peel (red peels give a golden colour to the flour); and then grinding and packaging. Processing fruit of low phytosanitary quality is more difficult and expensive, requiring careful sorting and peeling. While a niche market demand exists, modern supermarket logistics have made commercialization too expensive for small processing businesses, and none have survived the changes in supermarket supply strategies (Clement *et al.*, 2004).

Hearts-of-palm are an entirely different story. Off-shoots are harvested when they reach commercial dimensions, which depend on factory and market demands for heart-of-palm. For the international market there is essentially one basic quality: true or export heart-of-palm is a cylinder composed of a tender petiole-sheath enveloping the developing leaves above the apical meristem. This also explains the name, as the apical meristem is truly the heart of the palm, as all leaves and stem arise there. The true heart commands a higher price when it has a narrow diameter, and is called 'extra fine'. In Brazil, there is a demand for three heart-of-palm dimensions: thin (1.5–2.5 cm) hearts to be canned for the export markets; medium (2–4 cm) hearts for both the bottled and the fresh markets in Brazil; and thick (3–6 cm) hearts for the Brazilian *churrascaria* market (restaurants that specialize in barbecued meat with thick hearts-of-palm as garnish), either bottled or fresh.

For all national markets (and a few minor international markets) there is a second quality: the tender stem tissue below the apical meristem. When fresh or processed, this stem tissue has the same flavour as the heart, but a different texture, as the stem is fibrous parenchymous tissue and the heart is leaf sheath, petiole and blade tissue. The stem tissue commands a much lower price, and is presented in different sizes and shapes, but provides the industry with larger earnings because it comes as free material with the stems they buy from the farmers. All industries also offer chunks and slices of true heart or tender stem that doesn't meet their other standards. These are sold very cheaply to restaurants and pastry shops that don't demand higher quality materials.

For hearts-of-palm with 2–3 cm diameter, off-shoots are harvested when they attain diameters of larger than 9 cm, measured at 20–30 cm above the ground. Off-shoot diameter and other morphological characteristics are correlated with heart-of-palm yield, but in practice only diameter is measured to determine if the off-shoot is ready for harvest because there is a good correlation between yield and diameter under normal nutritional conditions. In Brazil, the slightly larger-diameter hearts are more easily evaluated by height than diameter (Clement and Bovi, 2000), and this has become standard practice for both the processed and the fresh markets.

When off-shoots are ready for harvest, they are cut and the outer fibrous leaf sheaths are removed. Two non-commercial leaf sheaths, surrounding the heart-of-palm, are normally left to protect it from rapid moisture loss and mechanical damage during transport. Ideally the heart-of-palm should be transported to the processing plant on the day of harvest to minimize moisture loss. If transport delays are anticipated, more leaf sheaths should be left surrounding the heart-of-palm, a paraffin/beeswax mixture should be applied to the cut ends, and they should be stored in a shady place. These postharvest treatments will normally conserve fresh heart-of-palm for 4–6 days without significant moisture loss or fungal infection.

All processing is done following Codex Alimentarius regulations (FAO/WHO, 1985). The Codex is designed to guarantee safe food for consumers. Unfortunately, flavour and appearance are lost en route. This helps explain why the world market for this product is essentially saturated and why Costa Rica lost market share to Ecuador over the last decade – in a saturated market, price determines who gets the sales. In Brazil, Costa Rica and Hawaii (USA) a new market for fresh heart-of-palm (and tender stem) is being developed by numerous small entrepreneurs. This new market is still only a niche, but appears to have great promise.

MAIN CULTIVARS AND BREEDING No named cultivars have been brought to market. Rather, the breeding effort aims at general population improvement to maintain the variability that helps control pests and diseases. This strategy is perfect for heart-of-palm production, which is now based principally on the Pampa Hermosa (Yurimaguas, Peru) landrace because of its spinelessness, rapid growth and good quality (Mora Urpí *et al.*, 1999). This strategy is not good for the fruit market, since consumers desire uniformly high quality fruit, which are not abundantly found in open-pollinated landrace populations. A new selection strategy is being tried in Peru to remedy this and will certainly be adopted in the rest of Latin America.

Basic production parameters in one region may serve as a reference for comparing production in other regions, and offer targets for agronomic and genetic improvement programmes. Production parameters (Mora-Urpí *et al.*, 1999; based on 5000 plants/ha) for heart-of-palm in Costa Rica are:

- time from plantation establishment to first harvest of all plants (9 cm off-shoot diameter) should be 18 months;
- number of harvested off-shoots should 8000/ha in the first year of production (12–24 months) and 10,000/ha each year thereafter;
- field-harvested shoots should contain 70% export quality hearts and 30% tender stem quality;
- average yield of export-quality heart-of-palm after processing should be 1.35 t/ha, beginning in the second year of production (10,000 harvested off-shoots/ha, each yielding 135 g of export quality and 50 g of stem quality).

In Brazil, with somewhat different internal market demands, these production parameters vary a little, with slightly longer time frames given that plants must grow for another few months to attain Brazilian size specifications. Another difference is that the longer time frame allows a larger tender stem section, giving better returns to the processing operations. Charles R. Clement

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Bactris spp.

Bactris Jacq. ex Scop. (*Arecaceae*) is one of the largest genera of palms in the Americas and is notorious for the degree to which most species are armed with black spines – on the stems, leaves and inflorescences. In addition to the economically important *Bactris gasipaes* (treated separately in this volume, see previous entry) many other species produce edible fruit (Table A.50). It is likely that fruit of species other than those listed can be consumed.

World production and yield

The species of *Bactris* treated here are exploited chiefly from wild populations or, at best, small plantings established by subsistence agriculturists, thus no production data are available.

Uses and nutritional composition

No nutritional information is available on these species. The mesocarp pulp of many of the fleshy-fruited species have an agreeable flavour that has been likened by some to that of grapes. They are eaten fresh or juiced to make a refreshing beverage.

Botany

TAXONOMY AND NOMENCLATURE The taxonomy of *Bactris* is still poorly understood despite the ubiquity of the genus in tropical forests throughout the Americas. Henderson *et al.* (1995) recognize 64 species. Several of these form large complexes that may ultimately be split up into distinct species. The genus is classified in the tribe *Cocoeae* of subfamily *Arecoideae*.

DESCRIPTION In general, many *Bactris* species can be described as medium-sized, spiny clustering palms, but the genus includes non-spiny species, tall-growing species and solitary-stemmed species as well. Leaves are most frequently pinnate but can be simple, and the canopy holds between four and 20. Leaflets are typically clustered in groups that radiate in different planes, but some species have regularly arranged pinnae. The leaf sheath of most species extends above the point of insertion of the petiole. Spineless species are the exception, but in a few species the spines are reduced in size or restricted to the leaflet tips. The inflorescences are spike-like or branched to one order and are borne from among the leaves. The rachillae are slender, and separate male and female flowers are arranged on them in a triad of one central female flanked by two males, but the female flower may be missing on some branches or portions thereof. The one-seeded fruit vary from globose to ovoid to ellipsoid, and are coloured green, orange, red or dark purple. They are generally smooth. A group of purple-fruited species have a distinctive cup-like structure at the proximal end of the fruit. The mesocarp can be either mealy or juicy. The seed is covered by a bony endocarp with three pores near its middle.

ECOLOGY AND CLIMATIC REQUIREMENTS *Bactris* species are distributed from Mexico and the West Indies through Central America and throughout tropical South America. They are chiefly denizens of wet tropical rainforest, usually at lower elevations. They have little tolerance of frost and prosper with year-round rainfall.

REPRODUCTIVE BIOLOGY Weevils have been implicated as pollinators of some *Bactris* species (Essig, 1971; Urpi, 1982). The typical *Bactris* phenological syndrome is short nocturnal anthesis of the pistillate flowers followed by a brief period of staminate anthesis (Henderson *et al.*, 1995).

Horticulture

PROPAGATION Solitary-stemmed *Bactris* species are propagated by seed, which should be fresh. The pulpy or mealy mesocarp must be cleaned from the seed before sowing. Vegetative propagation of clustering species is possible by division.

Alan W. Meerow

Table A.50. *Bactris* species other than *B. gasipaes* with edible fruit.

Species	Synonyms	Subspecies	Common name	Origin	Characteristics	Fruit uses	References
Bactris arundinaceae Trail.	Syn. of *B. tomentosa* var. *tomentosa* according to Henderson *et al.*, 1995		Palmeira lú-I (Brazil)	Brazil	Clustering, flattened, yellowish leaf spines, spicate inflorescence, fruit purple-black	Pulp	Martin *et al.*, 1987
Bactris brongniartii	*B. burretii* Glassman, *B. marajaacu* Barb. Rodr., *B. piscatorum* Wedd. ex Drude		Marajá (Brazil), chacarra, cubarro (Colombia), bango palm (Guyana), ñejilla (Peru), caña negra (Venezuela)	Amazon region and adjacent areas	Clustering, often rhizomatous; leaflets bifid at tip; spine flattened and yellowish brown in middle; fruit purple with cup-like structure	Pulp	Henderson *et al.*, 1995
Bactris concinna Mart.		var. *concinna*, var. *inundata*, var. *sigmoidea*	Marajaú (Bolivia), chontilla (Ecuador), ñejilla (Peru), marajá (Brazil)	Western Amazon	Stems clustered, to 8 m, 1.5–5 cm wide; fruit congested, irregularly and narrowly obovoid, 2–4.5 × 1–2.5 cm, purple black	Fleshy fruit marketed locally. Pulp eaten fresh. Also fed to animals	Fouqué, 1973; Henderson *et al.*, 1995
Bactris guineensis (L.) H.E. Moore	*B. horrida* Oerst., *B. minor* Jacq, *B. oraria* L.H. Bailey, *B. rotunda* Stokes		Sp: corozo, lata (Colombia), biscoyol (Costa Rica), coyolito (Nicaragua), uvita de monte (Panama), piritu, uvita (Venezuela), uiscoyol	Central America to north of Colombia and Venezuela	Stems clustered, spiny, to 3 m, 2.5–3 cm wide; fruit depressed globose, 1.5–2 cm, purple black	Pulp eaten fresh. Refreshing drink	Fouqué, 1973; Henderson *et al.*, 1995
Bactris macana (Mart.) Pittier	*B. caribaea* H. Karts., *B. dahlgreniana* Glassman		Sp: chontilla (Bolivia), chinamato (Colombia), pijuayo del monte (Peru), macanilla (Venezuela); Po: pupunha brava	Venezuela (Barinas, Cojedes, Zulia), Colombia (north and Valle), Peru (Huánuco, Madre de Dios), Brazil (Acre, Rondônia) and Bolivia (Santa Cruz)	Stems solitary or clustered, spiny, to 12 m, 10–20 cm wide; fruit subglobose to obovoid, 1–1.6 cm, orange. Possibly the wild ancestor of *B. gasipaes*	Edible fruit	Henderson *et al.*, 1995

Bactris major Jacq.	*B. subglobosa* H. Wendl., numerous others	var. *major*, var. *megalocarpa*, var. *infesta*, var. *socialis*	Sp: marayáu (Bolivia), corozo de gallina, lata (Colombia), huiscoyol (El Salvador, Guatemala, Honduras, Nicaragua), jahuacté (Mexico), caña brava (Panama), cubarro, moporo (Venezuela), viscoyol; Po: marajá; En: beach palm, beach spiny club palm, hones (Belize); Fr: zagrinette	Coasts of Central America and north of South America	Stem forming dense clumps, 10 m, 2.6 cm wide, with spines 5 cm long; fruit ellipsoid or obovoid, 2.5–4.5 $\times$ 1.3–3.5, apiculate, purple black; mesocarp yellowish, fibrous and juicy	Pulp eaten fresh, drinks; seed sometimes eaten as well	Fouqué, 1973; Henderson *et al.*, 1995
Bactris maraja Mart.	*B. monticola* Barb. Rodr., *B. piranga* Trail., numerous others	var. *chaetospatha*, var. *juruensis*, var. *maraja*	Sp: chontilla (Bolivia, Colombia, Peru), cacharra, espina (Colombia), uvita (Panama), ñeja (Peru), uva de montaña, piritu (Venezuela), niejilla; Po: marajá, marja açu, tucum bravo	Lowlands from Costa Rica to north of South America including central and western Amazon, the Guianas and Bahia in Brazil	Stems clustered, spiny; fruit widely depressed, obovoid, 1–2 cm, purple black, occasionally minutely spinulose; mesocarp juicy	Pulp eaten fresh; seed sometimes eaten	Cavalcante 1991; Henderson *et al.*, 1995
Bactris setosa Mart.	*B. cuyabensis* Barb. Rodr., *B. polyclada* Burret		Po: tucum, jucum	Atlantic coast of Brazil	Stems clustered, to 6 m, 3–4 cm wide, spiny; fruit depressed-globose, 1–1.5 $\times$ 1.5–2 cm, purple black; mesocarp juicy	Juicy pulp	Martin *et al.*, 1987

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Borassus flabellifer palmyra palm

Palmyra palm, *Borassus flabellifer* L. (*Arecaceae*), is a slow-growing fan palm with a broad Old World distribution and a venerable history of cultivation by man. Its sap is an important source of sugar and the fruit and seeds have been consumed by people for centuries.

World production and yield

Each palm may bear between six and 12 bunches of about 50 fruit/year. An average crop of *B. flabellifer* in Ceylon is 350 fruit.

Uses and nutritional composition

The chief product of the palmyra is the sweet sap (toddy) obtained by tapping the tip of the inflorescence, as is done with the other sugar palms and, to a lesser extent, with the coconut. Small fruit are pickled in vinegar. In April and May in India, the shell of the seed can be punctured with a finger and the sweetish liquid sucked out for refreshment like coconut water. Immature seeds are often sold in Indian markets. The kernels of such young seeds are obtained by roasting the seeds and then breaking them open. The half-grown, soft-shelled seeds are sliced longitudinally to form loops, or rings and these, as well as the whole kernels, are canned in clear, mildly sweetened water, and exported. Tender fruit that fall prematurely are fed to cattle. The pulp of mature fruit is sucked directly from the wiry fibres of roasted, peeled fruit. It is also extracted to prepare a product called punatoo in Ceylon. It is eaten alone or with the starch from the palmyra seedlings. The fresh pulp is reportedly rich in vitamins A and C. The fruit contains, per 100 g, 43 calories, 87.6 g water, 0.8 g protein, 0.1 g fat, 10.9 g total carbohydrate, 2.0 g fibre, 0.6 g ash, 27 mg calcium, 30 mg phosphorus, 1.0 mg iron, 0.04 mg thiamine, 0.02 mg riboflavin, 0.3 mg niacin and 5 mg ascorbic acid.

Botany

TAXONOMY AND NOMENCLATURE While seven species have been described in the genus *Borassus*, it is likely than ony three or four will remain after detailed revision of the genus. Some authors feel that only a single species, *B. flabellifer*, should be recognized. It is member of the tribe *Borasseae*, subfamily *Coryphoideae*, all dioecious costapalmate fan palms. *Borassus aethiopicum* is very similar in all respects to *B. flabellifer*.

DESCRIPTION The palmyra palm is a large tree up to 30m high and the trunk may have a circumference of 1.7 m at the base (Fig. A.13). There may be 25–40 fresh leaves. The leaves are leathery, grey-green, fan-shaped, 1–3 m wide, folded along the midrib, and divided to the centre into 60–80 linear-lanceolate, 0.6–1.2 m long, marginally spiny segments. Their strong, grooved petioles, 1–1.2 m long, black at the base and black-margined when young, are edged with hard spines. The palms are dioecious, and male and female inflorescences differ in their order of branching (the males twice, the female unbranched or branched but once). The staminate flowers are borne on catkin-like rachillae, the pistillate flowers on thicker branches. The fruit are large drupes, 10–20 cm in diameter, brown, with a fibrous mesocarp. They contain two or three large seeds.

ECOLOGY AND CLIMATIC REQUIREMENTS Palmyra palm grows from the Persian Gulf to the Cambodian–Vietnamese border and is commonly cultivated in India, South-east Asia,

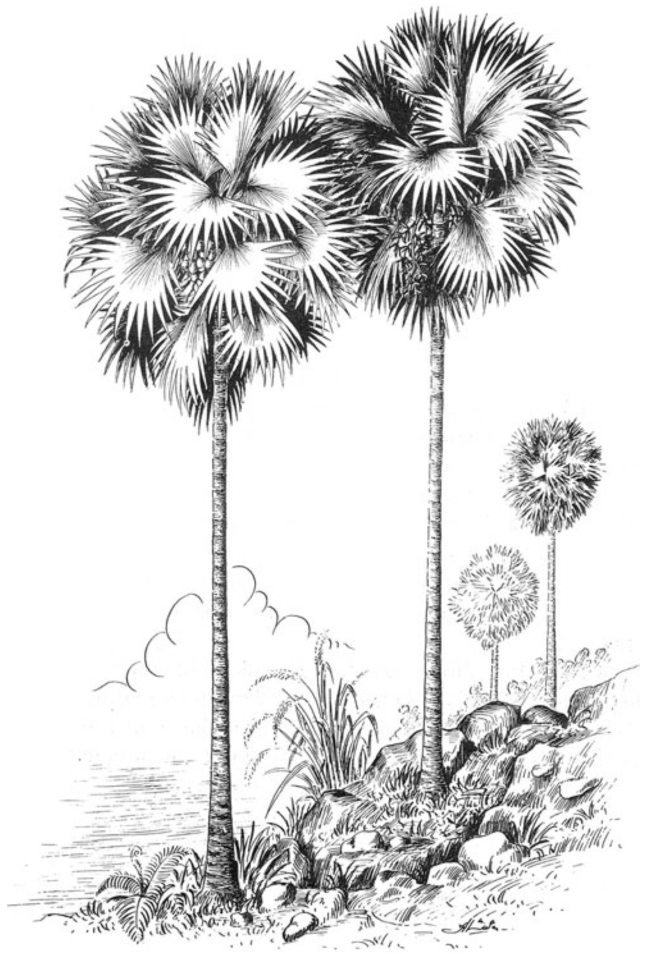

Fig. A.13. *Borassus flabellifer* palm (with permission from Sitijati Sastrapradja from Palem Indonesia, Lembaga Biologi Nasional, 1978).

Malaysia, tropical Africa and occasionally in other warm regions including Hawaii and southern Florida. Its area of origin is not known but undoubtedly man has influenced its range, and large populations, in many areas covering thousands of hectares, that appear 'wild' may be naturalized from introductions made more than 2000 years before the present. It is found in seasonally dry areas in the main, and is hardy to about –4°C. Though well adapted to dry, tropical climates, the palmyra grows better with regular irrigation, but will not tolerate waterlogged soils.

REPRODUCTIVE BIOLOGY Inflorescences begin to appear in November–December, but anthesis does not occur until March. Fruit mature in July and August.

FRUIT DEVELOPMENT The coconut-like fruit are three-sided when young, becoming rounded or more or less oval, 12–15 cm wide, and capped at the base with overlapping sepals. The outer covering is smooth, thin, leathery and brown, turning nearly black after harvest. Inside is a juicy mass of long, tough, coarse, white fibres coated with yellow or orange pulp. Within the mature seed is a solid white kernel (endosperm) which resembles coconut meat but is much harder. When the fruit is very young, this kernel is hollow, soft as jelly and translucent like ice, and is accompanied by a watery liquid, sweetish and potable.

Horticulture

PROPAGATION The seeds of palmyra palms germinate remotely and deeply, producing a very long cotyledonary petiole ('sinker' or 'dropper') that requires a deep container. The cotyledonary petiole may bury itself as much as 0.5 m below ground before a shoot forms. Seeds begin to germinate in 2–6 weeks.

MAINTENANCE AND TRAINING Palmyra palms are very slow growing, and do not even show any aerial stem elongation for the first 15–20 years of their life. Flowering may begin at 12–15 years of age, and will continue for about 50 years.

DISEASES, PESTS AND WEEDS Bud rot fungi such as *Pythium palmivorum* and *Phytophthora palmivora* are the most serious pathogens of palmyra palms, but a number of other fungal diseases cause foliar blights. Rhinoceros beetle (*Oryctes rhinoceros*), black-head caterpillar (*Nephantis serinopa*) and red palm weevil (*Rhynchophorus ferrugineus*) can seriously infest the palms (Duke, 2001).

MAIN CULTIVARS AND BREEDING Some regional variation, mostly in terms of ecological tolerances, has been selectively developed, but no formal cultivars are recognized.

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Brahea dulcis palma de sombrero

Palma de sombrero, suyate, capulín and soyate, *Brahea dulcis* (Mart.) Becc. (*Arecaceae*), is a widespread fan palm found in Mexico and Central America, the edible fruit of which are sweet and of an agreeable flavour.

Related species with edible fruit include *Brahea armata* S. Watson, blue hesper palm, which is found in northern Baja California and north-west Mexico. The Yuman Indians grind the seeds of this palm into a meal, and also eat the fruit fresh and use the juice for drinks. Guadalupe palm, *Brahea edulis*, native to Guadalupe Island off the coast of Baja California, also has edible fruit and it is said to taste similar to dates. It is extremely rare in the wild, due to predation by feral goats (Henderson *et al.*, 1995). Also *Brahea aculeata* from western Mexico is said to have edible fruit.

Uses and nutritional composition

Brahea dulcis is not produced commercially. The fruit are eaten locally. The fruit are picked when ripe and can be eaten fresh or made into preserves. With refrigeration they can be stored for a month or longer.

Botany

TAXONOMY AND NOMENCLATURE The genus *Brahea* consists of six to nine species of mostly Mexican fan palms, though several species range south to Central America. They are found in dry woodland to semi-desert. It is classified in the tribe *Corypheae* of the subfamily *Coryphoideae*. Some synonyms for *B. edulis* include *Brahea bella* L.H. Bailey, *Brahea calcarea* Liebm., *Brahea conzatti* Bartlett and *Brahea salvadorensis* H. Wendl. Ex Becc. Henderson *et al.* (1995) list a number of others.

DESCRIPTION *Brahea dulcis* is a solitary or clustering fan-leafed palm with stems reaching 2–7 m in height and 12–20 cm in diameter. The stems often lean. The canopy consists of ten to 15 dull-green, sometimes waxy, palmate leaves with toothed petioles. The blade is split down to its middle into 30 to 50 stiff segments. The long, arching branched inflorescences emerge from among the leaves and are densely hairy. The one-seeded fruit are ovoid, 1–1.5 cm long and brown or green.

ECOLOGY AND CLIMATIC REQUIREMENTS *Brahea dulcis* is found in dry, oak woodlands or open areas on rocky, calcareous soils from 300 to 1700 m. Though hardy to at least –5°C, it grows poorly in humid, subtropical or tropical climates, but thrives in Texas, Arizona and California and similar climates. It ranges from eastern and southern Mexico up the Mexican Pacific coast and south as far as Nicaragua.

Horticulture

Propagation is from seed, which germinate in 2–4 months. The seed stores well at room temperature for at least a year. It is rather slow growing. It and other *Brahea* species are planted as ornamentals in semiarid climates with mild winters.

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Butia capitata pindo palm

Pindo palm, also known as jelly palm, butiá and cabeçudo, *Butia capitata* (Mart.) Becc. (*Arecaceae*), is a modest-sized single-stemmed palm widely grown as an ornamental in warm temperate and subtropical areas of the world. The fleshy/fibrous fruit is pleasantly sweet and flavourful.

Related species with edible fruit include *Butia eriospatha* (Mart.) Becc., which is found in open areas and within Araucaria forests of southern Brazil and is very similar in appearance to *B. capitata* but the spathe bract of the inflorescence is densely tomentose. The fruit of this species are soaked in alcohol to make a beverage. *Butia yatay* (Mart.) Becc. is larger in all respects than *B. capitata*, and is reportedly hardier. It ranges from southern Brazil to northern Argentina and Uruguay.

Uses and nutritional composition

This palm is not produced commercially and the fruit of *B. capitata* are eaten locally or made into preserves. No information on their nutritional value is available.

Botany

TAXONOMY AND NOMENCLATURE *Butia* is a small genus of about eight species closely related to *Syagrus* and capable of hybridizing with species of that genus. Most of the species are endemic to Brazil. *Butia capitata* occurs in two distinct and widely separated population clusters, and some palm specialists have advocated recognizing the southernmost populations as a distinct species, *Butia odorata* (Henderson *et al.*, 1995). The genus is classified with the tribe *Cocoeae* of subfamily *Arecoideae*.

DESCRIPTION Pindo palm is a solitary-stemmed feather palm growing 2–6 m in height. The trunk can reach about 0.5 m in diameter and remains clothed in old leaf bases for many years. The canopy consists of 18–32 arching leaves that vary from yellowish green to greyish green. Each leaf is 2.5–3 m long. The petiole is short, broad and armed with fibre spines. Arranged regularly along the rachis are 44–48 pairs of stiffly upright leaflets that form a distinct ‘V’. The inflorescence is many-branched but fairly short, substended by a conspicuous woody bract. Yellow male and female flowers are borne on the same rachillae. The ovoid fruit are 1.8–3.5 cm long, 1.2–2.2 cm wide, vary from yellow to orange and contain one to three seeds surrounded by a bony endocarp with three pores near the middle.

ECOLOGY AND CLIMATIC REQUIREMENTS *Butia capitata* is a palm of open savannah (the *cerrado* and *restinga* vegetation of Brazil), growing on sandy soils from southern Brazil into northern Argentina, Paraguay and Uruguay at low elevation. It is hardy to at least –12°C.

Horticulture

PROPAGATION Pindo palm is easily propagated from seed, which germinates unevenly over several months to a year unless the bony endocarp surrounding the seed(s) is cracked.

DISEASES, PESTS AND WEEDS Bruchid weevils sometimes infest the seed.

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Calamus rotang rattan

Rattan, *Calamus rotang* L. (*Arecaceae*), is one of nearly 400 species of mostly climbing vines found throughout South-east Asia, Australasia and tropical Africa. The genus is the largest in the entire palm family. The most important economic use of these vining palms is for their long, strong and flexible stems (canes) that are a significant source of export income for the countries where they grow. The seeds of many species are surrounded by a sweet, pulpy aril that is locally consumed. *Calamus rotang* is the type species for the genus and is used herein as representative.

World production and yield

The collection of fruit for consumption can only be considered an incidental use for rattan vines. The production of cane for furniture manufacture is an important industry in India, the Philippines, Malaysia and other areas rich in species. In the Philippines, the industry provides jobs for 10,000 people, and the value of raw rattan has been estimated at US$50 million, with finished products valued at US$1.2 billion (Duke, 2001). Cirebon, a city in West Java, Indonesia, produces almost half of all Indonesian rattan products and exports 1500 containers of furniture each month, worth US$15 million. The Malaysian Timber Council estimated the total value of rattan furniture exported from Malaysia at over US$90 million.

Uses and nutritional composition

The fruit of *Calamus ornatus* contains, per 100 g, 79 calories, 0.6 g protein, 1.2 g fat, 18.6 g total carbohydrate, 0.5 g fibre, 19 mg calcium, 10 mg phosphorus, 1.7 mg iron, 0.06 mg thiamine, 0.01 mg riboflavin, 0.9 mg niacin and 5 mg vitamin C (Duke, 2001). The subacid pulp surrounding the seed is thirst quenching. The fruit are sometimes pickled in brine as well, and the seeds are also edible. These uses are minor ones by comparison to the great economic importance of the long flexible stems of the many species of rattan vines.

Botany

TAXONOMY AND NOMENCLATURE The taxonomy of the rattans is poorly understood, no doubt due to the difficulty in collecting specimens of the spiny stems, but at least 400 species are estimated to be in the genus *Calamus*. *Calamus* is one of several genera in the subfamily *Calmoideae* that are called rattans, all of which consist primarily of high-climbing vines.

DESCRIPTION The slender stems of *C. rotang* can be up to 200 m in length, and typically climb into the canopy of rainforest trees. The leaf sheaths and petioles are armed with straight or recurved spines. The leaves are 60–90 cm long, pinnate with numerous, narrow leaflets, 20–23 cm long and 1.3–2 cm wide, sometimes with spines on one or both surfaces along the midrib. The staminate inflorescence is slender, whip-like, branched to one order, and often spiny. The pistillate inflorescence is slightly more robust, with catkin-like, recurved branches. The apex of the inflorescence is modified as a climbing grapnel by which the stems are able to ascend to the canopy of forest trees over 100 m tall. The fruit are 1.5–2 cm in diameter, pale yellow in colour and covered with overlapping scales in vertical rows.

ECOLOGY AND CLIMATIC REQUIREMENTS Rattans are forest-dwelling plants in the wild, and are more abundant in primary than secondary forest. They are exclusively tropical plants and have no tolerance of frost, preferring acid soils with abundant moisture and organic matter. Most rattan in commerce was historically harvested from the wild, which has resulted in significant reduction in their occurrence.

REPRODUCTIVE BIOLOGY All *Calamus* species are dioecious palms. Alloysius (1999) observed no clear relationship between flowering and climatic conditions in *Calamus manan* Miq. in Malaysia. Alloysius (1999) reported that *C. manan* flowered each year in October–December with fruit maturing 16–17 months later. Staminate plants flower for a longer period than pistillate plants. Anthesis occurs at night, suggesting nocturnal insects (moths) might be pollinators, with bees the main diurnal flower visitors. Bogh (1996) studied phenology and pollination of *Calamus longisectus* Griff., *Calamus peregrinus* Furt., *Calamus rudentum* Lour. and an unidentified species in Thailand. He found that staminate plants flowered almost continuously for several months, while pistillate plants have much shorter flowering periods. He also determined that *Trigona* bees were the most important pollinators.

FRUIT DEVELOPMENT Abdullah (2000) reported that fruit production took 8–9 months for *Calamus palustris*, and 12–13 months for *Calamus scipionum* and *Calamus ornatus* in peninsular Malaysia.

Horticulture

PROPAGATION Rattans are propagated chiefly by seed, but vegetative propagation by division of clumps or by suckers is possible. The pericarp is removed from the fruit, which is then fermented in water for about a day, after which the seed is cleanly squeezed from the pulp by hand. The seed is dried in the shade, treated with fungicide, then planted directly or stored in moist sawdust for several days. Seeds begin to germinate in 65–100 days. Seedlings about 15 cm tall with four or five leaves are planted directly in the field. Two seedlings are planted in each hole, each hole spaced 2 m on centre.

MAINTENANCE AND TRAINING In order to grow properly, rattan has to be planted under some sort of tree cover, such as logged-over forest, secondary forest, fruit orchards, tree plantations or in rubber plantations.

NUTRITION AND FERTILIZATION Fertilization at 6 g per plant of 20:10:5 N:P:K is recommended shortly after planting, and an organic mulch is beneficial during the first 2–3 years (Duke, 2001).

DISEASES, PESTS AND WEEDS The fungi *Catacaumella calamicola*, *Doratomyces tenuis* and *Sphaerodothis coimbatorica* are significant foliar pathogens of rattans (Duke, 2001). Various wood-boring insects can infest the canes after harvest.

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Cocos nucifera coconut

The coconut (*Cocos nucifera* L., *Arecaceae*) is instantly recognized and obviously different from any other fruit or nut. The coconut palm is romantically associated with beautiful tropical beaches and is the most widespread and most easily recognizable of all palm trees. The closest botanical relatives (*Cocoidae*) largely occur in South America yet the centre of diversity for this important crop species is in the islands of South-east Asia and the Pacific. From the mid-19th century until the 1960s, the dried kernel of the coconut, copra, became the most important source of vegetable oil in international markets. The oil is used for making candles, soap and high explosives.

Strictly speaking the coconut is not an achene but a drupe (like a plum). Its characterization as a 'nut' has tended to hide the significant value of the fibres in the husk of the mature fruit and the watery endosperm that fills the cavity of the immature fruit. It is these two characters, rather than the oil content of the kernel, that account for the original natural spread of the coconut, by floating, and its value to people travelling long distances at sea. Air space between the fibres and the volume of the nut cavity gave coconut its most distinguishing feature – the ability to float hundreds or thousands of kilometres between tropical oceanic islands and germinate, even on newly emerged volcanic islands. This ability enabled its earliest, pre-human, dispersal. Subsequent human dissemination to places that it could not float to made the coconut the first truly pantropical plant and it quickly became the most convenient source of vegetable oil (for more than a century from the mid-1800s to the late 1900s) for high lauric acid content. Although the demand led to considerable colonial plantation developments during that time, today more than 95% of coconut production is in the hands of small, economically weak producers. Coconut palms grown by these farmers are already less productive than African oil palm. Neither of these labour-intensive tropical crops are able to directly compete with mechanically harvested, genetically modified, high lauric rapeseed (canola). The future of the coconut is assured by its multitude of uses and its natural beauty in the tropical landscape.

World distribution and yield

The coconut (cocoa-nut, cokernut (archaic); côco, coquos (Portuguese); coco, cocotero (Spanish); cocotier (French); kokosnuss (German); kokosnoot (Dutch); mnazi (Swahili); narikal (Arabic); kerala, narial (Hindi); tennai (Tamil); pol (Sinhala); kelapa (Malaysian and Indonesian); niyog (Tagalog); and niu (Polynesian/Hawaiian)) is found throughout the tropics. The greater number of coconut types in South-east Asia–Melanesia that have numerous local names and uses and unique insect and crab associations, attest to a long presence, making this region the centre of diversity. This region is assumed to be the centre of origin, with the coasts of America at the ends of eastward and westward movement, possibly from New Guinea and Polynesia with man or by drifting (Ward and Brookfield, 1992). The coconut cultivars on the Pacific coast of tropical America, from Mexico to Peru, are indeed distinct from those in the coasts and islands of the Caribbean and the Atlantic coasts of South America and West Africa but this can be attributed to 16th-century Portuguese and Spanish activities.

The closest botanical relatives of the coconut (once classified as other *Cocos* species) occur in South America, southern Africa or Madagascar raising the possibility that the true centre of origin for *Cocos* was at the conjunction of South America and southern Africa when those two continents were part of the Gondwana super-continent. If that were so, then a sea level, coastal distribution of a primordial coconut due to natural dispersal by floating (Harries, 2002) occurred synchronously with the movement of the Indian sub-continental tectonic plate from Gondwana across the primordial Tethys Sea. Geologically, this is supported by tropical marine sediments identified in Himalayan strata and the presence of cocosoid fossil fruit and stems (Sahni, 1946) on the Indian subcontinent. Further prehistoric spread into the Pacific is indicated by cocos-like fruit in New Zealand and, more contentiously, a fossil fruit in Australia and pollen cores in the Cook Islands. Such natural dispersal of ancestral coconut palm can account for the predominance of coconut cultivars with 'wild type' attributes on some tropical coasts and remote islands from the Indian Ocean to the mid-Pacific. Subsequently, domestication in South-east Asia–south-west Pacific, followed by introgression of wild and domestic types, led to human dissemination inland, upland and by boat to coastlines to which the wild type could not float.

The numerous uses of the coconut palm and its fruit are sometimes thought to have led to its wide cultivation in the tropics. The reverse is the case. It had a wide natural dissemination before Polynesians, and then Europeans, took it for one use in particular – as a source of pure, fresh, sweet drinking water – to regions to where it could not float. The other uses, such as coir fibre for ropes, became important for the mercantile activities of sailing ships and then oil, from copra (the dried endosperm of the nut) led to coconuts being traded commercially everywhere along sea coasts, grown at inland sites having an adequate water supply, and even planted in agriculturally unsuitable places in the tropics.

Uses and nutritional composition

Humans have used this palm for thousands of years for food, thatch, fibre and wood, and it entered commercial trade as oil for lamps, candles and soap. Coconut fruit is used fresh at both the immature and the mature stage. The kernel (solid endosperm) from mature coconuts can be shredded and dehydrated to become desiccated coconut, or coconut oil can be extracted and processed as an edible oil from the fresh kernel or as an industrial oil from the kernel that has been dried (in the sun, over a fire, in a kiln) or fried (in hot oil) to copra. The outer husk (mesocarp) of the fruit ('nut') is used as a fibre (coir), along with a non-fibrous product, coir dust (cocopeat). It now has widespread uses in horticulture as a replacement for peat moss.

There has always been local trade in immature fruit and dehusked mature nuts for eating but modern technology is making coconut water available internationally. Fresh coconut water is an important adjunct in media for tissue culture. The juicy, jelly-like endosperm in the young nuts is highly prized for eating out of the shell, for the water and for use in cooking. Immature ('green', 'jelly') coconuts are harvested 7–9 months after pollination by a climber so that the entire bunch can be lowered by rope to the ground to avoid damage. The epidermis is uniformly fresh in colour (shades of green, brown, red or yellow depending on variety) and smooth, while the coir is white. The dehusked fruit is about 10 cm in diameter weighing about 500 g, having 100 g endosperm, 120 g shell and 250 g liquid endosperm (water). The liquid endosperm in fresh 'green' coconuts can have 130–620 ml water and 48 g/kg sugar, depending on the stage of harvest, and is at a maximum 7–8 months after anthesis. The water is marketed in sterilized long-life packs in South-east Asia and Brazil. Mechanical damage will cause the white coir to turn brown and can cause nut cracking. Younger nuts rupture with less force than mature nuts (108 versus 537 kg) (Tongdee, 1991). The nuts are held in a cool place until processed or sold at market. In Thailand, the green nut is trimmed and shaped, removing most of the husk. The final product has a flat bottom, round body with a pyramid top and the eyes showing. Alternatively, all the husk is removed before dipping in the sulphite solution.

To enter the fresh market chain, mature nuts are dehusked before shipment. The dry nuts should be brown, free from fibre, damage and cracks and of the required weight or size (35 to 45 cm in circumference). The nuts are shipped in sacks or cardboard cartons. Postharvest stress cracks are directly related to coconut weight loss (Burton, 1982). Waxing of the nuts minimizes water loss and dramatically reduces fruit cracking. The shelf life is 2–3 months at 12°C before the residual liquid has evaporated or the shell has cracked because of desiccation. Low humidity and high temperature must be avoided.

Mature nuts for copra, coir or desiccated coconut are left on the palm until 11 months or more from pollination when the fresh skin colour shows dry, brown patches to being fully brown and the coir is brown. Mature nuts of some varieties/cultivars fall to the ground when ripe and can be collected, but more commonly all nuts on one or more ripe bunches are cut using a blade on a pole at regular intervals every 4–6 weeks, throughout the year. Monkeys can also be trained to harvest coconuts. Mature nuts are comparatively light and bulky, while green nuts are three times more dense.

The oil is extracted from copra and used for soap, detergent and margarine, while the desiccated coconut is used in confectionery. The processing of copra and the use of the husks has been extensively reviewed (cf. Woodroff, 1970; Ohler, 1999). The fresh kernel (28% whole nut) contains 25–44% oil, 35–62% water, 9–14% carbohydrate, about 5 mg/100 g vitamin C, as well as vitamins B1, B2 and B3 (Table A.51). Coconut oil becomes solid at temperatures below about 25°C and was used as 'vegetable butter' until the hydrogenation process for making margarine from other vegetable oils was developed in the 1890s. However, the use of glycerin, a by-product of soap manufacture, to make nitroglycerine expanded the demand for copra at the time of World War I (Harries *et al.*, 2003) and also in World War II, when Japan took control of all major coconut-producing countries.

Table A.51. Proximate fruit composition of coconut (Source: Leung *et al.*, 1972; Siong *et al.*, 1988).

	Amount in 100 g edible portion			
Variable	Immature	Mature	Water	Toddy
Proximate (g)				
Water	81.4	55	94	86
Calories (kcal)	122	296	22	43
Protein	1.9	35	0.2	0.3
Fat	11.9	27.2	0.4	0.4
Carbohydrate	4	13.7	4.5	10
Fibre	0.7	3.8	–	Trace
Ash	0.8	1	0.5	
Minerals (mg)				
Calcium	11	13	24	Trace
Phosphorus	42	83	18	–
Iron	1.1	1.8	0.3	Trace
Sodium	51	16	5	34
Potassium	257	340	130	109
Vitamins (mg)				
Ascorbic acid	7	5	3	29
Carotene	Trace	0	0	Trace
Thiamine	0.05	0.04	Trace	0.02
Niacin	0.8	0.6	0.1	Trace
Riboflavin	0.03	0.03	Trace	0.01

Numerous coconut recipes exist for its use in breads, waffles, cakes, sweets, cookies, pies, ice cream, soup and other main-course cooked dishes and the health benefits of dietary coconut oil are becoming better known (Fife, 2000). In the Philippines, acetic acid bacteria produce a 'cartilaginous' material from coconut water called nata de coco that is used in a number of desserts.

The fibre from the husk is used for ropes, mats and geotextiles. More recently the residual coir dust (cocopeat) is replacing peat moss for environmentally sustainable, horticultural seed-sowing and potting mixtures. Unopened coconut inflorescences are tapped and the exudate (toddy) collected and fermented for an alcoholic brew (palm wine) of up to 12–13% alcohol. It is also distilled to produce a 'whisky'. Alternatively, the toddy is boiled down to produce a treacle or sugar. Freshly gathered toddy has about 8.6% total soluble solids, pH 3.6, 0.23% crude protein, 0.6% sucrose, 5.7% reducing sugars and can have about 5% alcohol depending upon collection frequency and hence the time allowed for fermentation to occur.

Botany

TAXONOMY AND NOMENCLATURE The genus *Cocos* is monotypic, containing only the highly variable *C. nucifera* L. and occurs within the *Arecoideae* subfamily, tribe *Cocoeae*, as do other economic palms such as the peach palm (subtribe *Bactridinae*), oil palm (subtribe *Elaeidinae*) and betel nut (Uhl and Dransfield, 1988). Previously, the genus contained over 30 other species that occurred in Central and South America; these are now assigned to several other genera. A classification of *C. nucifera* by analysis of the proportions of husk, shell and endosperm in the fruit (Harries, 1978) identified the geographical and historical distribution of populations with wild-type, domestic-type and introgressed-type characteristics. Recently, sequence-tagged microsatellites and amplified fragment length polymorphism (AFLP) methods have been used to analyse genetic diversity (Teulat *et al.*, 2000). While no truly 'wild' coconuts are known, wild-type coconuts have been identified in the Philippines (Gruezo and Harries, 1984), Australia (Buckley and Harries, 1984) and elsewhere (Harries, 1990a).

DESCRIPTION This palm can grow 20–30 m high and live 80–100 years. The stem has only one terminal growing point, no axillary vegetative buds and only rarely suckers from the underground portion of the stem. Loss of the terminal meristematic growing point leads to death. Branching of the stem has been reported but is rare. During the initial years of growth the stem gradually increases in thickness and then this diameter is maintained until about 10 m when there is a gradual reduction in diameter. Poor nutrition can also reduce stem diameter. Early rapid stem growth occurs until fruiting, then the rate of stem growth declines. The absence of a lateral cambium layer means that there is no secondary thickening and no capacity to repair injury. Stem strength and flexibility is due to the fibrous sheath surrounding the numerous vascular bundles in the stem periphery and a large number of smaller bundle fibres in the stem vascular bundles (Tomlinson, 1990).

As a monocotyledonous plant, the coconut has an adventitious root system. The primary roots are uniformly thick, as are the secondary and tertiary, which have progressive smaller diameters. These roots are produced from the base throughout the plant's life. A 25-year-old palm can have 1500–4000 roots arising at the base of the bole or stem. The long-lived primary roots produce branch roots about the same thickness and short-lived rootlets. The older part of the main roots and branches becomes sclerotic. About 25% of the roots grow vertically downwards while the majority spread horizontally and can reach 20 m from the palm and about 2 m below the surface. However, about 70% of the roots are found within a 1 m radius of the stem to a depth between 0.1 and 0.5 m (Cintra *et al.*, 1993). The initial roots of the germinating seedling can grow 1 cm/day, although this rate slows after about 3 months of growth. Pruning of roots induces root branching and continued growth.

The crown of the plant has about 30–40, open, 3–6 m long leaves (fronds), 10–14 of which subtend fruit bunches at different stages of development (Fig. A.14). There are also 30–50 unopened fronds in the crown. Leaves are produced in succession, 8–20/year and take 4–5 months to emerge from the sheath. The phyllotaxy is 5/2 or about 144° (Davis, 1970). The rate of leaf production is higher in dwarf palms (17/year) than tall palms (12/year). Leaves survive 3–3.5 years after they are fully opened. After about 30 years, there is a gradual reduction in the rate of emergence, leaf life and length and therefore nut yield (Foale *et al.*, 1994). Each leaf has 200–250 parallel-veined leaflets that are 70–80 cm long and 2.5 cm wide at the base of the leaf, and about 45 cm long and 1.3 cm wide at the apex.

Fig. A.14. Leaf, flower and fruit of *Coco nucifera* (Source: Vozzo, 2002).

The leaves intercept about 44% of the incident light depending upon season and plant density (Nair and Balakrishnan, 1976). This light interception makes coconut suitable for mixed cropping. The functional leaf area in a plantation is dependent more upon the intensity and duration of seasonal drought and less on plant density. Damage to the leaves by insects, storms or leaf pruning or clipping can lead to significant nut yield reduction if more than 40% of the leaf area is lost. The reduction in nut yield is due to nut shedding and premature nut fall (Bailey *et al.*, 1977). The impact of 50% leaf loss on yield can continue for 5 months and the loss of 70% of the leaves for 17 months after defoliation. The proportion of dry matter partitioned to the fruit can be as high as 62%, in this C-3 plant (Corley, 1983).

This monoecious palm carries both staminate and pistillate flowers borne on an axillary inflorescence (spadix) at each leaf. Dwarf forms may begin flowering in 3 years, tall forms in 5–7 years. The first inflorescence may be all male, later inflorescences will also produce female flowers. The immature spadix is enclosed by a prophyll and peduncular bracts (spathes). The spadix when mature and after emergence from the bract is 1.2–1.8 m long, straw to orange coloured and a simply branched rachis. Each branch (rachilla) bears one or more female flowers near the base and numerous male flowers above. There are generally up to about 50 female flowers per bunch and possibly thousands of small male flowers.

The globose pistillate flowers are about 2.5 cm long and 3 cm in diameter with a reduced round perianth surrounding the base. There is a short style with three stigmas, three ovules are produced though normally only one is fertile. The staminate flowers are small (3 mm) non-symmetrical with small sepals and three longer petals and six stamens. Pollinating insects are attracted by a small drop of nectar in each newly opened male flower and by a prolonged nectar supply for 2–3 days during the period of stigma receptivity of each female flower.

ECOLOGY AND CLIMATIC REQUIREMENTS The palm grows between latitudes 23°N and 23°S, with favourable temperatures (27°C ± 7°C) and ground water or high, evenly distributed rainfall, at elevations up to about 1000 m above sea level. The canopy of coconut intercepts only about 40–50% of the incident light. There is also little change in the canopy spread with age and the limited root spread makes this an ideal crop for intercropping. Numerous crops are grown under coconut: fodder grass and other pastures for grazing, coffee, cacao, long-kong, duku, pineapple, banana, maize, mango, citrus, ginger, medicinal, aromatic and spice crops (black pepper), yams, sweet potatoes, beans and groundnuts. Inter-cropping increases the income of small growers. Cash crops are used among young coconut planting, and more long-term crops such as bananas can be planted in alternate rows (Ohler, 1999).

Though the palm is grown on a wide range of soil types, it yields best on rich river alluvial deposits with good drainage. In most tropical countries, it grows on beach sands having low nutrient levels. In these sandy conditions, it requires higher land or freshwater swamps to carry nutrients via percolation towards the beaches. Management of coconuts on clay soil is difficult, good drainage being essential. Soil pH of acid clays (pH 5.0) to coral-derived sands (pH 8.0) are tolerated (Murray, 1977).

Total rainfall of between 1300 mm and 2300 mm/year is required for good production and the pattern of rainfall is more important than the total amount. Irrigation is needed in a new planting until the root system reaches the dry season water table. In the absence of a water table, trickle irrigation is recommended. Large plantations are not normally irrigated, though nut and copra yield are reduced by drought. The rate of application varies with soil type and weekly applications of 40–50 l/plant on an oxisol have been recommended in India during the dry months (Salam and Mammen, 1990). The mean transpiration rate of mature coconut palm is about 7.5 $g/cm^2/s$ and leads to a loss of about 90 l/day in each palm (Kulandaivelu, 1990). Lower application rates mean that the palm is still drawing some water from the soil.

It takes about 44 months from flower primordium initiation to fruit maturity, including the 12 months from anthesis to fruit maturity. Drought (or an extended dry season of 3 consecutive months) leads to inflorescence abortion, button shedding, premature nut fall and low final nut yield. Hence, rainfall in the first 3 months of nut development determines crop size 12 months later. The effects of prolonged drought can persist for up to 30 months.

Lightning can cause significant damage and leads to disease at the damage site. Malaysia and Sri Lanka both report lightning as a major contributing factor to disease.

A mean temperature of 27°C and diurnal variation of 6–7°C is considered optimum. These are found on tropical sea coasts where the sea acts as a buffer against rapid temperature changes. Mature coconut palms have survived frost and snow in Florida but inflorescence abortion occurs at temperatures below 15°C. Temperature is the deciding variable in altitude of cultivation, a 20°C mean monthly temperature being the minimum. At the equator, the limit for commercial production is up to 1000 m and at 18°N (Jamaica) to 150 m. High maximum temperatures can also decrease yield.

Too much shade or very cloudy conditions lead to poor palm growth. The influence on yield has not been studied due to the long nut development period. A minimum requirement of 2000 h/year of sunshine has been suggested (Fremond *et al.*, 1966).

If adequate soil moisture is available, coconuts can tolerate high winds. The windward palms may show some yield reduction. Strong winds from hurricanes or cyclones can lead to palm death by the crown being broken off, but palms that are blown over may survive and root along the stem.

REPRODUCTIVE BIOLOGY Early flowering can be encouraged by full sunlight, unrestricted water supply and additional fertilizer applications. Reductions in these factors delay flowering and constant shading can delay flowering indefinitely. The inflorescence primordium is formed very soon after the leaf. Little primordium growth takes place until the subtending leaf growth has finished its expansion. The inflorescence then begins to rapidly differentiate, followed by a phase of elongation with the inflorescence opening about 12–13 months later. The number of spadices produced depends on the rate of leaf production and amount of spadices aborted. The number of pistillate flowers per spadix varies with cultivar, palm age, season and palm management. Spadix abortion is more common in young palms and during drought (Menon and Pandalai, 1957).

The staminate flowers begin opening at the distal end of the spadix during the morning, falling in the afternoon and the whole process continues for upwards of a month on the same spadix. There is a sweet scent at anthesis and nectar production from the pistillodes in the base of the staminate flowers. The female flowers produce nectar as they open from the distal end, and anthesis lasts 6–15 days. Normally staminate flower anthesis has finished before pistillate flowers are receptive on the same spadix forcing cross-pollination in most cultivars. However, during the warmer months, inter-spadix pollination on the same palm is possible in 40–50% of the palms (Patel, 1938). Some dwarf cultivars have male and female phases coinciding, leading to variable out-crossing (Ashburner, 1995a). The presence of nectar and sweet scent leads to considerable bee activity on both male and female flowers. Flies and other insects may also be involved in pollination and wind pollination may occur to a limited extent.

After anthesis, there is a period of immature nut (button) shedding, most occurring in the first month. This shedding can vary from 55 to 95% of the pistillate flowers and is due to a number of causes: defective pollination, drought, disease, insects or poor palm condition. There is a further shedding of more mature nuts just before they are full grown and before the endosperm has begun to form. This shedding is often greater following a drought and accentuated by heavy rainfall following drought. ‘Barren’ nuts can also develop, having an aborted embryo. A higher number of female flower and nut set is sometimes observed after tapping for toddy. In addition, dwarf and hybrid palms carry a heavy load of nuts when they first come into production. This last observation and biennial bearing suggests a role for assimilate supply and demand in button nut shed and immature nut fall (Foale, 1993). Several hormone sprays particularly 2–4D and coconut water can double button set and increase nut yield when applied after fertilization is completed (Gangolly *et al.*, 1956). Nut yield has been correlated with a number of palm characters: total number of open leaves; rate of leaf production; trunk length; trunk girth; and number of pistillate flowers (Menon and Pandalai, 1957).

FRUIT DEVELOPMENT The coconut fruit is a fibrous drupe, containing a hard-shelled ‘nut’. The mature fruit is either ovoid and angular or spherical, depending on cultivar, 20–30 cm long, weighing from 1–2 kg. It has a thin epidermis, covering a thick fibrous mesocarp (coir), within which is a hard lignified endocarp (shell) that is brown when mature. The ‘wild type’ has a long, angular fruit, containing an ovoid nut whereas in the ‘domestic type’ both the fruit and the nut are more spherical or oblate because the proportions of husk, shell and endosperm differ due to natural or domestic selection (Harries, 1978). Inside the endocarp, at maturity, the white flesh of the kernel (endosperm) is about 12–15 mm thick with a large central cavity. The pea-sized embryo lies in the flesh under the ‘soft eye’, one of the three generative pores at the basal end of the nut. The embryo weighs *c.*1/1000 of the fruit weight. Occasionally, there will be two or three viable embryos, one under each generative pore.

The fruit take approximately 12 months to reach maturity, depending on cultivar. About 32% of the endosperm is deposited in the first 8 months and 94% by the 11th month of development. When young, the mesocarp comprises the major portion of the nut and increases in thickness and number of fibres up to maturity (Shivashankar, 1991). The shell is already differentiated before fertilization and further development occurs after the mesocarp has differentiated, about 4 months after fertilization. The endosperm is the last to develop and begins as a liquid containing free nuclei and some cells. These cells begin to coalesce towards the periphery of the embryo sac on the endocarp about 7 months after fertilization. Additional cells are formed and adhere to the endocarp, resulting in the cellular peripheral endosperm that is initially translucent and jelly-like, hardening to a white flesh at 11 months. Oil content in the endosperm parallels its development. Coconut water begins to form about 3 months after fertilization and reaches a maximum at 8 months after fertilization then declines. The coconut water is of cytoplasmic origin but in mature coconut there are no free cells.

As maturity approaches, the fibrous mesocarp begins to dry, becoming reddish brown. This dehydration and the shrinkage of the amount of liquid endosperm reduces the nut mass from 3–4 kg at 9 months to 1.5–2 kg at 12 months. For fresh consumption, the fruit is harvested immature (7–8 months) when the endosperm has begun to form and is jelly-like (Tongdee, 1991) before it gradually thickens and hardens. The coconut water has a maximum of 6% soluble solids, 8–9 months after fertilization. Mature coconuts (10–11 months) are also used after the hardening of the endosperm. The endosperm is shredded and squeezed to produce ‘coconut milk’ and ‘coconut cream’.

Horticulture

PROPAGATION The coconut is only propagated by seed. Mother palms should be selected on the basis of performance (a high number of good-sized fruit) over 3 years or longer. Fruit (seed nuts) are best reaped when the fresh skin colour is just starting to turn brown and while they contain adequate liquid and can be heard to ‘splash’ when shaken. Immature fruit (full of water and very heavy) or over-mature fruit (with no water and very light) should be rejected. The selected seed nuts can withstand normal harvesting but careful handling may avoid damage and consequential loss of viability. Setting in a nursery should take place immediately since germination can occur during storage, resulting in twisted and deformed shoots. Speed of germination is a taxonomic characteristic (Harries, 1981). Plantlets can also be obtained from excised embryos after 5–6 months of culturing, avoiding the need to handle large and heavy nuts (Assy Bah, 1986).

The nuts are normally germinated in nurseries using a sandy soil, often now in polythene bags (450 × 450 mm). The use of polythene bags minimizes root disturbance during transplanting and reduces ‘transplanting shock’. Initially, the nuts need to be watered daily to assure uniform germination and development. Sometimes the epidermis is trimmed from the germ end of the nut to facilitate water penetration and germination. The shoot appears after several weeks. There is a relationship between the speed of germination and vigour, and the productivity of the palm grown from it, hence the slow germinating and less vigorous seedlings are culled.

As germination commences, the embryo develops a spongy haustorium ‘apple’ inside the seed cavity for nutrient absorption and a shoot that emerges through the soft eye. When coconuts are processed to copra many may have started to germinate and, in Sri Lanka and elsewhere, the spongy haustorium is eaten as a vegetable delicacy. The endosperm is not completely absorbed in 5 months, having about 60% of the solid endosperm still present after 9–18 months (Menon and Pandalai, 1957). Coconut seedlings may therefore have adequate amount of stored nutrients in the nut till transplanting but fertilizer application can stimulate growth.

Transplanting can take place soon after the nuts have sprouted (4–6 months), sometimes up to 9 months. This should be scheduled so that germination occurs in time to transplant at the start of the wet season. The cleared land is planted commonly on a triangular pattern, rows running north–south, with 6–10 m between plants to obtain optimum number of palms/ha. A wider spacing is used for the tall varieties (8–10 m) than the dwarf varieties (6–8 m). A spacing of 9 m gives 160 palms/ha. Organic manure is frequently added to the planting hole that is big enough to accept the plant without significant root disturbance. Mulch may then be put around the plant after the hole is refilled. If irrigation is available, the seedling should be watered as soon as possible to stimulate root development.

ROOTSTOCKS The coconut is difficult to vegetatively propagate. Attempts to generate coconut palms by tissue culture have achieved only a handful of plants since the 1970s, despite the fact that coconut water (from the immature fruit) is a vital ingredient in tissue-culture media for many other plant species.

PRUNING AND TRAINING The coconut palm, unlike the date palm and the oil palm, is ‘self-pruning’ throughout its life, dead leaves and over-mature fruit hang for a few months before falling to leave a clean stem (some exceptions may be due to growing conditions or unspecified abnormality). Since all parts of the palm can be used, leaf trimming is sometimes practised. Trimming can reduce yield.

NUTRITION AND FERTILIZATION During seedling growth, fertilizer application is recommended, such as 50 g/plant of equal parts of calcium phosphate, potassium chloride and magnesium sulphate on two occasions (Fremond *et al.*, 1966). The lack of uniformity and variability in response of planting material, the large areas required for trials, difficulty in recording data on tall palms, seasonal effects and the long period before fertilizer effects are seen, are considered to be major difficulties in fertilization experiments. Nitrogen, potassium and magnesium have been shown to significantly influence production. The amount of minerals exported in the harvested product is greatest in the husk: 67% of the potassium (K) and 85% chloride (Ochs *et al.*, 1993). Leaf analysis data have suggested critical levels for the leaflets of the 14th leaf: nitrogen (N) 1.8–2.0% dry mass, phosphorus (P) 0.12%, K 0.8–1.0%, calcium (Ca) 0.3–0.4% and magnesium (Mg) 0.3% for talls (Magat, 1978, 1979; Rognon, 1987). For hybrids, 2.2% N, 0.12% P, 1.4% K and 0.2% Mg are recommended. Chloride has been shown to significantly effect growth with critical concentration of 0.5–0.6% (Magat *et al.*, 1988). Nut water analysis is useful for K but not other nutrients.

POSTHARVEST HANDLING AND STORAGE Maturity, size, freedom from blemishes, cracking and free from fibre of husked coconuts, and wet or mouldy eyes are the main quality characteristics. Coconut milk is obtained by removing and grating the hard, white flesh and squeezing out the milky juice. Young coconuts are harvested 6–9 months after flowering, as the nut approaches full size and the skin is still green and the short stem (rachilla) on the top of individual coconuts that originally held the male flowers (in Thai called 'rat-tail') becomes half green and brown. In immature nuts, the skin surface around the calyx (cap) on the top of coconuts is creamy-white or a whitish yellow. When the area surrounding the cap is green the coconut is regarded as mature and is 10–12 months old. At maturity the skin begins to change from green to yellow then brown and the 'rat-tail' is entirely brown.

There are no specific grades, but informal grades are usually based on size and weight. Mature US dehusked coconuts are sold in 34–36 kg woven plastic or burlap sacks containing 40–50 coconuts, plastic mesh bags of 12 coconuts or cartons with 20–25 film-wrapped coconuts, 17–18 kg. After the husk is removed from immature coconuts in South-east Asia, they are shaped, dipped in bisulphite, film wrapped, and sold in single-piece cartons containing 10–16 nuts. Alternatively, all the husk is removed and then dipped in sodium bisulphite before packing. Bisulphite is not approved in the USA for this purpose.

Room cooling is most often used for mature husked nuts, though the nuts can be forced-air or hydro-cooled. Rapid temperature changes of 8°C can cause cracking of mature coconuts. Mature coconuts with husk can be kept at ambient conditions for 3–5 months before the coconut water has evaporated, the shell has cracked because of desiccation or sprouting has occurred. Storage at 0–1.5°C and 75–85% relative humidity (RH) is possible for up to 60 days for mature de-husked coconut and 13–16°C and 80–85% RH for 2–4 weeks. Low humidity and high temperature are to be avoided. Immature nuts have green skins that turn brown after 7 days at 0°C.

Young coconuts are normally held at 3–6°C and 90–95% RH, and husked-wrapped, shaped fruit can be held for 3–4 weeks. Shaped young coconuts not treated with bisulphite brown in 12 h, but when treated with 0.5–1.0% sodium meta-bisulphite the nuts can be held at ambient temperature for 2 days before browning occurs, and if treated with 2% sodium meta-bisulphite can be held at ambient temperature for 2–7 days. Young coconuts that are not de-husked can be stored for a longer period (28 days at 17°C) as the husk acts as an insulator and appears to increase the storage life of young coconuts.

DISEASES, PESTS AND WEEDS Bud rot, basal stem rot and grey leaf blight can be important diseases (Table A.52). Other fungal diseases of coconut such as leaf rot (*Helminthosporium halodes*) can cause losses (Nambiar and Rawther, 1993). The viroid diseases caused by single-stranded RNA such as cadang-cadang (Philippines) and tinangaya (Guam) can be tested for using molecular probes (Hanold and Randles, 1994), as can the virus causing foliar decay disease in Vanuatu (Randles *et al.*, 1986), thus avoiding transmission of infected material. Lethal yellowing disease is epidemic in parts of the Caribbean and West Africa (Arellano and Oropeza, 1995) and related diseases have been identified in Indonesia (Allorerung *et al.*, 1999). The disease is caused by a phytoplasma spread by a plant hopper (Jones *et al.*, 1995) and is a major threat of quarantine concern as it also infects more than 30 other palm species. The Malayan Dwarf and other varieties from South-east Asia show high to medium levels of resistance to lethal yellowing disease, as does the F_1 hybrid, Maypan. The Centre for Information on Coconut Lethal Yellowing (CICLY) at http://groups.yahoo.com/group/CICLY makes current information on this disease available online.

Over 700 species of insects have been recorded to associate with coconut, of which 165 are peculiar to coconut. Only a few are serious pests (Fremond *et al.*, 1966; Gallego, 1985). *Oryctes* spp., especially the rhinoceros beetle (*Oryctes rhinoceros*), burrow into the petiole and penetrate the young immature leaves sometimes causing death of the palm through secondary bacterial or fungal infection. The palm weevil *Rhynchophorus palmarum* is the vector for the red ring disease nematode (Table A.53) and other *Rhynchophorus* spp. cause damage by laying eggs in the petiole and foliage. Scale insects (*Aspidiotus destructor*) attack the leaflets and cause loss of palm vigour. Leaf-eating and leaf-mining beetles (*Brontispa* and *Promecotheca*) and caterpillars of various moths and butterflies can cause severe damage to leaves if not controlled. Total loss of fruit production in otherwise healthy palms can be caused by infestation of fruit sucking bugs, *Promecotheca* (in Africa) and *Amblypelta* spp. (in the Solomon Islands). The coconut eriophyid mite, *Aceria guerreronis*, which seriously reduces fruit size, was first recognized in Mexico in the 1960s and has subsequently been reported elsewhere in Latin America, all over the Caribbean and West Africa and is currently active in India and Sri Lanka. Monkeys, squirrels and rats cause problems in localized areas to nursery seedlings, young palms and immature nuts that are chewed open (5-month-old nuts are particularly preferred) for their water content. Despite its close association with coconut, in Melanesia and Polynesia, the robber crab (*Birgus latro*) is not a pest. It can climb the trunk of the coconut palm but it does so to escape danger, and not to feed off the nuts that it, reputedly, cuts off after climbing into the crown. The real relationship between this land-living crab and the coconut is to enable its short-lived aquatic larval stage to disperse long distances to other islands, by floating (Harries, 1983).

Weed control is essential during plantation establishment. Failure to control weeds in the 2–4 m area around each palm can lead to shorter leaf length and fewer new leaves produced per year, fewer open bunches and nuts set per palm (Romney, 1988). The larger diameter (4 m) circle is more beneficial for the 39–50-month-old palms.

Table A.52. Some important diseases and nematodes of coconut (Source: Nambiar and Rawther, 1993; Ploetz, 1994).

Common name	Organism	Parts affected	Distribution
Bud rot and nut fall	*Phytophthora palmivora*, other *Phytophthora* spp.	Heart leaves chlorotic, wilted and easily removed extending to stem apex. Affected nuts shed	All coconut growing areas
Basal stem rot	*Ganoderma* spp.	Similar to drought; gradual wilting leaf collapse and drooping; growth slows	All coconut growing areas
Grey leaf blight	*Pestalotiopsis palmarum*	Small yellow to brown spots on the leaflets and rachises coalescing into irregular necrotic areas	All coconut growing areas
Stem bleeding	*Chalara paradoxa* (*Thielaviopsis paradoxa*)	Infected roots, decay of pith leads to slow palm decline. Trunk pith decays when infected, reddish brown exudate from trunk infection site	All coconut growing areas
Cadang-cadang	Viroid (RNA), lethal disease (CCCVd)	Slow infection, nuts become rounded, leaflets fine non-necrotic translucent yellow spots, inflorescence becomes necrotic. Related viroid found outside the Philippines but cadang-cadang only recognized in the Philippines	Philippines (specific locations)
Foliar decay	Virus (single-stranded; circular DNA)	Progressive yellowing, necrosis and death. Transmitted by plant hopper to imported varieties; local varieties are resistant	Vanuatu
Lethal yellowing	Phytoplasma (previously mycoplasma-like organism (MLO)), plant hopper as vector	First reported from Cuba and Jamaica in 1800s. Rapid spread, palm death 3–6 months after first symptoms: nut drop after latent phase, new inflorescence black. Yellowing of foliage from the oldest leaves on very susceptible tall types, brown in more resistant tall and dwarf types. Bud death, no control, resistant varieties and hybrids	Caribbean (islands): Cuba, Cayman, Dominican Republic, Haiti, Jamaica; (Gulf coast): Florida, Texas, Mexico, Belize, Guatemala, Honduras. West Africa: Cameroon, Ghana, Nigeria, Togo. East Africa: Kenya, Mozambique, Tanzania
Red ring disease	*Burasaphelenchus cocophilus* (obligate parasite of many palms). The vector is a weevil	Severe insect damage to crown and infects the palm resulting in leaf yellowing and internal red ring symptom about 70 cm around the inoculation point of the stem. Sanitation reduces vector population	Latin America and Trinidad

Table A.53. Major insect pests of coconut.

Common name	Organism	Parts affected	Country/region
Rhinoceros beetle	*Oryctes* spp.	Foliage and growing point	Asia and Pacific; Africa
Palm weevil	*Rhynchophorus* spp.	Stem and growing point (vector of red ring)	Asia, Latin America
Scale insect	*Aspidiotus destructor*	Foliage	Widespread
Leaf-eating and leaf-mining beetles	*Brontispa* and *Promecotheca*	Foliage; serious on seedlings	Pacific but now reaching parts of South-east Asia
Moths and butterflies	Various	Foliage and inflorecences	Locally important
Locusts and grasshoppers	Various	Foliage	Locally important
Coconut fruit bugs	*Pseudotheraptus wayii*	Developing fruit	Africa
	Amblypelta spp.		Solomon Islands
Coconut fruit mite	*Eriophyes guerreronis*	Developing fruit	America, Africa, South Asia
Plant hopper	*Myndus* spp.	Vector of lethal yellowing, blast and foliar decay	America (leaf yellowing), West Africa (blast) and Vanuatu (foliar decay)
	Ganoderma spp.	Similar to drought; gradual wilting leaf collapse and drooping; growth slows	All coconut growing areas

MAIN CULTIVARS AND BREEDING This very variable species has a chromosome number of $2n = 32$. The terms variety, cultivar, ecotype, population are often used interchangeably but Latinized distinctions between *typica* for tall cultivars and *nana* for dwarf cultivars are less useful than the system of naming types according to their origin and habit (e.g. 'Jamaica Tall') sometimes with fruit colour (e.g. 'Malayan Yellow Dwarf'). Tall cultivars tend to be slower to begin flowering and are generally (but not always) cross-pollinated, while dwarf cultivars are generally (but not always) self-pollinated (Table A.54). Dwarf cultivars are more precocious and the first fruit may be at or close to ground level – hence the terminology 'dwarf'. Although they are never as high or as vigorous as tall cultivars, they can reach 30 m high in 60 years. The colours green, red and yellow seen in the petioles and fruit serve to differentiate between blocks of self-pollinated

Table A.54. The characteristics of tall and dwarf types of coconut and example of populations.

Characteristics	Dwarf type	Tall type
Height	8 m	25 m
Leaf production per year	16–18	About 12
Juvenile period	1.5–3 years	6–8 years
Pollination	Self-pollinate	Out-crossing
Fruit	Smaller	Large
Disease resistance	Some resistance to lethal yellowing	Susceptible
Undesirable	Periodicity in bearing Less adaptable Weaker leaf and bunch attachment Smaller nuts Lower copra production More water	Height for harvesting
Populations	Green Catigan-Davao Philippines Tacunan-Davao Philippines Aromatic Thailand Yellow Malayan-Malaysia/Ivory Coast Red Malayan-Malaysia/Ivory Coast Cameron-Cameron, West Africa	Laguna-Philippine Macapuno-Philippine Tahiti-Tahiti West African Tall-Ivory Coast Rennel-Solomon Islands

dwarf populations but are less obvious in cross-pollinated tall populations that tend to be mixtures of green- and bronze-coloured individuals. However, colours help to identify off-types when hybrids are produced between yellow dwarf seed parents and tall pollen parents. Commercially, dwarf cultivars are considered to be less productive, more sensitive to poor conditions and have lower quality copra. Some dwarf cultivars are more resistant to serious virus and phytoplasma diseases than tall cultivars. Morphological markers, disease, isozyme and molecular markers are becoming available (Ashburner, 1995b; Ashburner *et al.*, 1997; Teulat *et al.*, 2000).

Of the population types, one of the most interesting for fresh or green coconut use is the macapuno type. Whereas the mature normal endosperm is hard and compact around the periphery of the cavity, in the macapuno type it is soft and curd-like, filling the entire cavity (Nunez and de Paz, 1990). The endosperm cells of macapuno are large and multinucleate, having low intercellular adhesion (Sebastian *et al.*, 1987) and have a higher cytokinin activity than non-macapuno nuts. Macapuno endosperm has reduced hemicellulose content in the cell walls and a different cell-wall sugar composition. A type similar to the Philippine macapuno has been reported in India as 'Thairu thengai' (Menon and Pandalai, 1957), in Sri Lanka as 'Dikiri', in Thailand as 'Maphrao Kathi', in Indonesia as 'Korpyor' and 'Dua Dac Ruot' in Vietnam. The macapuno character is probably a single recessive gene hence the homozygous palms need to be grown in isolation to ensure 100% yield of macapuno. Dwarf types have been selected from this normally tall type. However, the nuts do not sprout, although the embryo, once removed from the nut and washed free of endosperm, can be grown aseptically *in vitro*. Another variant is a fragrant cultivar, 'Nam Hom', a dwarf type that smells like pandanus leaf, that has been produced in Thailand and is now used for export. The water in 'Nam Hom' is not as sweet as another Thai dwarf variety 'Nam Wan' that has 6.5–7% total soluble solids at the green stage. In Sri Lanka, a cultivar 'Tembili' (King Coconut) has sweeter water and is grown for drinking only.

Increased yield of copra per unit area, was the aim of most breeding programmes (Santos, 1986), except where diseases or selection for the fresh market criteria take precedence (Harries, 1990b). Yield increase can be achieved by increasing the number of nuts per palm, rather than the amount of copra per nut, earliness of bearing (possibly linked to the annual rate of leaf production), palm vigour and disease resistance. Approaches have generally involved germplasm collection and evaluation, selection and progeny testing, crossing and evaluation in different growing regions for adaptability. The rate of improvement is limited by the long juvenile phase, low rate of plant multiplication, difficulty of making controlled crosses with some types, large seed size and its poor storability, high outcrossing of tall types leading to highly heterozygous offspring and the diverse environments used for coconut production. Successful hybrids between dwarf and tall types include 'Maypan' ('Malayan Dwarf' × 'Panama Tall'), 'Mawa' ('Malayan Yellow Dwarf' × 'West African Tall') and 'Maren' ('Malayan Red Dwarf' × 'Rennel Tall'). 'Maypan' was produced for planting in areas subjected to lethal yellowing disease (Harries and Romney, 1974) and, like 'Mawa', achieves higher yields by early bearing and increasing the number of nuts (Ooi and Chew, 1985; Bourdeix *et al.*, 1990) and, like 'Maren', has satisfactory fruit size (Illingworth, 1991).

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Elaeis guineensis oil palm

The oil palm, *Elaeis guineensis* Jacq. (*Arecaceae*), is an economically important crop to many third world countries in the humid tropics. It is the highest yielding and a highly profitable oil crop and is relatively easy to grow by large plantations and small farmers alike. It is the leading export oil crop providing a major source of external revenue to a number of countries and its versatile uses spawn a host of domestic industries. Oil palm cultivation has most of the elements of an environmentally sustainable crop suitable for tropical countries: mature oil palms replace the climax vegetation lost in degraded forests; use of a leguminous cover crop in the immature phase protects and replenishes organic matter and nutrients in the soil; efficient recycling of the crop waste (e.g. pruned fronds, bunch stalks, mill-waste fibres, sludge, shells) to the fields; and contribution towards rural-community development. The industry is well supported by very organized and sophisticated research and development and marketing programmes.

Historical origins

The African oil palm, *E. guineensis*, the oil palm of commerce, is indigenous to tropical Africa, concentrated in the rainforest areas of the West and Central African countries of Angola, Cameroon, Congo, Ghana, Ivory Coast, Nigeria and Zaire. The species occurs as semi-wild groves usually close to settlements of indigenous peoples as the oil palm fruit is an important dietary source of fat and vitamins to these people.

Crude palm oil obtained from the pulp or mesocarp of the fruit is the primary internationally traded commodity. Oil palm plantations were started in South-east Asia by the Europeans very early in the 20th century to obtain a substitute for animal fat in the production of wax, candles and margarine. They started with seedlings that originated from the four thick-shelled dura palms in Bogor Botanic Gardens, Java. The four palms presumably originated from the same fruit bunch in Africa and came to Indonesia via Amsterdam and Mauritius. With increasing demand for the oil as a food as well as other non-food uses and the availability of improved cultivars, especially the thin-shelled tenera hybrid, oil palm plantations have expanded tremendously since 1911 and continue to do so.

World production and yield

In terms of the world's total oils and fats production of about 121 million t, palm oil (21%) occupies second place next to soybean oil (25%). This will soon change. Palm oil, with 19.1 million t, worth about US$7.5 billion annually, dominates (47%) the international edible oil trade (Oil World, 2002). It is produced from about 7.4 million ha of plantations. Malaysia accounts for 48% of the production, Indonesia 35%, and others (Colombia, Ivory Coast, Nigeria, Papua New Guinea) the remainder. As the oil palm is a very productive (3–5 t/ha/year of oil) and profitable crop, its areas are expected to increase further, particularly in Indonesia and Colombia.

Uses and nutritional composition

The palm fruit produces palm oil from the mesocarp and kernel oil from the nut. Typically an oil palm fruit bunch will produce 20–25% palm oil and 3–5% kernel oil.

Crude palm oil, the main commodity, obtained from the sterilized mesocarp is refined, bleached and deodorized to give refined palm oil. Refined palm oil can be used directly or blended with other oils as cooking oil, salad oil, shortenings, margarines and spreads. Refined palm oil can be fractionated to give olein (liquid) and stearin (semi-solid) and with further fractionation gives fatty acids and alcohols, intermediate commodities traded and used in food and oleochemical (e.g. detergent, lubricant, plastics, pharmaceuticals, cosmetics) industries. Stearic acid is a cocoa butter substitute. Palm oil or as methyl ester (palm diesel) can be used as biofuel. However, 80% of palm oil is used as food but its other uses are increasing (Fig. A.15). Palm kernel oil competes with coconut oil in the food and oleochemical uses.

Prompted by health and environmental concerns besides profit motive, added value products from secondary and waste products from the palm oil industry are also gaining importance. Carotene in crude palm oil has been processed into a vitamim A supplement and a food dye. Tocols extracted from palm oil have been encapsulated and marketed as palm vitamin E. Sterols, squalene, co-enzyme Q and phospholipids, components of palm oil, have applications in pharmaceutical, nutraceutical, food and cosmetic industries. Kernel cake and sludge cake from the mill waste have use as animal feed while the bunch-fibre waste can be used directly in the plantation as organic mulch or processed into compost, or burnt together with the nut shells to provide power to the mill and the plantation residential community. Surplus power can be supplied to the national grid.

Palm oil contains *c.*50% saturated fatty acid and 50% unsaturated fatty acid (Table A.55) but some doctors, nutritionists and traders have equated it with coconut oil as saturated oils from tropical palms. Consumption of high amounts of such oils would predispose the individual to heart disease. Proponents of palm oil counter-argue that the saturated component is mainly palmitic acid that does not cause a rise in blood cholesterol. It has also a large component of monounsaturates (oleic acid, 40%) and substantial amounts of polyunsaturates (linoleic acid, 10%). Palm oil also contains antioxidants (carotene, tocols) which, besides conferring deep-frying stability, have anti-cancer and anti-atherosclerosis properties. It does not require hydrogenation in the production of margarines. Hydrogenation leads to the production of the trans fatty acids.

Nevertheless, improvement in the degree of unsaturation of palm oil is being sought through breeding and genetic transformation means. The target value is an iodine value of 70 (*c.* 70% unsaturation) to put it on a competitive basis with olive oil. Besides appeasing consumer health concerns, a more liquid oil from unsaturation allows it to penetrate the salad-

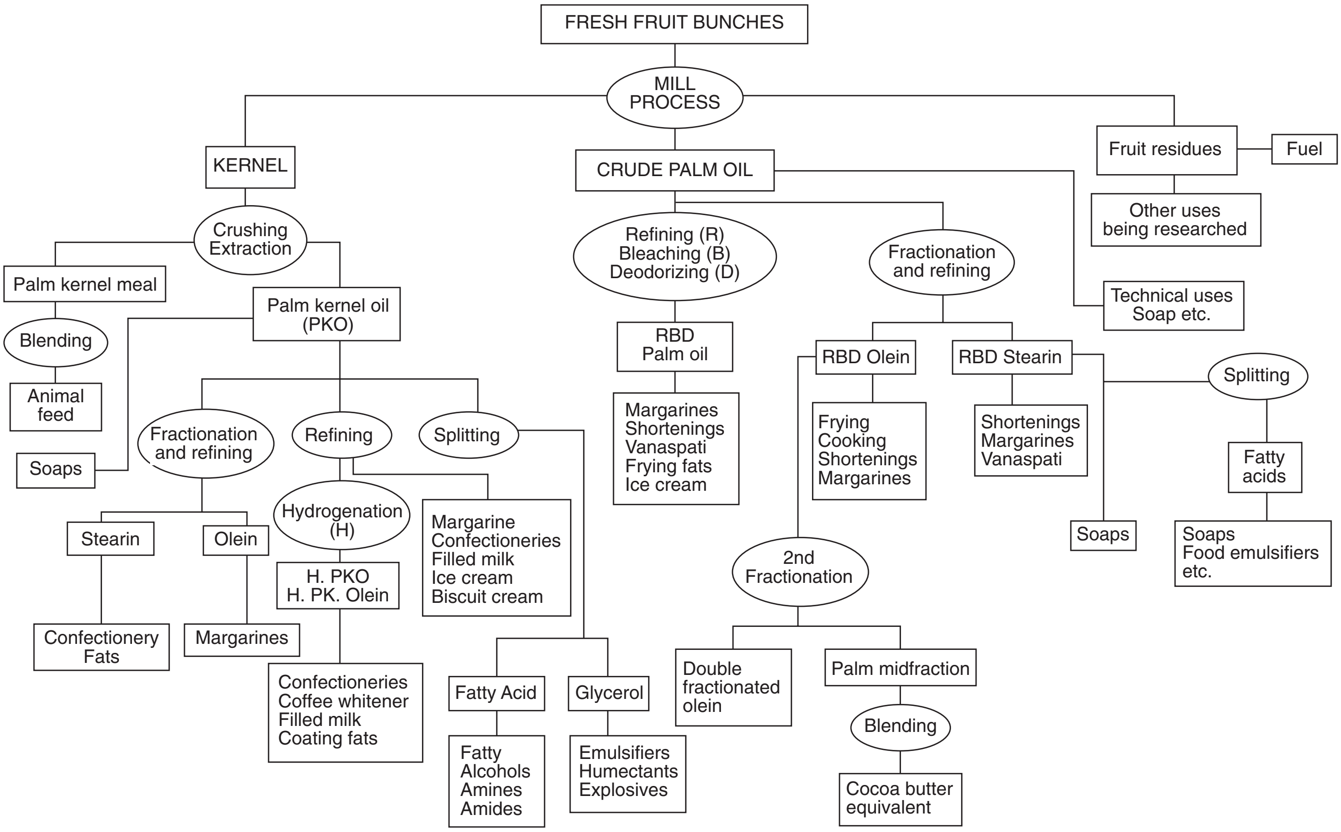

Fig. A.15. Uses of palm oil (Source: Pantzaris, 1997).

Table A.55. Variability of fatty acid composition in oil palm populations (Source: Arasu 1985; Rajanaidu, 1990; Rajanaidu *et al.*, 2000).

	Content (%)				
Fatty acid	Nigerian *Elaeis guineensis*	PORIM[a] *E. guineensis*	IRHO[b] *E. guineensis*	*Elaeis oleifera*	*E. oleifera* × *E. guineensis*
C14:0 (myristic)	0.3–3.1	0.9–1.5	0.3–1.6	0.1–0.3	0.1–0.5
C16:0 (palmitic)	37.4–46.6	41.8–6.8	34.7–50.1	14.4–24.2	22.4–44.7
C18:0 (stearic)	3.8–14.7	4.2–5.1	3.1–8.8	0.6–2.2	1.4–4.9
C18:1 (oleic)	33.0–55.9	37.3–40.8	32.0–46.0	55.8–67.0	36.9–60.1
C18:2 (linoleic)	5.4–15.8	9.1–11.0	10.0–16.0	6.0–22.5	8.3–16.8
Iodine value	43.8–69.8	51.0–55.3	–	67.4–91.9	–

[a] PORIM, Palm Oil Research Institute of Malaysia.
[b] IRHO, Institut de Recherche pour les Huiles et Oleaginuex.

and cooking-oil markets of the temperate countries. Genetic variability for unsaturated fatty acid and other oil quality traits are deficient in advanced oil palm breeding populations.

Botany

TAXONOMY AND NOMENCLATURE The genus *Elaeis* belongs to the *Palmae* or *Arecaceae* family and subfamily *Cocoidea*e. Jacquin in 1763 first described the African oil palm, *E. guineensis* Jacq. The American oil palm, *Elaeis oleifera* Cortes, which has a slower-growing procumbent habit with leaflets in one plane and different fruit traits, was known earlier as *Elaeis melanococca* and *Corozo oleifera*. Both species have $2n = 32$ chromosomes and hybridize readily but the hybrids exhibit varying degrees of sterility. The third species, *Elaeis madagascariensis*, is thought to be a variant of *E. guineensis*. There are also named vegetative and fruit variant forms of *E. guineensis*: leaf form – idolatrica (fused leaflets); fruit form – mantled/poissoni (fleshy mantle), dura (thick shell), tenera (thin shell), pisifera (shell-less); immature fruit colour – nigrescens (black/dark purple), virescens (green) and albescens (white).

DESCRIPTION The oil palm tree is mainly grown from seed, which takes about 100–120 days to germinate in nature after accumulating sufficient heat and moisture to break the dormancy. In commercial seed production, controlled seed germination is achieved by heating (37–39°C) the seeds at 18–20% moisture for 40–60 days and then setting for germination at 22–23% moisture under ambient conditions.

The oil palm has only one terminal bud. Stem growth in the first 3 years in the field is mainly in base enlargement. It can grow to a height of 25–30 m but in commercial fields it is replanted when it becomes too tall (12–15 m) for harvesting. The oil palm stem anatomy, typical of monocotyledons, consists of the cortex formed by the extension of the leaf bases; the pericycle comprising numerous vascular bundles with fibrous phloem sheaths embedded in sclerotic ground tissue, providing mechanical support for the stem; and the central core of less dense vascular bundles embedded in parenchyma ground tissue. The apical bud or meristem produces the leaf, which comprises the petiole, rachis and leaflets. The petiole is 1.3–2.5 m long, triangular in cross-section with spiny upper edges. The rachis in a mature palm measures 5.5–7.0 m long bearing 300–400 leaflets. The leaflets vary in length according to their position along the rachis with the middle being the longest at 1.2 m. Leaflet width ranges from 4 to 6 cm. The leaves are arranged spirally, seen as two sets of eight and 13 leaves running in opposite directions. A well-grown mature oil palm has 41–50 leaves, each having a dry weight of 4.5–5.5 kg and a leaf area of about 10 m^2.

The oil palm has a typical fibrous root system The hemispherical meristematic bole (*c.*80 cm diameter) grows downwards 40–50 cm into the soil. About 6000–10,000 primary roots extend > 20 m horizontally from it. Secondary roots branch out at right angles, upwards and downwards from the primary roots followed by tertiary roots from the secondary and quaternary from the tertiary, decreasing in size and length accordingly. The structure of the different roots is essentially similar with an outer epidermis, lignified hypodermis surrounding a wide cortex with large lacunae for root respiration and non-lignified root tips. The primary roots presumably have palm anchorage and conduit functions while the others are for water and nutrient absorption. Total root length may exceed 60 km.

The oil palm is monoecious bearing male and female flowers in separate clusters (Plate 15A, B). The inflorescence is a raceme with flowers occurring on spikelets arranged on a large spadix enveloped by two fibrous spathes. The male inflorescence has a stalk about 40 cm long bearing 100–300 spikelets, each 10–30 cm long. Each spikelet holds 400–1500 sessile, male flowers with six stamens each having bilobed anthers. A male inflorescence produces 10–50 g of pollen with viability lasting 3–8 days. The female inflorescence with a shorter and stouter stalk carries around 150 fibrous spikelets bearing five to 30 flowers each. The female flower has a protective spiny bract, two floral bracts and two whorls of three perianths each. At receptivity, the trifid stigma curves outward to receive the pollen. The stigmatic lobes are creamy white with sticky glandular central tissue. They turn pink after the first day, light brown on the second and violet on the third. The receptive period lasts 2–4 days and after pollination and fertilization, the stigma turns black and woody. Both male and female flowers develop and mature from the base of the spikelets upwards. They emit a characteristic aniseed smell.

Upon fertilization, the female inflorescence develops into an ovoid fruit bunch bearing between 500 and more than 4000 fruit and weighing 10–50 kg in a fully mature palm. Each fruit is a sessile drupe, ovoid-oblong shape, 2–5 cm long, about 2 cm wide and weighing 3–30 g (Plate 15D). It contains a kernel enclosed by an endocarp (shell), an oil rich mesocarp and a coloured exocarp. In the commonly grown nigrescens type, the fruit exocarp is black or dark purple turning to orange red at maturity.

REPRODUCTIVE BIOLOGY The oil palm flowers continuously in successive cycles of male and female inflorescences ensuring cross-pollination. Although the pollen is small and light (22×33 μm) and can be wind dispersed, in nature, pollination is mainly by weevils (*Elaeidobius kamerunicus*) and to a lesser extent by *Thrips hawaiiensis*. The insects are attracted to the flowers by the strong aniseed smell during anthesis/receptivity in search of food. Between 60 and 70% of the flowers develop into fruit. Inflorescence initiation commences at 37–39 months before fruit ripening and sex differentiation at 19–22 months. Good nutrition, high light intensity or low moisture deficit favours the development of female inflorescences while stress conditions favour male inflorescence production. Female inflorescences may abort a few months before receptivity and bunch abortion may occur a few months after pollination under severe water or other stress conditions.

FRUIT DEVELOPMENT Normally, only one of the three ovules is fertilized to form a seed within the fruit. The ovary develops rapidly from 16 to 90 days after pollination when maximum size is reached and the endosperm (kernel) completely fills the endocarp (shell). The mesocarp develops simultaneously attaining its maximum weight at about 130 days after pollination. The next phase involves the solidification of the kernel, which takes about 55 days, and the simultaneous oil synthesis in the kernel and the mesocarp. The latter process commences at 70 days from pollination, increases exponentially from 100 days and reaches the peak at 155–188 days. Maximum oil is attained in the mesocarp when at least 6% of the fruit have abscised.

In the typical nigrescens fruit the external ovary wall changes its colour from white to pale yellow prior to pollination, the fruit becomes dark pink at 60 days, black at 140 days and then orange-red at ripening. In the less common virescens type, the colour is greenish before turning orange at maturity, while in the albescens it remains pale yellow. At this stage, the fruit start to abscise and oil synthesis stops. Fruit ripening occurs at 120–200 days after pollination, depending on environmental conditions and genotype.

ECOLOGY AND CLIMATIC REQUIREMENTS The natural habitat of oil palm is riverine forests or freshwater swamps. It cannot thrive in primaeval forests and does not regenerate in tall secondary forests. It has adapted to diverse ecological zones in the tropical belt (longitudes *c.*15°N–15°S), from savannah to rainforests and highlands (< 1500 m) although it is widely grown on lowlands. It can grow on most tropical soils with adequate water supply. The best oil palm growth and yields are obtained from coastal and riverine alluvium without an acid sulphate (jarosite) layer within 75 cm, and deep (> 100 cm) soils of volcanic or sedimentary origin, and acid sands. Soils with pH 4–6 and slopes of < 20° are suitable. It can tolerate temporary flooding or a fluctuating water table, as found along rivers. Waterlogged, shallow lateritic, loamy sand to sand, stony or woody, peaty soils would confer low yields.

The ideal rainfall is 2000–2500 mm/year without any dry season (monthly rainfall < 100 mm). However, the oil palm can withstand annual rainfall between 650 and 4500 mm with 2–4 months of dry period. Severe moisture deficits of > 200 mm/year may induce male inflorescence and floral and bunch abortions. The suitable temperature for oil palm is a mean maximum temperature of 28–34°C and mean minimum temperature of 21–24°C. Oil palm growth is arrested below 15°C while floral abortion and delayed fruit maturity occur below 18°C. The oil palm being a C3 plant requires full sunlight for maximum photosynthesis. The desirable sunshine hours should exceed 5 h/day or 1825 h/year provided the high sunshine hours are not accompanied by drought, high water vapour pressure deficit (> 1.8 kPa) and/or extreme temperatures (> 38°C). The solar radiation should be at least 12 $MJ/m^2/day$.

Horticulture

PROPAGATION The oil palm is an out-breeding species. Commercial propagation is through hybrid seeds. Typically, tenera hybrids (thin shell, thick-mesocarp fruited palms) are obtained by controlled pollination of the thick-shell fruited dura female parent with the shell-less fruited female-sterile pisifera male parent (Plate 15C, D). Commercial seeds are mixtures of hybrids derived from parents which are non-true inbreds and the parents on each side may or may not be related. Consequently, considerable genetic variability exists among commercial palms.

MAIN CULTIVARS AND GENETIC IMPROVEMENT The main oil palm cultivars are designated by the parental populations, for example 'Deli' × 'AVROS', 'Deli' × 'Yangambi', 'Deli' × 'La Me'. Here is a brief description of the major parental populations.

- 'Deli' – This is the thick-shelled dura variety derived from the four Bogor palms. Subsequent distribution and selections in other countries led to the development of sub-populations, for example 'Ulu Remis', 'Elmina', 'Serdang', 'Dabou'. The 'Dumpy' and 'Gunung Melayu' are short variants. The 'Deli' is known for its bigger bunch and fruit. It is the source of dura mother palms in all major commercial hybrid seed-production programmes.
- 'AVROS' – This originated from the Djongo (best) palm in Zaire's Eala Botanical Garden and further bred in Sumatra, Indonesia to give rise to the well-known progenitor, SP540. Descendants of this palm have been widely distributed to become the source of pisifera parents for major seed producers worldwide, for example Colombia, Costa Rica, Indonesia, Malaysia, Papua New Guinea. 'AVROS' pisiferas are noted for their high oil-yielding and vigorous growth-conferring attributes.
- 'Yangambi' – This originated from the same source as the Djongo palm and thus has similar attributes to 'AVROS'.
- 'La Me' – This resulted from the breeding programme of CIRAD (Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement) from the 'Bret 10' palm in La Me, Ivory Coast. Descendents of the progenitor, 'L2T', are the pisifera parents of major seed-production programmes in Ivory Coast and Indonesia. 'La Me' progenies typically exhibit high bunch number, smaller bunch and fruit and smaller stature.

Other known but less widely used pisifera sources are 'Binga' (Palm Bg 312/3), derived from 'Yangambi', 'Ekona' (Palm Cam. 2/2311) from Cameroon and 'Calabar' (Palm NF 32.3005) from Nigeria.

Genetic improvement objectives High oil yield is the primary objective of genetic improvement. Improvement in oil content and smaller sized, high harvest-indexed palms for higher density plantings are aimed towards this. Ease of harvesting is important in labour scarce countries such as Malaysia. Short palms with long-stalked fruit bunches having non-abscising ripe fruit with a distinct colour change (e.g. virescens) will facilitate harvesting. Improvement in oil quality, particularly unsaturation, has received much attention in Asian programmes. High carotene oil palms are also being sought. These quality traits are in the domains of the *Oleifera* genome and wild *Guineensis* accessions and have to be introgressed into advanced *Guineensis* materials by backcross breeding or by genetic engineering because of hydrid sterility and the poor agronomic traits from the donor species.

With the development of the genetically more uniform hybrids and clones, breeding for adaptability and tolerance to abiotic (e.g. drought, mineral deficiency) and biotic (e.g. disease and pest) stresses would assume importance. *Fusarium* wilt resistance and drought tolerance are important objectives in African and American programmes. Breeding for *Ganoderma* (basal stem rot) resistance appears to become mandatory in many Asian programmes. Tolerance to magnesium deficiency is an important breeding objective in Indonesia and Papua New Guinea.

Breeding The shell trait exhibits monogenic inheritance. The thick-shelled dura is homozygous dominant, the shell-less pisifera is homozygous recessive and the thin-shelled tenera is the heterozygote exhibiting incomplete dominance. In breeding, 'Deli' dura mother palms are regenerated (100%) from dura × dura crosses of selected parents. The pisiferas being female sterile are regenerated from tenera × tenera and tenera × pisifera crosses of selected parents. The former cross gives 25% dura, 50% tenera and 25% pisifera progenies, while the latter cross gives 50% tenera and 50% pisifera progenies.

Oil palm hybrid seeds are obtained from recurrent selection progammes. In the modified recurrent method, the dura parents are selected based on the individual's performance for commercial seed production and for further breeding. The female sterile pisiferas are selected as male parents for commercial seed production based on their dura × pisifera progeny tests. Pisifera improvement is effected using phenotypically selected teneras. In the other modified reciprocal recurrent selection method, dura × tenera progeny tests are done instead. Selfs of the dura and tenera parents are planted at the same time as the progeny test. Based on the progeny test, the superior progenies are reproduced as commercial dura × pisifera hybrids using the parental selfs. Further breeding involves the progeny tested dura and tenera parents. This scheme produces more genetically uniform hybrids.

In vitro *propagation* Commercial mixed hybrids exhibit considerable variability in the field with individuals varying more than 30% from the group mean. The differences are not entirely genetic. Nevertheless, it stimulated the successful development of the *in vitro* propagation technique in the oil palm that cannot be vegetatively propagated and had been considered a recalcitrant species for *in vitro* propagation. *In vitro* propagation of oil palm is achieved via somatic embryogenesis from callus cultures using young leaf explants (Plate 15E). Large-scale commercial clonal propagation has been hampered by the spectre of somaclonal variation, manifested as mantled parthenocarpic fruit leading to fruit bunch abortion and consequent partial or full sterility (Plate 15F); the inefficiency of the cloning process; and the inefficiency of palm selection for cloning requiring rigorous clonal field tests. With the demonstration of the feasibility (improved cloning efficiency, low somaclonal variation) of recloning field-tested clones and the liquid suspension culture technique, large-scale commercial propagation of proven clones appears assured.

Cloning the parents of superior hybrids to produce biclonal (both clonal parents) or semi-clonal (one clonal parent) hybrid seeds is an alternative approach albeit with lower genetic improvement expected.

Genetic modification Transgenic oil palms carrying the Basta resistance gene obtained through the biolistics approach are at the field-testing stage. High oleic transgenic oil palm are in the pipeline. The production of polyhydroxy butyrate (PHB) by oil palm for biodegradable thermo-plastic production is a recent research initiative. There is a host of other possibilities. Transgenic palms can be commercially propagated as clones or used as breeding parents for hybrid seed production.

The development of molecular markers (e.g. restriction fragment length polymorphism (RFLP), amplified fragment length polymorphism (AFLP), microsatellites) has allowed breeding parents, families and populations to be accurately segregated pedigree-wise for population genetic study, breeding strategy and intellectual property ownership applications. Molecular markers linked to quantitative trait loci of desirable traits (e.g. shell thickness, virescens, embryogenesis) are being sought to develop marker-assisted selection to improve breeding efficiency.

Stringent field-testing protocols are being drawn up to ascertain the agronomic, environmental and consumer health acceptability of genetically modified (GM) oil palm.

CULTIVATION *Land preparation* This operation involves land clearing, drainage of wet areas, terracing on hills and construction of a network of roads for transport. The existing vegetation may be secondary logged jungle or a perennial tree crop such as rubber, cocoa or oil palm. Careful timing of land preparation is important to ensure the field is ready for planting at the onset of the rainy season.

Clearing Burning is the traditional method of land clearing for oil palm cultivation. The environmentally friendly zero-burn technique is now widely adopted in both new clearing and replanting of oil palm. The existing vegetation is usually mechanically cleared and stacked in windrows parallel to the planting rows. In an oil palm replant, the old stand is mechanically felled and the trunk chipped and stacked (using an excavator fitted with a sharpened-lipped bucket) to accelerate decomposition. Where pests (e.g. termites) and diseases (e.g. *Ganoderma* spp.) are prevalent, burning may be allowed by the relevant authorities. To control the *Oryctes rhinoceros* beetle, the standing palm or chipped palm residues are increasingly being mechanically pulverized to destroy potential beetle breeding sites.

Drainage and terracing Drainage is often required for the very productive flat coastal and alluvial plains to ensure a well-aerated rooting zone and to remove excess water during the wet season. The water table should ideally be > 60 cm below the soil surface.

Terracing is not necessary on rolling terrain of < 10° slopes, although conservation terraces spaced 25–30 m apart are important. On slopes > 10°, contour terracing is critical not only for soil and water conservation but also to provide access for field upkeep, fertilization and harvesting. Terraces are usually 3–4 m wide and 10 m apart with a back slope of 3–5°. Palms are planted along the terraces at varying distances apart (depending on the slope) to achieve a density close to 138–149 palms/ha. Wide terraces allow mechanization of fieldwork and must be incorporated in the land preparation process.

Layout of road system A well-planned road system is fundamental to efficient crop production and an essential component of land preparation. On flat to undulating terrain, field roads are usually spaced at 200 m apart with connecting roads at every 1 km. On hilly terrain roads should ideally have < 8° slopes and run diagonally across the slope. Road density depends on terrain and typically about 100–150 m/ha is required. Requirements will be reduced with mechanized in-field collection of harvested bunches.

NURSERY *Planting materials* Tenera hybrid seedlings are currently being planted in commercial fields. Commercial plantings of clones are constrained by the high cost and limited supply of proven clones. Seeds are usually obtained only from specialist seed producers to ensure legitimate and proven hybrids. Typically young oil palm seedlings are raised in a nursery for 12 months before field planting. Optimum conditions in the nursery ensure only uniform, vigorous and healthy seedlings are planted out in the field.

Prenursery In a two-stage nursery, germinated seedlings are first planted in small polyethylene bags or seedbeds filled with sandy loam or sandy clay loam soil for about 4 months before transplanting into large poly bags in the main nursery for another 8 months. Prenursery allows for more efficient management and use of space and water. A round of culling is done before transplanting into the main nursery. Shade is not essential but is often provided in the form of overhead nettings or cut palm fronds. Shade is reduced progressively and removed completely before the third month.

Main nursery The prenursery seedlings are transplanted into large poly bags spaced at 1 × 1 m in a triangular pattern in the main nursery. Germinated seeds may also be planted directly into the large poly bags as a single-stage nursery. Single-stage nurseries require more labour, supervision, space and water but seedlings have been reported to grow faster by about 2 months. Routine nursery practices of watering, fertilizer application and pest and disease control are carried out. Only the best uniformly grown seedlings are transplanted into the field.

FIELD PLANTING *Planting density* All commercial plantings adopt an equilateral triangular spacing ranging from 9 to 9.8 m giving a planting density of 149–120 palms/ha for maximum light capture by the single terminal palm canopies. The optimum density depends on the terrain, soils, growing conditions and genotype. On favourable soils and flat to gently rolling terrain, a density of 138 palms/ha is optimum. On more marginal conditions (e.g. peat soils), where palms are smaller and inter-palm competition is reduced, higher density planting (up to 160 palms/ha) is preferred to maximize yield per hectare.

Planting Planting is usually timed to coincide with the beginning of the wet season. Planting holes are usually dug with a tractor-mounted auger and 0.25–0.5 kg of phosphate rock is applied into the hole before the seedling is planted manually.

Establishment of leguminous cover crop Due to the long period (> 3 years) between land clearing and full palm-canopy covering, a creeping leguminous cover crop is planted immediately after land preparation to reduce soil erosion, suppress weed competition and improve soil fertility through nitrogen fixation, organic matter enrichment and nutrient transfer and recycling. This improves soil aeration, rooting and water conservation. A mixture of *Pureria phaseoloides*, *Calapogonium muconoides* and *Calapogonium caeruleum* leguminous cover-crop seeds is commonly sown at a rate of 5–10 kg/ha. A small starter dose of compound fertilizer is applied at 1–3 weeks after germination and three split dustings of phosphate rock totalling 600–1000 kg/ha given at 1, 3 and 5 months after germination. *Mucuna cochinchinesis* is gaining popularity due to its fast-growing habit enabling rapid ground cover and weed suppression and it is also shade tolerant.

IMMATURE PHASE The immature phase from planting to the start of regular harvesting varies between 24 and 36 months or more depending on growing conditions and management considerations. This is a crucial period in that large, fast-growing and vigorous palms are not only more precocious but are also higher yielding. The palms are also most susceptible to weed competition and pests and disease attacks at this age. Therefore the best possible care and growing conditions are given to these palms. Poorly established retarded palms and runts are replaced within the first 2 years to avoid over-shading by surrounding palms. Small farmers may plant a cash crop (e.g. pineapple, banana, papayas, melon) in the inter-rows during this period.

MATURE PHASE Under favourable growing conditions, the oil palm begins to produce flowers and fruit by 15 months after field planting and regular harvesting commences at 24–30 months. Fresh fruit bunch (FFB) yield increases rapidly over the first 4 years of production reaching a plateau by 8–10 years after planting. During peak production, yields of > 30 t/ha/year are common for well-managed plantings in good growing areas. The economic lifespan of an oil palm planting ranges from 20 to 30 years depending on growing conditions. Fields are replanted when the palms become too tall for economic harvesting. Social and other economic considerations also affect replanting decisions.

AGRONOMIC PRACTICES *Weeding* Weeds compete with the oil palm for water, nutrients and light and can suppress crop growth and production. Thick weeds also hinder access for field operations. The preferred method of weed management in immature plantings is to have a thick leguminous cover to smother the weeds in the inter-rows. Common weeds in Malaysia and Indonesia are: *Imperata cylindrica* (lallang grass), *Mikania* sp., *Clidemia* sp. and *Chromolaena odorata* (Siam weed). From planting, a clean-weeded palm circle of 1.5–2.0 m diameter and increasing to 4 m as the palms mature is maintained primarily to prevent weed competition. Manual circle weeding is preferred during the first year but the use of herbicides, at the risk of contaminating the young palm, is now common practice due to labour constraints. Young palms are sensitive to systemic and hormonal herbicides (e.g. glyphosate, diuron, 2,4-D amine) which can cause canopy twisting or spear snapping or parthenocarpic fruit development. The recent innovative use of a perforated 2.4 × 3 m ultraviolet-resistant plastic mulch over the palm circle after planting reduces the need for frequent, manual weeding in the first 6 months and minimizes chemical scorching of the lower leaves in the first 2 years. The whole first year's requirement of compound fertilizers is broadcast onto the palm circle before the plastic mulch is laid down thus saving labour costs for up to eight fertilizer applications otherwise needed.

For mature palms, clean-weeded palm circles are maintained to reduce weed competition and to facilitate loose fruit collection. Inter-row and path weeding is equally important to suppress the growth of competitive weeds, to provide easy access for routine upkeep and harvesting operations as well as to maintain a non-competitive ground cover for soil, moisture and nutrient conservation. Soft grasses (e.g. *Paspulum* sp., *Axonopus compressus*) and ferns (e.g. *Nephrolepis* sp.) are thus retained. Systemic herbicides applied with medium- and low-volume sprayers are the preferred method for weed control. Spraying intervals are aimed to break the seed-production cycles of the weeds. Biological control of weeds on a research scale has been attempted, for example the use of the leaf-eating caterpillar *Pareuchaetes pseudoinsulata* against *Chromolaena* in Indonesia and Malaysia.

Major pests and diseases The oil palm being a tropical perennial crop provides a continuous supply of food, host medium and suitable growth environment for a range of pests and diseases. Routine pest management is thus needed throughout the crop's life. Integrated pest management is generally advocated. This involves crop monitoring for infestations/infections and their prevention from exceeding economic thresholds by employing various cultural, physical, chemical and biological control measures.

Insect pests commonly reported to cause economic damage in Malaysia and Indonesia are the leaf-eating caterpillars, for example bagworms, *Metisa plana*, *Pteroma pendula* and *Mahasena corbetti*; and nettle caterpillars, *Setora nitens*, *Darna* sp. and *Setothosea* sp. They can cause severe defoliation resulting in significant yield losses. The planting of nectar-producing plants such as *Cassia cobanensis* and *Euphorbia heterophylla* to enhance the population of natural enemies of leaf-eating caterpillars as a preventive measure has been attempted in Malaysia. The potential of mass production of microbial pathogens of these leaf-eating caterpillars for commercial applications is also being explored. The current method of control used in outbreaks is trunk injection of systemic insecticides (e.g. methamidophos and monocrotophos) and spraying with chemicals with short residual effects (e.g. cypermethrin). In recent years, rhinoceros beetles (*Oryctes rhinoceros*) have become an important pest of replanted palms in Malaysia, Indonesia and India. Adult beetles burrow into the soft meristem tissues of the palms to feed, disfiguring the developing foliage and this may lead to the consequent death of the palms. Fortnightly spraying with cypermethrin is the current control method. The beetles breed in the decaying palm biomass so experiments are being conducted using cultural control measures to speed up decomposition of the old palm biomass to deprive the beetles of suitable breeding sites. Biological control programmes involving trapping adult beetles with pheromone baits followed by infection with a pathogenic virus before being released, and augmentative release of the pathogenic fungus *Metarhizium* sp. into the old palm residues have been reported.

Coptotermes curvignathus termites cause severe losses of young palms planted on peat in Malaysia and Indonesia. They bore into the meristem tissue in the crown to feed, causing death within 6–12 months after infestation. A current common control measure is to drench the crown and soil around the base of the infested palms with the insecticide Fipronil. The use of baits containing sublethal doses of insecticides that could be carried to the nests by the workers to destroy the reproductive queens has been reported.

Rats (*Rattus tiomanicus*, *Rattus diardii* and *Rattus argentiventer*) are a chronic pest of oil palm that require recurrent control measures. In young palms, rats feed on the frond bases, male flowers and fruit. In mature palms they feed on the mesocarp and kernel of the developing fruit causing 5–10% losses in oil yield. The common method for control is the use of anticoagulant-based baits. This is sometimes augmented with biological control using barn owls (*Tyto alba*).

Jungle fringe plantings are prone to damaging attacks by larger mammalian pests such as elephants, wild boar, porcupines and monkeys.

Serious arthropod pests in South America include the *Tetranchus* sp. spider mite, and the lepidopterans *Leptopharsa gibbicarina* and *Sagalassa valida*, the former two attacking the leaves while the latter attacks the roots.

Most reported diseases of oil palms are caused by fungi, however, some diseases of economic importance have implicated viruses (e.g. ring spot disease in India), bacteria (e.g. *Erwinia* sp. in little leaf disease in Zaire) and nematodes (*Bursaphelenchus cocophilus* in red ring disease in South America). In most cases, management of these diseases is through cultural control by excluding the disease organisms from areas where it is not known to occur, destroying diseased palms and control of the associated vectors of these diseases. In addition, providing the palms with optimum growth conditions and balanced nutrition would maximize vigour and minimize infection incidences.

Basal stem rot (*Ganoderma* sp.) is an important disease of oil palm in most countries where it is grown. In young palms, the external symptoms normally comprise one-sided yellowing or mottling of lower leaves followed by necrosis and retarded growth. In mature palms, common symptoms are the presence of multiple unopened leaf spears and pale canopy. Tissues of the infested stem give a characteristic dry rot and the palm collapses with severe rotting. Basidiomata may be produced on the dead palm tissues. Disease incidence increases with age of the palms with reported incidence as high as 67% at 15 years resulting in a 46% reduction in yield. Infected young oil palms normally die within 6–24 months after the first appearance of symptoms, but mature palms can take up to 2–3 years to die. Cultural measures to exclude and destroy the inoculum of the disease is the current method of control. Infected palms are felled and chipped into small slices and spread out thinly to hasten decomposition, and the soil around the bole is dug up to expose the infected roots. The inoculation of oil palm seedlings with vesicular-arbuscular mycorrhizal fungi to prevent infection of the palms in the field is being explored. Screening for disease-tolerant genotypes is also being pursued. *Ganoderma* disease of palms is the subject of an international cooperative research effort coordinated by CABI.

Vascular wilt caused by *Fusarium oxysporum elaedis* is a serious disease of oil palm in West Africa and has been introduced into South America. It is a soil-borne disease attacking young and older palms. In infected older palms the older leaves desiccate and the rachis break at some distance from the base, the disease moves up the spiral leaving reduced-sized chlorotic green leaves at the crown and the palm may remain in this state for a while before collapsing. In young palms, the symptom of 'lemon frond' appears at the upper mid-crown before drying and this then progresses to the younger leaves and results in the subsequent death of the palm. Tolerant genotypes are available; a nursery screening technique has been developed and is routinely used in breeding programmes in West Africa.

Lethal bud rot hampers oil palm expansion in South America. Its pathogenic basis is in contention although some resistant cultivars have been claimed. Sudden wither or marchitez sorpressiva used to be a serious disease of oil palm in South America but has been brought under control with eradication of infected palms. It is caused by the flagellate

Phytomonas sp. which is transmitted by *Lincus* sp. of the Pentamidae. Blast is an important nursery-seedling disease in West Africa. The causal agent is unknown but a vector (*Recilia mica*, Jessidae) has been implicated.

Crown disease occurs sporadically on 2–4-year-old palms with characteristic symptoms of bending young leaves. Palms generally recover readily from the disease with no apparent defect but severe and extended symptoms retard early development and reduce yield. Disease susceptibility is known to be under the control of a recessive gene and a modifier gene and can be bred out. The 'Deli' material is particularly susceptible.

Pruning Inflorescences and fruit bunches occur at the frond axils. The subtending leaf of a ripe bunch is usually removed at harvesting. However, not every leaf will carry a fruit bunch and regular pruning is necessary to remove excess leaves. For tall palms, excess leaves trap loose fruit and obstruct visibility of ripe bunches for harvesting. In early palm maturity pruning twice a year is needed but when fully mature, an annual pruning round suffices. Over-pruning, especially during early maturity, is detrimental due to reduction of leaf area. A general guide is to maintain a full canopy with at least two leaves below the oldest bunch for young palms (< 8 years) and one leaf for older palms. Harvesters usually carry out pruning during low-cropping periods, using the same tools as they use for harvesting. Pruned leaves are spread over the inter-rows as organic mulch and are very effective for soil conservation.

Soil and water conservation Soil erosion can be very serious especially when hilly terrains are cleared for planting. Despite the high annual rainfall in the tropics, periodic water stress is not unusual due to uneven distribution of rainfall and high evapotranspiration demand. The need for effective soil and water conservation is well recognized and emphasized in well-managed commercial oil palm plantations where terrace plantings, cover-crop planting and mulching are used as discussed earlier.

Nutrition and fertilization Nutrient demand is very high for a high-yielding stand of oil palm. This is due to its potential for very rapid vegetative growth and the precocious and very rapidly ascending yield pattern from the onset of maturity to peak yields in years 8–10 after planting. Thus, large quantities of nutrients particularly nitrogen (N) and potassium (K) are immobilized each year in the vegetative tissue and exported in the harvested crop (Fig. A.16). The annual uptake of N and K for a stand of mature palms yielding 25 t/ha/year FFB is estimated at 193 kg/ha/year N and 251 kg/ha/year K, respectively. As the oil palm is mainly grown on highly weathered acid soils in the tropics, adequate and balanced fertilization is essential to realize and sustain the palms' high genetic growth and yield potential. Fertilizer rates may vary from 110 to 185 kg/ha/year N and 185–300 kg/ha/year K depending on soil fertility and actual yield levels. Other important nutrients are phosphorus (P) and magnesium (Mg) and these are applied at rates of 50–60 kg/ha/year P and 30–40 kg/ha/year Mg. Among the micronutrients, boron (B) is most important especially on sandy soils. Applications of copper (Cu) and zinc (Zn) are often required with peat

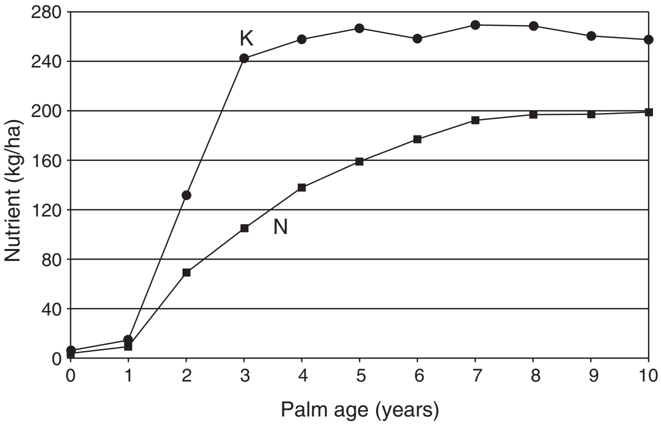

Fig. A.16. Estimated annual nitrogen (N) and potassium (K) uptake (kg/ha) in oil palm (Source: Ng, 1977).

plantings. Application rates are usually 100–200 g/palm of borate and copper sulphate or zinc sulphate, respectively. Consequently, the costs of fertilizers and application constitute the single largest component of production cost (> 60% of field cost, 20% of total cost) in oil palm plantations. Understandably, fertilizer usage is a major focus of most R&D and advisory programmes.

The system of fertilizer recommendations and management for oil palm is well developed based on a vast database of experimental results and practical experience. Palm nutrient requirements are estimated based on the nutrient balance approach where nutrient inputs from the soil, recycled in palm residues and mill by-products and from the rain are balanced against nutrients exported through the crop, immobilized in the tissues and lost via run-off, leaching or soil immobilization (Fig. A.17). Any shortfall is augmented as applied fertilizers. Leaf analysis is usually carried out annually and soil analysis every 3–5 years to assess and monitor the palm and soil nutrient status, respectively.

Based on the above nutrient balance approach, an integrated site-specific fertilizer recommendation system (INFERS) has been developed for the diagnosis of fertilizer requirement in Malaysia and has been subsequently expanded into an oil palm agronomic recommendation system called ADEPT™. This system includes an empirical site yield potential model (ASYP), to estimate the yield potential for each unique site; INFERS, to provide a balanced nutrition for

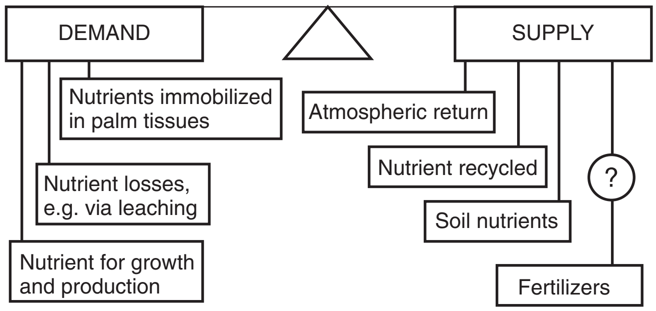

Fig. A.17. Components of nutrient balance in oil palm.

optimum growth and yield; and a 'Best month' expert system to optimize timing of fertilizer application. A Global Positioning System (GPS) and Geographical Information System (GIS) have also been incorporated in the ADEPT^{TM} to facilitate implementation, display and communication. These developments are geared towards precision agriculture for more accurate fertilizer recommendations to sustain high growth and production.

HARVESTING *Ablation and sanitation* Only in less favourable growing conditions is ablation (removal of first inflorescences) carried out 20–24 months after planting, to promote vegetative growth and root vigour. Otherwise, ablation is unnecessary. Usually a round of sanitation pruning (removal of dried, dead leaves, old flowers and rotten early bunches) is carried out about 6 months prior to regular harvesting.

Ripeness standard During ripening (15–20 days) carbohydrates accumulated in the fruit are converted into oil. When the fruit has fully ripened and the oil content is at its maximum, it loosens and detaches from the bunch. Once detached, the free fatty acid (FFA) content increases rapidly due to breakdown of glycerides by the microbial lipase enzyme.

Harvesting of under-ripe bunches would result in lower oil content, while harvesting over-ripe bunches would result in more loose fruit lost and high FFA levels in the oil. The optimum ripeness standard is in between these two extremes. A practical guide is five to ten loose fruit per bunch for <8–10-year-old palms and one to five loose fruit for older palms when harvesting is done at 10–14 day intervals.

Harvesting interval Fruit bunches are produced throughout the year although there is a distinct peak and trough in the annual cycle. Harvesting of ripe bunches is therefore a year-round activity done at intervals of 8–14 days. Harvesting at intervals of 7 days or less is usually not economic especially during the trough period. Conversely, harvesting intervals exceeding 15 days will result in an excessive number of loose fruit, incurring higher labour costs in loose-fruit collection. Any ripe bunches inadvertently missed will become seriously over ripe or rotten by the next harvest. Harvesting intervals of 10 days are recommended but may be extended to 15 days during peak yield cycles.

Harvesting At the start of production, the young palms produce many, relatively small (2–5 kg) bunches. As the palms mature, fewer but bigger bunches (up to 50 kg or more) are produced. Harvesting is done manually by skilled harvesters. Young palms are harvested using a long chisel with a broad, sharp cutting edge. As palms get taller with age, this is replaced by a sickle attached to a light but strong bamboo or extensible aluminum pole (up to > 12 m). Prototypes of mechanical harvesting cutters and machines are being tested. The harvested bunches and loose fruit are collected and deposited at specific points along collection roads. Traditionally hand-baskets, wheelbarrows and buffalo-drawn sledges are used. Terrain permitting, mechanical in-field collection is done using a mini-tractor fitted with a mechanical grabber and high-lift trailer which then dumps the crop onto bins or trucks for transport to the palm oil mill for processing within 24 hours.

PROCESSING Upon arrival at the palm oil mill the harvested bunches are sterilized by pressurized steam (about 40 psig) in an enclosed chamber to facilitate the stripping of fruit from the bunch and to stop the enzymatic conversion of oil into FFA. The sterilized FFB are then mechanically threshed to strip off the fruit. The empty fruit stalks/bunches (EFB; about 22% of FFB, containing 0.72% N, 0.08% P, 2.64% K, 0.27% Ca and 0.12% Mg on a dry-matter basis) are returned to the field as fertilizer/soil ameliorant. The stripped fruit are then sent to a mechanical digester, which pulps and heats the mesocarp to rupture the oil-bearing cells. The resultant mash is transferred to a screw press to extract the mesocarp oil (crude palm oil or CPO; about 20% of FFB). The CPO is then screened, purified and vacuum dried and stored in a specially constructed storage tank for onward shipment to the buyers (refiners). CPO buyers would usually specify that it should contain < 5% FFA, and moisture and dirt content < 0.25%. The nuts are separated from the screw press cake, cracked and the kernel (about 6% of FFB weight) extracted. The oil and kernel extraction rates (OER and KER, respectively) are based on the amounts of oil and kernels processed from the FFB. The kernel contains about 50% oil, mainly lauric oil similar to coconut oil. Extraction of kernel oil is carried out in a separate mill usually outside the plantation.

PRECISION AGRICULTURE AND TECHNOLOGICAL INNOVATIONS Precision or site-specific agriculture implies the concept of using information about variability in site, climate and palms to manage distinct units within a field with best practices for optimum profitability, sustainability and protection of the environment. Traditionally, oil palm plantations are divided into *c*.40 ha management units. Although soil and terrain are usually taken into consideration in delineating blocks, it is often not possible to achieve a satisfactory degree of uniformity within the blocks for uniform application of inputs.

With recent advances and affordability in GPS, GIS and Variable Rate Application (VRA) technologies, the reduction in size of the management units to that of the size of a harvesting task of about 1 ha for yield monitoring and application of fertilizer and other inputs is now feasible. GPS/GIS/Remote Sensing technologies have enabled more accurate mapping of field boundaries (roads, waterways, terrain) and coupled with recent innovative technological tools (e.g. information technology, computers, hand-held organizers, sensors), which can be linked to mechanized field operations, would allow the plantation management to be more precise and efficient. Roads, drains and terraces would be planned more efficiently. It may be possible in the near future that yield records can be captured digitally and accurately, yield maps drawn and poor yielding fields delineated, to be followed by remedial agronomic inputs (fertilizers, pesticides) perhaps using VRA technology. These concepts are currently being tested. It is envisioned that the future plantation manager will eventually become a knowledge worker with ready access to the case history and potential of each of their management units and to the latest knowledge and tools to achieve the best productivity from their plantation.

Concluding remarks

As per capita intake of edible oil is still low in many countries and palm oil is the cheapest, most profitable and versatile oil, oil palm plantations are likely to expand further in developing countries with suitable climates, particularly in South-east Asia and South America. In countries with a mature oil palm industry such as Malaysia with increasing costs of production, the challenge is to maintain sustainability, profit-wise and environmentally. This will have to be met through increased investments in research for new palm oil uses, improved cultivars and precision farming.

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Elaeis oleifera corozo

Corozo or American oil palm, *Elaeis oleifera* (H.B.K.) Cortes. (*Arecaceae*), is the only member of this genus of two species found natively in the Western hemisphere. It is used as an oil source to some extent throughout its range.

World production and yield

Rarely cultivated, the American oil palm is primarily an extractive resource from wild stands, and there is very little production data available. Fruit range from 8.5 to 12.8 g in weight and clusters rarely more than 22 kg. Annual yields average about 25 kg of fresh fruit, which equals nearly 13,000 individual drupes (Balick, 1979a, b). About 75–85% of the oil contained in the fruit mesocarp is recovered. Though the oil extracted from the fruit is higher quality than that of *Elaeis guineensis*, the American oil palm is much less productive.

Uses and nutritional composition

The fruit contains 30–50% oil, the seed (kernel) only slightly less. The fruit oil is nearly 50% saturated fat (33% palmitic), but it also contains a sizable fraction of unsaturated fatty acids of which 50% is oleic and 12% linoleic (Duke, 2001).

Botany

TAXONOMY AND NOMENCLATURE The American oil palm is the only other species in the genus *Elaeis* other than the African oil palm, *E. guineensis*. Synonyms include *Alfonsia oleifera* H.B.K., *Corozo oleifera* (H.B.K.) Bailey and *Elaeis melanococca* Gaertn. emend. Bailey.

DESCRIPTION The American oil palm is a fairly small, often procumbent single-stemmed palm. The stem is 1–6 m long and up to 0.5 m in diameter. Typically only the upper 1–3 m of the trunk is erect; the proximal portions lie on the soil surface, rooting from their lower surface. The arching, feather-like leaves are several metres long and number 30–40 with 35–90 two-ranked leaflets per side, without the basal swelling found in *E. guineensis*. The petiole is spiny. Male and female inflorescences are produced on the same plant, often sequentially. The flower stem is a short-stalked, congested cluster of 100–200, sharp-pointed spike-like branches up to 16 cm long. The flowers are sunken into their surface. The (usually) one-seeded, ellipsoid fruit are crowded into rounded, conical clusters and ripen from yellow to red. Each fruit is 2–3 cm long. Many of the fruit are reportedly parthenocarpic.

ECOLOGY AND CLIMATIC REQUIREMENTS *Elaeis oleifera* ranges through Central America and northern Colombia at low elevation, with scattered occurrences in the Amazon basin, perhaps the result of human introduction. It is usually found in low-lying, moist soils along watercourses. While sometimes observed in drier forests, between 1700 and 2200 mm of annual rainfall is considered optimal (Duke, 2001). Soils with a pH of 4–6 are suitable for cultivation, and the palm has no tolerance of freezing temperatures.

REPRODUCTIVE BIOLOGY Bees are thought to be the primary pollinators of American oil palm, with some wind pollination as well. While the palms primarily produce separate staminate and pistillate inflorescences, bisexual inflorescences are sometimes observed.

FRUIT DEVELOPMENT Fruit ripen from January to June, the clusters held fairly close to the ground. Typically, five clusters of ripe fruit are produced each year. Palms are generally in excess of 10 years of age before production begins. Fruit ripen in 6 months after pollination.

Horticulture

PROPAGATION On the rare occasions when the American oil palm is deliberately cultivated, seeds are sown directly into germination beds and seedlings transplanted into a field site in 1–1.5 years. Seed germination begins after several months, and can continue erratically for over a year. Seedlings can also be container grown.

NUTRITION AND FERTILIZATION Applications of ammonium sulphate and potassium sulphate at a rate of 225 g/palm are recommended shortly after planting in the field (Duke, 2001). On magnesium-deficient soils, 227 g magnesium sulphate or slowly soluble kieserite should be added. These amounts can be increased to 450 g/palm over the next 4 years.

TRAINING AND MAINTENANCE Young seedlings need to be kept well irrigated and shaded from too much direct sun. The seedlings are slow growing, and 7 years may transpire before a normal-sized leaf is formed. Cover crops and inter-cropping with other food plants is often practised.

DISEASES, PESTS AND WEEDS Many of the same pest and disease organisms that attack African oil palm in the Americas can also affect the American oil palm (see entry on *E. guineensis* for specific information).

MAIN CULTIVARS AND BREEDING The American oil palm has been bred with the far more economically important African species in order to increase the oil quality of the more productive *E. guineenesis*. Some of these hybrids have then been reproduced clonally via tissue culture. Alan W. Meerow

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Euterpe oleracea assaí

Assaí, *Euterpe oleracea* Mart. (*Arecaceae*), is a slow-growing, clustering palm of the Amazonian rainforest. Assaí grows on indundated soils of the Amazon basin and similar areas of northern South America, often close to the coast. The fruit, and especially the liquid extracted from the pulpy mesocarp, is an important food resource in tropical America.

Related species with similar uses include *Euterpe precatoria*, known as assaí de terra firma, a single-stemmed (solitary) palm, growing to a maximum of 20–22 m in height. The crown shaft is composed of 14–19 leaves, each reaching 3.5–4.5 m in length. A large number of pendent leaflets confer a unique, ornamental appearance to this palm. The stem and root system are similar to those of *E. oleracea*. The inflorescences are larger than those of *E. oleracea*, bearing a larger number of rachillae (70–76) and flowers. The flowers are lighter in colour, usually a pale yellowish pink (male) and light brown (female). The fruit are globose, 1.0–1.8 cm in diameter, dark purple when mature, with a thin (0.5–1.5 mm thick) and juicy mesocarp from which a beverage very similar to açaí or or vinho de açaí is prepared. *Euterpe precatoria* occurs almost exclusively in non-inundated forests. Its floral biology and reproductive system are similar to those of *E. oleracea*.

World production and yield

Few data are available on production of assaí, which occurs only within the area of the palm's natural range, since it is chiefly harvested from wild populations. About 4000 ha of exploited assaí forest on Marajó Island in Brazil produced 7 t of pure and sweetened assaí pulp for export to the USA in 2000. One stem on average produces four to eight fruiting stems annually, each one yielding approximately 4 kg of fruit.

Thus, one stem can provide 16–32 kg of fruit, with a mean of 24 kg/year (Bovi and de Castro, 1993).

Uses and nutritional composition

The assaí palm is an extremely important indigenous resource for people in areas bordering the Amazon estuary (Strudwick and Sobel, 1988). It has been the focus of considerable research directed towards its commercial exploitation (Calzavara, 1972; Anderson, 1988; Brondízio, 2002). People harvest the fruit by climbing the palms, cutting the inflorescence and extracting the fruit pulp mechanically or by hand. The nutrient content is reportedly as follows: 1.25–4.34% (dry weight) protein; 7.6–11.0% fats; 1–25% sugar; 0.050% calcium; 0.033% phosphorous; and 0.0009% iron (Mota, 1946; Campos, 1951; Altman, 1956). It also has some sulphur, traces of vitamin B1 and some vitamin A. Calorific content ranges from 88 to 265 kcal/100 g, depending upon the concentration. It is processed into beverages, ice cream and pastries and is sold at local or regional markets, and also by the local businesses that process the fruit (known in Brazil as as açaílandias). Mixed with cassava flour or rice, it is consumed in great quantity (2 l/day/capita) by the population of the lower Amazon River. The flavour has been described as nutty with a metallic aftertaste. The texture is creamy to slightly oily. Details of assaí processing, consumption, and marketing can be found in Strudwick and Sobel (1988). Assaí liquid, locally called açaí or vinho de açaí (though not alcoholic), is highly perishable and this factor has restricted its export. However, the dehydrated liquid can be kept for 115 days after preparation (Melo *et al.*, 1988), and in this form, as well as frozen pulp, it has been imported into the USA and Europe in recent years, where it is sold in health food stores and used an ingredient in so-called 'energy' beverages. The inner stems (palm heart) are also extracted and eaten locally, as well as canned for export.

Botany

TAXONOMY AND NOMENCLATURE *Euterpe* consists of seven species (Henderson and Galeano, 1996) of monoecious pinnate-leafed, solitary or clustering palms ranging from Central America to northern South America and Trindad in the West Indies. Assaí is also known by the common names murrap, naidi (Colombia), pinot (French Guiana), manaka (Surinam) and manac (Trinidad).

DESCRIPTION *Euterpe oleracea* produces several stems reaching up to 20 m in height. The slender trunks are grey at maturity and 7–20 cm in diameter. A skirt of roots is usually visible at the base of the stems, and in swampy conditions, upward-growing pneumatophores may be formed. The crown consists of eight to 14 leaves, each 2–4 m long. The leaf bases are tightly sheathing and form an attractive, smooth crown shaft that can be green or variously yellow, red or purple. The 50–62 widely spaced leaflets are pendulous in orientation on the rachis, and can reach nearly 1 m in length. The many-branched flower stems reach about 1 m in length, emerging from below the crown shaft. The inflorescence is composed of a central stiff rachis with an average of 54 lateral branches (rachillae), each of which bears clusters of two lateral staminate (male) flowers and one central pistillate (female) flower, except at the terminus where only staminate flowers occur. The flowers are unstalked (sessile). The purplish male flowers are 4.5 × 2.7 mm; the purple to light brown female flowers are 3.2 × 2.6 mm. The ultimate branches are densely covered with light brownish-white hairs. The fruit is a 2 cm diameter drupe that is purple at maturity (some assaí populations that have mature green fruit are known locally as white assaí). The mesocarp is sweet and pulpy.

ECOLOGY AND CLIMATIC REQUIREMENTS Assaí can form extensive stands in swampy forest and along river courses in rainforest. In the Amazon estuary, it may occur in huge, monospecific populations. It is intolerant of dry situations and prefers an organic acidic soil, high humidity and warmth. It is most adaptable to humid, tropical climates where temperatures rarely drop below 10°C.

REPRODUCTIVE BIOLOGY *Euterpe oleracea* is monoecious; each inflorescence produces numerous, small, sessile staminate and pistillate flowers. Staminate flowers mature before the pistillate flowers, thus promoting outbreeding. However, a variable amount of self-pollination can occur depending on the synchronization between inflorescences in the same or different stems. The pollinators are predominantly small bees and flies, as well as beetles. The palms can achieve reproductive maturity in as few as 4 years under excellent conditions. Individuals growing under the forest canopy take longer to start flowering. Assaí palms flower year-round, but drought may induce inflorescence abortion (Jardim and Anderson, 1987). Seed dispersal over short distances is by rodents. Long-distance seed dispersal is accomplished by birds (Zimmermamm, 1991) and passively by water.

FRUIT DEVELOPMENT The maximum number of fruit clusters per plant is about eight, although three or four is typical. On any stem, there will usually be infloresecences and fruit at all different stages of development, from flower stems enclosed in the bracts to clusters of ripe fruit. Fruiting occurs throughout the year, but the peak period of production is the dry season, July–December.

Horticulture

PROPAGATION Only recently has there been interest in developing production plantations of *E. oleracea* (Nogueira *et al.*, 1995). Slow initial growth and considerable mortality of seedlings have been the main problems to its successful establishment in the field (Bovi *et al.*, 1987).

Assaí seeds are recalcitrant and sensitive to both dehydration and low temperature during storage (Araujo and de Silva, 1994). Refrigeration will kill the seeds. Seeds are best air-dried for several days to 1 week after removal from the fruit, then stored in plastic bags at room temperature, but for as short a time period as possible. Seed stored for 15 days had 33.3% moisture content and 79% germination (Araujo and de Silva, 1994). After 2 months of storage germination was reduced to 28%, and to 8% after 7 months. Seed usually germinates in 4–8 weeks, but germination may continue for nearly a year (Bovi and de Castro, 1993).

Chup (1999) found beneficial effects on growth of assaí by inoculating seedlings in containers with arbuscular mycorrhizal fungi. Ledo *et al.* (2002) reported successful somatic embryogenesis from *E. oleracea*, which may have utility in the rapid propagation of selected clones in the future.

NUTRITION AND FERTILIZATION The most productive assaí stands are located on moist, organic, acid soils. No data on mineral nutrition and fertilization are available.

DISEASES, PESTS AND WEEDS No major pests or diseases of assaí have been reported. Zorzenon and Bergmann (1995) described fruit and seed predation on *E. oleracea* by *Xyleborus ferrugineus* (Coleoptera: Scolytidae). Seed germination was reduced by 80%.

MAIN CULTIVARS AND BREEDING No cultivars of assaí palm have been developed. Though no formal breeding effort has been carried out on the species, interspecific hybrids between *E. oleracea* and *Euterpe edulis* have been produced in Brazil (Bovi *et al.*, 1987). Alan W. Meerow

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Hyphaene thebaica doum palm

Doum palm, *Hyphaene thebaica* (L.) Mart. (*Arecaceae*), is an African palm distributed from western India through the Middle East and south to tropical Africa. It is most common in coastal East Africa and in Eritrea. Though never cultivated as far as is known, people have used the fruit and seeds for centuries throughout its range. Other species in the genus are used similarly. In Egypt, the doum palm has been revered as a sacred tree, symbolizing masculine strength.

World production and yield

The doum palm is merely exploited from wild populations throughout its habitat, thus no data are available. A mature tree (6–8 years old) produces about 50 kg of fruit annually.

Uses and nutritional composition

The unripe seeds are edible, but the bony endocarp renders the ripe ones of sufficient durability to be used as a weapon. The hardened endosperm of the ripe seed has been used as vegetable ivory. In Africa they have been crushed and utilized as a millet substitute. The mesocarp of the fruit, though fibrous and tough, can be variably sweet and pleasant tasting, suggestive of carob or even ginger. They are often processed into a beverage, but in the deserts of northern Africa, the mesocarp is a significant source of nutrition. Seeds contain 4–5% protein. The plumule of the young seeding just below ground is eaten as well. Like so many palms, many other parts of the plant are used for fibre, forage and construction. A variety of medicinal uses have been reported as well.

Botany

TAXONOMY AND NOMENCLATURE *Hyphaene* consists of six to ten species of fan-leafed palms of arid and semi-arid areas of the Old World. They are most diverse in Africa and there is little doubt that man has influenced their distribution, either by deliberate or accidental introduction. *Hyphaene thebaica* is the most widely distributed species in the genus. It is a member of the tribe *Borasseae*, a group of dioecious palms distributed about the perimeter of the Indian Ocean and its islands. Various other vernacular names include zembaba (Amharic), dom (Arabic), gingerbread palm (English) and mkoma (Swahili).

DESCRIPTION The doum is one of the few palms that branch dichotomously on the aerial stem, one or more times, and eventually can reach 10 m in height. The stiff leaves are large and costapalmate (fan-shaped with an extension of the petiole into the blade). The leaves are ribbed and the petiole is fiercely armed with sharp teeth. The palms are dioecious. Staminate and pistillate inflorescences, produced from between the leaves, are similar catkin-like (male) or club-shaped (female) branches that arise in clusters from a central rachis. The entire inflorescence can exceed 1 m in length. The small individual flowers are in sunken pits densely arranged on these branches. The fruit is a drupe about 5 cm in diameter that turns yellowish brown at maturity.

ECOLOGY AND CLIMATIC REQUIREMENTS Doum palm populations achieve their greatest size and productivity in moist, tropical climates and can form thick stands along watercourses in hot, dry areas. They are found in more arid situations as well, however, fruit size and production is diminished where the palms are subjected to great water stress. Doum palm is also able to withstand a few degrees of frost, though cold tolerance probably varies with geography.

REPRODUCTIVE BIOLOGY Staminate and pistillate inflorescences are found on separate plants of the doum palm. Pollination is by wind. Elephants and baboons are significant fruit dispersal agents, but human agency has probably had an impact on the present distribution of the palm.

FRUIT DEVELOPMENT Doum palms first fruit at 6–8 years of age. The fruit ripens in 6–8 months, often remaining on the plant until the next flowering season.

Horticulture

PROPAGATION Propagation of doum palm is by seed and secondarily by separating and establishing basal offsets that sometimes form at the base of the trunk. Seeds germinate slowly (up to a year) and remotely (the cotyledonary petiole or ‘sinker’ emerges and grows deeply into the soil before the formation of the seedling shoot axis) and a great deal of underground development takes place before the first seedling leaf emerges. It is best if the fruit wall is removed and then the seed planted. The seeds are best planted singly in deep containers, or directly in the ground (about 20 cm deep). Soil needs to be kept moist for 2–3 months to ensure germination; after that, the seedlings can withstand as much as 10 months of drought. Young plants should be transplanted with care, as the seedling stem is easily damaged. Field-grown plants transplant with difficulty until an aerial trunk is formed; even then root pruning, not necessary for most palms, is recommended when moving larger plants.

NUTRITION AND FERTILIZATION Little is known of the doum palm’s mineral nutritional needs, but growth is best in a rich, sandy loam, with a pH of 6.5–7.5. It tolerates moderate salinity. In Florida, it has proven tolerant of nutrient poor soils.

DISEASES, PESTS AND WEEDS The nuts of the palm can be parasitized by the scolytid beetle *Coccotrypes dactyliperda*.

Alan W. Meerow

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Jubaea chilensis Chilean wine palm

Chilean wine palm, coquita, *Jubaea chilensis* (Molina) Baillon (*Arecaceae*), is mainland Chile’s only native palm, and was almost extirpated in the wild for sap collections. Now it is protected by law. The fruit is sweet and edible, as is the endosperm of the seed, which has a taste similar to coconut.

World production and yield

The harvest of the fruit of the Chilean wine palm is an incidental use for the palm, for which no data are available.

Uses and nutritional composition

The sweet, fleshy mesocarp of the fruit is eaten fresh, and the nuts (endocarp and endosperm) are either eaten fresh or used to make various confections. The main traditional use for the palm was the tapping of the stem for sap collection as a sugar source (and fermented as a source of palm wine). The palm is decapitated for this purpose.

Botany

TAXONOMY AND NOMENCLATURE Only one species is recognized in the genus. It is closely related to the monotypic genera *Juania* from the Juan Fernandez Islands off the coast of Chile, and is known to hybridize with species of *Butia* and *Syagrus*. Some synonyms include *Cocos chilensis* (Molina) Kunth, *Jubaea spectabilis* Kunth and *Micrococos chilensis* (Molina) Philippi.

DESCRIPTION Chilean wine palm produces a massive solitary dark grey trunk 1 m or more in diameter and 10–15 m tall that is usually swollen at the base or sometimes towards its middle. A dense canopy of 40–50 green to grey-green pinnate leaves is formed that may be 6–8 m wide and up to 6 m tall. Each leaf is

2–4 m long on short petioles with many 60 cm long, stiff, two-ranked leaflets. The inflorescences, which are produced from among the leaves, are once-branched, 1–1.5 m long, and bear numerous purple flowers in clusters of a central female flanked by two males. The round fruit are orange, one-seeded and about 4 cm in diameter.

ECOLOGY AND CLIMATIC REQUIREMENTS The habitat of the Chilean wine palm is dry river courses or sparsely vegetated Andean foothills of western Chile between 32° and 35°S latitude at low elevation, but the range is now much more restricted. Due to cutting of the palms for sap harvest and land clearing, the number of Chilean wine palms has decreased from an estimated 5 million to about 12,000 over the past five centuries. *Jubaea chilensis* is adapted to a Mediterranean climate with wet winters and dry summers, and performs best in similar climates elsewhere in the world. As a rule, it does grow very well in humid subtropical and tropical climates. It is believed to be hardy to −9°C.

REPRODUCTIVE BIOLOGY AND FRUIT DEVELOPMENT Flowering is from November to December in habitat (May to June in the northern hemisphere), with fruit that ripen starting in January (July in the northern hemisphere). Individual palms may require as much as 60 years before they flower and fruit.

Horticulture

Seed is sown as soon as it is ripe and can take 6 months or longer to germinate.

Alan W. Meerow

Mauritia flexuosa buriti

The buriti palm, *Mauritia flexuosa* L.f., (*Arecaceae*) is one of the most extensively utilized palms of the Amazon region. It is a dioecious, single-stemmed, fan-leafed palm, broadly distributed throughout northern South America east of the Andes, most typically in inundated soils. The fruit pulp is eaten directly, dried into flour or fermented. Most, if not all, of the fruit consumed is harvested from wild populations.

Common names throughout its range (Dugand, 1972; Glassman, 1972; Bohorquez, 1977; Borgtoft-Pedersen and Balslev, 1990) include buriti (from the Tupi Indian language: mburi'ti), buriti-do-brejo, coqueiro-buriti, buritizeiro, miriti, muriti, muritim, muritizeiro, muruti, palmeira-dos-brejos, carandaguaçu, carandaiguaçu (Brazil); moriche (Venezuela, Trinidad); ita (Guyana); palmier bâche (French Guiana); achual, aguaje, auashi, bimón, buritisol, mariti, muriti, moriche (Peru); caranday-guazu, ideuí (Bolivia); and cananguche, chomiya, ideuí, mariti, miriti, muriti, moriche (Colombia).

World production and yield

It is estimated that an individual buriti palm could yield 200 kg of fruit/year (Lleras and Coradin, 1988), from which approximately 24 kg of oil could be extracted. A density of 150 plants/ha could result in a harvest of 3600 kg of mesocarp oil/year. Bohorquez (1976) reports harvests of 19 t of fruit/ha/year from plantations of 100 palms/ha in Peru, a net of 190 kg fruit/plant. From the Peruvian *aguajale* described by Kahn (1988), Peters *et al.* (1989) estimated 6.1 t/ha/year of fresh fruit, with a local market value of US$1525. It is likely that large stands of *M. flexuosa* occupy at least 1000 km^2 in Amazonas. Thus, an estimate of the quantity of buriti fruit produced in the region would be about 600,000 t, the great majority of which is consumed by wildlife.

Uses and nutritional composition

From the fresh, pulpy mesocarp of the buriti's fruit, a beverage known as 'buriti wine' or 'vinho de buriti' is prepared. Fruit are first softened in warm water for a few hours, left under leaves for several days (they are collected and often fall naturally before fully ripe). The slow treatment is said to enhance flavour. The pulp is extracted by hand, diluted with water and strained. Buriti wine is consumed fresh, sweetened, or mixed with manioc flour, as is done with assaí (*Euterpe oleracea*). Fresh pulp is made into a confection, doce de buriti, and used in ice cream. The liquid is also diluted further, sweetened and frozen like popsicles (dim-dim in Brazil, curichi in Peru). The pulp is also dried and ground into flour. The complete range of products is widely used and figures importantly in the local commerce of the Amazon basin (Cavalcante, 1988; Padoch, 1988). Lima (1987) reported that a 20-day treatment with doce de buriti eliminated all symptoms of hypovitaminosis A in children, a syndrome that, ironically, is quasi-epidemic in the region. In the Orinoco River delta of Venezuela, Indians make a type of bread from the pulp (Braun, 1968). An alcoholic beverage is also sometimes made by fermenting a mash of the fresh pulp. Oil is also extracted from the fruit.

Though only 12–13% of the fruit dry weight, the buriti pulp is an important source of calories, proteins and vitamins for the people of the Amazon region (Table A.56). The pulp contains about 3 g of protein, 10 g fat, and 120 to over 200 calories/100 g of fresh pulp (Chaves and Pechnik, 1946, 1949; Leung and Flores, 1961; Bohorquez, 1977). The mesocarp oil is also very high in vitamin A, and may represent one of the highest concentrations of carotene in the plant kingdom. Rizzini and Mors (1976) reported 300 mg of β-carotene/100 g of dry mesocarp, a level three times that of African oil palm (*Elaeis guineensis*).

Botany

TAXONOMY AND NOMENCLATURE Until recently, buriti was known as *Mauritia vinifera* and was considered distinct from miriti or buriti-do-brejo (*M. flexuosa*) on the basis of male inflorescence, fruit size and habitat differences. *Mauritia vinifera* was considered endemic to the central planalto of Brazil. It is now treated merely as an ecological variant of *M. flexuosa*. One other species is recognized in the genus. *Mauritia* and the related *Mauritiella* are the only fan palms classified outside of the palm subfamily *Coryphoideae*, and are members of the rattan group, subfamily *Calamoideae* (Uhl and Dransfield, 1985).

DESCRIPTION The buriti is a robust, solitary-stemmed palm reaching 30 m in height. The roots often form pneumatophores in flooded soils (Granville, 1974). The eight to 20 fan-shaped (costapalmate) leaves form a large crown. Each leaf consists if a 2.5 m long blade divided into several hundred segments, and

Table A.56. Nutritional value of 100 g of buriti palm mesocarp (Source: de Castro (1993).

	Chaves and Pechnik (1946, 1949)	Bohorquez (1977)[a]	FAO (1986)	Altman and Cordeiro (1964)	Leung and Flores (1961)
Constituent	Fresh	Fresh	Dry	Dry weight	Dry weight
Calories	120.0	143.0	–	–	265
Water (%)	71.8	72.8	–	68	72.8
Proteins (g)	2.9	3.0	5.5	5.2	3
Fats (g)	10.5	10.5	31.0	26.2	10.5
Fibre (g)	11.4	11.4	23.0	27.5	11.4
Ash (g)	1.2	1.2	2.4	2.9	1.2
Calcium (mg)	158	113.0	–	–	–
Phosphorus (mg)	44	19.0	–	–	–
Iron (mg)	5	3.5	–	–	–
Vitamin A (mg)	30.0	12.0	30.0	–	–
Thiamine (mg)	–	0.3	0.1	–	–
Riboflavin (mg)	–	0.23	–	–	–
Niacin (mg)	–	0.7	–	–	–
Vitamin C (mg)	50.5	26.0	52.5	–	–

[a] Exocarp included.

an equally long petiole. A skirt of dead leaves often hangs down below the crown. Plants are either male or female. The hanging inflorescences are similar in both sexes and arise from the axils of the leaves. Each flower stem is about 2 m long and bears many conspicuous bracts. The flower-bearing branches or rachillae number several dozen, and are catkin-like on the males; the females are shorter and thicker. Male flowers are in pairs on the branches; the female flowers are solitary. The fruit are spherical or ellipsoidal, 4–5 cm in diameter and 5–7 cm long. They are covered with brownish-red scales. The pulpy mesocarp varies from yellow through orange to reddish orange in colour. The endocarp (inner fuit wall) is soft. Each fruit contains up to a dozen round seeds with brownish coats and solid, white endosperm (Wessels-Boer, 1965).

ECOLOGY AND CLIMATIC REQUIREMENTS *Mauritia flexuosa* is restricted to permanently or seasonally flooded soils. It is found throughout Amazonia, from the Orinoco valley of Venezuela in the north, through French Guiana and the northern coast of the Brazilian state of Amapá, and west up to the Andean foothills in Colombia, Ecuador, Peru and Bolivia. It is common throughout north-eastern Brazil, from Maranhão to Bahia states. It extends into the *cerrado* vegetation of the central Brazilian states of Minas Gerais and Mato Grosso do Sul (formerly *M. vinifera*), but is limited to river margins and swamps. Also it occurs in Trinidad and Tobago. The palms are found in small groves along watercourses that wind through the non-flooded upland rainforests, and eventually form large stands, often to the exclusion of other tree species, in the major Amazonian estuaries (Peters *et al.*, 1989). These are known as *aguajales* in Peru. In western Amazonas, buriti zones cover thousands of hectares along floodplains. The *cerrado* populations of Central Brazil form groves called *veredas* along riverbanks and other hydric sites (Bondar, 1964). The buriti thrives in full sun and humid, tropical conditions, and has little or no tolerance of freezing temperatures. Growth on dry soils is slow and the plants appear stunted.

REPRODUCTIVE BIOLOGY Flowering and fruiting in buriti occur annually, but irregularly distributed throughout the year. In central Amazonas, flowering occurs at the end of the rainy season to the beginning of the dry season, from May to August (de Castro, 1993). The fruit ripen during the following rainy season and are offered in local markets from December to June. Urrego (1987) reported similar phenology in Colombia. In Iquitos, Peru, mature fruit are abundant in the markets from February to August, with a distinct shortage from September to November, due to seasonal fluctuations (Padoch, 1988). In eastern Amazonas, in Belém, Cavalcante (1988) reports that mature fruit appear in the markets from January to July. Heinen and Ruddle (1974) reported two flowering seasons in the Orinoco delta of Venezuela: one, primarily male plants, appears to be initiated by the commencement of the rainy season; a second takes place in December, amidst the rainy season, and is dominated by female palms. However, mature fruit are found throughout the year, but with two peaks, one from August to October, and a less abundant period from February to April. Gender ratios in natural populations are not well understood. Urrego (1987) reported that 15–20% of male plants in a population are sufficient to provide optimum fruit production.

FRUIT DEVELOPMENT The palms begin to bear fruit when they attain about 6 m of height, usually in 7 or 8 years from seed germination. They yield for several decades, the amount of fruit declining after 40–50 years (Bohorquez, 1976; FAO, 1986). Unfortunately, tall palms with large fruit crops are frequently cut down to make harvest easier, and exploited populations dominated by male plants are a noticeable consequence in Amazonas.

The mature fruit are dark red in colour and fall from the trees. They quickly deteriorate, and must be collected before they ripen fully if shipped.

Horticulture

PROPAGATION Buriti is propagated exclusively by seed. Bohorquez (1976) observed 100% germination after 75 days for seed collected no more than 10 days before sowing. When seed was collected 3–4 weeks before sowing, germination was reduced to 55% at 120 days. Seed from single-seeded fruit that was 8 days old began to germinate after 92 days, with 48% of the seeds germinating between 120 and 150 days, and a final germination of 52% (Storti *et al.*, 1989). Seeds from double-seeded fruit started to germinate after 55 days, with 41% germinating between 120 and 150 days and a final germination of 64%. Pretreatment of seed in running water at 29°C for 5 days and immersion in a 100 ppm solution of gibberellic acid for 72 h, increased final germination to 58% and 68%, respectively, but did not alter germination frequencies (Storti *et al.*, 1989). Little is understood about seedling development and optimum size and age for transplanting (Bohorquez, 1977). De Castro (1993) observed seedling development in different levels of shade over 15 months, and concluded that shade is beneficial during the early stages of growth. Once stem development, referred to as 'establishment growth' by Tomlinson (1990), is completed, the buriti requires full or near full sun for best growth.

NUTRITION AND FERTILIZATION Nothing is known about mineral nutrition and fertilization for the buriti palm.

DISEASES, PESTS AND WEEDS Little has been reported concerning pests and diseases of buriti palms. The large weevil *Rhynchophorus palmarum* (Curculioniodae), the larvae of which bore through the trunks of palms, is known to infest damaged or otherwise stressed buriti palms. In fact, palms are sometimes deliberately damaged to attract the weevils, as the larvae are eaten by many indigenous people of the Amazon region (Suarez, 1966; Padoch, 1988; Borgtoft-Pedersen and Balslev, 1990).

MAIN CULTIVARS AND BREEDING No cultivar selection or breeding efforts have been initiated on the buriti palm. De Castro (1993) suggests that seed could be collected from the best palms in each population and sown *in situ* or nursery grown then transplanted back into the buriti zone to improve the quality of the population. As the palms grow in sites that are marginal at best for agricultural development, sustainable exploitation and wise management of natural populations could provide a role in Amazonian development without resulting in environmental degradation (Peters *et al.*, 1989).

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Nypa fruticans nipa palm

Nipa palm, *Nypa fruticans* Wurb. (*Arecaceae*), is a mangrove palm that can form large populations along tidal estuaries in south Asia and Australasia. The endosperm of the seed is edible and consumed at various stages of development. Many other parts of the palm are used as well, with the tapping of the flower stems for the sugary sap being the most important.

Uses and nutritional composition

The gelatinous stage of the endosperm is consumed directly or else preserved in syrup. Once solidified, it may be ground up into a meal. The seeds contain 71–78% carbohydrate, much of which is starch.

Botany

TAXONOMY AND NOMENCLATURE *Nypa fruticans* is the only species classified in the subfamily *Nypoideae* of the palm family. It is thus considered quite isolated from the other palms, and is in fact one of the earliest palms identifiable in the fossil record (Uhl and Dransfield, 1987).

DESCRIPTION Nipa palm grows from a dichotomously branching, prostrate stem that often remains underground (Fig A.18). In time, a single plant can form a network of creeping stems. Each stem branch holds fewer than a dozen, 5–9 m long, sub-erect pinnate leaves, each with numerous 1.2–1.5 m long lanceolate leaflets. The inflorescence is 1–2 m long and spadix-like, with the male flowers born on catkin-like lateral branches and the female flowers in a congested head. The female flowers are much larger than the male. The fruit are aggregated in a globular head that is dispersed as a unit capable of floating.

ECOLOGY AND CLIMATIC REQUIREMENTS Nipa palm forms large populations in heavy muds of tidal estuaries from India and Sri Lanka to Australia. It also occurs on the Solomon and Ryukyu Islands, and is naturalized in parts of tropical Africa. It is extremely salt and flood tolerant. Tropical conditions are required for growth.

REPRODUCTIVE BIOLOGY Pollination of nipa palm is by drosophilid flies.

Horticulture

PROPAGATION Nipa palm is propagated by seed or detached stem branches.

TRAINING AND MANAGEMENT Management strategies of natural nipa palm stands are oriented for maximum sap production, rather than fruit production. Natural stands are sometimes managed by thinning to between 2500 and 3500 palms/ha, at a spacing of 1.5–2 m. Wider spacing (380–750 trees/ha) has been advocated by some (Duke, 2001). Four hours of inundation appears to be beneficial for the growth of nipa palms, which may achieve 2 m of height in their first year from seed. Nuts are harvested throughout the year.

Fig. A.18. *Nypa fructicans* palm and fruit (with permission from Sitijati Sastrapradja from Palem Indonesia, Lembaga Biologi Nasional, 1978).

DISEASES, PESTS AND WEEDS Grapsid crabs damage young nipa palms (Duke, 2001). Alan W. Meerow

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Oenocarpus bataua patauá

Patauá, *Oenocarpus bataua* Mart. (*Arecaceae*), the batauá or patauá palm, is a robust, feather-leafed (pinnate) canopy palm of northern South America, and one of most common palms in the region. A beverage is prepared from the fruit, but of greater importance is the oil obtained from boiling them, which has been favourably compared to olive oil. The quantity and quality of this oil has repeatedly resulted in the citation of this palm as an underutilized plant with great economic potential.

Related species include *Oenocarpus bacaba* Martius (bacaba: Brazil) which is widely used in northern South America as a source of vinho de bacaba, a thick, somewhat oily juice prepared from the slurry of mesocarp and water. The bacaba is a large, single-stemmed palm growing both in flooded and in non-flooded areas in rainforest ecosystems. In the latter ecosystem, bacaba may form high-density stands. *Oenocarpus balickii* F. Kahn (sinamillo: Peru) occurs in Amazonian Peru, Brazil and Colombia and is similar to *Oenocarpus mapora* but differs by its single stem, larger number of leaflets and smaller drupes. It is frequent on well-drained rainforest soils. A drink is made from the fruit. *Oenocarpus distichus* Martius (bacaba-do-leque: Brazil) is found on sandy soils of seasonally dry forest in south-eastern Amazonas. The palm differs from bacaba by its opposite leaves; the latter species has spirally arranged leaves. The fruit of this species is used to prepare vinho de bacaba by people of the south-eastern Amazonas. *Oenocarpus mapora* Karsten (bacabinha: Brazil) is found from southern Central America through north-western South America and the fruit of this species is made into vinho de bacaba. It is a clustering palm of smaller stature than most *Oenocarpus* spp. It typically occurs as dispersed individuals within terra firma or seasonally inundated forest. Two apparent hybrids also exist in the wild, *O. bacaba* × *O. bataua* and *O. bacaba* × *Oenocarpus minor*. The presence of natural hybridization bodes well for future breeding programmes designed to improve yields, tolerance to stress, reduced time to maturity, etc.

World production and yield

Despite acclaim as an overlooked agronomic resource, few data on yield of the patauá palm have been accumulated. On average, a patauá palm yields two fruiting stems annually, with a mean weight of about 15 kg, although individuals producing as many as five fruiting stems have been reported under favourable conditions (Balick, 1988). Each fruit contains 6.5–8% oil by fresh weight (Blaak, 1988). Sirotti and Malagutti (1950) estimated that a natural population in Venezuela consisted of 400–500 reproductively mature palms/ha, of which just over 70% bore fruit. Balick (1988) suggests that the most productive spacing for an agroforestry plantation would likely be more like 204–216 plants. Balick (1988) estimated that 100 fruiting plants would produce 1.6 t of fruit. Peters *et al.* (1989) estimated 3.5 t based on 104 plants/ha. From a hectare of wild palm stands, yields will vary from 1.6 to 1.5 t of fresh fruit, from which 112–260 kg of patauá oil can be expected to be extracted (Balick, 1993). If Balick's predicted plantation density is accurate, per hectare yields of 3.27 t of fruit and 240–525 kg of patauá oil could be expected.

Traditionally, the oil was extracted by mashing the mesocarp, heating and pressing it in a tipitipi, a long woven tube (Balick, 1986, 1988), which successfully extracted only about one-third of the oil (Blaak, 1988). Technology similar to that utilized for African oil palm (*Elaeis guineensis*) would increase extractive yield to at least 85–89%. Ironically, South America is currently a net importer of olive oil. During World War II, when a world shortage of olive oil occurred, Brazil exported over 200 t/year of patauá oil (Pinto, 1951). Unfortunately, most of the harvest was accomplished by felling mature trees in natural populations.

Uses and nutritional composition

The oil extracted from the mesocarp of patauá is virtually identical to olive oil in appearance and fatty acid composition (Balick, 1986, 1988). Patauá oil is highly unsaturated, with 78 ± 3% monounsaturated fatty acids and 3 ± 1% polyunsaturated fatty acids (Table A.57). Indigenous people in Amazonas consider it second to no other wild plant as an oil resource.

In the Amazon basin and northern South America, Amerindians produce a thick non-alcoholic juice with a nut-like flavour from the fruit mesocarp. Its high protein content and unsaturated oils make it an excellent nutritional addition to local diets (Balick and Gershoff, 1981; Table A.58). Patauá oil is considered a cure for minor bronchial and pulmonary infections (Balick, 1986).

Botany

TAXONOMY AND NOMENCLATURE Long treated as a species of the segregate genus *Jessenia*, *O. bataua* is one of nine species distributed throughout from Central America through northern South America south to Brazil and Bolivia (Henderson, 1994). Synoynms include *Jessenia bataua* (Martius) Burret, *Jessenia polycarpa* Karsten and *Jessenia repanda* Engel. Other common names include batauá, milpesos, seje, trupa, chapel, patawa, turu, unguraui, komboe, yagua and aricauguá.

DESCRIPTION The patauá is a large (15–25 m), single-stemmed palm with a trunk of 15–25 cm diameter at breast height. The crown consists of eight to 16 spirally arranged, large, pinnately compound leaves that may reach 10 m in length (the petiole is about 1 m long, the blade 3–8 m). The 100–200 segments (pinnae) are arranged in a single plane along the rachis. The paniculate inflorescence has several hundred branches (rachillae), each about 1 cm long, bearing numerous cream-coloured flowers. Each panicle may bear over 1000 round, dark purple drupes, each 2.5–4 cm in diameter and containing a single seed.

ECOLOGY AND CLIMATIC REQUIREMENTS On upland soils of terra firma rainforests, patauá has a scattered distribution of mostly juvenile palms (Kahn, 1988). The species has not been reported above 950 m elevation (Balick, 1986). In flooded swamps, *O. bataua* can form huge, virtually unbroken stands (Peters *et al.*, 1989). It is to be expected that patauá has little or no resistance to frost.

Table A.57. Fatty acid composition of patauá mesocarp oil (in % total oil).

Fatty acid	Jamieson (1943)	Balick and Gershoff (1981)[a]
Myristic	–	–
Palmitic	8.8	13.2 ± 2.1
Palmitoleic	–	0.6 ± 0.2
Stearic	5.6	3.6 ± 1.1
Oleic	76.5	77.7 ± 3.1
Linoleic	3.4	2.7 ± 1.0
Linolenic	–	0.6 ± 0.4
Unsaturated (%)	79.9	81.6 ± 4.7

[a] Mean + SD of 12 samples.

Table A.58. Amino acid composition of patauá mesocarp protein (mean and + SD of seven samples) (Source: Balick and Gershoff, 1981).

Non-essential amino acids	mg/g protein	Essential amino acids	mg/g protein
Aspartic acid	122 ± 8	Isoleucine	47 ± 4
Serine	54 ± 3	Leucine	78 ± 4
Glutamic acid	96 ± 5	Lysine	53 ± 3
Proline	75 ± 8	Methionine	18 ± 6
Glycine	69 ± 4	Cystine	26 ± 6
Alanine	58 ± 4	Phenylaline	62 ± 3
Histidine	29 ± 4	Tyrosine	43 ± 5
Arginine	56 ± 2	Threonine	69 ± 6
		Valine	68 ± 4
		Tryptophan	9 ± 1

REPRODUCTIVE BIOLOGY Little is recorded on flowering phenology of this palm. Fruit ripen from April to November.

FRUIT DEVELOPMENT Some authors have reported that patauá takes 10–15 years to fruit (Balick, 1988). As with most palms, however, this time may be reduced by modifications in the agroecosystem, especially by reducing competition and enriching the nutrient content of the soil. Balick (1986) observed a plant in Ecuador that fruited precociously, at less than 2 m from the ground. The patauá germplasm bank being organized at the Centro de Pesquisas Agropecuárias do Trópico Umido, in Belém, Pará, will provide information on the precocity of different genotypes in plantations. This trait generally has a moderate to high heritability and can be selected for in an improvement programme.

Horticulture

PROPAGATION Fresh seed should be de-pulped, and placed in warm water (50°C) for 30–60 min. Treated in this manner, 90–98% germination can be expected within 2 months (Balick, 1988). Viability diminishes quickly, with major losses occurring in as little as a month. Germination is best conducted in part shade. As soon as the seedling has at least one leaf, it should be transplanted to a container with well-drained organic media and grown under 50% shade for the first year. Inoculation with mycorrhiza (St John, 1988) increases growth.

Seedlings intended for transplanting into natural stands or rainforests can be directly planted from the nursery, while plants that will be established plantation-style must be adapted to full sun first. Young transplants can be shaded for the first few weeks using a folded leaf from an adult palm. Blaak (1988) recommends 7 m square spacing for field plantings.

NUTRITION AND FERTILIZATION Blaak (1988) suggested that 1.5 kg of fertilizer/plant should increase yields twofold. No other information is available on mineral nutrition and fertilization of patauá palms.

DISEASES, PESTS AND WEEDS No information on diseases, pests and weeds is available. Balick (1988) noted that patauá palms in Colombian agroforestry settings produced more fruit than those in primary forest, suggesting that lessening competition from other plants has beneficial effects on production.

MAIN CULTIVARS AND BREEDING No sustained improvement efforts have yet been undertaken for the patauá palm. The presence of at least two putative hybrids in nature, *O. bacaba* × *O. bataua* and *O. bacaba* × *O. minor*, suggest that future breeding programmes would be a worthy avenue of pursuit.

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Phoenix dactylifera date palm

Date palm, *Phoenix dactylifera* L. (*Arecaceae*), is a major fruit crop in arid regions such as North Africa and the Middle East. The fruit are the main income source and staple food source for local populations and have enormous significance in the economy, society and environment in arid regions. During the last century, dates were introduced to Australia, Mexico, Pakistan, South Africa and the USA.

History and origins

Dates are one of the oldest known fruit crops and have been cultivated in the Middle East and North Africa for thousands of years (Zohary and Hopf, 2000). The earliest known record in Iraq (Mesopotamia) shows that its culture was probably well established as early as 5000 years ago. This long history of date palm cultivation in the regions and the wide distribution of date palm beyond its original ranges have made it difficult to pinpoint its centre of origin. Although the origin of dates is unknown, date palms most likely originated from the ancient Mesopotamia area (southern Iraq) or western India. There are two hypotheses about the origin of dates, one suggesting that the date palm descended from one or several species of the genus *Phoenix* cultivated in their natural habitats, and the other suggesting it is a hybrid of several unknown *Phoenix* species. From its centre of origin, date cultivation spread throughout North Africa and the Middle East wherever conditions were favourable.

The earliest dissemination of date palms must have been by seeds carried by human beings from oasis to oasis. Date culture had apparently spread into Egypt 3500 years ago, although it did not become important until later, when it spread westward across North Africa from Egypt. The spread of date culture was facilitated by the introduction of the camel into this area in the 6th century, which made the transport of off-shoots possible. The spread of date cultivation accompanied the expansion of Islam and reached the northern outpost in southern Spain and an eastern extension into Pakistan. Until recently, expansion of date culture south of the Sahara Desert was limited because of lack of water. The Spanish were the first to introduce date palms to America. In the past century, dates were introduced to the desert areas of the Colorado River in North America, the Atacama Desert in South America, the Kalahari of South Africa and the great central desert of Australia.

Throughout the history of the Middle East, the date has had a very important influence. Without the date, no large human population could have been supported in the desert regions. The caravan routes existed for centuries mainly for the transport of dates. Early on, date cultivation achieved a high level of status in the Middle East, and became a sacred symbol of fecundity and fertility. Many ancient beliefs and other representations indicate the importance of the date palm for millennia. Dates had great spiritual and cultural significance to peoples in the region. The date palm and date culture are depicted on ancient Assyrian and Babylonian tablets, including the famous Code of Hammurabi, which contained laws pertaining to date culture and sales. The date palm is also found in ancient Egyptian, Syrian, Libyan and Palestinian writings. It is in Egyptian culture that the date palm achieves its greatest esteem.

World production and yield

The worldwide production of dates reached 6,259,688 t in 2002. The top ten date producing countries in 2001 were Egypt, Iran, Saudi Arabia, United Arab Emirates (UAE), Iraq, Pakistan, Algeria, Oman, Sudan, and Libyan Arab Jamahiriya. The top five date exporting countries in 2001 were UAE, Iran, Pakistan, Tunisia and Iraq. The top five date importing countries in 2001 were India, UAE, Pakistan, France and Syria. The European and US markets are also important export markets of dates. Egypt is the largest date producing country, where production has increased from 439,539 t in 1982 to 1,113,270 t in 2002. Egyptian production accounted for 17.8% of worldwide date production in 2002 on 29,461 ha of dates harvested, and it had one of the highest yields/ha in the world. In UAE, there were about 1.5 million date palms in 1971 when the country was founded, and an estimated 18 million date palms in the mid-1990s. UAE also has one of the largest date tissue culture (TC) establishments and produces millions of TC date palms annually.

Uses and nutritional composition

Date fruit are usually eaten fresh or dried. Dates can be eaten from the middle of the Khalal stage to the Tamar stage depending on the cultivar (the fruit ripening stages are explained under ‘Fruit growth and development’). Dates in the Khalal stage are at their largest size and highest sugar content. In areas with marginal heat accumulation, there is often not much ripening beyond the Khalal stage. Consumption of Khalal dates is generally confined to areas near production in North Africa and the Middle East. Where there is slightly more heat, dates must be eaten at the time they begin to soften as there is not enough heat to dry them out before they ferment. However, in warmer regions, dates dry down to a soft, dry fruit stage and then may be classified as ‘soft’, ‘semi-dry’ or ‘dry’. Soft dates pass through the Rutab stage and remain soft at Tamar, with high moisture content. Semi-dry dates also pass through Rutab, but dry out further at Tamar. Semi-dry dates account for the majority of varieties. Dry dates (‘bread’ dates) do not pass through Rutab but dry out quickly and have the lowest moisture content at harvest. In humid climates, dry dates may be relatively soft but in most instances of production are quite hard and brittle. These categories are somewhat arbitrary and are influenced by climate and production practices, some varieties may classify differently depending upon these factors (Dowson and Aten, 1962).

Dates are a high-energy food source with high sugar content. About 72–88% of the dry matter in dates is sugar and few ripe dates have any starch. As ripening progresses, the sucrose is hydrolysed into ‘invert’ or ‘reducing’ sugars, a mixture of glucose and fructose, depending upon variety, cultural practices and other factors. Soft and semi-dry dates are primarily of the reducing sugar type (having higher levels of sucrose hydrolysed), while dry dates are mostly of the sucrose type (having a lower proportion of the sucrose hydrolysed) (Rygg, 1975; Vandercook *et al.*, 1980; Ahmed *et al.*, 1995). Dates are a good source of iron and potassium, a fair source of calcium, chlorine, copper, magnesium and sulphur, and contain a small amount of phosphorus and 16 kinds of amino acids (Vandercook *et al.*, 1980) (Table A.59). These minerals accumulate during maturation (Ahmed *et al.*, 1995). Dates contain small amounts of vitamins A, B_1 and B_2, and substantial amounts of nicotinic acid. Aqueous extracts of date fruit also have potent antioxidant and anti-mutagenic properties.

In addition to being consumed as fresh or as dried fruit, dates are pressed into a large cake. Other products include: date honey made from the juice of fresh fruit; date sugar; date sap for making beer or wine; date palm flour made from the pith of the trees; oil from the seeds; and the palm heart eaten in salads. There are also non-food uses. For instance, seeds can be used as animal feed or strung as beads. The wood of date palms can be used for doors, beams, furniture, rafters and firewood; leaves can be used for matting, baskets, roofing, fencing and shelter; and fibres from dates can provide thread and rigging for boats. Also dates are used as folk remedies for many medicinal purposes. Recently the date palm has been used as an ornamental and in landscapes in southern Europe and the USA.

Botany

TAXONOMY AND NOMENCLATURE Date is a diploid ($2n = 2x = 36$), perennial, monocotyledonous plant belonging to the family of *Arecaceae/Palmaceae*. The name of date palm originates from its fruit; 'phoenix' from the Greek means purple or red (fruit), and 'dactylifera' means the finger-like appearance of the fruit bunch. Some authorities claim that the word phoenix itself has referred to the date palm since ancient times, and others believe that the date palm has characteristics of the legendary phoenix bird. The genus *Phoenix* is distinguished from other genera of pinnate-leaved palms by the upward and lengthwise folding of the pinnae and the furrowed seeds. The taxonomy of *Phoenix* has been somewhat confused in the past, with most authors recognizing approximately 17 genera (but not necessarily the same genera). The recent revision of *Phoenix* recognizes 13 species including *P. dactylifera* (Barrow, 1998). All species are native to the tropical or subtropical parts of Africa or southern Asia. This is in contrast to other species of *Phoenix*, which have often been reported under different species names, albeit mostly in the genus *Phoenix* (Barrow, 1998). Most *Phoenix* species are cross compatible.

Table A.59. Proximate fruit composition of dried medjool date edible flesh (Source: USDA, 2004).

Proximate	%
Water	21.3
Energy (kcal)	277
(kJ)	1160
Protein	1.81
Lipid (fat)	0.15
Carbohydrate	74.97
Fibre	6.7
Ash	1.74
Minerals	**mg**
Calcium	64
Iron	0.9
Magnesium	54
Phosphorus	62
Potassium	696
Sodium	1
Vitamins	**mg**
Ascorbic acid	0
Thiamine	0.05
Riboflavin	0.06
Niacin	1.61
Vitamin A	149 IU

Dates are grown on a wide variety of soils throughout the world, from sand to clay. However, production is improved if soils have the maximum water-holding capacity consistent with good drainage. Some sandy soils require high levels of irrigation and fertilization. Hard pans or perched water tables can result in shallow root systems or poor growth due to anaerobic conditions or soil-borne pathogens. Soils with poor drainage can result in saline or sodic soils, which are found in many areas of date production.

Date palms are considered having the highest tolerance to saline conditions among all tree crops, tolerating up to 4.0 dS/m before yield reductions are noted. This assessment was based upon work done in Indio, California by Furr and associates. Furr and Armstrong (1962) compared mature date palms irrigated with water salinized to 4–8, 8–12 and 16–24 dS/m with non-salinized controls. They reported no reductions in leaf growth rate, yield, fruit size and quality, or chloride ion (Cl^{-1}) content of the leaf pinnae. Growth of date palm seedlings linearly decreased as electrical conductivity rose from 6.5 to 39.0 dS/m; however, accumulation of sodium (Na^+) and Cl^- ions in leaf tissue was not observed. This suggests that reductions in seedling growth were due to osmotic rather than specific ion effects. Young date trees were more sensitive to these effects than mature trees. None the less, very saline conditions can cause reductions in yield and quality. Date palms experience yield reductions if the EC of the soil exceeds about 4 dS/m or if the EC of applied irrigation water exceeds about 3 dS/m. If total soluble solids in irrigation water exceed several hundred ppm, an extra quantity of water should be applied for leaching. The leaching ratio for date palms is estimated to be from 5 to 20, depending upon the salinity.

DESCRIPTION The date palm has an erect columnar trunk, 40–50 cm in diameter (without leaf sheaths) that may reach a height of 20–28 m or more (Fig. A.19). The trunk may have one to several suckering off-shoots at or near the base. In cultivation, the off-shoots are removed for propagation purposes (discussed under 'Propagation'). If the off-shoots are left attached, it can result in a clumping or thicket-like growth habit. The root system of the date palm does not have a

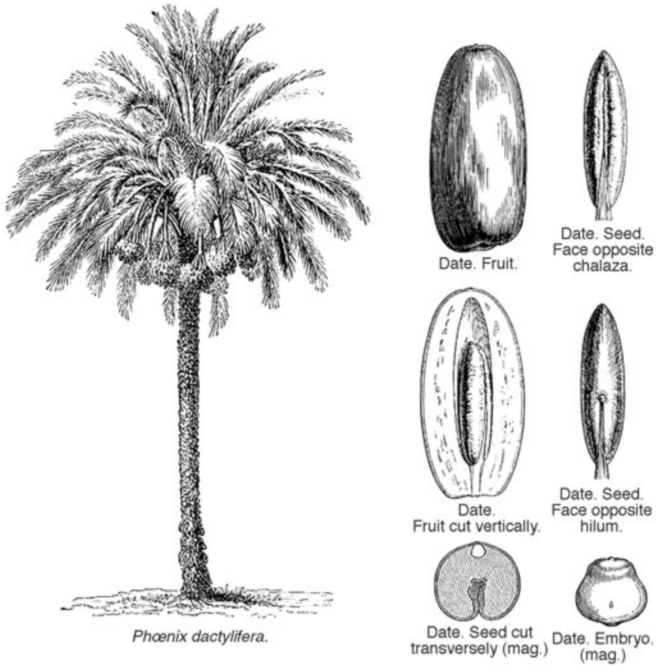

Fig. A.19. Leaf, flower and fruit of date (Source: Le Maout, 1877).

taproot. The root is fibrous and pneumatic. It may extend several metres laterally and 6 m or more in depth, although the bulk of the roots are distributed within 2 m of the trunk both laterally and in depth. The crown of the date palm consists of 60–150 leaves depending upon variety, growing condition and cultural practices. Morphological differences in leaf, spine, pinnae and fruit are commonly used to characterize the varieties. The leaves of the date palm have a lifespan of 3–7 years. The colour ranges from light to dark shades of green. The leaves are glaucous in different degrees depending on the variety and age of the leaves. The leaves are 3–7 m in length, based on the measurement of the blade from the lowest spine to the tip of the terminal leaflet. Leaves with a blade length less than 335 cm are considered short, from 335–427 cm as medium, and long if more than 427 cm. The midrib or petiole is triangular in cross-section, with its greatest width at the base, tapering rapidly towards the apex. The midribs are straight or with different curvatures depending upon the variety, are vertical in orientation, and are armed with rows of pinnae (also referred to as leaflets) on each side. The pinnae are long, narrow and folded upward and lengthwise. Varieties differ in the number, thickness, length, breadth and relative stiffness of the pinnae and how they droop or curve down. A characteristic of the genus *Phoenix* is that the leaves have terminal leaflets, and the basal leaflets are modified into spines. The length and breadth of the pinnae are important morphological characters for varietal description. Pinnae with length less than 61 cm are considered short, 61–75 cm as medium, and long if more than 75 cm. The breadth of pinnae is considered short if less than 3.8 cm, medium from 3.8 to 4.4 cm, and broad if more than 4.4 cm. The pinnae usually grow in groups of two or more, relatively close together at the point of attachment to the midrib and separated from other groups by a space greater than that between the pinnae within the group. Groups of two or three pinnae are common, but some varieties have four or more. The lower leaflets near the base of the trunk are modified into stout spines. The number and length of the spines differ with variety and age. Spines with a length of less than 10 cm are considered short, 10–15 cm medium, and long if more than 15 cm. The shortest spines are at the base of the spine area and the longest near the pinnae. Date palms have a phyllotaxic arrangement of leaves in which leaves are arranged in spirals of five and 13 in one direction around the trunk, and in spirals of eight in the opposite direction.

Date palm is dioecious, meaning that it has separate female and male trees. Occasionally hermaphroditic trees or flowers are observed. The inflorescences of male and female trees differ in morphology. Inflorescences of both sexes are enclosed in a hard, fibrous cover (the spathe) during the early stages of annual development. The spathe protects the delicate flowers from heat and sunlight until they are ready to perform their reproductive functions. The flowers (and later the fruit, on female trees) are borne on a flat, tapering peduncle or rachis, commonly known as the 'fruit stalk' in female varieties. This is relatively short (50 cm) and upright in male trees, whereas in female trees it is longer (100 cm) and upright at the beginning of the flowering season, later elongating and drooping. The inflorescence consists of many unbranched rachillae, commonly known as 'strands', arranged in spirals on the rachis. The rachillae of male spathes are crowded towards the end of the rachis, and are short and robust. Male flowers are waxy white, and crowded along the length of the rachilla. There are usually three sepals and three petals. The yellowish-green female flowers (also usually with three sepals and three petals) are borne in clusters of three along the entire length of the long, slender rachillae, which are more evenly distributed along the rachis than in the males. Just before flowering, the inflorescence that arises in the axis of the leaves pushes up through the fibrous sheaths that form the leaf bases. The spathe cracks longitudinally at anthesis. Only the portion of the rachilla that bears flowers is exposed. Only one ovule per flower is fertilized, producing a single date fruit. After anthesis, no noticeable change is observed in the size of the flower-bearing region. The fruit stalk elongates 50–60 days after flowering and pushes out the portion of the inflorescence that does not bear flowers to a length of 60–120 cm.

Date fruit are variable in size and shape, depending upon variety, climate and cultural practices. The shape of the date fruit is characteristic of the variety, and is most distinct during the Khalal stage. Fruit shapes are oblong, elliptical, oval, ovate or obovate. Date fruit are generally 4–7 × 2–3 cm, and 60 g or more in weight. The calyx is persistent and useful in varietal identification. Skin colour is green in the early stages (through Kimri). At Khalal, fruit become distinctive colours ranging from yellow to red and brown. As the fruit matures through the Rutab and Tamar stages, it generally becomes darker and is usually some shade of brown at harvest. The mesocarp is sweet, thick and fleshy, or dry and thin depending upon the time of harvest. Commercial harvest of the earliest varieties begins in August in the northern hemisphere, with the last of the late varieties being harvested in November. Date seeds are variable in size and shape, but are generally elongate with pointed apices. Seed size ranges from 20 to 30 mm by 5 to 8 mm.

ECOLOGY AND CLIMATIC REQUIREMENTS The date can grow in very hot and dry climates, and is relatively tolerant to salty and alkaline soils (Zaid and De Wet, 2002). It needs a long, intensely hot summer with little rain and very low humidity from pollination to harvest, but with abundant underground water near the surface, or irrigation as in desert oases or river valleys. It can grow in temperatures ranging from 12.7 to 27.5°C, withstanding up to 60°C and sustaining short periods of frost down to −5°C. The ideal temperature from pollination to the fruit ripening stages ranges from 21 to 27°C. Date roots are adventitious and grow horizontally for a long distance. The fruit of dates vary in size, ranging from 2 to 60 g in weight, from 2 to 11 cm in length and from 1 to 3 cm in width depending on the cultivar. For proper maturing of fruit, dates require prolonged summer heat without rain or high humidity during the ripening period. Dates are grown in a wide variety of soil, but soil with maximum water-holding capacity consistent with good drainage is desirable. Dates are widely grown in the arid regions between 15° and 35° N, from the Canary Islands and Morocco in the west to India in the east. Date flowers when the shade temperature rises above 18°C and forms fruit when the temperature is over 25°C. Early work using 0°C as a base indicated that a heat accumulation of over 5100° was necessary for production of acceptable date fruit (Dowson, 1982). Swingle (1904) used the figure of 18°C as the lower limit (based upon maximum temperature), since this is the temperature necessary for flowering. Using this figure, Swingle found that good quality dates needed at least 3000° over the period of May–October (184 days).

Although date palms have a high water requirement, they are adapted to arid, low rainfall conditions. Rain during the flowering and pollination season can affect fruit set. High humidity can increase the incidence of diseases or disorders. Extremely high and low humidity can cause soft, sticky or extremely dry fruit, respectively. Ideally, rainfall is non-existent and humidity is low from bloom to harvest. Winter rain not damaging the fruit can alleviate saline soil conditions.

REPRODUCTIVE BIOLOGY The date is wind pollinated in nature but insect pollination is possible. One male tree produces sufficient pollen for pollination of approximately 50 female trees. Commercially, few male trees are grown in the gardens and pollen is collected for artificial pollination that is critical for successful production. Artificial pollination is an ancient practice in North Africa and the Middle East, and is mentioned in the cuneiform texts of Ur, Egypt, 4300 years ago. Fresh pollen is better than stored pollen for pollination. Male spathes are traditionally cut a few days before or after they split and then placed in a dry, shaded area for drying. High temperatures, sunlight and moisture can cause deterioration of date palm pollen. Strands are cut from the spathes and stored in bags or containers so pollen that falls from them will not be lost. If larger quantities of pollen are to be extracted, the flowers are generally placed over a wire sieve, which is then placed over a container for pollen collection and storage. Mechanical pollen collectors are used sometimes. Date palm pollen can be stored for several months at moderate temperatures under dry conditions. Longer-term storage requires stricter conditions. The pollen needs to be well dried and placed in an airtight container, if possible with some sort of desiccant. Storage at 'refrigerator temperatures' (4–5°C) is usually done, but lower temperatures (–4 to –20°C) are also appropriate (Nixon and Carpenter, 1978). Cryogenic storage of date palm pollen for research is also possible. Growers usually have preferred or special male trees that are selected based on experience and some general properties. Early blooming is valuable, since it assures a pollen source when the females begin to flower. Size and number of male inflorescence affects the amount of pollen produced. Individual flowers that adhere to the strands are preferable, and the pollen content of the individual flowers should be abundant. In areas where inflorescence rot occurs (discussed under 'Diseases, pests and weeds') pollen should be taken only from healthy males. Pollen of the earliest and latest inflorescences may have lower quality.

The most common method of pollination used today is to cut individual strands from male flowers and place two or three of them within the strands of the female flower within a few days after flowering. Twine is then tied around the female strands to make sure that the male strands stay in place and that the female strands do not become entangled. Pollination of female flowers can be done before or after the spathes crack naturally. The spathe can be split or removed artificially and pollen can be applied to the inflorescence. If male flowers cannot be used within a few days of collection, it is better to use dried pollen. Dried pollen may be used undiluted or mixed with a carrier such as flour or talc. The simplest method is to coat a cotton swab with pollen, sprinkle this over the female inflorescence, and then place the cotton ball within the female strands. A modified technique utilizes hand-made puffing devices with tubes for delivering the pollen from the ground. Large-scale mechanical pollinators capable of pollinating over 30 ha/season are in existence, but are used mainly in highly developed production areas where labour is scarce and expensive (Nixon and Carpenter, 1978). Mechanical pollination is less efficient in terms of both pollen used and fruit set. However, yield and quality can be indistinguishable from hand-pollinated dates if thinning is adjusted accordingly.

Pollination of 60–80% of the female flowers should result in adequate fruit set. Covering the inflorescence with paper bags after pollination can increase fruit set. Cultivars differ in the length of time during which maximum fruit set can be achieved, from up to 7 days before spathe cracking to 10 days afterwards. Usually 2–4 days after the spathe opens is best. Cultivars require different amounts of pollen for maximum fruit set; usually two to three strands of male flowers are adequate. Environmental conditions also influence fruit set. Pollen grains have the highest germination rate from 25 to 28°C, and low temperature (< 21°C) can result in low fruit set. Pollination is best achieved from mid-morning to mid-afternoon (10:00 a.m.–3:00 p.m.). Rain or dust storms before or afterwards can reduce fruit set.

Cultivars differ in their fruit set percentages. For instance, cultivar 'Zahidi' has a high fruit set percentage and 'Hayany' has a naturally low fruit set percentage. Incompatibilities or partial-incompatibilities between different female and male cultivars result in poor fruit set. The range of compatibility has not been fully investigated. Pollen of other *Phoenix* species are compatible with dates. Different pollen sources can influence the size and shape of seeds ('xenia' effect). Different pollens have direct effects on fruit size, fruit shape, yield and ripening time. This pollen effect on tissue outside the embryo and endosperm is called 'metaxenia'. The 'metaxenia' can reduce fruit ripening time from 10 to 60 days depending on the growing season, resulting in more return because higher prices are gained for earlier fruit. Also it may be beneficial if total heat units are low to enable proper ripening and if rain is avoided near the end of the season in some areas. Metaxenic effects in date palms have been reported in many countries.

FRUIT GROWTH AND DEVELOPMENT The fruit develops after fertilization from one of the three carpels within each of the pistillate flowers. If pollination or fertilization failed, all or one of the three carpels can develop into parthenocarpic fruit. A parthenocarpic fruit with three carpels is called a 'parthenocarpic triplet' (PT) and fruit with one developed carpel is called a 'parthenocarpic single' (PS). The PT fruit are hollow inside and PS fruit contain degenerated seeds. PS fruit are larger than PT fruit, but smaller than seeded fruit. All three types of fruit can be found on the same tree with various proportions. Between 15 and 20 days after spathe cracking, one of the three carpels begins to develop much more rapidly than the other two carpels in pollinated flowers or sometimes in unpollinated flowers. After 60–90 days, depending on the cultivar, significant differences in fruit size development can occur between seeded, PS and PT fruit. Growth rate and development of seeded fruit show a sigmoid growth curve. Most growth in size and weight occurs near the end of the Kimri stage and at the beginning of Khalal. Most fruit growth occurs 40 days after spathe crack and the fruit reach maximum size about 120 days after spathe crack (Reuveni, 1986). Natural fruit drop occurs 25–35 days after spathe crack, when PT and PS fruitlets can drop. For cultivar 'Deglet Noor', about 50% of the flowers develop into mature fruit. There are two distinct waves of fruit drop for 'Deglet Noor'. The first wave occurs 30–35 days after spathe crack and lasts for about 1 month. The second wave starts about 100 days after spathe crack and also lasts for about 1 month. This second wave of fruit abscission is sometimes referred as 'June drop'. The timing and duration of fruit drop vary by cultivars and locations.

The date fruit goes through four distinct ripening stages. Arabic terms, Kimri, Khalal, Rutab and Tamar, are used to represent the immature green, the mature full coloured, the soft brown and the hard raisin-like stages, respectively (Reuveni, 1986). In the Kimri stage, fruit increases size and weight rapidly until the Khalal stage. The colour changes from green at Kimri to the characteristic mature colour at Khalal. The rate of gain in size and weight during the Khalal stage decreases slightly until the fruit reach full size and weight. The fruit remain turgid, astringent and contain substantial amounts of water-soluble tannins at Khalal. The fruit in the Rutab stage are characterized by darkening of the skin to an amber, brown or nearly black colour, accompanied by softening, decreasing astringency and increasing insoluble tannins. In the final ripening Tamar stage, the fruit lose much of their water to a point where the sugar to water ratio is high enough to prevent fermentation, similar to raisins or dried prunes. The physical and chemical composition of the fruit change during development and ripening. Water content is 75–80% in young fruit, dropping to 40–60% at the beginning of ripening and decreasing rapidly afterwards. In general, the sugar content is about 20% at early Kimri, increasing steadily to about 50% at the beginning of Khalal, and finally accumulating at a fast rate and reaching 68–88% of dry matter at maturation.

Horticulture

The average date palm produces about 40 kg of fruit annually. Cultivation with high input regularly produces 100 kg of fruit annually but in underdeveloped regions date palm may produce 20 kg fruit or less. The female plants start producing dates at 4–6 years old and reach full production within 15–20 years. The average economic life of a date garden is 40–50 years; some can grow for 150 years.

Traditional date palm culture in North Africa and the Middle East developed around oases or in riverbeds. Date palms in oases are often of secondary importance to annual crops or other tree crops grown beneath them. Date palms in oases are usually derived from seedlings and off-shoots. The oasis may be isolated and the seedlings may be quite inbred and more uniform than trees that hybridized readily. Tree spacing in these areas is often irregular. Trees are closer together than in plantation-type settings. Off-shoots often are not removed and trees retain multiple trunks. The date growers in the traditional manner are often poor and lack resources and manual labour is performed for all tasks. Carpenter (1981) and Ferry (1996) cite the following problems in traditional date culture: crowding of trees; retention of old or unproductive trees; planting mixed varieties and/or seedlings; salt accumulation; poor drainage; insufficient irrigation, fertilization or tillage; lack of insect and disease control; competition with other crops; soil degradation; and water scarcity. Jaradat (2001) considered drought, high salinity, aged trees, bayoud disease and genetic erosion as the major constraints for date palm production worldwide.

If irrigation water is available, more industrial-style date palm plantations are possible if climate and soils are appropriate. Large-scale plantings of dates in the 20th century are planted utilizing off-shoots or tissue culture (TC) derived plants that are uniform. The common spacing is 9–10 m in both directions, with planting density of 120 trees/ha. In marginal climate areas, date palms are planted more closely together. Date palms are generally a cash crop and receive better care and greater inputs than in traditional oases. Most literature involving cultural practices of dates were performed in and aimed at this type of production, and it may not be applicable to more traditional cultivation.

PROPAGATION Three methods are used for date palm propagation. The most common method is the vegetative propagation of off-shoots, which ensures the genetic identity of maternal varieties. Off-shoots are developed from axillary buds on the trunk near the soil surface. Dates produce off-shoots when they are young and occasionally when they are mature. Some varieties sucker more than others, but most trees produce 10–30 off-shoots. After 3–5 years of attachment to the parental palm off-shoots produce roots and are ready to be removed. To promote rooting of off-shoots, the base of the off-shoots should be in contact with moist soil for at least 1 year before cutting. The size and weight of the off-shoots ready for cutting vary by variety, ranging from 10 to 30 kg in weight and from 20 to 35 cm in diameter. The best time for cutting off-shoots is after the soil begins to warm up in late spring and early summer. Soil temperatures should be at least 20°C. In general, no leaves should be removed from an off-shoot until it is cut from the parent palm. If a palm is crowded with off-shoots, the leaves of smaller ones are sometimes cut back close to the bud to slow the growth and the larger off-shoots are removed first. The smaller off-shoots can be used for subsequent cuttings. The soil is first dug away from the off-shoots with a sharp, straight-bladed shovel. A ball of soil, 5–8 cm thick is left attached to the roots. For dry or sandy soil, irrigation several days before cutting makes it easier to dig and ball the off-shoots. A sharp chisel with the flat side facing the off-shoots allows the connection between the off-shoots and parental palm to be cut. Some pruning is always done after removal of the off-shoots. The old leaf stubs and lower leaves are cut off close to the fibre, the basal 0.6–1.5 m of the off-shoot being left bare. Between ten and 12 leaves around the bud are kept and tied close together. The terminal portion of the leaves beyond the tie is cut off. The root ball should be kept moist between cutting and planting. Balling with wet burlap is often used with off-shoots that are to be shipped for long distances. Most varieties can be planted at a 10 × 10 m spacing. After planting, the off-shoots should be kept moist for a few weeks by light, frequent irrigation. Best results in planting off-shoots occur when medium or large, rather than small, off-shoots are used.

The second propagation method is using chance seedlings from sexual crosses. Seedlings are not identical to the maternal trees and are not uniform genetically, varying greatly in their production and fruit quality. Seedlings are also called 'Khalts', 'Balady', 'Sairs', 'Deguouls' or 'Mantours'. About 50% of the seedlings are male although they cannot be identified until trees began to flower in 4–6 years. Date groves consisting of 'Khalts' are considered marginal. Production and fruit quality from these marginal groves are greatly reduced, compared with groves developed from off-shoots. Date seeds usually germinate readily when planted in well-aerated soil at a depth of 3–5 cm after the weather warms up in the spring. Seeds may be planted either in nursery rows or directly in permanent or semi-permanent locations. Two or three seeds may be placed in each permanent location to ensure germination and later all but one of the seedlings can be removed. Date seeds stored in moderate temperature can retain viability for at least 5–6 years.

The third date propagation method is through TC from shoot tips, through either embryogenesis or organogenesis. TC was first developed in the 1970s to 1980s. The massive expansion of date palm plantations in Egypt, Saudi Arabia, UAE and Jordan has led to the extensive use of TC-derived date palms since there are insufficient off-shoots for expansion. A TC programme was also initiated under the threat of bayoud disease in Morocco. Organogenesis can be achieved using auxiliary buds and apical meristems, while embryogenesis can be done through a callus stage from various meristematic tissues like shoots, young leaves, stem, rachilla, etc. Cultivars respond to TC differently, and different optimal conditions are needed for each cultivar. It takes about 6 years to reach production through the TC process and 8 years to reach commercial quantities. TC has been used for *in vitro* selection against the fungus responsible for bayoud disease. It offers opportunities for mutation selection and genetic transformation. In general, TC progenies have similar characters as those derived from off-shoot propagation. These include leaf morphology, vegetative characteristics, flowering and fruit set, fruit physical properties (length, diameter, dimension ratio, circumference, volume, weight, flesh weight, flesh weight ratio, hardness and length), seed physical properties (length, circumference, diameter and weight) and fruit chemical composition (% moisture, % dry matter, pH, % protein, % crude fibre, % ash, % pectin, % soluble solid and % insoluble solid). The TC-derived progenies do tend to revert into a more juvenile phase.

One of the main problems with TC propagation is somaclonal variation (off-types). These somaclonal variants exhibit several typical phenotypes including variegation in leaves, variation in leaf structure and overall plant growth patterns, trees that do not form inflorescences or produce abnormal floral development, and trees that produce seedless parthenocarpic fruit. Other somaclonal variants occurred through the organogenesis TC method and have been reported from countries such as Israel, Jordan, Morocco and Namibia. These variants grow very slowly after planting with a stunted appearance (dwarfism), lower number of leaves and a low rate of total growth. Most somaclonal variants can be detected in the early stages, however, some can only be detected in the field, several years after planting or after flowering, fruit set and maturation of the trees. In Saudi Arabia, dwarfism was reported in 13.3% (of 1260 trees) of the TC-derived 'Barhee' cultivar and 20% (of 403 trees) of the TC-derived 'Khalas' cultivar, and 75.6% (of 2000 trees) of the mature 'Barhee' trees from TC failed to set fruit. Supernumery carpels (four, five and six carpels compared with the normal three carpels) occurred at frequencies of 7.8–16.9%, 2.4–7.7% and 0.7–3.5%, respectively. The frequency of somaclonal variation in TC-derived date palms can occasionally be very high and the mechanisms causing this variation are unclear and are under investigation. In order to reduce the percentage of somaclonal variation, organogenesis instead of embryogenesis is used to generate date seedlings in UAE. Various methods have been utilized to assess the genetic basis of this variation, including representational difference analysis.

PRUNING AND FRUIT THINNING When applied to date palms, the word 'pruning' has a somewhat different meaning than when applied to deciduous fruit trees. The commonly practised pruning of date palms is the removal of dead and dying leaves. This is often done after fruit harvest or in synchronization with other cultural operations such as tie-down or bagging. Dry, dead leaf bases are difficult to cut and it is easiest to remove the senescing leaves before they dry out completely. Sometimes dead leaves are retained to provide some cold protection. In addition to the removal of senescent leaves, the basal spines are removed from the previous year's leaf growth during the winter months to facilitate pollination and bunch management operations and prevent injury to workers.

In general, living green leaves are kept as the productivity of date palms is related to the number of leaves retained. An insufficient number of leaves can reduce fruit quality in the current season and fruit set and yield the following season. Date palm leaves remain alive for 7 or more years, and do not normally fall off. If trees are left un-pruned, an excessive number of leaves may exist and this increases the relative humidity (RH) in the fruit zone of the tree's crown and the incidence of disorders. An excessive number of leaves may also increase water stress. In varieties with long fruit stalks, removing leaves up to the point where the lower portions of the bunches are exposed is the preferred practice; for varieties with shorter fruit stalks this results in the removal of too many leaves for optimal production. With these shorter-stalked varieties, relatively few leaves should be removed or bunch removal should be performed in order to retain an adequate leaf:bunch ratio. This ratio is about eight to ten leaves per bunch when normal thinning practices are followed. Older date palms (20 years old and above) usually do not retain green leaves below the fruiting zone.

Fruit thinning is often practised in date culture and has a number of beneficial effects. Fruit thinning ensures adequate flowering in the following season, lessens the chance of a small crop and reduces alternate bearing tendency. Fruit thinning also increases the size of the fruit (especially important in 'Medjool' and other large-fruited varieties), improves fruit quality and advances ripening. Bunch compactness and weight are reduced by thinning, thus facilitating bunch management operations later in the season. Fruit thinning in date palms is carried out in three ways: removal of entire bunches; reduction in the number of strands per bunch; and reduction in the number of fruit per strand.

Reducing the number of strands per bunch or the number of fruit per strand is referred to as 'bunch thinning'. It is recommended that bunches be uniformly thinned by 50–75% of the normal load of flowers (Nixon and Carpenter, 1978). The procedure is slightly different for long- and short-stranded varieties. In long-stranded varieties, such as 'Deglet Noor' the lower third of all the strands in the bunch is removed. Ideally, the total number of flowers in an average strand should be counted in order to make this reduction more precise. Strand length reduction has its maximum effect when done at the time of pollination. Removal of entire strands from the centre of the bunch to reduce the total number of strands by 33–50% is also practised and can be done at the time of pollination, but is normally delayed until the cluster has emerged further. The beginning of thinning is delayed until 6–8 weeks after pollination so that set can be observed and the thinning ratio adjusted appropriately. Short-stranded varieties, like 'Khadrawy', need to be thinned slightly differently. Only 10–15% of the strand length should be removed, while removal of the centre strands increases to 50% or more. In some cases, only centre strand removal is used on short-stranded varieties. Timing for these operations is the same as for long-stranded varieties. Carpenter (1981) states that thinning should result in 1000–1500 fruit/tree. Over thinning however, can result in puffing and blistering of the skin, and cutting back strands can increase the incidence of checking, blacknose and shrivel. Variety, climatic conditions and cultural practices all influence the appropriate level of thinning. The individual grower should observe and record this information to assist in long-term management of the date garden.

Removal of individual flowers or fruit from the strands is slightly more effective in increasing fruit size than reducing the length or number of strands. However, fruit removal is less practised due to the cost. Fruit removal is time consuming and so labour costs are high. It is practised mainly with 'Medjool' where the premium price obtained for large, high quality fruit justifies the added expense.

Removal of entire fruit bunches is sometimes practised to reduce the number of bunches to an appropriate level. This number is dependent upon the age, size, vigour, variety and number of leaves on the date palm. Some of these factors may be influenced by cultural practices such as irrigation and fertilization. In order to establish date palms, all bunches should be removed from off-shoots for the first 3 years after planting. Thereafter, the number of bunches allowed may be increased by one or two per year. Date palms reach full production at 10–15 years of age, at which time they may support 10–15 bunches of dates. Mature date trees may carry up to 20 bunches if bunch removal is not practised. This can result in poor crops or alternate bearing. Certain bunch classes are higher priority for removal: early and late bunches, which are usually small and poorly pollinated; bunches with poor fruit set or with broken stalks or other structural damage; and excess bunches on one side or quadrant of the tree. In the USA, mature 'Deglet Noor' trees with 100–120 leaves are able to produce 12–15 moderately thinned bunches without alternate bearing; this results in eight or nine leaves per bunch (Nixon and Carpenter, 1978).

After pollination, bunches are usually tied to the leaf stalks. This is done by carefully pulling the bunch through the leaves below the level of the bunch and tying the fruit stalk to the midrib near the base of the leaf. This should be done when the fruit stalk is near the end of elongation but is still pliable. Tie down prevents breakage of the leaf stalk from the weight of the fruit, reduces damage from wind or high-pressure spray, and facilitates other bunch operations. It is not usually necessary until the fruit is about 75% of its final weight. This practice is easier with long-stalked varieties. Varieties with short fruit stalks are sometimes tied to leaves adjacent or even slightly above the bunch (Nixon and Carpenter, 1978).

Bunches of dates are commonly covered (bagged) in the USA. This practice has several advantages. Primary among these is protection from high humidity and rain, which can cause the physiological defects of checking, blacknose and splitting (discussed under 'Diseases, pests and weeds') and can also result in rot and souring from secondary pathogens. Bagging can also reduce losses from birds and minimize sunburn. Brown craft paper is generally used, although in some instances white paper has been found to reduce sunburn. More recently, cotton or nylon mesh bags have been used; these have the advantage of superior ventilation. It is important that the bags be open enough that humidity does not build up within the bag, therefore plastic bags should not be used. Bunches are usually bagged at the Khalal or late Kimri stage. In some countries, mesh bags are used to exclude at least some insects (Carpenter, 1981). Sometimes, bunches are spread open with wire rings prior to Khalal to reduce humidity-induced problems (Nixon and Carpenter, 1978).

NUTRITION, FERTILIZATION AND IRRIGATION Date palms require a large amount of water for vigorous growth and high yield of good quality fruit. However, they are able to withstand long periods of drought under high temperatures. Date palms under drought conditions are stunted and unproductive. Productivity is determined by the quality and reliability of the water. Date palms in oases or riverbeds may have some irrigation management by the construction of basins, borders or canals. Flood irrigation is the oldest form of irrigation and is still utilized in many areas. Furrow and basin irrigation are also quite old in application. These methods are inexpensive and easy to apply, but they are not efficient in water usage and are labour intensive. Sprinkler irrigation is the oldest 'modern' method of irrigation, and results in a more efficient but expensive use of water. For young date palms, use of traditional sprinklers could place water onto the growing point and cause damage. Recently, micro-sprinklers and drip irrigation have been utilized in date palm plantings. These modern irrigation practices allow more precise management of the amount and placement of the water.

When flood, furrow or basin irrigation is used, bearing date gardens are usually irrigated every 1–2 weeks during the summer and every 3–4 weeks during the winter. Frequency depends upon soil texture and weather conditions. In the main US production area of the Coachella Valley, 220–300 m^3/tree/year are required for mature, producing date palms, with 24–36 m^3/tree/month being needed during the summer (Nixon and Carpenter, 1978). Consumptive water use by mature date palms was approximately 104–168 m^3/tree/year, with the highest monthly use being about 15–25 m^3/tree in July. Short stature cultivars such as 'Khadrawy' use less water than other cultivars. Mature trees of various varieties were reported to use approximately 144 m^3/tree/year in central Iraq. Dowson (1982) notes work by various investigators that list annual water use per date palm in the range of 138–364 m^3 in numerous growing regions. Crop coefficients for estimating evapotranspiration are not well established for date palms. The Food and Agriculture Organization (FAO) estimate was 0.95 (Allen *et al.*, 1998). A study done in UAE developed crop coefficients ranging from 0.66 to 0.90, depending upon the time of year, while in Iraq crop coefficients were reported to be 0.75–1.00, with a seasonal average of 0.85.

Responses of date palms to irrigation were based upon the observation that growth (as reflected by the rate of elongation of the central unexpanded leaf) reflected soil water depletion. Using this observation as an index, soil water limits date palm growth about 4 weeks after irrigation during the summer months, with soil water potential being about −0.08 MPa at a 75 cm soil depth. When irrigation was withheld to the point where there was a 15–20% reduction in the rate of leaf elongation during the summer, fruit size was reduced, fruit moisture content was decreased, and fruit ripening was earlier. With 'Maktoom', a soft cultivar, under moderate rainfall, limiting irrigation reduced shrivel and blacknose with no reduction in size, grade or yield when water stress occurred during the harvest period. A slight reduction in growth of the tree occured under water stress, but the number of leaves and inflorescences was not affected. Excess amounts of water did not increase tree growth or fruit yield and quality.

Fertilization is needed to sustain production and fruit quality of date palms. However, little information is available. Many date producers follow the traditional fertilization practices, which vary by region within countries. In traditional date gardens, fertilization is often done by application of animal manure, with chicken manure being preferred due to its higher nitrogen (N) content. Although use of inorganic fertilizers is common, manure is sometimes used in plantation-type production of dates at a rate of 11–34 t/ha. Manure is generally applied in the autumn or winter, or in the spring after removal of cover crops (Nixon and Carpenter, 1978; Dowson, 1982).

Most date palm fertilization research has involved N or other macro-elements. Furr *et al.* (1951) reported that 'Deglet Noor' date palms receiving N fertilization over a 7-year period showed no response to fertilization during the first 3 years, but showed increased growth and yield over the last 4 years. The N content of pinnae and other tissues was significantly higher in the fertilized trees, and generally correlated with yields. However, in a different experiment, 'Khadrawy' palms did not respond to fertilization and there were no differences in mineral content of tissue. Young, non-bearing 'Medjool' date palms did not respond to N fertilization. In Algeria, no response to fertilization was found because all mineral needs of the date palms were supplied in the irrigation water. Conversely, in Qatar, date palms do respond to fertilization and yield was positively correlated with leaf N content and inversely with leaf potassium (K) content. In Saudi Arabia, heavy N fertilization increased date yields but decreased quality as compared to a more moderate rate of fertilization.

Responses of date palms to fertilization are dependent upon growing conditions, including soil texture and pH and other cultural practices. Date palms remove a certain amount of nutrients from the soil each season, mostly from fruit and leaf pruning. In Algeria 72 kg of N, 5 kg of phosphorus (P) and 27 kg of K were removed each year from 120 date palms (1 ha). In Saudi Arabia, 1 ha of date palms was estimated to lose 56 kg N, 6 kg P and 50 kg K annually. Lower losses of N and P were reported in the USA: 25 kg N and 2 kg P; however, loss of K was greater at 74 kg. Up to 78 kg N was reported to be lost annually in California. These values are taken by multiplying the mineral concentrations in leaves and fruit by yield and pruning mass and do not take into account nutrients that would be necessary to support annual growth of leaves and the permanent structure, nor soil-associated losses. A comprehensive study establishing appropriate nutrient levels in date palms has not been conducted.

DISEASES, PESTS AND WEEDS The date palm is affected by many diseases, pests and weeds but the incidence of a particular problem varies with the area and cultural practices. Reports of disease and pest outbreaks in specific countries or locales may be found in technical journals and on the world-wide web (e.g. the Plant Protection and Pest Information Service of FAO). There have been no reports of viral or viroid diseases of date palms so far; only fungus- and phytoplasma-caused diseases as reviewed by Elmer *et al.* (1968), Carpenter and Elmer (1978), Djerbi (1983) and Zaid *et al.* (2002). Much of the following is summarized from those references. A concise list of reported diseases (as of the date of publication) is given in Carpenter (1991). A list of diseases and disorders of date palms is in Table A.60. Most diseases of date palms are fungal pathogens, some disease are caused by phytoplasmas. The common control of most diseases of date palms include sanitation practices, use of clean off-shoots or materials from tissue culture, quarantine, reducing moisture by fruit thinning, bagging fruit and changing irrigation practices.

A list of reported insect pests of date palms is in Table A.61 and reviewed by Howard *et al.* (2001). Most insect pests of dates are controlled by chemicals, biological control, pheromone trapping, quarantine and sanitation practices. Insect pests attacking stored fruit are controlled by chemical fumigation.

Rodents can be pests of dates. Various types and species of rodents attack date palms. Rodents may eat date fruit either on the tree or in storage. Some also eat the inflorescence. Underground-dwelling rodents damage roots and also interfere with irrigation. Control of rodents is by trapping or poisoning.

Many weed species are associated with date palms around the world. The composition of the weed flora varies with

Table A.60. Common names, causal organisms or factors, symptoms and countries/region where date palm diseases and disorders were reported.

Common names	Causal organisms or factors	Symptoms	Reported countries/region
Bayoud	*Fusarium oxysporum* f. sp. *albedinis*	Attacks vascular system, causes browning and necrosis of the fronds, eventually kills the plant	Algeria, Morocco
Inflorescence rot	*Mauginiella scattae*	Infection of spathes, destruction of inflorescences	North Africa and Persian Gulf region
Black scorch (fool's disease)	*Thielaviopsis paradoxa*	Necrosis of leaves, inflorescences, trunk, vascular system, and terminal buds	
Graphiola leaf spot	*Graphiola phoenicis* (Moug) Poit.	Infection occurs in sub-epidermis of leaves and later emerges as small, black spots	North and Central Africa, Persian Gulf region, USA
Diplodia disease	*Diplodia phoenicum* (Sacc) Fawc. & Klotz	Attacks leaves of off-shoots and terminal buds, and results in death of off-shoots	
Brown leaf spot	*Mycosphaerella tassiana* (De Not) Johns	Necrosis of leaves	North Africa
Omphalia root rot	*Omphalia* spp.	Premature leaf death, reduced growth and decline, necrotic roots	USA
Belâat disease	*Phytophthora* spp.	Decline and death of young leaves and death of terminal bud	North Africa
Pre-harvest fruit rot	*Alternaria* spp., *Sepergillis* spp., *Helminthosporium* spp., *Macrosporium* spp.	Fruit rot begins at Khalal through Rutab and Tamar stages	
Al wijam	Mycoplasm-like organism	Decline and death starting from terminal bud	Saudi Arabia
Brittle leaf disease	Mycoplasm-like organism	Chlorotic and dry leaves, and stunting	North Africa
Lethal yellow	Mycoplasm-like organism	Desiccated, greyish-brown leaves, rotting of terminal bud, loss of tree crown	
White-tip dieback	Phytoplasm organism		North Africa
Dry bone	Unknown	Irregular white blotches and streaks on leaves, later with reddish-brown margins	USA, North Africa
Forun disease	Unknown	Rapid and fatal decline in 3–5 years, starting with auxiliary bud abortion, stunting of young leaves, flattering stature of older leaves	Mauritania
Rhizosis/rapid decline	Unknown	Fruit drop or shrivel on the bunch, pinnae of older leaves become discoloured, young leaves wilted, death of the fronds	USA
Bending head	Unknown	Central cluster of fronds forms a fascicle with a bent tip, death of older leaves, necrosis of terminal bud and a heart rot, trunk bends or breaks	North Africa and Mauritania
Barhee disorder/bending barhee syndrome	Unknown	10-year-old trees lean to the south at 5–90° angles, reduction in fruiting bunches	Iraq, Israel, USA
Blacknose	Physiological disorder?	Shrivelled and darkened tip of the fruit	Egypt, USA
Crosscuts	Anatomical defect	Breaks at the base of fruit stalks and leaf petioles	Iraq, Israel, Pakistan, USA
Whitenose	Caused by dry wind	Dry wind at early Rutab cause rapid maturation and drying of the fruit	Iraq, North Africa
Black scald	Unknown	Well-delineated blackened areas on the sides and tips of the fruit	USA
Root-knot nematode	*Meloidogyne* spp.		Algeria, USA

Table A.61. Common names, causal organisms, symptoms and countries/region where date palm pests were reported.

Common names	Causal organism	Description	Reported countries/region
Parlatoria or white scale	*Parlatoria blachardii* Targ.	Presence in foliage and fruit, fed on leaf stalk basal tissue, death is rare	All date producing areas except USA
Red date scale	*Phoenicococcus marletti* (Ckll)	Symptoms similar to parlatoria scale, un-thriftiness look in severe infection, small losses	All date producing areas
Green scale	*Asterolecanium phoenicis* (Ramachandra Rao)	Heavy infestation results in fruit scarring and economic losses	Egypt, Israel and Persian Gulf areas
Red palm weevil/Indian palm weevil	*Rhynochophorus ferrugineus* Oliv.	Infestation initiates through crown of the palm and ends in apical bud, palms collapse and die from heavy infestation	India, Pakistan, Egypt and Persian Gulf areas
Palm stem borer	*Pseudophilus testaceus* Gah.	Infestation through trunks and leaves, extensive damage could happen	Egypt, United Arab Emirates and Persian Gulf areas
Boring beetles	*Oryctes* spp.	Feed on tender leaves, spathes and apical buds; adult insects may kill the tree	
Fruit stalk borer	*Oryctes elegans* Prell	Mining by the borer weakens the tree and results in frond breakage	Saudi Arabia, Middle East
Nitidulid beetles	*Carpophilus dimidiatus* F., *C. hemiperus* L., *Urophorus humeralis* F., *Haptoncus luteolus* Erich.	Fruit damaged during ripening and curing stages on the trees, on the ground or in storage	USA
Carob moth	*Ectomyelois ceratoniae* Zeller	Larvae attack dates in the field, packing houses and in the market	Asia, North Africa and Mediterranean areas of Europe
Indian meal moth	*Plodia interpunctella* Hbn.	Larvae feed on ripe dates on the tree or postharvest	Algeria, Israel, Libya and USA
Greater date moth	*Arenispes sabella* Hmpsn.	Attack spathes and fruit stalks that results in dehiscence of the bunch	India, North Africa, Middle East
Raisin moth, almond or fig moth	*Cadra* spp.	Attack stored and ripening dates	
Desert locust	*Schistocera americana gregaria* Forsk.	Feed on leaves and fruit; may destroy entire crops and consume entire canopy	North Africa and Middle East
Termite	*Microcerotermes diversus* Silv. and other species	Attack roots, trunks and leaves; weakened trees may collapse; off-shoots may be killed by termites	
Old world date mite (*Bou faroua* or Goubar)	*Oligonychus afrasiaticus* McGr.	Abraded and discoloured leaves and fruit after infestation, webbing can cover fruit bunches in heavy infestation causing premature fruit drop and a decrease in fruit quality	North Africa, Middle East, Iran and Saudi Arabia
Banks grass mite	*Oligonychus pratensis* Banks.	Damage is similar to old world date mite	North Africa, Middle East and USA

locale, cultural practices and season. Some common weeds found in date palm plantations are halfa (*Imperata cylindricum*), Bermuda grass (*Cynodon dacytlon*), nutsedges (*Cyperus* spp.), *Chenopodium* spp., *Juncus* spp. and Johnson grass (*Sorghum halapense*). Although weeds have often been reported to cause more economic losses than other pests, their deleterious effects – and therefore their control – are often overlooked. In some cases, the difference between a weed and a cover crop is not obvious. In addition to their competitive effects, weeds can also serve as alternate hosts for insects and pathogens. Weed control, when implemented, may be mechanical, cultural or chemical.

HANDLING AND POSTHARVEST STORAGE In North Africa and the Middle East, some dates are harvested at the Khalal stage when they are yellow or red, depending on the cultivar. Most American and European consumers find them astringent (high tannin content). Most dates are harvested at the fully ripened Rutab and Tamar stages, when they are high in sugar content and low in moisture and tannin. The quality of the fruit is determined by fruit size, colour, texture, cleanliness and freedom from defects (sunburn, insect damages, sugar migration to fruit surface and fermentation) and decay-causing pathogens. Dry dates and some semi-dry types are usually harvested once, at full maturity. Soft dates and some semi-dry types are harvested on several occasions during the season due to uneven ripening. Ripening is usually uniform through a bunch, so it is more economical to harvest entire bunches rather than individual fruit. Labour costs sometimes dictate frequency of harvest, even though this lowers the overall quality of the product. Most date harvesting is done manually. Pickers climb the trees assisted by climbing gear or ladders; usually, there is a belt that can be clipped to several fronds to support the picker. More recently, hydraulic lift platforms have been used to gain access to the crowns of date palm trees. In some cases, hydraulic lifts are used for bins but pickers scale the trees in the traditional manner. The fruit are then separated from the bunches by a shaker. This type of mechanically assisted harvest is best suited to drier types of dates. A machine that shakes an entire tree in order to harvest dates has not yet been successfully demonstrated.

In many traditional date-producing areas, dates are still hand sorted in the field and then sold at local markets or by other means. More industrialized date production relies upon packing and storage facilities and to hold them until shipped. In many cases the equipment used in date packing houses is modified from that designed for other large-volume crops. Date packing operations may be private or cooperative, may range in size from small to large, and may be modern or less so. Within the packing house, there are a number of procedures used to ensure the quality. Fumigation, although sometimes done in the field, is generally the first treatment that dates are subjected to upon arrival at the packing house. By the 1960s and 1970s, methyl bromide had emerged as the fumigant of choice (Rygg, 1975; Nixon and Carpenter, 1978). However, environmental concerns have led to a proposed phase-out of methyl bromide, and use of other treatments. Alternative fumigation treatments used on dates in the past have included phosphine, carbon disulphide, hydrocyanic acid and ethylene oxide. Some of these compounds are quite toxic and may have their own detrimental environmental effects. Other alternatives include physical filtering, irradiation and controlled atmospheres (Glasner *et al.*, 2002).

After fumigation, the dates may be cleaned. In small operations, this can be done with damp towels attached to shakers; larger operations use washing devices with revolving brushes or jets. They are then dried with hot air or placed in a dehydration room. After cleaning, the dates are sorted to remove culls and to separate the fruit into uniform lots. Sorting into size categories may be done mechanically but for quality standards it requires human sorters. Industrialized date production generally has to adhere to governmentally mandated grade standards based on factors such as colour, uniformity of size and physical appearance. Dates are packed into various types of containers for storage, shipping and marketing. Perhaps most common are cardboard boxes or flats. In poor or marginal date-producing areas, dates may be packed into whatever container is available or marketed in bulk. In some countries, whole bunches are packed into containers.

As with many commodities, economics dictate that some date fruit be stored. The higher the moisture content of the dates, the more perishable they are. Very dry dates can be stored without refrigeration. Refrigeration is necessary for long-term storage of most dates. The optimum storage temperature is at 0°C for 6–12 months, depending on the cultivar. Semi-soft dates like 'Deglet Noor' and 'Halawy' have a longer storage life than soft dates like 'Barhee' and 'Medjool'. For long-term storage 18°C can be used. These lower temperatures are also better for soft types of dates. Generally, stored dates should be maintained at 20–25% moisture content for optimum quality. Maintaining this moisture content requires tight control over temperature and storage humidity. The optimum RH for storage of dates is about 70–75% when stored at room temperature (24°C), increasing to 80–85% for storage at 0°C. Soft dates require slightly lower storage humidity than semi-soft and dry types to retain their moisture content. Dates are not a chilling sensitive commodity (Kader, 1992). A few artificial processes can be utilized to increase the quality of dates, including artificial ripening, dehydration and hydration. Artificial ripening (also called 'curing') is not practised to a large degree, but is sometimes used when dates are picked at a less than fully mature state. This may occur in regions with marginal heat accumulation; when conditions are such that the Tamar stage occurs very quickly after Khalal, so that some fruit are at Khalal while others are shrivelling; and when fruit are picked at Khalal for other reasons. Artificial ripening is done in specialized rooms where temperature and humidity are tightly controlled. The dates are held at high temperature (35–46°C) and humidity (70–80% RH) for a period of several hours to several days. The actual conditions depend upon variety (soft varieties requiring higher temperatures), state of maturity and other factors, and generally a great degree of experience is required for successful artificial maturation (Rygg, 1975). Semi-dry and soft date types must often be dehydrated unless they are consumed immediately or stored at very low temperatures. Temperatures are lower than for artificial ripening (*c.*30°C), as are levels of RH. Air movement is important, and RH should not fall below 50%. Dehydration times range from several days to a week or more. The actual amount of dehydration depends upon the objective, long-term storage needing a greater degree of dehydration (moisture content of 23–30%, or lower in some cases) than for consumption at a fairly close date (moisture content of 30–35%). An alternative for soft varieties is to cool them to −18°C for storage immediately after cleaning (Rygg, 1975). Hydration is necessary when dates become overly dry due to unusually hot and dry climates, inadequate irrigation or delayed picking. The moisture content of such dates needs to be increased for consumer acceptance. Hydration is accomplished by saturating the fruit with water or steam. Commonly in California, hydration consists of holding 'Deglet Noor' dates at 60°C in live steam (0.36 kg/cm^2) for 4–8 h. Conditions vary somewhat in other countries (Rygg, 1975).

Dates are a non-climacteric fruit with a very low respiration rate (Kader, 1992) thus their deterioration rate is lower than many other commodities. However, there are some conditions that contribute to deterioration. Physiological deterioration in dates includes both oxidative and non-oxidative darkening and sugar spotting. Other physiological conditions that are not deterioration per se are considered defects or blemishes and are discussed in the previous section, 'Diseases, pests and weeds'. Spoilage caused by yeasts is usually due to *Zygosaccharomyces* spp. or *Hansenula* spp. as these genera are most tolerant of high sugar contents. Moulds and bacteria are considered less important in date deterioration (Rygg, 1975).

As mentioned in the section 'Uses and nutritional composition', dates may be processed into various products, including pitted pressed dates, date paste, pickles, syrups, sugar, alcohol, candies, etc. For more extensive information on methods of processing, the reader is referred to Barreveld (1993). Further information on other aspects of date packing can be found in Dowsen and Aten (1962), Rygg (1975) and Glasner *et al.* (2002).

MAIN CULTIVARS AND BREEDING Nomenclature of date palm cultivars is very confusing because of the long history of cultivation, wide exchanges of date palm germplasm, dioecism and seedling propagation. Large numbers of synonyms and homonyms exist from country to country for many cultivars. The same cultivar sometimes may have different names from oasis to oasis. Furthermore, transliteration of Arabic names into other languages can further confuse the issue. Different genetic marker systems have been used to study the genetic diversity and relationships among date palms, including morphology, isozymes, restriction fragment length polymorphisms (RFLP), random amplified polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP) and Representational Difference Analysis.

Worldwide, there are over 3000 cultivars of which some 60 are widely grown throughout the major date-growing countries. Hundreds of cultivars have been reported in different countries, particularly in North Africa and the Middle East. For example, over 450 date cultivars have been reported in Iraq, over 800 in Algeria and over 220 in Morocco. Most cultivars currently grown have resulted from thousands of years of selection from chance seedlings. Descriptions of additional cultivars are available in Nixon (1950); however, these are somewhat biased towards those varieties that have proven useful in the USA. Nixon (1950) lists most of the early accounts by US Department of Agriculture (USDA) plant explorers for further reference. Other literature regarding date cultivars is somewhat limited. Some of the leading date cultivars are briefly described below.

'Deglet Noor', meaning 'date of the light' in Arabic, also known as 'Deglet Nour', 'Deglet Nur' or 'Deglet Nuur', is believed to have originated near Touggourt in the Algerian Sahara in the 17th century. It is a dry or semi-dry date and very popular in European and US markets. It is commonly grown in Algeria and Tunisia. Fruit have a very attractive appearance, turning light red in Khalal, amber brown in Rutab and light brown in Tamar, and a distinctive and delicate flavour. Fruit size is 40–50 × 20–25 mm, with medium thick skin adhering to the 4–5 mm thick flesh, and with a medium brown seed. 'Deglet Noor' performs best in relatively light soil underlain by loam or silt soil, and in a relatively hot and dry environment. Weather requirements limit the production of 'Deglet Noor' to northern Africa and California; it is not possible to grow it in the hot and humid Persian Gulf region.

'Medjool', meaning 'unknown' in Arabic, also known as 'Medjhool', 'Medjehuel', 'Mejhul', 'Mejhoul', 'Tafilalet', 'Tafilelt' or 'Tafilat', is believed to originate from the Tafilalt district of Morocco. It is a large soft date widely accepted by the market. The fruit has an orange-yellow colour with a fine reddish-brown stippling at Khalal, ripening to an amber colour, turning into reddish brown, and more or less translucent in appearance at Tamar. Fruit size is 38–60 × 26–32 mm, with medium thick skin adhering to 5–7 mm thick flesh and a dark brown seed. The fruit is moderately soft and mildly rich in flavour. The 'Medjool' in Morocco was nearly wiped out by bayoud disease in the early 1900s. The USA and Israel are the major producers of 'Medjool'. Due to the superior quality of this cultivar, it is being produced in large numbers by tissue culture and its importance as a cultivar is therefore increasing worldwide.

'Barhee', also transliterated as 'Barhi', 'Berhi' and 'Birhi', is a name of uncertain meaning, but possibly is associated with the hot 'barh' winds that occur near Basra, Iraq, its place of origin. 'Barhee' is a soft date of high quality. Due to its low astringency during the Khalal stage, it is one of the major cultivars marketed at that stage. The fruit is yellow at Khalal, turning to amber at Rutab and amber to reddish brown at Tamar. 'Barhee' dates are 32–37 × 23–30 mm, with medium thick skin. 'Barhee' palms are robust with stout trunks but few off-shoots. Like 'Medjool', the high quality of 'Barhee' fruit has made it one of the most widely utilized cultivars for production by tissue culture.

'Deglet Beida' ('Degla beida', 'Daqlah Baydahi') originated in Algeria. The fruit ripens early in the season and is a dry type, medium sized, 37–45 × 20–23 mm, oblong or narrowly oblong with skin moderately thick and relatively smooth, yellow when immature, very light pale brown or buff at maturity and when cured. The flesh is firm and the flavour is good. The tree is of medium vigour with a medium-heavy trunk and is said to be quite salt tolerant.

'Halawy', also transliterated as 'Halawi', 'Hallawi' and 'Hellawi', is an important Iraqi cultivar. The fruit is semi-dry, 35–45 × 17–20 mm, oblong, thin skinned, with soft flesh and a rich flavour. Colour is yellow at Khalal, darkening to a deep translucent brown at Tamar. Yields are good at 70–90 kg/tree.

'Hayany' ('Hayani') is from Egypt and shows prolific off-shoot production. The early ripening fruit is large, 45–55 × 22–28 mm, oblong-elliptical, with medium thick skin that is deep red when immature, but almost black at maturity. The flesh is soft and watery with a mild flavour, lacking distinct quality. Trees are of medium vigour with a slender trunk and moderately arched leaves. It produces good yields (110–140 kg/tree).

'Khadrawy', also transliterated as 'Khadrawi', 'Khadhrawi' and 'Khudrawee', is a distinctive cultivar from near Basra, Iraq. It grows slowly and mature palms are considerably shorter than other cultivars. The fruit is soft, oblong-ovate, 33–40 × 20–24 mm, with skin medium thick, yellow at Khalal, turning amber at Rutab and reddish brown at Tamar. The 'Khadrawy' has good quality fruit with a rich but not cloying flavour, but it is only moderately productive.

'Khalasa' ('Khalaseh', 'Khalasi', 'Khalas', 'Khulas', 'Khlas') is from Arabia. The fruit is a semi-dry type, 30–40 × 19–23 mm, oblong-oval, with a thin skin that is yellow when immature, and amber to reddish brown at maturity. The flesh is very tender and melting and the flavour is rich and delicate. The fruit ripens mid-season. The tree is moderately low in vigour and the trunk is medium heavy.

'Rhars' (also called 'Ghars') originated in Algeria. The very early ripening fruit is a soft type; large, 45–55 × 20–24 mm, and oblong-ovate. The skin is medium thick and medium tough, yellow when immature and amber to reddish brown at maturity. The flesh is soft and melting; the flavour is rich and sweet but rather cloying, of good quality but very susceptible to checking from rain or high humidity. It yields 90–115 kg/tree when losses from checking do not occur.

'Samany', also transliterated as 'Samani' and 'Samiani', and having the synonym 'Rashedi', originated in Egypt. The fruit ripens mid-season and is a soft type, very large, 50–60 × 25–35 mm, and oblong-ovate. The skin is thin and tender, yellow when immature, dull amber to brown at maturity. The flesh is soft but rather coarse with a mildly sweet flavour early in the season, becoming rather insipid later. Fruit quality of 'Samany' is good early in the season (Khalal, early Rutab) but disappointing later.

'Zahidi', also known as 'Zahdi', 'Zadie', 'Zaydi', 'Zehedi' or 'Zaheedy' originated from northern Iraq and is widely grown in Iraq. 'Zahidi' has a compact crown. The fruit ripens in mid-season and has a distinctive obovate shape. It is yellow in Khalal, with the softer portions turning light brown and the drier basal portions fading to yellow or straw colour in Rutab, and in Tamar the softer portions turn reddish brown and the drier portions light brown. Fruit size ranges from 34 to 40 × 23 to 25 mm, with thick and tough skin adhering to the 4–5 mm thick flesh, with a large greyish-brown seed. The fruit is semi-dry, with no special flavour.

The long life cycle, juvenility period and dioecism of date palms make breeding a challenge. The determination of the sex ratio in sexual progenies is believed to be controlled by a single gene. In general, progenies are segregated for a 50:50 female to male ratio. A sexual chromosome with nucleolar heterochromatin has been identified that might be used for sex determination. So far no molecular markers linked to sex expression of date palm have been identified. Empirical selections at the local level are common for choice clones from chance seedlings, and are subsequently clonally propagated from off-shoots. A backcross-based breeding programme spanning over 30 years was initiated at the USDA Date and Citrus Station at Indio, California, USA in 1948. Due to problems of sterility and low vigour from inbreeding depression, no useful backcross progenies were produced. Moreover, the female cultivars produced, while having some interesting or desirable characteristics, have not proven more useful than the established commercial cultivars. A similar programme was carried out starting in 1943 at the Institut de Technologie et de Developpement de l'Agriculture Saharienne at El-Oued, Algeria. This programme has also not shown impressive results. These two programmes illustrate the long time frames needed for conventional breeding and the disappointing results of considerable effort.

Because of these obstacles, date palm improvement programmes have turned towards biotechnological approaches, including the use of TC for mass production of clones and identification of molecular markers associated with desirable traits. Most current biotechnologically based date palm improvement programmes have focused on pest and disease resistance, particularly related to the bayoud disease. Research into selecting clones resistant to bayoud has been carried out in Morocco and Algeria for several decades. Some resistant clones have been identified or produced and subsequently propagated by tissue culture for further evaluation. The future of date palm improvement will be based even more on biotechnological techniques, such as marker-assisted selection, somatic hybridization and possibly the production of transgenic date palms.

Regarding the status of genetic diversity in *P. dactylifera*, the long history of exploitation and selection means that possibly there are no 'wild' examples left of this species. There may be a few wild groves still growing around oases, springs or seepage areas, but most of the trees that currently exist are the end results of an unknown number of acts of selection. This includes trees which are not currently cultivated and may appear to be growing wild in oases, abandoned gardens, etc. Probably evolutionary change due to human selection has been relatively low, so there is a certain amount of genetic diversity present in date palms. This is reflected in the many local cultivars, which have been selected for their adaptations to local conditions. Characteristics such as off-shoot production, tolerance to humidity and fruit characteristics have been documented (Krueger, 2001).

Due to the market acceptance of dates like 'Deglet Noor' and 'Medjool' and successful TC propagation of popular cultivars, this handful of cultivars is replacing traditional cultivars in many date-growing countries. Due to their high quality, 'Medjool' and 'Barhee' have become the predominant cultivars propagated by TC, and these cultivars often replace traditional cultivars when older blocks are replanted. Additionally, population growth and developments, such as hydraulic projects and desertification, threaten areas of traditional date production, where there is the greatest chance of genetic diversity existing. Due to these factors, genetic resources of dates are decreasing at a rapid pace and urgent conservation of diverse date germplasm is needed. There has been some effort towards establishing *ex situ* collections of date palm germplasm. However, there are only about a dozen in the world, and the majority of these appear to consist mostly of elite cultivars (Jaradat, 2001; Krueger, 2001). It is hoped that in the future, more attention will be paid to the conservation of native or potentially wild date palms.

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Phytelephas spp. tagua

Tagua, ivory nut palm, *Phytelephas* spp. Ruiz & Pav. (*Arecaceae*), consists of six species of single-stemmed or clustering, dioecious, feather-leafed palms found in wet, tropical forests from Panama to Bolivia. They are the source of tagua or vegetable ivory (the hardened endosperm of the seed) which was once the raw material of a significant industry for the manufacture of buttons. Today, the ivory-like properties of tagua have garnered renewed interest in the light of the world ivory ban and current attention to products of sustainable tropical agroforestry systems. As the six species are similar enough to each other morphologically and have all been exploited regionally, it is best to treat them together.

World production and yield

From 1840 to 1841, tagua was a small component of Colombia's total exports (Ocampo, 1984). The export volume mushroomed 20 years later when tagua numbered in the top five Colombian exports (Tovar Zambrano, 1989), as well as one of the five most important Ecuadorean forest products (Acosta Solís, 1944). From 1875 to 1878, tagua constituted just over 3% of all Colombian exports (Tovar Zambrano, 1989). In 1929, a peak year, over 25,000 t of Ecuadorean tagua was exported, with a value US$1.2 million (Acosta Solís, 1944). This would be about US$15 million in today's dollars. Exports of tagua from Colombia declined in the 1920s and disappeared about 1935. Ecuador continued to produce tagua, but exports declined after 1941, and tagua disappeared from trade almost completely by about 1945 (Barfod, 1989).

In the latter part of the 19th century and into the first half of the 20th, the manufacturing of buttons from tagua was a major industry. A fifth of all buttons made in the USA in the 1920s were fabricated from tagua (Acosta Solís, 1944). Plastic eroded the demand for tagua in the 1930s and the industry shrunk to almost nothing (Barfod, 1989). Button production never died off completely, however, and a small button industry survived in Ecuador. This continued to produce the tagua disks from which tagua buttons were manufactured in Japan, West Germany and Italy (Barfod *et al.*, 1990).

Few statistics are available on tagua yields from the boom years, but Acosta Solís (1944, 1948) estimates that one plant of *Phytelephas aequatorialis* produces approximately 30 kg of dry, husked vegetable ivory annually. Bernal and Galeano (1993) suggest that a more realistic average is one-half to one-third of that figure. A stand of wild tagua palms (250–500 palms/ha, assuming half are female) can yield 2.25–4.0 t/ha/year of usable tagua (Bernal and Galeano, 1993).

Uses and nutritional composition

The hardened endosperm of the seeds of the tagua palm is its principal product. Dense and incredibly tough, the off-white coloured endosperm resembles ivory when polished, and is in fact often referred to as 'vegetable ivory'. Unlike true ivory, tagua is water soluble and will completely dissolve if immersed for long periods of time. It can be softened by hydration and then re-hardens when allowed to dry (Acosta Solís, 1944). Tagua nuts polish very nicely and are easy to colour with various dyes. The nuts are carved into a diverse assortment of items, including chess pieces, figurines and tool and utensil handles. Tagua handicrafts are particularly well developed in Ecuador. Buttons were the most important end product during the heyday of the tagua industry, and several initiatives oriented towards rainforest conservation have resurrected the production of tagua buttons. The world ban on elephant ivory has furthered increased interest in tagua jewellery and other fashion items.

The endosperm of the tagua nut is primarily composed of mannan A (45–48%) and mannan B (24–25%), two long-chain polysaccharides (Aspinall *et al.*, 1953, 1958; Timell, 1957). The liquid endosperm of young fruit is made into a drink, and the gelatinous transitional stage is also sometimes consumed. Both the outer and the inner mesocarp layers of the fruit are edible, but the inner is preferred for its flavour and modest oil content. This, however, is a minor use. The seeds contain (per 100 g) 5.3 g protein, 1.6 g fat, 91.6 g total carbohydrate and 9.3 g fibre (Gohl, 1981). No information on the nutritive properties of the mesocarp is available.

Botany

TAXONOMY AND NOMENCLATURE *Phytelephas* is one of three recognized genera in the oldest subfamily of the *Arecaceae*, the *Phytelphantoideae*, with many unique characteristics of flower and fruit morphology. The treatment herein follows Henderson *et al.* (1995), who recognize two of Barfod's (1991a) subspecies of *Phytelephas macrocarpa* as distinct species. *Phytelephas aequatorialis* was once treated as the monotypic genus *Palandra* O.F. Cook. In addition to tagua, the species are known vernacularly as yarina in many areas.

DESCRIPTION *Phytelephas aequatorialis* Spruce is a single-stemmed palm that can reach 12 m in height. The stem is 25–30 cm in girth, with conspicuous spirally arranged leaf scars. The crown consists of several dozen large, pinnate leaves, as much as 8 m in length. A skirt of dead foliage often persists below the live leaves. Each leaf has over 100 narrow leaflets on each side of the rachis, up to 90 cm long and 6–7 cm wide. These are two-ranked, though sometimes the middle pinnae are clustered and then arranged in several planes.

Phytelephas tumacana O.F. Cook is very similar to *P. aequatorialis*, but has fewer leaves.

Phytelephas macrocarpa Ruiz & Pav. is solitary or clustered, but has a very short stem that may be entirely underground or else functioning as a pseudo-rhizome. It has fewer leaves with fewer leaflets, all two-ranked.

Phytelephas schottii H. Wendl. is similar, but always solitary.

Phytelephas seemannii O.F. Cook is also single-stemmed, but the stem becomes decumbent and roots develop on the lower side. The older portions of the stem eventually die, thus the palm creeps along the ground. It bears 25–35 leaves reaching 7 m in length, with about 90 leaflets two-ranked on each side of the rachis.

Phytelephas tenuicaulis (Batrford) Henderson forms clusters of two to eight stems, 1.5–7 m tall and up to 10 cm in diameter. Each stem holds between eight and 20 leaves with 35–73 pinnae on each side.

All species are dioecious, with separate staminate and pistillate plants. Inflorescences are produced among the leaves and the two sexes are very different in appearance. Male inflorescences are long, cylindrical, fleshy spikes, up to 1.5 m long, densely packed with 300–500 spirally arranged flower clusters, each with two pairs of cream-coloured male flowers. The flowers are about 1 cm long and have 150–700 stamens. Pistillate inflorescences are much shorter than the staminate ones and may be hidden by the crown or (on short-stemmed species) buried in leaf litter. Each bears several to as many as 30 stalkless pistillate flowers towards their tips. The pistillate flowers are very large (up to 15 cm long). The staminate flowers of *P. aequatorialis* are borne on long stalks; those of *P. macrocarpa*, *P. schottii*, *P. seemannii* and *P. tenuicaulis* are sessile (unstalked); on *P. tumacana*, they are short-stalked.

The fruiting stems of the tagua species are round heads up to 30 cm diameter of 15–20 closely appressed, pressure-angled, dark-brown fruit, each up to 15 cm in diameter. The thick outside layer is thick, woody and spiny; the underlying yellow or orange mesocarp is thin, fleshy and oily. Each contains five or six seeds of variable size and shape, but averaging 3 × 5 cm. The endosperm is fluid, then gelatinous, and finally hardens.

ECOLOGY AND CLIMATIC REQUIREMENTS Species of *Phytelephas* are found from the Pacific lowlands of Panama, Colombia and Ecuador, the Magdalena River valley in Colombia, and north-western Amazonas in Colombia, Ecuador, Peru and Brazil. *Phytelephas aequatorialis* is endemic to western Ecuador, from the northern border with Colombia Azuay province in the south. *Phytelephas macrocarpa* ranges through north-western Amazonian Colombia, Ecuador, Peru and Brazil. The related *P. schottii* is restricted to the valleys of Magdalena and Catatumbo rivers in Colombia (Barfod, 1991b). *Phytelephas seemannii* is the northernmost distributed species, from the Chocó region of Colombia to eastern and central Panama. *Phytelephas tumacana* is an endangered species in a small area of south-western Colombia (Bernal, 1989).

Phytelephas species are most common on alluvial soils below 500 m elevation, where soil temperatures remain over 18°C. *Phytelephas aequatorialis* and *P. schottii* can climb to 1000–1200 m. The species grow best in moist, shady areas with rainfall in excess of over 2500 mm annually. However, *P. schottii* can be encountered on steep slopes in fairly dry locations in north-eastern Colombia.

Phytelephas may form large stands called taguales in Colombia and Ecuador, that range between 1 and 25 ha or more, inhabited by 240–500 palms/ha. Stands of the palms are often left in pastures after deforestation. The palms set fruit, but establishment of new seedlings is low to non-existent. With few exceptions (Acosta Solís, 1944; Mora Mora, 1990), tagua palms have not been cultivated. Rice fields have replaced taguales in many areas of western Colombia.

REPRODUCTIVE BIOLOGY Various bees, beetles and flies visit *Phytelephas* flowers, and beetles are considered the most frequent pollinators (Henderson *et al.*, 1995). Acosta Solís (1948) reported year-round flowering and fruiting of *P. aequatorialis*, while Barfod (1991b) claims that flowering of *Phytelephas* species is concurrent with the dry season in areas with one. Tagua nuts are gathered continuously, at least from perennially moist regions, but peak production does coincide with the drier months. The seeds are dispersed by rodents, such as pacas (*Agouti paca*) and agoutis (*Dasyprocta* spp.), who transport the seeds from the taguale, feed on the fleshy mesocarp or bury the seeds. Palms will continue to produce fruit for at least 100 years.

FRUIT DEVELOPMENT Tagua nuts are produced only by pistillate palms. When ripe the fruit disintegrates and the individual seeds, enclosed by the fleshy mesocarp, fall to the ground. The tagua nuts are gathered from the ground, after rodents have cleaned the orange fruit flesh from around them.

The nuts are dried for several weeks to 1 year. The endocarp surrounding the seeds is brittle after curing, and is removed. When this is accomplished, the endosperm is still covered in a thin, brown seedcoat.

Horticulture

PROPAGATION Except for small areas in Ecuador (Acosta Solís, 1944), tagua has never been cultivated. In the heyday of the tagua industry, campesinos tossed seeds in abandoned garden spots, and merely suppressed weeds while the palms established, typically beginning to bear fruit in 15 years. Germination requires 4–9 months or longer. Shade appears essential during the juvenile period.

MANAGEMENT Male palms are frequently thinned from taguales in Ecuador to make room for females. Tagua seems to produce best under partial illumination (as under the thin canopy found in riverside forest). Palms growing in full light usually have smaller leaves than palms growing in shade. However, much basic research on the development and production of tagua under different conditions remains to be done and this research is currently being conducted or planned in Colombia and Ecuador.

In Ecuador, tagua is often found in association with fruit-bearing tree species such as breadfruit (*Artocarpus altilis*), cacao (*Theobroma cacao*) or timber species such as *Cedrela odorata* and *Cordia alliodora*. It is believed that these are remnants of abandoned agroforestry developments in former taguales, and could serve as models for modern, sustainable management of remaining ones.

NUTRITION AND FERTILIZATION No information is available.

DISEASES, PESTS AND WEEDS The larvae of a large weevil similar (perhaps identical) to the giant palm weevil (*Rhynchophorus palmarum*) infests the stems of tagua, killing the palm (Acosta Solís, 1948). *Rhynchophorus palmarum* is the vector of the nematode that causes red ring disease, which has caused great losses among cultivated coconuts and African oil palms in South America. Inhabitants of the Chocó region of western Colombia report that *P. seemannii* is susceptible to the disease.

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Salacca zalacca salak

Salak, *Salacca zalacca* (Gaertn.) Voss. (*Arecaceae*), is the correct name, though *Salacca edulis* is still found in the literature (Mogea, 1982). It is most commonly referred to as salak (in Indonesia, Malaysia and the Philippines). Other names are sala and rakam (ragum, ragahm, rakum) (Thailand); snake fruit, snake palm and salak palm (English); yingan (Myamar); keshi sa laka and she pi guo zong (Chinese); fruit à peau de serpent, fruit de palmier à peau de serpent and salacca aux fruit à peau de serpent (French); salakpalme, salak, schlagenfrucht and zalak (German); sarakka yashi (Japanese); and salaca (Spanish).

World production

Salak is widely cultivated in the wetter parts of the Indo-Malay region and found as an understorey palm in Java and southern Sumatra.

Uses and nutritional composition

The ripe fruit is normally consumed fresh and there is an export market for high quality graded fruit in cartons. The edible part is non-fibrous, has a sweet taste and crisp texture and is yellowish white to brown in colour. Peeling can be tedious as the small spines on the skin can cause itchiness. It is also candied, pickled, dried and fresh unripe fruit are made into a salad. The fruit is also canned in syrup. The flesh can be minimally processed with a plastic cover wrap or an edible coating, and held at 5–10°C for about 1 week.

Harvest indices have not been set up though harvesting is delayed until the astringency and acidity have reached a minimum. Other factors that are used when considering when to harvest are when 160 days have passed since flowering, the fruit colour changes from dark brown to reddish brown, and firmness and ease of fruit detachment. Spadices should be individually harvested at the optimum stage. Overripe fruit is tasteless and has off-odour. The fruit is low in vitamins and oil (Table A.62).

Botany

TAXONOMY AND NOMENCLATURE *Salacca zalacca* (salak) and a related species *Salacca wallichiana* C. Martins. (known as rakam in Thailand, salak kumbar and salak renkam in Malaysia) provide edible fruit. *Salacca wallichiana* is shorter and more compact than *S. zalacca*. The synonyms are *Calamus zalacca* Gaertn., *Salacca edulis* Reinw., *Salacca zalacca* (J. Gaertn.) Voss ex Vilmorin, *Salakka edulis* Reinw. ex Blume. Subspecies have been described for Indonesia *S. zalacca* (Gaertn.) Voss var. *amboinensis* (Becc.) J.P. Mogea, known in English as Bali salak palm and in Malay as salak bali, and *S. zalacca* (Gaertn.) Voss var. *zalacca* known in Malay as salak jawa.

DESCRIPTION This creeping and tillering palm has a short stem up to 1.5 m, with very short internodes and shallow roots. It does form basal suckers but does not form large clumps. When the trunk comes in contact with the soil it sends out roots. This palm grows rapidly, reaching 1.5 m within 4 years. The feather-like pinnate leaves (7 m long) have grey to blackish, long, thin, sharp spines on the petiole (Fig. A.20), midrib margins and leaflets (Maggs, 1984). The dark green leaflets are 20–70 cm long by 2–7 cm wide. To assure fruiting, ten leaves per plant are necessary for 'Pondoh' cultivar and 16 for 'Bali'.

This usually dioecious palm produces an axillary stalked spadix that is initially enclosed by the spathe. The male spadices (7–15 × 0.7–2 cm) occur in bunches of four to 12 (Schuiling and Mogea, 1992). The larger female flowers are borne on shorter spadices (7–10 cm long), with 15–40 per inflorescence and nine to 12 inflorescences/year. The flowers are borne in pairs in the axils of the scales. The male flower has six stamens borne on a reddish, tubular corolla with

Table A.62. Proximate analysis of salak fruit per 100 g (Source: Leung *et al.*, 1972; Siong *et al.*, 1988).

Proximate	g
Water	80
Calories (kcal)	77
Protein	0.7
Fat	0.1
Carbohydrate	18.4
Fibre	0.4
Ash	0.6
Minerals	**mg**
Calcium	8
Phosphorus	9
Iron	0.3
Sodium	6
Potassium	168
Vitamins	**mg**
Ascorbic acid	4
Carotene	0.05
Thiamine	0.2
Niacin	2.4
Riboflavin	0.008

Fig. A.20. *Salacca edulis* palm and insert showing fruit (with permission from Sitijati Sastrapradja from Palem Indonesia, Lembaga Biologi Nasional, 1978).

minute pistil lobes that shed pollen in the early morning. The tubular corolla of the female flower is yellow-green outside, dark red inside and has a triocular ovary with a short trifid red style and six staminodes. Inflorescence development from emergence takes 80–90 days.

ECOLOGY AND CLIMATIC REQUIREMENTS The palm thrives under humid tropical lowland conditions with 1700–3100 mm rain/year (Kusumo, 1995). The rainfall should be uniformly distributed, with only a short dry season, otherwise irrigation or a high water table is needed. Availability of water may determine seasonality of fruiting patterns; uniform water availability provides regular flowering and fruiting. A temperature range of 22–32°C is reported to be required. Salak grows from sea level to 300–500 m depending upon the distance from the equator. Fruit yield and quality decline in cooler areas or at higher elevations. This palm is normally grown under shade and is sometimes intercropped with other tree crops such as mango, jack fruit, durian, rambutan, mangoesteen, banana or rubber. Shaded (25%) young salak plants grow faster and have higher production. Mature plants do not normally require shading as they begin to self shade each other. A free draining soil (pH 6–7) with high organic matter is preferred. The shallow rooting system does not stand flooding. It can be grown on sandy soils with irrigation.

REPRODUCTIVE BIOLOGY The palm starts flowering 3–4 years after sowing from seed and after 2–3 years for suckers. It may be productive for up to 50 years. Like other palms, a dry period is not required to induce flowering. This plant is normally cross-pollinated, however, some cultivars (monoecious 'Bali') are self-pollinated. Insects (weevils and other beetles) are thought to be the natural pollinators (Mogea, 1978), but hand pollination is practised when natural pollination is deficient. The palm flowers and sets fruit continuously but there are harvest peaks on the island of Bali in June–July and December–February in other parts of Indonesia. The December–February harvest peak in Indonesia coincides with flowering in the first half of the dry season after a smaller June–July harvest.

Pollen is collected by covering the inflorescences with a paper bag or the cut inflorescences or florets are dried in an oven at 35°C. The collected pollen can be stored for 6–12 months at 4°C and used for pollination. Stored pollen is diluted with talcum powder before pollination of inflorescences that can be done at any time of the day if there is no moisture (dew) on the stigma. Wet pollen and stigma are susceptible to fungal attacks.

FRUIT DEVELOPMENT Fruit mature 5–7 months after pollination. The 15–40 tightly packed globose to ellipsoid drupes per spadix (about 50 g) are 5–7 × 5 cm tapering to a point. The most noticeable feature is the numerous yellow to brown united scales that end in a small spine and cover the skin. The scales develop from the exocarp. There are usually three, 2–8 mm thick edible fleshy sarcotesta seeds per fruit (blackish nuts) and a white somewhat translucent homogenous endosperm. The taste has been compared to a combination of apple, banana and pineapple. The aroma is due to esters and lactones, with carboxylic acids giving the slightly sour, pungent odour; no terpenoids have been detected (Wong and Tie, 1993).

Horticulture

PROPAGATION The palm can be propagated from seed, suckers, layering or stem cuttings. Micro-propagation procedures are being developed. After removal of seeds from the fruit, viability is quickly lost, with germination falling from 55% after 1 week to no germination after 2 weeks. Seeds are planted directly into the field or in a nursery then replanted 4 months later. Seeds should be planted into moist conditions with an organic mulch covering. Young palms require shade (25%) during the first year of establishment.

Plants from seeds flower in 3–4 years with > 50% of the plants being male. Layered trees fruit in 2–3 years. Layers and suckers should come from a mature clump, in which three to four shoots develop each year, though the thorns make sucker removal difficult. A split bamboo tube is used to encase the sucker and this is pushed into the soil until rooting occurs. After rooting takes place, the bamboo tube and sucker can be removed with less danger. The stem from mature plants (7–10 years old) with all leaf sheaths removed can also be cut into sections, each with a lateral bud, dipped in fungicide and rooting hormone and planted in a nursery.

Drainage is essential to avoid waterlogging and organic matter needs to be worked into the soil before planting. Since the crop is frequently interplanted with other tree crops that provide shade, spacing information is limited, 2–6 m on a square giving 2000–3000 plants/ha has been recommended. Male plants, if necessary, are planted at a rate of 2–20%, dispersed among the female trees.

PRUNING AND TRAINING Basal suckers are removed so as not to reduce yield of the mother palm. Lateral shoots may be spared to grow into fruiting stems or for vegetative propagation. If the stem becomes tall, it looses vitality; to rejuvenate it, earth is pushed up around the stem. Alternatively, tall plants are cut off or bent over to touch the ground and the stem covered with earth, compost and manure to stimulate rooting.

Fruit thinning to six to eight per inflorescence is practised about 3 months after flowering to provide space for the remaining fruit. The supporting leaf is sometimes also pruned to allow fruit bunch development and the plant is fertilized (1–2 kg/plant).

NUTRITION AND FERTILIZATION Manure and compost, ammonium sulphate, urea, superphosphate and potassium chloride have been tried. Excess nitrogen is reported to lead to strong vegetative growth that increases the risk of plants falling over, and having large fruit with poor postharvest life. Adequate use of fertilizer may make shading less necessary than previously assumed (Schuiling and Mogea, 1992). Besides potassium, magnesium, sulphur, boron and zinc are reported to limit growth of 'Bali' and 'Pondoh' cultivars. A fertilizer rate per plant of 300 g ammonium sulphate, 38 g urea, 175 g potassium chloride, 200 g dolomite, 3.8 g borax and 3.4 g zinc sulphate for 'Pondoh' and the same, except only 150 g per plant of dolomite for 'Bali' has been recommended. Half is applied after harvest and the other half 30 days later, broadcasted around the plant at the outer canopy line (Kusumo, 1995).

Irrigation is necessary if the superficial root system does not reach the water table. Dry spells in excess of 10 days indicate the need for irrigation. Irrigation during dry spells can lead to more even fruiting throughout the year. Plants need 0.7 times the evaporation rate (4–4.5 mm/day) on a 6 × 6 m spacing, about 100–118 l/plant/day.

DISEASES, PESTS AND WEEDS A number of diseases have been reported (Table A.63), though the importance of each is unreported. Sanitation is practised to reduce infection pressure. A layer of granular-looking flesh adheres to the kernel in ripe fruit and is referred to as 'masir'. The cause of 'masir' is unknown. Fruit splitting can also occur in fruit approaching maturity that receives excess rain after a short drought. Post-harvest fruit rot caused by *Thielaviopsis* spp. can be controlled by dipping fruit in 50°C water for 3 min (Kusumo, 1995).

Larvae of weevils (*Omotemnus miniatocrinitus*, *Omotemnus serrirostuis*) tunnel into the top of the palm and can cause severe damage. The weevil, *Nodocnemis* sp., though a pollinator, can damage young fruit bunches by boring into the fruit. Other pests include leaf-eating caterpillars, leaf rollers and scabs. Rodents such as rats and squirrels can cause losses.

Until leaf canopy closure occurs, weed control is essential. Mechanical weed control is normally practised.

POSTHARVEST HANDLING AND STORAGE Fruit are harvested by cutting the bunches, with a mature palm bearing 20 kg/year. In Indonesia, fruit are handled in bamboo baskets and considerable losses occur due to mechanical injury that leads to spoilage. Fruit can be washed in water or brushed with a dry brush. Good, undamaged fruit should be selected and can be stored at 12–15°C for up to 2–3 weeks. Lower storage temperatures lead to chilling injury, the symptoms being skin pitting and discoloration and the flesh can turn brown and become soft (Mahendra and Janes, 1994). At ambient temperatures, fruit last about 7–10 days.

MAIN CULTIVARS AND BREEDING Indonesia has numerous cultivars (Kusumo, 1995) that are distinguished by place of origin and cultivation. 'Bali' is monoecious bearing both hermaphroditic and male flowers, while dioecious cultivars include 'Condet', 'Gading', 'Pondoh' and 'Suwaru'. Cultivars vary in fruit taste, mesocarp texture, colour of flesh and rind, and place of production (Yaacob and Sabhadrabandhu, 1995). 'Pondoh' is sweeter but has only 52% edible flesh, while the others are 70–80% edible. 'Bali' with about 80% edible flesh has the same sugar level (20%) as 'Pondoh', but has twice the acid content (0.44 versus 0.23%). The larger 'Swaru' fruit, though sweet and moist, has poor keeping quality. Frequently, a cultivar will not perform well outside the region in which it was selected.

The dioecious nature of many cultivars leads to wide variation in their progeny; hence upon selection of a suitable clone, vegetation propagation is used. Seedless forms do occur and are preferred. Soft fruit spines, thick flesh, sweet and aromatic taste, and high yields are frequently the desired characteristics. Thornless salak cultivars would be very useful. A thornless *Salacca* spp. has been found in Thailand (Polprasid and Salakpetch, 1989), but unfortunately, it has poor fruit quality and low productivity. A number of related species are being investigated for potential use (Hambali *et al.*, 1989).

Robert E. Paull

Table A.63. Some diseases and disorders of salak.

Common name	Organism	Parts affected
Fruit rot	*Mycena* sp.	Mycelium growth on the fruit branches
Flower wilt	*Fusarium* sp.	
	Marasmius palmivorus	Flower
Leaf spot	*Pestalotia* sp.	Black spots on leaves
Pink disease	*Corticium salmonicolor*	Plants and fruit
Fruit rot	*Thielaviopsis* spp.	Fruit
	Ceratocystis paradoxa	
	Fusarium sp.	
	Aspergillus sp.	

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Serenoa repens saw palmetto

Saw palmetto, *Serenoa repens* (Bartr.) Small (*Arecaceae*), is a shrubby palm native to the south-eastern USA that forms large clusters from a prostrate, branching stem. The fruit, while not particularly palatable, yields an effective treatment for benign prostate enlargement. Though not approved by the Food and Drug Administration (FDA) for this use in the USA, large quantities of fruit are shipped to Mexico and Europe annually for processing.

World production

Fruit production of saw palmetto is primarily from management of wild stands. Typically 0.4–0.5 kg of fruit are produced on each inflorescence. In some cases, individual inflorescences can produce up to 12 kg of fruit. Average fruit yield for a site is approximately 200 kg/ha; however, yields can vary from less than 100 kg/ha to more than 1500 kg/ha (Carrington *et al.*, 1997). Fruit collected for pharmaceuticals sold for over US$6/kg in 1995. Total estimated value of fruit sold in 1996 was approximately US$5 million (Carrington *et al.*, 2000).

Uses and nutritional composition

Free fatty acids and phytosterols within the fruit are effective in treating benign prostatic hyperplasia (Tasca, 1985; Braeckman, 1994; Wilt *et al.*, 1998).

Botany

TAXONOMY AND NOMENCLATURE Only a single species is recognized in the genus *Serenoa*. It is classified in the tribe *Corypheae* of subfamily *Coryphoideae*. Synonyms include *Sabal serrulata* (F. Michx). Nutt. ex Schult. & Schult f. and *Serenoa serrulata* (F. Michx). Nutt.

DESCRIPTION Saw palmetto stems typically lie prostrate at the soil surface but can grow upright and reach heights of 5–7 m. Multiple, persistent, palmate leaves up to 1 m wide emerge from the stem's terminal buds. They vary from olive green to silvery blue. Short recurved spines line the petioles, giving rise to the common name. Flowers are perfect and borne on paniculate inflorescences that emerge from among the leaves. The fruit is a one-seeded ellipsoid drupe with a fleshy mesocarp, 1.6–2.5 mm long and 1.2–1.9 cm wide. The fruit mesocarp has a strong odour of butyric acid. Fruit colour turns from green to yellow to orange, and then to bluish black when fully ripe.

ECOLOGY AND CLIMATIC REQUIREMENTS Saw palmetto is endemic to the coastal plain of the south-eastern USA. The northern limits of its range extend from south-eastern Louisiana through Tifton Georgia to Charleston County, South Carolina (Hilmon, 1968; McNab and Edwards, 1980). Saw palmetto occurs as a major understorey plant in seasonally wet pine flatwoods, well-drained scrubby flatwoods, and on sandy berms and dunes along rivers and the coast (Tanner *et al.*, 1996). It grows in a variety of conditions from shade to full sun. Saw palmetto occurs on a wide range of soil types but most commonly is found on seasonally flooded, sandy, acidic podosols typical of flatwoods ecosystems in the lower coastal plain, but it readily colonizes calcareous sandy soils near coasts, and on limestone in southern Florida. Annual rainfall varies from 114 cm in the northern part of its range to over 150 cm along the south-eastern coast of Florida. Rainfall also becomes more seasonal going from north to south, with increasingly more rainfall occurring during summer. In southern Florida, the southernmost part of its range, 64% of average annual rainfall occurs from June to September (Hilmon, 1968).

REPRODUCTIVE BIOLOGY Saw palmettos primarily reproduce vegetatively through suckers from the main stem. In time, extensive clumps of genetically identical clones can be formed. Saw palmettos must be at least 0.6 m in height to flower (Carrington *et al.*, 2000). Inflorescences emerge from buds at the bases of previous season's leaves in February–April, and flowering occurs from April to June (Hilmon, 1968). Flowers are insect pollinated (Tanner *et al.*, 1996). The European honeybee (*Apis mellifera* L.) is the primary pollinator but over 30 other insect poliinators have been reported. Saw palmettos flower heavily about every 2–4 years. Fruit are bird and mammal dispersed (Tanner *et al.*, 1996) and ripen in August–November.

Horticulture

PROPAGATION Seed germination ranges from 20% after 15 months in field conditions to 55% after 6 months under lab conditions (Hilmon, 1968). Seeds can remain viable for up to

1 year, but germination rate is reduced (Carrington *et al.*, 2000). Seed germination may be enhanced if the seeds pass through an animal digestive system (Tanner *et al.*, 1996).

MANAGEMENT Growth of saw palmetto is slow, between 0.6 and 2.2 cm/year of stem elongation (Hilmon, 1968; Abrahamson, 1995). It has been estimated that some saw palmettos may be 500–700 years old (Abrahamson, 1995; Tanner *et al.*, 1996). The most cost-efficient practice to increase fruit production is prescribed burning (Carrington *et al.*, 2000). Optimal burning frequency is every 5–8 years. Soil fertilization has been used to increase coverage of saw palmetto (Carrington *et al.*, 2000).

DISEASES, PESTS AND WEEDS Emerging saw palmetto inflorescences are subject to attack by cabbage palm caterpillars (*Litoprosopus futilis* G. & R.) and green fruit are subject to anthracnose (*Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. in Penz.) (Carrington *et al.*, 2000). Giant palm weevil (*Rhynchorphorus cruentatus*) is believed to infest saw palmetto stems. Removal of competing vegetation in wild stands may increase fruit production.

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Syagrus spp. syagrus

Syagrus, *Syagrus* spp. Mart. (*Arecaceae*), is distributed broadly in South America, with a particular diversity of species in seasonally dry to xeric regions of central and eastern Brazil. The seeds of virtually all of the species are edible, a number of which yield oil, and many of the species also have edible fruit. None of the species is cultivated commercially for its fruit and seeds.

Uses and nutritional composition

Nutritional composition has been determined for the fruit of one species, *Syagrus coronata* (Table A.64). It might be assumed that profiles for other species would be similar.

Botany

TAXONOMY AND NOMENCLATURE Thirty species of *Syagrus* are recognized, many of which were once treated as species of *Cocos* (Glassman, 1987; Henderson *et al.*, 1995), to which the genus of *Syagrus* is thought to be fairly closely related. Generic synonyms that were still recognized until recent taxonomic work include *Arecastrum* (Drude) Becc., *Arikury* Becc., *Arikuryoba* Barb. Rodr. and *Rhyticocos* Becc. The species readily hybridize where they occur together.

DESCRIPTION
Syagrus spp. are small to large, mostly solitary-stemmed palms, with pinnately compound leaves. The leaf sheaths are frequently fibrous and the petiole is sometimes armed with fibre spines. The leaflets are most often arranged in clusters along the rachis, green or grey-green, and with brown scales on the underside. Specific details about various species are listed in Table A.65. The flower stems emerge from among the leaves and are always subtended by a persistent peduncular bract (spathe). They may be branched to one order or spicate. The flowers are unisexual and borne on the rachillae in triad clusters of a central female flanked by two males. The fruit are ellipsoid, spherical or ovoid, often have a prominent beak, and can be coloured green, yellow, orange, brown or red. The

Table A.64. Chemical composition of the pulp and nut from the fruit of the licury palm (*Syagrus coronata*) (Source: Crepaldi *et al.*, 2001).

	Mean and standard deviation	
Constituent	Pulp	Nut
Moisture (%)	77.4 + 0.16	28.6 + 0.8
Calorific value (kcal/100 g)	108.6	527.3
Ash (%)	1.4 + 0.06	1.2 + 0.01
Lipids (%)	4.5 + 0.3	49.2 + 0.08
Nitrogen (%)	0.5	2.2 + 0.01
Protein (%)	3.2	11.5 + 0.03
Total carbohydrates (%)	13.2	9.7
Xanthophyll	Trace	ND[a]
α-Carotene	Trace	ND
β-Carotene (mg/g)	26.1 + 0.7	ND
Vitamin A (ER)	4.4 + 0.1	ND
α-Tocoferol (mg/g)	3.8 + 0.4	ND
Ascorbic acid	Trace	ND

[a] ND, none detected.

Table A.65. Some *Syagrus* spp. with edible fruits and/or seeds.

Name	Common name(s)	Distribution	Ecology	Habit and size	Leaves	Fruit	Seed
Syagrus botryophora (Mart.) Mart.	Pati, patioba	Atlantic coast of Brazil from south Sergipe to north Espirito Santo states	Rainforest on lateritic clay below 400 m	10–20 m tall, solitary	10–15, 3 m long, arching, with 100–150 rigid, ascending leaflets per side of rachis	Ellipsoid, 3.5–4.5 cm long, 2.2–2.5 cm wide, white to yellow-green, human consumption not reported	Rich in edible oil
Syagrus cardenasii Glassman	Corocito, saro	Bolivia	Seasonally dry forest on dry hills at 400–1800 m	2–3 m tall, clustered or solitary, stem mostly underground	8–12, 1–2 m long, with 32–74 clustered leaflets per side, grey	Ovoid, 2–3 cm long, 1.5–2 cm wide, brown, mesocarp with pineapple flavour	Human consumption not reported
Syagrus comosa (Mart.) Mart.	Babão, catolé	Central and eastern Brazil	Open cerrado vegetation, often on rocky slopes to 1200 m	1–7 m tall, aerial or subterranean stem	6–12, 1.5 m long, with 38–82 leaflets per side in dense clusters of two to four	Ellipsoid, 2.5–3 cm long, 1.5–1.8 cm wide, green, edible	Human consumption not reported
Syagrus coronata (Mart.) Becc.	Licuri, ouricuri	North-eastern Brazil	Caatinga, semi-deciduous forest, transitional vegetation	4–15 m tall, solitary	15–30, arranged in five twisted vertical rows, greyish green, with 80–130 rigid leaflets per side in clusters of two to five	Ellipsoid, 2.5–3 cm long, 1.7–2 cm wide, yellow-green to orange, with brown hairs, sweet, edible mesocarp	Edible
Syagrus flexuosa (Mart.) Becc.	Acumã, côco de campo	Eastern and central Brazil	Cerrado, woodlands, sandy to rocky soils to 1200 m	3–7 m tall, usually clustering, leaf bases persistent	7–15, 1 m long, dark green, 38–80 leaflets per side, in clusters of 2–5, waxy white below	Ellipsoid, beaked, 3–3.5 cm long, 1.5 cm wide, yellow, edible	Human consumption not reported
Syagrus inajai (Spruce) Becc.	Curua rana, inaya-y, peh-peh	Guianas and northern Brazil	Rainforest to 500 m	Solitary, 5–28 m	15–18, 3.5 m long, 51–110 flaccid leaflets per side in clusters of two to seven	Ellipsoid, 3–4.5 cm long, 2–3 cm wide, yellow, human consumption not reported	Edible
Syagrus oleracea (Mart.) Becc.	Catolé, guariroba	Eastern Brazil	Semi-deciduous forest to 800 m	Solitary, 7–22 m	15–20, spirally arranged, 2–4 m long, 100–150 leaflets per side, rigid, waxy green, in clusters of two to five	Ovoid, 4–5 cm long and 2.5–3 cm wide, beaked, greenish to yellow-green, edible and sold locally	Seed oil
Syagrus romanzoffianum (Cham.) Glassman	Chirivá, pindó, jeribá, guariroba, queen palm	Central and south-eastern Brazil, northern Argentina, eastern Paraguay and Uruguay	Various forest types, from dry to moist	Solitary, 12–20 m tall	7–15, 3–5 m long, arching, plumose, 150–250 leaflets per side in clusters of two to five, the tips pendulous	Ovoid, 2–3 cm long, 1–2 cm wide, yellow to orange, edible	Human consumption not reported
Syagrus schizophylla (Mart.) Glassman	Aricuriroba, licurioba	Atlantic coast of north-east Brazil	Restinga forest, sandy soils, low elevation	Usually solitary, 3–6 m tall, leaf bases persistent	8–25, 1–2 m long, leaf sheaths with fibre spines, 18–48 leaflets per side, two-ranked, rigid, regularly arranged	Broadly ellipsoid, 2–3 cm long, 1.5–2.5 cm wide, bright orange, edible and sweet	Human consumption not reported
Syagrus smithii H.E. Moore	Catolé	North-west Amazon region	Lowland rainforest on non-inundated soils to 400 m	Solitary, 6–12 m tall	5–18, 2.5–3 m long, 83–94 leaflets per side, irregularly arranged; sometimes produces undivided elliptical leaves	Ellipsoid, 6–8 cm long, 3–4 cm wide, yellow, human consumption not reported	Edible and reportedly delicious

mesocarp is fibrous and often fleshy. The fruit contain one to two seeds surrounded by a bony endocarp with three pores at one end.

ECOLOGY AND CLIMATIC REQUIREMENTS *Syagrus* spp. occur from Colombia east to French Guiana and south to Uruguay and northern Argentina, with a single species in the West Indies. The greatest diversity of species is found on the central planalto of Brazil. Most species are found in seasonally dry vegetation on sandy or rocky substrates. A few species inhabit wet forests of the Amazon region or Brazil's coastal Atlantic rainforest; only two occur in the Andes. The species are strictly tropical and subtropical in their climatic requirements. *Syagrus romanzoffianum* is able to withstand temperatures to −4°C without injury.

REPRODUCTIVE BIOLOGY *Syagrus* spp. are predominantly insect-pollinated and the fruit of most species are dispersed by animals. The seeds of several species are an important, in some cases the exclusive, food for certain parrots during their breeding season.

Horticulture

PROPAGATION Solitary-stemmed *Syagrus* spp. are propagated exclusively by seed; the few clustering species can be carefully divided. Fresh seed germinates readily, with germination times varying from 6 weeks to over a year. The dryland-dwelling dwarf species with subterranean stems are particularly slow growing; *S. romanzoffianum* is the fastest (in fact, one of the faster growing of all palm species), and is a very common ornamental in subtropical regions.

DISEASES, PESTS AND WEEDS Some *Syagrus* spp. are susceptible to the lethal yellowing phytoplasma. A number of fungal pathogens can cause foliar blights or bud rots (Chase and Broschat, 1991). Alan W Meerow

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