Mangosteen

Garcinia mangostana L.

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THE FRUITS FOR THE FUTURE PROJECT

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The project includes 10 underutilised fruits which have potential for immediate development and for each ICUC is issuing a monograph summarising all that is known and a manual for the use of extension workers. This publication is the monograph for *Garcinia mangostana*.

Mangosteen - *Garcinia mangostana* L.
by Mohamad bin Osman and Abd Rahman Milan

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The International Centre for Underutilised Crops (ICUC) is an autonomous, non-profit, scientific research and training centre. It was established in 1988, originally based at the University of Southampton, UK, and moved its headquarters to IWMI, Sri Lanka in 2005. The centre was established to address ways to increase the use of underutilised crops for food, nutrition, medicinal and industrial products. The enhancement of currently underutilised crops is a key to food security, to the conservation of biological diversity and to the preservation and restoration of fragile and degraded environments throughout the world.

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Table of Contents

List of Tables

List of Figures

List of Plates

Abbreviations

ACC	Ethylene Precursor (1-aminocyclopropane-1-carboxylic acid)
ARC	Agricultural Research Centre
ASEAN	Association of Southeast Asian Nations
AVG	Ethylene inhibitor (aminoethoxyvinylglycine)
BA	Benzyladenine
BAP	Benzylaminopurine
BAPPEDA	Directory of Development Planning Board (Indonesia)
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CSC	Commonwealth Science Council
EMS	Ethyl Methanesulfonate
DA-AMAS	Department of Agriculture - Agribusiness and Marketing Assistance Service (Philippines)
DFID	Department for International Development (UK)
FAO	Food and Agriculture Organization of the United Nations
FRIM	Forest Research Institute of Malaysia
GA	Gibberellic Acid
IAA	Indole Acetic Acid
IBA	Indole Butyric Acid
IBPGR	International Board for Plant Genetic Resources (now IPGRI)
ICUC	International Centre for Underutilised Crops
IPB-UPLB	Institute of Plant Breeding - University of Philippines
IPGRI	International Plant Genetic Resources Institute
IRR	Internal Rate of Return
ISTR	International Society for Third-Sector Research
JETRO	Japan External Trade Organization
MARDI	Malaysian Agricultural Research and Development Institute
MOA	Ministry of Agriculture and Agro-based Industry Malaysia
NAA	Napthylacetic Acid
NAP3	Third National Agricultural Policy of Malaysia
NPV	Net Present Value
ODA	Overseas Development Association (now DFID)
PG	Phloroglucinol
PVP	Polyvinylpyrrolidone
RH	Relative Humidity
TDZ	Thidiazuron
TSS	Total Soluble Solids
UKM	Universiti Kebangsaan Malaysia
UTFANET	Underutilised Tropical Fruits in Asia Network
USDA	United States Department of Agriculture
WPM	Woody Plant Medium

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2005

Preface

Tropical fruits are important constituents in the daily diets of billions of people; and many such fruits are harvested from a wide range of minor species-either from wild trees or locally cultivated ones. Many such fruit trees have multi-purpose uses and their plant products satisfy a range of local non-food purposes ranging from medicines to timber.

There are numerous lesser-known tropical fruits which have received inadequate attention from agronomists and breeders, yet a number of such fruits have, from time to time, been recognized as worthy of more focus. This is because they can supplement diets with important minerals, vitamins and carbohydrates and they can also generate income thereby helping to alleviate poverty. Most of these fruits have been neglected by the scientific community because poor market structures, transport and storage methods may be constraining and their cultivation is still largely traditional.

The International Centre for Underutilised Crops has been involved in prioritizing a limited number of such lesser-known tropical fruits and promoting their use through technology development for better husbandry and marketing. National partners in Asia identified mangosteen as one such fruit deserving priority attention.

This book aims to gather together the information relevant to the production, processing, marketing and utilization of mangosteen in order to highlight current gaps in knowledge, to identify research constraints and to summarise appropriate technology for enhanced production. The book takes the format of a monograph and it will be disseminated to a wide audience in both developed and developing countries. A complementary manual for extension workers will supplement this monograph and be made available to field workers, policy workers and others so that better use can be made of the species.

Although this document contains information and large amounts of tables and figures that will benefit more the scientific community and the commercial sector, the book is also intended to benefit farmers or household families in the development of this potential fruit. Much of the agronomic information is derived from field trials, but the major proportion of Mangosteen production is currently carried out by small-holders and the intensive fertilizer and irrigation application examined during field trialing, is not a prerequisite for a satisfactory small-scale growing of the fruit crop.

The preparation and publication of this book has been funded by the UK's Department for International Development as part of a project called "Fruits for the Future". The fruits focused upon in this project are all being dealt with in the series of monographs and a list is provided on the rear cover of this book.

Since fruit trees play a major role in crop diversification programmes and also in Agroforestry systems, ICUC is pleased to record its thanks to its partner, the World Agroforestry Centre (ICRAF) in the production of this book.

We express our great thanks to the authors Dr. Mohamad bin Osman and Dr. Abd Rahman Milan and to Miss Angela Hughes, formerly of ICUC who coordinated the production of the manuscript. Thanks are also due to the Dr. Nazmul Haq, Director of ICUC, for his wisdom and helpful comments throughout. Miss Rosemary wise is thanked for producing the drawings of the species and Mr. Berekhet Berakhy who assisted the editorial process so ably.

J. T. Williams
Chief Editor

Chapter 1. Taxonomy

1.1 Introduction

The genus *Garcinia* L. belongs to the family Clusiaceae (syn. Guttiferae) which contains about 35 genera and up to 800 species. The family is pantropical and comprises mostly large evergreen trees, or erect shrubs, with smooth, thin bark and white or yellow latex.

Apart from *Garcinia* the family also includes *Mammea* with *M. americana* being the domesticated fruit-bearing mammy apple which is of some economic importance in Central and South America and the West Indies.

Garcinia mangostana L., the mangosteen, is a slow-growing tree, well-known for its fruits particularly in Southeast Asia. The fruits possess a sweet pulp which is eaten fresh, but also used in processed form. It is grown in other parts of the tropics and is one of the most praised tropical fruits.

There has not been a recent taxonomic revision of the species *Garcinia.* At present there is no clear, generally-accepted, system of sub-generic taxa which could aid the classification of related species. Information shows a high density of species in Southeast Asia and also in the Indian subcontinent, as well as in areas neighbouring Southeast and South Asia such as Indo-China. The genus also occurs in Africa. Martin *et al*. (1987) considered 4 species of *Garcinia* to be widespread, well-known and often used in Asia. These are *G. mangostana* the mangosteen, *G. cambogia* (Gaetrn.) Desr., *G. dulcis* (Roxb.) Kurz and *G. tinctoria* Wight. They noted that *G. dulcis* had a wider potential as a home garden fruit in the tropics, but other than *G. mangostana* the others had little potential. Kanchanapom and Kanchanapom (1998) were essentially of the same opinion. It is thought that of the species of *Garcinia,* about 40 produce edible fruits (Yapwattanphum *et al*., 2002; Pynaert quoted by Bourdeaut and Moreuil, 1970). Of the many wild species 27 have been used at some time for their fruit pulp in Southeast Asia and 11 have been used in South Asia. To these may be added *G. atroviridis* Griff. occurring in both the regions. Africa has some 15 species of *Garcinia* used locally for the fruit pulp.

Only 3 of the many old world minor species appear to have been moved to another region or continent and maintained a foothold after introduction: *G. cochinchinensis* (Lour.) Choisy native to Indo-China moved to Brazil, and Florida and often cultivated in Cambodia; *G. livingstonei* T. Anders from East and South Africa to Florida; and *G. tinctoria* to Australia and Madagascar. Whether they have greater potential as home garden crops or not, is not related to their introduction.

In this respect it is worth noting the evidence of incipient domestication and primitive cultivation for fruits of minor species. These include *G. atroviridis* and *G. hombroniana* Pierre, in Malaysia; *G. indica* Choisy in NE India; *G. multiflora* Champ. in Vietnam and Laos, and *G. pedunculata* Roxb. in Assam and Bangladesh. Pockets of domestication can be noted for the better-known minor fruit species e.g. *G. dulcis* in Indonesia, Malaysia and the Philippines; and *G. tinctoria* in India and Malaysia. *G. livingstonei*, in Africa, needs to be considered along with other species showing incipient domestication.

The above summary of minor species represents a current consensus of opinions concerning those with potential. Unfortunately a number of publications confuse the issue because they list minor species almost on an *ad hoc* basis. For instance, Roecklein and Leung (1987) list *G. dulcis* and also *G. lateriflora* (locally known as kariis or karii), and *G. multiflora* Ridl. (locally known as the birai fai tree) as useful minor fruit species; Thai sources tend to note *G. cowa* Roxb. ex D.C. (Cha Muang) and *G. bancana* Miq. (Cha Muang Paa or Tengkawan in Malay) as minor species; and Malay sources have often cited *G. costata, G. prainiana* King, *G. globulosa* Ridl., *G. microlineata* Planch and T. Anders and *G. parviflora* Miq. These citations result from records of fruits being widely gathered and eaten without any assessment of cultivation possibilities.

Rather like mangosteen and occasional wild species being confused with it due to morphological similarities (e.g. *G. dulcis*), so too are there other morphological groupings in the genus showing similarities and frequent misidentifications: *G. nigrociliata*, *G. cowa*, *G. scortechinii* King and *G. parviflora* form such a group.

Numerous species of *Garcinia* are also used for purposes other than edible fruits. Some have been important for their use in the paint and lacquer industries. Gamboge is a gum resin which is collected from incisions on the bark and is used as a pigment and traded on the world market. For this purpose *G. morella* Desr., distributed in India, Indo-China and Southeast Asia and *G. hanburyi* Hook f. in East India, Malaysia and also in Indo-China are important (Dwivedi, 1993). *G. cambogia* (Gaetrn.)Desr. and *G. cowa*

Roxb. are for the gum resin but more for medicinal use in Thailand, Malaysia and India.

In some cases species can be used for several local commercial purposes. A non-drying oil, similar to kokam butter, is extracted from the seeds of *G. indica, G. morella* and *G. cambogia* for use in cooking and confectionery (Thomas, 1965; Burkill, 1966; Dwivedi, 1993). In other cases fruits can be used as flavourings, especially acid fruits, and particularly to substitute for tamarind. For this purpose *G. atroviridis* is used in Peninsular Malaysia as well as *G. cambogia* in India and *G. planchoni* Pierre in Indo-China (Cox, 1976).

G. livingstonei has proved to be a successful rootstock for cultivated mangosteen (FAO, 1995). This use of wild species needs to be systematically explored (see chapter 9) and some early attempts are recorded by Burkill (1966).

1.2 Description of the genus *Garcinia*

The genus was named by Linnaeus for Laurent Garcin (1683-1757), a Swiss botanist with the Dutch Indies Company, who had published the first description of mangosteen (Corner, 1988).

The following description of the genus is based on Ridley (1967) and Whitmore (1973).

Evergreen trees or shrubs with a straight trunk tapering to a conical canopy. Branches in alternating pairs on the trunk at an acute angle, later becoming horizontal or drooping; very occasionally branches are modified to spines. Leaves are simple and entire, opposite or nearly so, or in whorls of 3; coriaceous, often with glandular and resinous cells; stipules 0 or occasionally minute. Flowers usually male or female on separate trees but occasionally bisexual (and if so usually only physiologically female). Flowers borne in tufts or singly in the axils of leaves but rarely terminal; unless solitary, they are imbricate, or more or less compound umbellate or panicled; flowers regular with 4 persistent sepals and with 4 petals; rarely 5-merous; petals red, pink, yellow or white. Male flower with 7 to many stamens inserted on a variously shaped receptacle, free or connate into 1 central column or 4-5 bundles. Female flowers with large hypogynous ovary mounted on a variously shaped receptacle; ovary many chambered; stigma very shortly stalked but mostly sessile, plate-like, entire or lobed, often developed as a lobed disk; female flowers usually with staminodes. Fruits are fleshy berries with a thick, leathery pericarp and contain 1-4 flattened seeds in a pulpy mass. Seeds are large; embryo is a solid mass representing the hypocotyl, obvious cotyledons are absent.

Trees possess vary hard timber and produce an abundant gummy latex. In the field the vegetative shape resembles the unrelated *Eugenia* but the branching, peg-like branch scars and the latex permits ready recognition of *Garcinia*. Species are mostly understorey trees of lowland evergreen forests although *G. livingstonei* of Africa is a species of scrubland and open forests.

1.3 Description of species

1.3.1 The mangosteen *Garcinia mangostana* L.

The following description relies on information provided by Lamoureux (1980), Corner (1988) and Verheij (1992).

Mangosteen is a small or medium height evergreen tree, 6-25m, with a straight trunk, symmetrically branched to form a conical crown. Leaves are opposite, entire and cuspidate at the apex, oblong-elliptical, shortly petiolate (1-2 cm) and the apical pair of leaves on a branchlet are clasping to conceal the terminal bud. Leaves (15-)19-23(-25) cm long and (4.5-)7-10(-13) cm wide, shining and coriaceous, dark green, rarely yellow green, glabrous above, dull pale green or yellow green beneath. Central and lateral veins of leaves paler in colour than the lamina and obvious to the eye. Trees bearing male flowers are unknown: although described by Roxburgh in 1832, Richards (1990) states that this must have been the flower of a related species.

Mangosteen shows obligate agamospermy. Female flowers are solitary, paired, or rarely 3 at apices of branchlets; pedicels 1.75-2 cm long and thick. Sepals 4 in 2 pairs, outer ones yellow-green 2 cm long, inner ones smaller with red margins. Petals 4, broadly obovate, 2-5 cm long and thick fleshy, yellow green with red margins or more or less entirely red. Staminodes many and shorter than the ovary, 1-2 seriate and 0.5 cm long. Ovary is broadly ellipsoid to globose, sessile and 4-8 celled. Stigma is sessile, 4-8 radiate and large in diameter. Fruit is a depressed-globose shaped berry with thick pericarp, dark purple in colour with fleshy sweet aril. Fruits retain persistent sepals and stigma lobes. All parts of the plant contain yellow latex.

Mangosteen is cultivated in home gardens throughout Southeast Asia and Indo-China (especially Vietnam and Kampuchea), extending eastwards to New Guinea. In historical times, cultivation has been introduced to Sri Lanka and South India (including the Andaman Islands) as well as parts of Central and South America, Australia and Florida, USA.

Mangosteen is known as mangostanier in French, mangostán in Spanish, mangostão in Portuguese and mangostane in German. There is a range of vernacular names in Malaysia and Indonesia including manggis, masta, mesta, mestor, semontah, and semetah. The name mangkhut is generally applied in Thailand, cay mang cut in Vietnam, mongkhut in Kampuchea and mangostan in the Philippines. In India the fruit is referred to as mangostin.

The species is not known in the wild. Records of occasional trees in forested areas almost certainly represent relics of former cultivation or access points to the forest where fruits have been discarded, or may be a misidentification of a related species such as *G. malaccensis* Hook. f. (Richards, 1990).

Mangosteen was described as *Mangostana garcinia* by Gaetner in 1790, but Linneaus' description of the genus *Garcinia* meant that the valid taxonomic name is *G. mangostana* L.

Figures 1-1 and 1-2, illustrate the leaves, flower and fruit of mangosteen.

Figure 1-1. Leaves and branch arrangment in mangosteen

Source: R. Wise

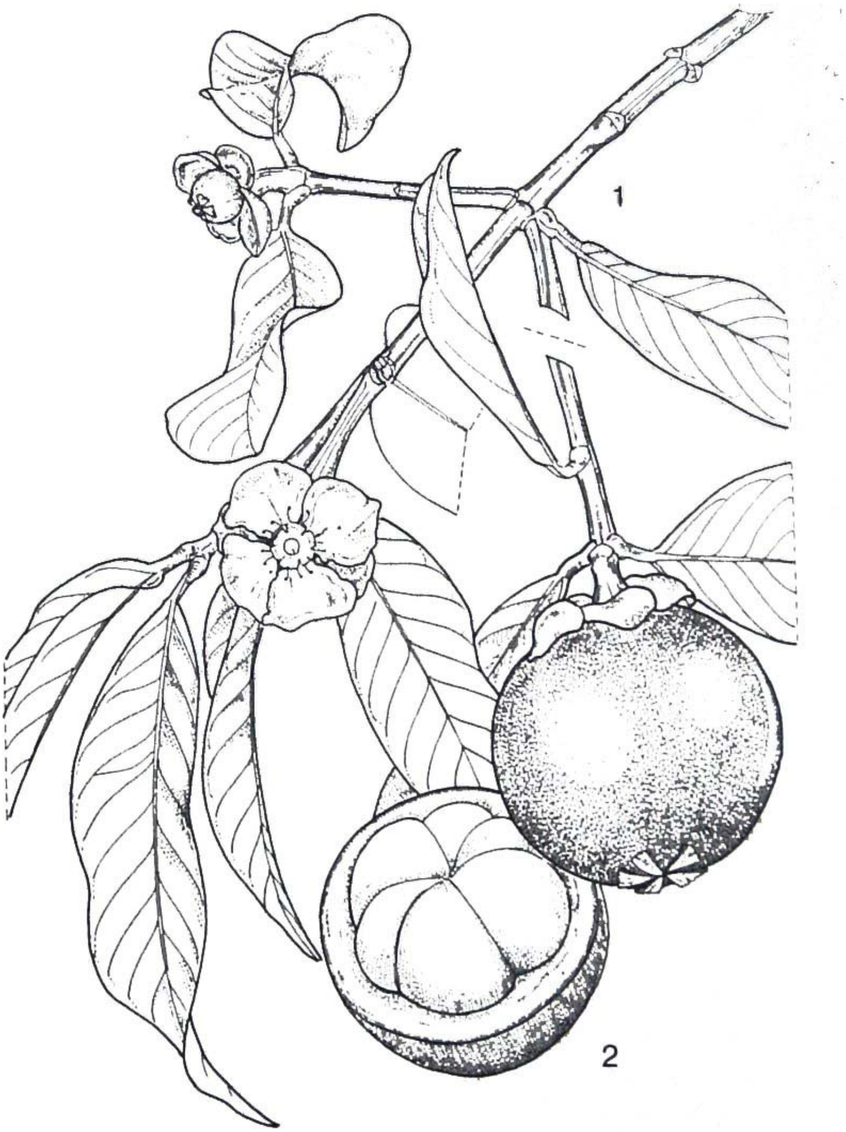


Figure 1-2. Fruits and flowers in mangosteen

Source: Verheij, 1992

1.3.2 Description of other locally important minor fruit *Garcinia* species

Only those species mentioned in section 1.1 are described below from details provided by Cox (1976), Lamoureux (1980) and FAO (1995). Ridley (1922) noted that the identity of several species of *Garcinia* was confused. In particular *G. dulcis* and *G. prainiana* were often confused with types of *G. mangostana*.

Asian species

G. dulcis

G. dulcis is a native of the Philippines, Indonesia (especially Java and Kalimantan), Malaysia and Thailand. It is also present in the Andaman and Nicobar Islands (Dagar and Singh, 1999). It is occasionally cultivated in all Southeast Asian countries. In Indonesia and Malaysia, the species is known as mundu and munu, in the Philippines it is called taklang-anak, vaniti and buneg, while in Thailand it is called ma phuut, buneg and ma phut. The species is a medium-sized bushy tree 5-20m high, similar in height to the mangosteen. It produces white latex in the branchlets and yellow latex in the fruits. The leaves are dark green, lanceolate often with hairy undersides, 10-30 cm long, 3-15 cm wide and opposite. Male flowers are creamy white in colour with a faint smell, arranged in small clusters mostly on the twigs behind the leaves. Female flowers have longer stalks and a much stronger smell, and produce copious nectar. The fruit is round, 5-8 cm in diameter, slightly pointed and turns orange when ripe. The fruit contains 1-5 large brown seeds enveloped in the edible pale orange pulp. The fruits are subacid and too sour to be eaten raw, but may be cooked and candied. The seeds are of pleasant taste.

***G. tinctoria* (D.C.) Wight**

Syn. *G. xanthochymus* Hook. ex T. Anders

G. tinctoria is often confused with *G. dulcis* and has a wide distribution in forests in Southeast Asia, Indo-China, the Indian subcontinent including the Andaman Islands (Dagar and Singh, 1999) and is also known in China. It is occasionally cultivated in India and in Malaysia.

In Malaysia, *G. tinctoria* is known as asam kandis, while in Thailand it is called mada luang. The heavy-bearing species, which had been tested under experimental conditions in the Malagasy Republic, Madagascar, proved hardier and far easier to grow than the mangosteen in Queensland (Stephens, 1935). *G. tinctoria* has been used in trials in Malagasy Republic, Madagascar and has grown well in orchards in Queensland, Australia (Stephens, 1935).The species is a medium-sized tree 10-20m high. The trees are found scattered in undulating lowland areas and peat swamp forests. The leaves are opposite, 7-15 cm long and 4-6 cm wide. Male flowers are pink to red in colour. The fruit is a small subglobose berry, 3-6 cm in diameter and turns yellow when ripe. The seeds are embedded in the edible orange pulp. The young shoots and fruits are edible and have a sour taste (Poomipamorn and Kumkong, 1997). The fruits are usually cooked.

G. atroviridis

G. atroviridis is native to Peninsular Malaysia, Thailand, Myanmar and Assam (India), and is also found in the Philippines. The tree is found growing in lowland forest. It is occasionally cultivated throughout its range. In Indonesia and Malaysia, it is known as asam gelugor or gelugor, while in Thailand it is called som khaek, somkhaek, sommawon or somphangun. The species is a large lofty tree 20-30m high, with its trunk fluted at the base. The tree produces colourless and watery latex. The leaves are large, dark glossy green, narrowly oblong and abruptly tapered at the apex, and opposite. The flowers are reddish. Male flowers, which are uncommon, are found in terminal clusters while female flowers are solitary. The fruit is large, 6-10 cm wide, nearly round, fluted with 12-16 ribs and grooves. The fruit ripens to an orange-yellow colour with both petals and sepals persistent at the base, and it tastes sour. In several countries, the unripe, but full-grown fruits are cut into slices and dried, and used in place of tamarind pulp for flavouring.

G. hombroniana

Syn. *G. opaca* King

This species is found in Malaysia and in the Andaman and Nicobar Islands. It is common on sandy and rocky coasts, or in secondary forests near the seas, In Malaysia, *G. hombroniana* is known as beruas, or sea-shore mangosteen, also manggis hutan and minjok, while in Thailand it is called waa. It is a small to medium-sized tree 9-18m high with grey bark, peeling off in small oblong flakes. It produces a white latex. The leaves are opposite, 10-14 cm long and 4-8 cm wide. Male flowers are creamy white to yellowish cream in colour. The fruit is round with thin rind, 5 cm in diameter, bright rose in colour with the scent of apples, and with the flat, disc-like stigma generally raised on the pointed end of the fruit. Fresh fruit is similar to a small mangosteen and has a taste like a peach (Ridley, 1922) but the pulp is somewhat sour.

G. indica

Syn. *G. purpurea* Roxb.

The species occurs in tropical rain forests up to 2000m especially in NE India. It is cultivated. It is a medium-sized tree producing globose fruit 2.5-3 cm in diameter. The pulp has an acid flavour and is used for jellies and syrups. It is a source of kokam butter. Fruits somewhat resemble the mangosteen and are called brindone. Both rind and pulp are dried and used commercially to flavour curries and syrups with a sour taste.

G. prainiana

G. prainiana is native to Malaysia and Thailand. In Malaysia, it is known as cerapu, cerpu, mencupu and kecupu. The species is a small to medium-sized tree up to 18m high with a narrow, dense and bushy crown. It produces white latex. The leaves are large and elliptic, 10-23 cm long, 4.5-11.5 cm wide, simple pointed or blunt, many ribbed and almost sessile. Five-petalled flowers are in dense clusters on the leafy twigs, pale yellowish to wholly pink in colour. The fruits are round and smooth, rather flattened, small 2.5-4.5 cm wide, ripening to orange-yellow with a blackish button-like stigma attached, and possess, thin rinds and pale orange, subacid but sweet pulp.

African species

G. livingstonei

G. livingstonei is distributed throughout Eastern and Southern Africa as a small tree up to 10m or a shrub. It is evergreen with a dense spreading crown, often multi-stemmed and often with a twisted trunk. Bark is brown-grey and contains yellow-red latex. Flowers male, female or bisexual in axils of leaves or on previous year's leafless growth. Fruits ovoid-globose

2.5-3.5 x 2.5-3 cm, orange to reddish in colour with acid sweet pulp, eaten raw or cooked.

There is a long list of vernacular names, especially in Malawi, Uganda, Zambia and Zimbabwe (see FAO, 1983).

The wild African mangosteen has been introduced to Florida, USA, and grows well and is hardy. However, the fruit is thin-fleshed and merits improvement (Mowry *et al.*, 1941; Chandler, 1958; Sturrock, 1959).

1.4 Key to the important Asian species of *Garcinia*

Corner (1988) provided a key and this has been modified to cover the species of interest in this monograph. Close wild relatives of mangosteen are included using data from Richards (1990) relevant to chapter 2 of this monograph.

Sepals and petals 5; young leaves pale green

Leaves nearly sessile; fruit yellow, flattened with

a button-like stigma; flowers pink…………………...*G. prainiana*

Leaves stalked; flowers yellowish white………………*G. dulcis*

Sepals and petals 4; young leaves pinkish to reddish

Fruits globose, pink, red or maroon

Pulp astringent………………………………*G. hombroniana*

Pulp sweet…………………………………..*G. malaccensis*

Fruits purple, pulp sweet/sour………………………..*G. mangostana*

Fruits yellow, orange, brown…………………………*G. atroviridis*

Chapter 2. Origin and Distribution

The mangosteen, as a cultigen, is indigenous to the Malay Archipelago (Wester, 1921; Bailey, 1946; Ochse *et al*., 1961; Palma Gil *et al*., 1972). Its cultivation extends throughout Southeast Asia, Myanmar and Indo-China, where it has diffused as a home garden and wayside species; although in recent times small orchards have been established in these regions, especially in Peninsular Malaysia, Borneo, Java and the Philippines.

2.1 Origin of mangosteen

Despite the many species with edible fruits, mangosteen is thought to be closely related to only 2 other species: *G. hombroniana* and *G. malaccensis*, themselves indigenous to Malaysia, although the distribution of *G. hombroniana* extends to the Nicobar Islands. *G. hombroniana* is mostly wild but also planted because its wood is valued and plant parts are used in medicine. *G. malaccensis* is always wild, never planted or cultivated and is a scarcer species with a scattered distribution. Mainly juveniles of *G. malaccensis* have been found in the permanent plot in Pasoh Reserve, Negeri Sembilan in Peninsular Malaysia (Saw *et al*. 1991).

Both wild species were well described by Ridley (1967) who stated that *G. malaccensis* resembles *G. hombroniana* to a degree and *G. hombroniana* resembles mangosteen. Richards (1990) stated that the three species, *G. malaccensis*, *G. hombroniana* and *G. mangostana* form a natural morphological grouping with no other close relatives.

Richards (1990) noted that both close relatives of *G. mangostana* are facultative agamospermous species and both are diploids. *G. mangostana* is a polyploid and probably tetraploid being an allotetraploid and having arisen as a hybrid between a cultivated *G. hombroniana* as the female parent and a wild *G. malaccensis* as the male parent. Chromosome number have been fond to be 2n=56-76, 88-90-96, 120-130 cited by EWM Verheij in Prosea (1992).

Male flowers are known in all *Garcinia* species except mangosteen and also possibly one unrelated wild species, *G. scortechinii* King, of Malaysia and Indo-China syn. *G. gaudichaudii* Planch. Hence sexual reproduction is possible in most species, but mangosteen is obligate agamospermous, yielding only female offspring. Male individuals in this dioecious genus have to be the product of sexual reproduction. In a number of wild species which can reproduce sexually, facultative agamospermy is known to occur in at least 10 species (Richards, 1990), and then production of multiple seedlings from seeds infers such a condition.

2.1.1 Characteristics of the mangostana - hombroniana - malaccensis species

According to Richards (1990) 13 characters differentiate the 3 species. In latex colour, fruit colour and possession of a sessile stigma, *G. mangostana* resembles *G. malaccensis*. In possessing a smooth stigma surface, clearly lobed stamen/staminode mass, fruit being globose and its surface being smooth, *G. mangostana* resembles *G. hombroniana*. Other characteristics such as flowering time, depth of stigma lobes, stigma diameter size, presence of staminodes on the female flower and taste of fruit typify *G. mangostana*, but for no character does the species fall outside the range of variability of the two wild species.

Table 2.1 (after Ridley, 1967 and Richards, 1990) characterises the 3 species.

Table 2-1. Characteristics of flowers and fruits of *G. mangostana*, *G. malaccensis* and *G. hombroniana*

	G. mangostana	*G. malaccensis*	*G. hombroniana*
Flowering time	Mar-Apr; Jul-Sept	Apr-Jul	Jan-Mar(-Jun)
Fruit colour	purple	maroon	Red
Fruit flavour	sweet/sour	sweet/insipid	Astringent
Male petals	-	red	Yellow
Stigma	4-8 lobes	Deeply 8-lobed	slightly lobed

2.1.2 Distribution of wild relatives of mangosteen in Malaysia

G. hombroniana is found both in montane and maritime forests and in secondary forests around kampongs in Peninsular Malaysia. However, it has been brought into cultivation within its natural range which encompasses Malaysia, the Nicobar Islands and Southern Thailand, cultivation having spread on a rudimentary scale to Southern India and Indo-China.

G. malaccensis is wild in tropical lowland forests of particularly Peninsular Malaysia.

2.2 Spread of cultivation of mangosteen

Apart from the cultivation of mangosteen in Southeast Asia and Myanmar, it was introduced into Sri Lanka about 1800 and thrives there in moist regions up to 600 m above sea level (Macmillan, 1935). It was first cultivated in India during the eighteenth century and between 1880 and 1890 plantings were made at the Kallar and Buliar stations in Madras State (Krishnamurthi *et al.*, 1964). It is now mostly seen on the lower slopes of the Nilgiri Hills between 360 and 1060 m and near Courtallam.

Mangosteen was introduced to the West Indies before 1955 and the seed was distributed through the Royal Botanic Gardens at Kew, UK (Popenoe, 1928). Materials were also introduced to Brazil about the same time. Outside Southeast Asia, cultivation was greatest in the West Indies.

Introduction to tropical Africa has not resulted in significant production, e.g. in Gabon, Ghana, Liberia and Tanzania (Zanzibar).

In 1901, plantings were made in the Malagasy Republic, Madagascar (Moreuil, 1971). Other introductions led to small scale production in Florida and Hawaii, USA, Honduras, Cuba, Dominica, Guatemala, Jamaica and Panama.

Although mangosteen was introduced to Southern Queensland and New South Wales, Australia, as early as 1854, there is no record that seedlings ever produced fruits. Later, introductions were made from Indonesia (Stephens, 1935).

2.2.1 Constraints to the spread of mangosteen

Mangosteen trees pass through a juvenile phase which can last anything up to 12-20 years, although good husbandry results in trees fruiting at 5-7 years after planting. The tree has exacting ecology limiting it to 10°N and 10°S of the equator (but up to 18° in frost-free areas) e.g. Malagasy and Queensland. A short dry season in needed to stimulate flowering but mangosteen can flower twice a year or sporadically and erratically. Annual rainfall of 1270 mm is necessary and the ideal temperature range is 25-35°C with RH over 80% (Krishnamurthi and Rao, 1962; Bourdeaut and Moreuil, 1970).

2.3 Distribution of *Garcinia* species

2.3.1 Asian species

In the introduction to chapter 1 of this monograph it was pointed out that there are frequent misidentifications of wild species of *Garcinia*. In the literature there are doubtful species listed as well as more robustly defined ones; and synonyms are often quoted as separate species. In addition the degree of hybridisation between wild species is unknown.

Nonetheless it is possible to provide a map of mangosteen and the wild species in Asia (Figure 2-1).

Figure 2-1. Distribution map of mangosteen and wild species in Asia

Analysis of existing information on country-wide distribution of *Garcinia* species shows the maximum density to the north of the Malesian Archipelago, with approximately 28 species in Malaysia, about 23 in Thailand, and possibly 20 in Indonesia and 19 in the Philippines. Countries bordering Malaysia such as Myanmar and countries of Indo-China have fewer species. The distribution nears its limit in the north east as it enters

Yunnan in China, although Hainan Island, China has its own 3 species. The Malesian distribution is linked to the tropical species found in the Andaman and Nicobar Islands with 18 species, only 5 also occurring further east (Dagar and Singh, 1999).

The Indian subcontinent possesses species especially typical of the northeast and Assam and of the South, especially Western Ghats and Tamil Nadu. Both these areas of distribution are linked to the Malesian distribution. However, one species *G. lanceafolia* Roxb., although in the tropical Andaman and Nicobar Islands, is spread throughout India in dry deciduous and evergreen forests. There are probably about 25 species from the Indian subcontinent.

Each area of distribution includes a limited number of endemic species: *G. indica* in the Western Ghats and *G. andamanica* in the Andamans of India; *G. hermonii* in Sri Lanka; *G. malaccensis* in Malaysia; *G. luzoniensis* in the Philippines and *G. xishuanbannariensis* in China.

2.3.2 African species

The wild species of Africa do not overlap in any way with the Asian species. About 20 species have been described, although the synonymy continent-wide has not been sorted out.

Essentially there is a clustering of species in the Congo Basin extending through coastal West Africa and in a broad band from Eastern through Southern Africa (Figure 2-2).

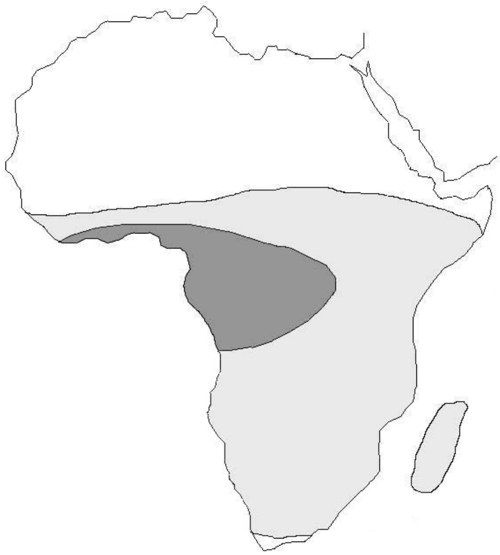


Figure 2-2. Species distribution through West, Central and East Africa

Sources: Bamps (1970) and FAO (1995)

The distribution of a good number of the Congolese species has been given by Bamps (1970) including G. *gerrardii* from South Africa. The distribution of *G. livingstonei i*s given by FAO (1988) as well as its synonyms: *G. baikeana* Vesque and *G. ferrandii* Chiov.

Chapter 3. Major and Minor Production Areas

In terms of agro-climatic requirements, mangosteen prefers deep, fertile, well-drained and slightly acidic soils with high organic matter. The plants do not grow well in soils with a high pH. The tree is adapted to heavy and well-distributed rainfall. Mangosteen requires high humidity and an annual rainfall of 1200 mm or more without prolonged dry periods. Some of the productive mangosteen plants are found growing near the banks of streams, lakes, ponds or canals where their roots are almost constantly wet. However, the plants require a short dry spell for flower induction. The optimum temperature range is 25-35°C. The agro-climatic requirements of mangosteen compared with some other tropical fruits are shown in Table 3-1.

Mangosteen is an important seasonal fruit throughout Southeast Asia. It is mainly consumed fresh, and is regarded by many as one of the best flavoured fruits in the world. Fruits can be stored successfully for short periods of time. It can also be canned, frozen or processed into juice, jam, preserve, syrup and candy. Demand often exceeds supply. As with most tropical fruits, the main markets of mangosteen are close to the areas of production.

It would be worth every effort to make this fruit better known especially in the developed countries (MOA, 2002). Due to the high durability of the fruit if transported under refrigeration and the shelf-life of two weeks, the fruits can be exported either fresh or frozen. The sharp sweet-sour taste and delicate flavour of the fruit appear to have great appeal in other areas and in particular China-Taiwan, Japan, Australia and Europe. Because of this there is a small but increasing international trade outside the Southeast Asian region, China-Taiwan is becoming a relatively big export destination. It is reported that mangosteen is culturally attractive in this area, because it is considered to be a 'cool' food in the yin-yang concept. Relating to this concept, mangosteen is consumed together with durian, to offset the 'hot' durian. Japan only imports frozen fruits due to plant quarantine restrictions (JETRO, 2002). Europe is an important and emerging market. Production for local consumption in Southeast Asia is now taking more and more account of export possibilities.

Table 3-1. Agro-climatic requirements of mangosteen compared with some other tropical fruits

Species	Climatic Requirements				Agronomic Requirements	
	Elevation	**Rainfall (mm)**	**Opt. Temp. (°C)**	**Length of dry season**	**Soil pH**	**Other**
Mangosteen	0-600	>1300	25-35	None or short	5.5-6.8	
Mango	0-700	1000-2000	24-27	4 months for flowering	5.0-7.5	
Durian	0-800	>1500	25-35	None or short	5.0-6.5	
Rambutan	0-600	>1500	25-32	None or short	4.5-6.5	
Langsat	0-700	<1500	25-35	Well-distributed rainfall	5.0-6.0	Not alkaline

Source: UDPSM (2002)

3.1 Major production areas

The major producing countries are found in Southeast Asia, namely Thailand, Malaysia, the Philippines and Indonesia (Figure 3-1). Most fruits in these markets are obtained from backyard plantings or from mixed fruit orchards. Only very few of the fruits are produced from commercial cultivation.

Detailed data on production in these four countries are not readily available. However, hectarage and production have been compiled from various sources and are shown in Table 3-2. It is apparent that the four countries have sizeable hectarage of mangosteen plantings, ranging from 1,354 ha in the Philippines (in 2000), 7,632 ha in Malaysia (in 1998), 10,750 ha in Indonesia (undated) to 11,000 ha in Thailand (in 2000). Production figures are only available for the Philippines and Thailand for the year 2000. About 85% of the total production of the four countries is in Thailand, and its production is expanding sharply compared with the other countries. The rate of expansion in Thailand is expected to continue for some time based on the ratio of non-bearing area to total production.

Table 3-2. The mangosteen hectarage and production figures for four major producing countries in Southeast Asia

Country	Year	Hectarage	Production (t)
Indonesia	Undated[1]	10,750	n/a
Malaysia	1998[2]	7,632	n/a
Philippines	2000[3]	1,354	4,692
Thailand	2000[4]	11,000	46,000

Sources: [1]BAPPEDA (2001); [2]MOA (2001); [3]DA-AMAS (2004); [4]Maneesin (2002).

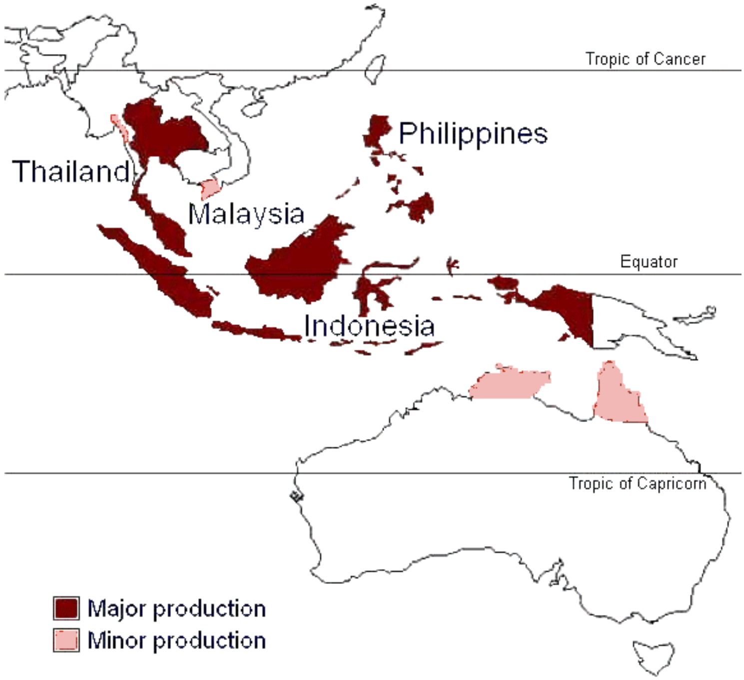


Figure 3-1. Major and minor production areas in Southeast Asia and Australia for mangosteen

Mangosteen production has remained relatively static, although there is some recent evidence of increased production. Rao and Rao (1998) reported mean annual production of fruits for 1980-81 in four countries in Southeast Asia including mangosteen, and their percentage change from the mean five years later in 1986-87 (Table 3-3). Mangosteen production figures for all countries were generally low compared to other fruits such as banana, pineapple, citrus, mango, rambutan, langsat and durian. In 1980-81, the annual production of four countries only totalled 96,000 t. However, the current total production by Thailand, Malaysia, Indonesia and Philippines has been estimated to be over 150,000 t by Downton and Chacko, (1998).

Table 3-3. Production fluctuations of fruits in Southeast Asia: Mean annual production (in '000 t) in 1986-87, and change (%) from the mean for 1980-81

	Indonesia		Pen. Malaysia		Thailand		Philippines	
	Prod	**Change**	**Prod**	**Change**	**Prod**	**Change**	**Prod**	**Change**
Banana	1994	-3	205	+5	572	-22	3788	-6
Pineapple	559	+119	154	+4			1947	+51
Papaya	225	-8	9	+137			91	-8
Citrus	530	+31	8	+10	559	-24	111	-14
Mango	416	+14	26	-11	380	20	324	-13
Durian	175	+14	243	+29	414	+58	27	+332
Langsat	64	-17	65	+37	101	-13	26	-36
Rambutan	146	+15	54	-10	447	+16		
Mangosteen			**27**	**+15**	**67**	**+7**	**2**	**+135**
Jackfruit			13	-26	392	+13	67	-29
Chempedak			59	+25	23	-5		
Guava			31		55	-36		
Sapodilla			15	-12			12	+10
Sugar apple					205	+11	6	-7
Avacado	68	+10					23	-13
Cashew	26				35	+83	4	+13
Total	**4203**		**909**		**3280**		**6104**	

Source: after Rao and Rao (1998)

The producing countries show several climatic regimes, and so the production seasons for mangosteen in these countries show some distinct differences (Table 3-4). Malaysia, Indonesia, Philippines, Thailand and Vietnam generally have similar production seasons with fruits available from May to January. However, their production seasons contrast to those of Australia, which has its production seasons from November to April. Australia also has a second production season which overlaps a little from the months of September to October. In the Southeast Asian region in September and October, mangosteen may not be available in the market because this is the end of the seasons of Thailand, Malaysia and Indonesia. The Philippine crop occurs at a time when Thai, Malaysian and Indonesia production is low since its production season is later. Thus, during this period, there is a window of opportunity for the Philippine mangosteen fruits to become available in August to November.

Export of mangosteen by major producing countries is relatively new, hence, data on export quantities and values are easier to obtain than the production figures. Verheij and Coronel (1992) reported that the total annual export value of mangosteen fruits in 1988 by Indonesia and Malaysia was small compared to that of citrus, mango, rambutan and durian (Tables 3-5 and 3-6). In that year, exports from Thailand and the Philippines were either nil or negligible. At present, out of the estimated production of 150,000 t cited above 5,000-10,000 t are exported in fresh and processed forms (Downton and Chacko, 1998).

Table 3-4. Production seasons of the major and minor mangosteen producing countries

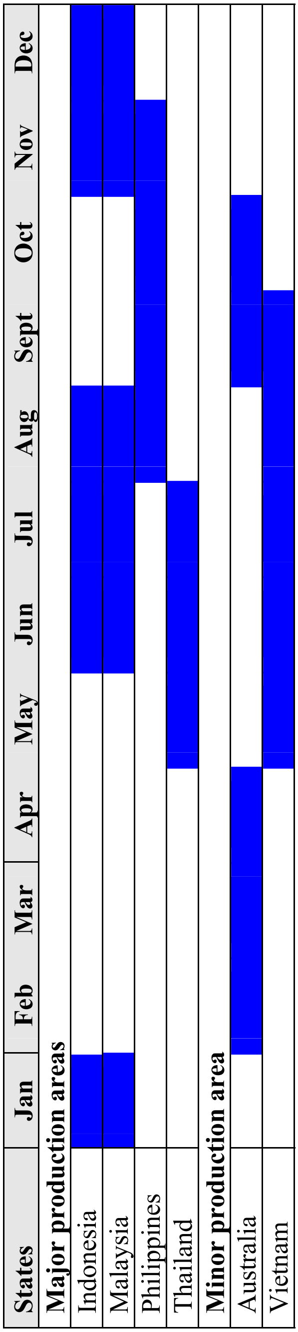


Table 3-5. Annual export in USD (× 1,000) of fruits (fresh and preserved) for four countries in Southeast Asia

	Indonesia (1988)	Pen. Malaysia (1988)	Thailand (1987)	Philippines (1988)
Citrus	131	688	4,666	832
Mango	552	202	3,051	19,760
Durian	300	14,538	11,971	-
Rambutan	40	231	5,645	-
Mangosteen	**261**	**204**	-	-
Langsat	278	29	-	-
Jackfruit	-	112	-	357

Source: after Verheij and Coronel (1992)

Table 3-6. Export quantity and export value of mangosteen for four countries in Southeast Asia

Country	**Indonesia**[1]		**Malaysia**[2]		**Thailand**[4]		**Philippines**[3]	
Year	1991	1996	1990	1998	1998	2002	1995	2000
Export quantity (t)	452	3283	1544	1062	1818	17326	326	4114

Sources: [1]BAPPEDA (2001); [2]MOA (2001); [3]DA-AMAS (2004); [4]Maneesin (2002)

Mangosteen production is described in further detail in each country, below.

3.1.1 Mangosteen production in Malaysia

As outlined in the Third National Agricultural Policy 1998-2010 (NAP3), the fruit industry in Malaysia will continue to be developed to meet the expanding demand for fresh and processed tropical fruits in both the international and domestic markets. Fifteen fruits have been identified for development. These are banana, papaya, pineapple, watermelon, starfruit, mango, durian, jackfruit, rambutan, citrus, langsat, chempedak, guava, sapodilla (ciku) and mangosteen. Special focus would be placed on mangosteen for the global market.

The cultivation of mangosteen and most other fruits in Malaysia has never previously been targeted for the export market. Few entrepreneurs willingly venture into mangosteen cultivation because of having to wait 10 years before adequate fruiting. The orchards in Malaysia are generally small and are usually found within villages or in their vicinity. They are mixed in nature, usually also including durian, rambutan, langsat, chempedak and jackfruit, but the area allotted to mangosteen is only a very small portion of the total acreage. Current production depends mainly on old mature mixed orchard holdings. It was only recently that pure stand plantings have been initiated.

The total acreage of mangosteen in Malaysia (including Sabah and Sarawak) is estimated to be between 7,000-8,000ha. The major mangosteen producing districts in Peninsular Malaysia are shown in Table 3-7. The mangosteen growing areas in Sabah are Sandakan, Keningau and Tenom.

The soil types considered most suitable for mangosteen are:

- Marine alluvium - Selangor, Kangkong and Chengai, Briah and Tualang series
- Riverine alluvium and flood plain areas - Penambang, Tok Yong, Chempaka, Lundang Tebok, Kerayong and Tawar series
- Hill soils - Bungor, Serdang, Jempol, Batang Merbau and Rengam series

Areas which are suitable for mangosteen cultivation in Peninsular Malaysia are show in Figure 3-2. The highly recommended districts include Barat Daya, Penang; Parit, Kuala Kangsar and Kinta, Perak; and Muar, Johor. The other districts which are suitable for mangosteen cultivation are Batang Padang, Perak; Jasin, Melaka; and Segamat, Johor. The other large stretches of suitable agroecological regions include many districts in Kedah, the East Coastal areas and Central Peninsular. Where there is a long dry season of 2-3 months, the crop requires supplementary irrigation. The pure stand equivalent acreage of mangosteen in Peninsular Malaysia hardly changed from 1971 to 1993 but increased thereafter (Figure 3-3). This increase could be due to statistical data reassessment or new plantings and a renewed interest in the crop.

Table 3-7. Major mangosteen producing districts in Peninsular Malaysia in 1986

States	Total Hectarage	Important Producing Districts	Total Hectarage
Kedah	236	Baling	63
		Kuala Muda	38
		Kulim	40
Perak	552	Kuala Kangsar	110
		Larut Matang	98
		Perak Tengah	182
		Kinta	53
Selangor	172	Hulu Langat	65
		Gombak	44
Negeri Sembilan	173	Kuala Pilah	71
		Seremban	51
Johor	216	Segamat	39
		Muar	124
Pahang	108	Kuala Lipis	26
		Jerantut	27
Kelantan	291	Kota Bahru	84
		Pasir Mas	36
		Jeli	91
Penang	100	Barat Daya	52

Source: MOA (1986)

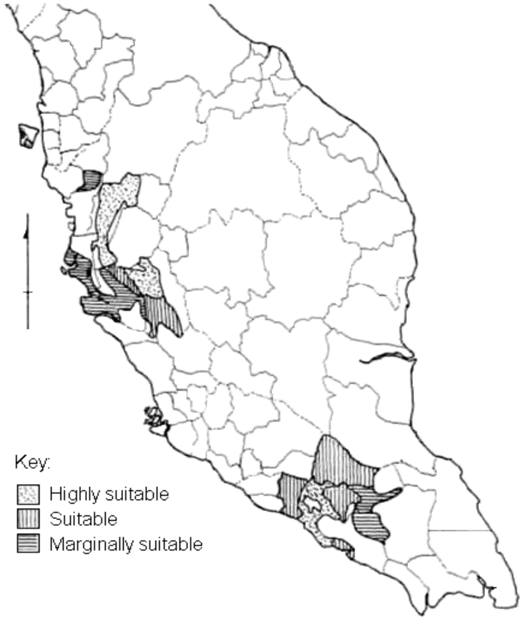


Figure 3-2. Districts suitable for mangosteen cultivation in Peninsular Malaysia

Source: MOA (1989)

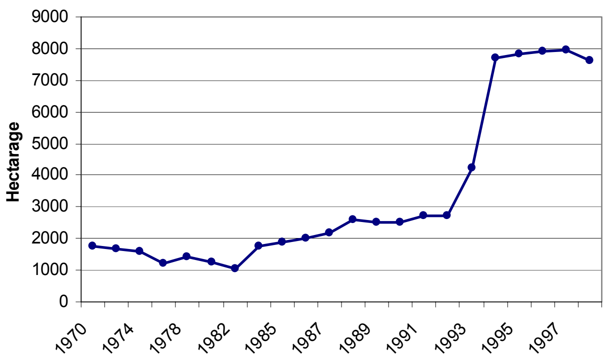


Figure 3-3. Mangosteen pure stand-equivalent hectarage in Peninsular Malaysia, 1971-1998

Sources: Mohd Khalid and Rukayah (1993); MOA (1989), (2002) A survey in 1980 indicated that over 62% of the mangosteen plants in Peninsular Malaysia were over 25 years old (Figure 3-4) (Chan *et al.*, 1981). The current production depends on old mature mixed orchard holdings, and the fruits are not of export quality. There had been very little replanting or new planting. This has led to a shortage of fruits, even for local markets.

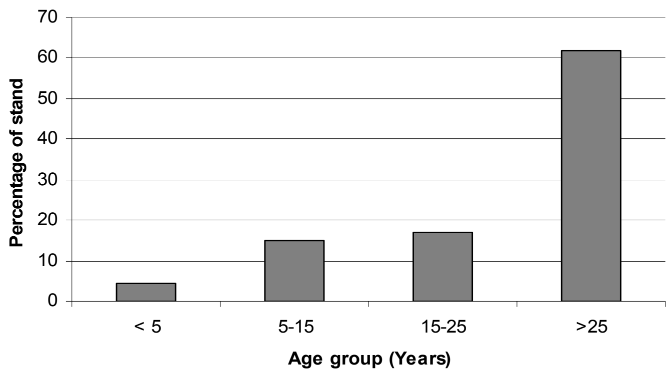


Figure 3-4. Percentage of mangosteen stand in Peninsular Malaysia by age

Source: Chan *et al.* (1981)

Mangosteen (together with durian and rambutan) are seasonal fruits and are only available once or twice a year. Generally, there are two fruiting seasons, one major and one minor (second season). The main fruiting season normally occurs between May and September, with a peak around July-August. The time of the minor season is less clearly defined and normally occurs November to February, with a peak around December (Table 3.8). The fruiting season can be 1-1½ months earlier or later depending on location of the producing districts. Problems of bienniality of fruiting also occur in mangosteen but could be reduced by proper fertilisation.

In 1990, the export quantity was 1,544 t valued at USD 456,000, and about a decade later, the export quantity has increased to 1,961t valued at USD 1,127,000. In the past few years, mangosteen fruits have been exported mainly to Singapore, China-Taiwan and Hong Kong (Fatimah *et al.*, 2003).

For the 1980-2000 period, the volume of fruits exported has shown strong fluctuations ranging from a low of 82 t in 1984 to a high of 3,168 t in 1994 (Figure 3-5). The export price of mangosteen has increased from USD 261 per t in 1996 to USD 574 per t in 1999.

There is good potential for exporting mangosteen to other overseas markets such as Brunei and Middle Eastern and European countries. The prospect for marketing mangosteen locally is bright due to an increase in demand and popularity of mangosteen by local consumers.

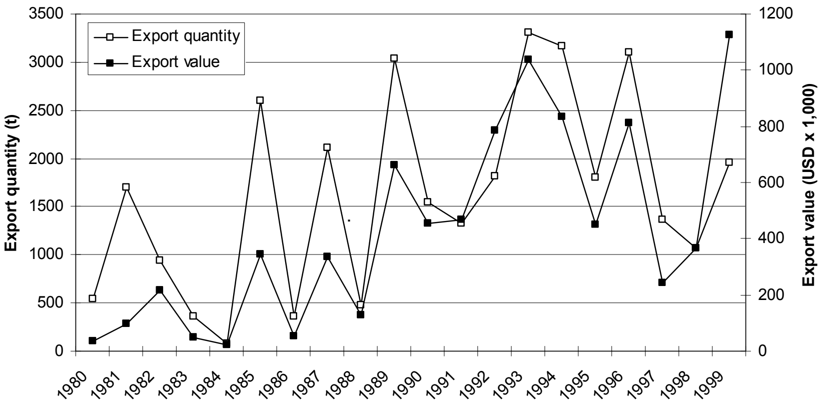


Figure 3-5. Export quantity and value of mangosteen by Malaysia, 1980-1999

Source: Mohd.Khalid and Rukayah (1993), MOA (2002)

Table 3-8. Production seasons of mangosteen in Malaysia

States	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pen. Malaysia												
Johor							■	■				
Kedah						■	■	■				
Kelantan							■	■	■			
Melaka							■	■				
N. Sembilan	■	■				■	■	■				
Pahang	■						■	■	■			
Perak	■	■	■			■	■	■				
Perlis						■	■	■				
Pulau Pinang					■	■	■					
Selangor	■	■	■		■	■	■					
Terengganu						■	■	■		■	■	
East Malaysia												
Sabah				■	■	■	■	■	■			
Sarawak	■										■	■

Source: MOA (1989)

3.1.2 Mangosteen production in Thailand

In Thailand, mangosteen cultivation is limited to the South and the East due climatic conditions. Commercial orchards have been well established in Surat Thani province in the South, and Chanthaburi and Rayong provinces in the East. In a study carried out in Rayong and Chanthaburi provinces, the average annual yields of mangosteen, durian and rambutan were 638 kg/rai, 1,756 kg/rai and 1,865 kg/rai while the market value was 31 baht/kg, 16 baht/kg and 11 baht/kg, respectively.

In 2000, the area planted to mangosteen was estimated at 11,000 ha with a total production of 46,000 t. Although currently Thailand is the world's leading supplier of mangosteen, mangosteen production remains to a large extent for domestic consumption.

Thailand produces a wide range of tropical fruits, comprising seasonal fruits such as litchi, rambutan, durian, mangosteen and non-seasonal fruits such as banana, papaya, pineapple and guava. Seasonal fruits are available from May to July while non-seasonal fruits are available all year round. The value of fruits exported from Thailand has increased considerably from USD 28.5 million (74,751 t) in 1992 to USD 150 million (341,321 t) in 2002 (Table 3.9). Important markets are Malaysia, Indonesia, China-Hong Kong, Japan and the UK, while mainland China also recently became a potential market.

Table 3-9. Quantity and value of fresh fruits exported from Thailand in 1992 and 2002

Commodity/ Year	Mangosteen	Banana	Durian	Litchi	Longan	Mango	Pomela	Others	Total
1992 Quantity (t)	1116	2241	15116	1447	12811	3947	5889	32184	74751
1992 Value (USD)	0.6	0.4	6.7	1.4	7.3	0.8	1.8	9.5	28.5
2002 Quantity (t)	17326	5213	85831	16110	113168	17326	7518	78829	341321
2002 Value (USD)	8.6	1.9	42.6	9.4	47.5	8.6	2.5	29.3	150.0

Source: Maneesin (2002); Exchange used is USD 1=40.8 baht

Mangosteen fruits are exported in fresh and frozen forms. Mangosteen is shipped fresh from Thailand to Hong Kong in 11 kg boxes or corrugated carton. It was reported that each 11 kg box fetched a price of USD 2.00 or USD 2.24 per kg. In 2003, about 500 t of fresh mangosteen were reported to have been exported to Japan, after lifting of a ban on fresh mangosteen import into Japan. Japan now permits fresh mangosteen import on condition that the fruits are given steam treatment for 58 minutes at 46°C to eradicate insects.

Thailand has a tropical monsoon climate. The climate shows a distinct seasonal pattern of rainfall, with a major peak in October-December, exemplified in the Songkla Lake Basin region. The seasonal growth and development sequences (phenology) of fruit crops in the area, including mangosteen, normally corresponds with the annual rainfall pattern (Figure 3-6). Typically, mangosteen fruits are available in May (20%), June (35%), July (35%) and August (10%).

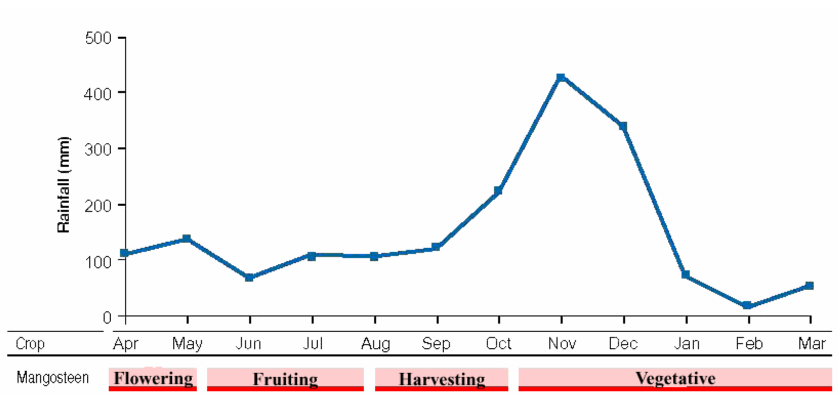


Figure 3-6. The seasonal growth and phenology of mangosteen corresponding with the annual rainfall pattern in Songkhla Lake Basin

Source: Panapitukul and Chatupotel (2001)

3.1.3 Mangosteen production in Indonesia

Fruit orchards in Indonesia are generally found in villages and contain several fruit species. Mangosteen cultivation is found throughout the 30 provinces. In Sumatra, three variants of mangosteen have been identified in cultivation, namely: (i) trees with large leaves, producing big-sized fruits with thick rind, (ii) trees with medium leaves, producing medium-sized fruits, and (iii) trees with small leaves, producing small fruits Dede Juanda & Bambang Cahyono (2000).

The main provinces in decreasing order include West Java, West Sumatera, East Java, North Sumatera, Banten and Riau. Other provinces have also been noted, namely East Kalimantan, Central Kalimantan, North Sulawesi, Central Java, Jambi, Bangka Belitung, Bali, South Sumatera, Yogyakarta and Nanggroe Aceh Darussalam. The area planted with mangosteen was reported at 4,124 ha in 1999 and the area increased to 9,354 ha (Table 3-10). The production in 1999 was 19,174 ton with.average yield of 4.65 t/ha and this increased to 79,073 ton with an average yield of 8.45 t/ha (Table 3-11).

Table 3-10. Area planted with mangosteen by Provinces in Indonesia, 1999-2003 (ha.)

No	Province	1999	2000	2001	2002	2003
1	Nanggroe Aceh Darussalam	25	52	62	133	226
2	Sumatera Utara	248	155	449	341	657
3	Sumatera Barat	400	360	375	864	890
4	Riau	214	223	321	273	619
5	Jambi	187	142	198	275	464
6	Sumatera Selatan	329	462	197	180	289
7	Bengkulu	17	51	70	162	88
8	Lampung	50	53	52	94	123
9	Bangka Belitung	0	0	243	31	359
10	DKI Jakarta	0	0	0	0	0
11	Jawa Barat	1169	2312	634	2967	2601
12	Jawa Tengah	622	420	341	906	550
13	DI Yogyakarta	64	150	155	189	263
14	Jawa Timur	328	318	434	564	671
15	Banten	0	0	91	82	625
16	Bali	173	108	121	193	303
17	Nusa Tenggara Barat	59	22	28	47	80

No	Province	1999	2000	2001	2002	2003
18	Nusa Tenggara Timur	0	0	0	0	0
19	Kalimantan Barat	60	132	56	205	108
20	Kalimantan Tengah	28	99	93	99	110
21	Kalimantan Selatan	42	26	137	29	39
22	Kalimantan Timur	8	27	132	13	31
23	Sulawesi Utara	44	19	72	112	92
24	Sulawesi Tengah	8	21	40	66	36
25	Sulawesi Selatan	24	18	61	95	35
26	Sulawesi Tenggara	0	0	0	0	0
27	Gorontalo	0	0	8	90	37
28	Maluku	25	22	22	8	0
29	Maluku Utara	0	0	214	21	57
30	Irian Jaya	0	0	1	12	1
	Indonesia	4124	5192	4607	8051	9354

In East Java, the main production areas are in the districts of Renggalek, Ponorogo, Blitar Lumajang and Banyuwangi. In 2000/2001, Trenggalek was reported as the largest mangosteen producing district in East Java, comprising about 30,000 mature plants and new plantings of 500ha. In West Java, the main production areas are in the districts of Tasikmalaya, Jasinga, Ciamis, and Wanayasa. In the district of Tasikmalaya, a 25 ha planting in Puspahiang had been reported to have production capacity of around 212 t per year.

Indonesia exports fresh mangosteen to China (including Hong Kong and Taiwan), Japan, Singapore, the Netherlands, France and Saudi Arabia. In wet seasons, the export volumes have been reported to be around 200-350 t per month, valued at USD 250,000-350,000. In dry months, the volumes of export decrease to about 40-90 t per month. During the 1993-2002 period, the volumes of fruits exported increased from 1,074 ton in 1993 to 6,512 ton in 2002 (Figure 3-7). In 1993 the export value was at USD 1.12 million, while in 2002 the export value sharply increased to USD 6.96 million.

Mangosteen fruits from West Java have been priced at Rp. 7,500-20,000 per kg depending on quality and where the fruits were sold. The equivalent of Rp.100,000-150,000 per kg can be achieved when sold in Saudi Arabia, or USD 8-10 per kg in other overseas markets. However, only 5-10% of the harvested fruits actually pass the quality standards for export.

In the 1990-1997 period, mangosteen, durian and banana showed a strong increase in exports, registering average annual increments of 12.6%, 10.5%, and 39.1%, respectively, see Table 3-10. In terms of volume of exports, mangosteen surpassed the volume of durian exported.

Table 3-11. Area planted, yield per ha and production of some fruits in Indonesia, 1999-2003

Year	Statistics	Mangosteen	Banana	Durian	Mango	Orange
1999	Harvested area (ha)	4124	70512	24031	36981	25210
	Yield per ha (t/ha)	4.65	47.88	8.09	22.36	17.83
	Production (t)	19174	3375851	194359	826842	449531
2000	Harvested area (ha)	5192	73539	23021	44185	37120
	Yield per ha (t/ha)	5.08	50.95	10.29	19.83	17.35
	Production (t)	26400	3746962	236794	876027	644052
2001	Harvested area (ha)	4607	76923	49812	44208	35367
	Yield per ha (t/ha)	5.60	55.91	6.97	20.89	19.55
	Production (t)	25812	4300422	347118	923294	691433
2002	Harvested area (ha)	8051	74751	41033	184659	47824
	Yield per ha (t/ha)	7.71	58.65	12.80	7.60	20.24
	Production (t)	62055	4384384	525064	1402906	968132
2003	Harvested area (ha)	9354	85690	53770	158894	69139
	Yield per ha (t/ha)	8.45	48.75	13.80	9.61	22.13
	Production (t)	79073	4177155	741831	1526474	1529824

Source: Agricultural Statistics, Ministry of Agriculture of Republic of Indonesia, 2004

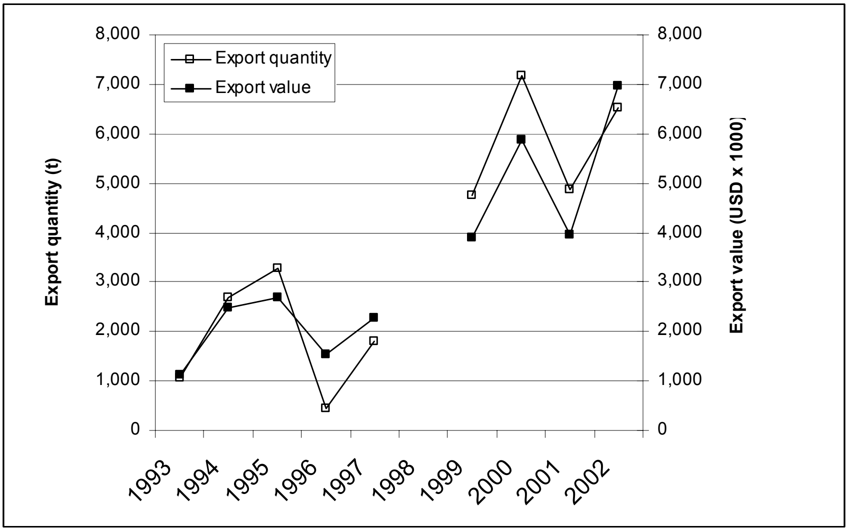


Figure 3-7. Quantity and value of fresh mangosteen fruits exported from Indonesia, 1993-2002

Sources: after Waruwu (2001) & Harisno (2004)

3.1.4 Mangosteen production in the Philippines

Except for banana which has a per capita consumption of 30-64 kg per year, Philippine consumption of other fruits is very low; for papaya, 1.49 kg, durian 0.40 kg and mangosteen only 0.02 kg per year (Chua, 2003). In the Philippines, mangosteen is generally available in August to November.

In 1998 the area planted to mangosteen in the Philippines totalled 1,200 ha, and showed an increasing trend (Figure 3-8). During 1994 to 1998, the area planted grew by 15.1%, but during 1997 to 1998, the area planted remained almost the same, with a growth rate of -0.48% (Table 3.12). Important producing areas are in the Sulu archipelago and several regions in Mindanao, namely Zamboanga del Norte, Davao del Norte, Misamis Occidental, Negros Oriental, Davao City, and Agusan del Sur. In 1998, Sulu represented 74.2% of the total area planted with mangosteen. It has been suggested that any expansion of production area could be in the Western Visayas and Southern Luzon. Table 3-13 shows the number of bearing plants for the top seven mangosteen producing provinces in the Philippines. It has been reported that the Philippines may be considered severely underplanted with mangosteen.

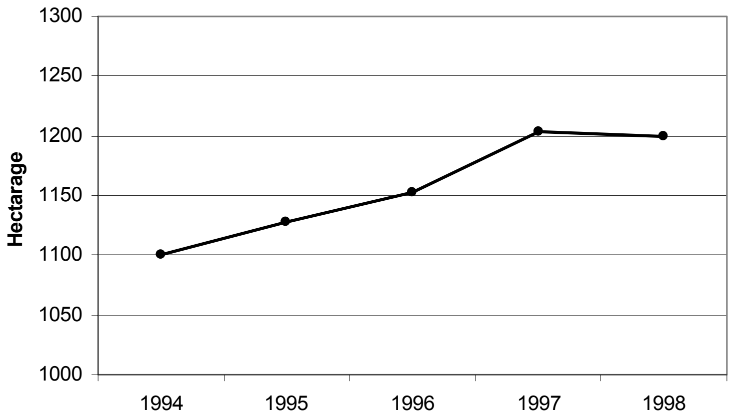


Figure 3-8. Mangosteen hectarage in Philippines, 1994-98

Source: DA-AMAS (2004)

The total volume of Philippine mangosteen production in 1998 was 5,237 t. From 1994 to 1998 the mean volume of production grew by 13.23%, but during 1997 to 1998, the volume increased only slightly, with mean growth rate of 4.07% (Table 3.14). Production in the Sulu area only showed a 1.04% growth rate while in Agusan del Sur 50% was recorded.

Mangosteen is produced mainly for the domestic market with minimal exports (Tables 3.15, 3.16).

The Philippines is geographically the closest potential supplier of mangosteen to East Asia, however, a constraint to export is the high shipping costs. In 1995 and 1998, there were minimal exports to Hong Kong and up until now, no significant exports have been recorded although the fruit has great potential both for domestic and export markets.

Whole frozen fruits or frozen pulp would appear to offer good potential for penetrating the European and American markets, since freezing eliminates the need for costly air shipment, and the need for quarantine against fruit fly, in the US and Japan. Availability of air cargo space to Saudi Arabia and the Gulf States would indicate that these fresh markets could be targeted.

Table 3-12. Area planted (ha) with mangosteen by top producing provinces in the Philippines, 1994-98

Province	1994	1995	1996	1997	1998	Growth Rate (%) 1994-98	Growth Rate (%) 1997-98
Sulu	892	892	892	892	890	-0.06	-0.22
Zamboanga del Norte	61	61	61	67	67	+2.46	0
Davao del Norte	38	40	40	41	41	+1.97	0
Misamis Occidental	10	10	10	35	35	+62.50	0
Negros Oriental	17	20	20	20	20	+4.41	0
Davao City	27	27	28	29	29	+1.85	0
Agusan del Sur	23	23	25	25	25	+2.17	0
Others	33	55	76	95	93	+45.45	-3.64
Total	1,101	1,128	1,152	1,204	1,200	+15.10	-0.48

Source: DA-AMAS (2004)

Table 3-13. Number of bearing mangosteen plants by top producing provinces in the Philippines, 1994-98

Province	1994	1995	1996	1997	1998	Growth Rate (%) 1994-98	Growth Rate (%) 1997-98
Sulu	133,716	133,716	133,716	133,716	133,716	+0.01	+0.00
Zamboanga del Norte	6,842	6,842	6,842	6,750	3,750	-11.30	-43.85
Davao del Norte	4,616	4,616	4,662	4,755	4,926	+1.68	+3.70
Misamis Occidental	1,380	1,380	1,380	1,936	1,936	+10.07	+0.00
Negros Oriental	2,500	3,000	3,000	3,000	2,940	+4.40	-2.00
Davao City	3,522	3,620	3,620	3,686	3,716	+1.38	+0.83
Agusan del Sur	1,600	1,650	1,700	1,785	1,785	+2.89	+0.00
Others	3,017	3,424	5,070	6,595	5,908	+23.96	-20.06
Philippines	157,193	158,248	159,990	162,257	158,711	+4.14	-7.67

Source: DA-AMAS

Table 3-14. Volume of mangosteen production by top producing provinces in the Philippines, 1994-98

Province	**1994**	**1995**	**1996**	**1997**	**1998**	**Growth Rate (%) 1994-98**	**Growth Rate (%) 1997-98**
Sulu	4,295	4,291	4,395	4,449	4,474	+1.04	+0.58
Zamboanga del Norte	239	235	238	236	217	-2.30	-8.09
Davao del Norte	134	149	155	165	164	+5.60	-0.67
Misamis Occidental	53	60	60	60	55	+0.94	-8.33
Negros Oriental	53	60	60	60	55	+0.94	-8.33
Davao City	49	53	58	58	51	+1.02	-13.21
Agusan del Sur	13	17	17	27	39	+50.00	+70.59
Others	53	68	94	156	156	+48.58	0.00
Total	**4,859**	**4,906**	**5,049**	**5,208**	**5,237**		

Source: DA-AMAS (2004)

Table 3-15. Supply and utilisation accounts of mangosteen in the Philippines, 1994-98

Supply			Utilisation				Nett Food Disposable per capita			
Year	Production	Import	Gross Supply	Export	Seeds	Feed and Waste	Processing	Total	kg/yr	g/day
1994	4,859	0	4,859	0	0	292	0	4,567	0.07	0.18
1995	4,906	0	4,906	0	0	294	0	4,612	0.07	0.18
1996	5,049	0	5,049	0	0	303	0	4,746	0.07	0.19
1997	5,208	0	5,208	0	0	312	0	4,896	0.07	0.19
1998	2,537	0	2,537	0	0	314	0	4,923	0.07	0.18

Source: DA-AMAS (2004)

Table 3-16. Export of mangosteen by the Philippines, 1994-98

Country	1994		1995		1996		1997		1998	
	Qty	Value	Qty	Value	Qty	Value	Qty	Value	Qty	Value
Hong Kong	-	-	-	-	-	-	-	-	4,114	3,000
China-Taiwan	-	-	326	163	-	-	-	-	-	-
Total	-	-	326	163	-	-	-	-	4,114	3,000

Quantity (Qty) in t, Value in USD

Source: DA-AMAS (2004)

3.2 Minor production areas

3.2.1 Mangosteen production in Australia

In Australia, about 50 ha (10,000-12,000 plants) have been planted in the Northern Territory and far north in Queensland. Whilst this is very small compared to the Asian industry, Australia enjoys a production advantage (Downton and Chacko, 1998). However, the mangosteen industry in north Queensland is struggling with lack of resources to promote distribution both within Australia and overseas. There are several on-going efforts to conduct trials with mangosteen (Anon., 2002), but it still suffers from being a new and small industry, compared to large industries with long traditions such as the banana or citrus industry (Sando, 2001). In the Australian domestic market, mangosteen fruits command a retail price of about AUS$ 2-3 per fruit. It is reported that there is a supply of about 10 t per year on the Sydney market.

In Queensland, mangosteen is available in two seasons, one from February to May, followed by another from September to December (Table 3.17).

Table 3-17. Mangosteen availability in the wet tropics of Queensland

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Queensland	Nil	Heavy	Heavy	Heavy	Medium	Nil	Nil	Nil	Heavy	Heavy	Medium	Medium

Heavy Medium Nil

Source: Chay-Prove (2004)

3.2.2 Mangosteen production in other countries

Vietnam

In Vietnam, mangosteen is cultivated only in the La Thieu area (Song Be Province) and in some fields in the Mekong Delta, where the soil is fertile, well-drained and not contaminated by salt (Ben Tre, Tien Giang and Hau Giang). There are five or six varieties of wild mangosteen known as Bua. Bua fruit is edible but its quality is inferior to mangosteen. The pulp is used to cook sour soup and the seeds are used for oil pressing (Global Directions, 2003). It has also been reported that 15,000 ha of rice fields have been turned into fruit gardens, specializing in the production of high-value and quality fruits such as Hoa Loc mango, Nam Roi grapefruit, durian and mangosteen along the banks of the Tien and Hau rivers (VOV News, 2003).

In Myanmar, it is reported that mangosteen is generally grown in Mawlamyaing, Kyaiktho (Mon State) and Kayin State, for example on Kyonka Mangosteen Farm in Paung, Mon State. Other fruits produced in the state are durian, rambutan, pineapple, citrus, and avocado (Sint, 1998). Data are not readily available.

USA

In Florida, mangosteen has been noted as an Asian fruit with little possibility of serious cultivation. In Puerto Rico, mangosteen, along with breadfruit and rambutan has been described as a fruit with potential importance (Holcomb, 1989).

Tropical speciality fruits reported by the Hawaii Agricultural Statistics Service were planted on 1,025 acres in 1995, and these include over 20 species including mangosteen (Cannon-Eger, 1997). On the Big Island of Hawaii, high value tropical fruits including durian, longan and mangosteen have now come to fruit bearing age (Anon., 1998).

Brazil

Mangosteen, up to now, has remained only as a botanical curiosity in tropical America. Efforts are being made to increase fruit production, in several regions in Brazil, such as the state of Pará, which is has 300 days of rain a year and a constant temperature of 32-33°C. In 1998, a group of papaya producers from Belém joined efforts as Pará-Export, to promote export to Europe and tried marketing papaya, mangosteen and passion fruit (Eurofruit Magazine, 1998). Several Japanese-Brazilian farmers in the

Bragantina zone have modest plantings of young mangosteen plants, which were planted in the late 1980s. The mangosteen is finding a ready market in fashionable shopping malls in São Paulo (Smith *et al*., 1995).

Chapter 4. Ecology

4.1 Climate

Species of *Garcinia* are found mostly in the warm and humid tropics of South and Southeast Asia as second storey trees. All wild species are adapted to shade and mangosteen is regarded as a shade-tolerant tree (Ochse *et al*., 1961; Palma Gil *et al*., 1972; Verheij, 1992). The mangosteen is rarely found in the forests but occasionally is found scattered at the edges as a relic of earlier habitations.

Specific climatic requirements limit the distribution of mangosteen to the equatorial band between 10°N and 10°S latitude (Havard Duclos, 1950; Verheij, 1992). This band provides the high temperatures and high relative humidity needed for growth. Evidence from successful introductions and cultivation in Honduras, Madagascar and the North Territory and Queensland in Australia, suggests the potential range would extend to 18° in frost-free areas either side of the equator.

Mangosteen is associated with areas of low elevation i.e. less than 500 m above sea level (Galang 1955; Palma Gil *et al*., 1972). Dede Juanda & Bambang Cahyono (2000) reported the elevation of 0-600 m. It can be cultivated at higher elevations but has a slower growth rate (Nakasone and Paull, 1998). Cultivation at higher altitudes is characteristic in India.

4.1.1 Water

Mangosteen appears to require an uninterrupted water supply with a short dry season of 15-30 days, the latter initiating flowering.

Ideally, the rainfall should be well distributed throughout the year. It has been reported that an annual rainfall above 1,270 mm is necessary (Firminger, 1869). Dede Juanda & Bambang Cahyono (2000) reported a suitable rainfall of 1,270-2,500 mm per year, favourably with ten wet months.

In cultivation it appears that any stress due to water deficit should be avoided and irrigation may be necessary from time to time and especially during the dry season. Mangosteen trees can withstand some water logging but not drought.

However mangosteen trees can grow successfully in other areas when a constant supply of water is provided through irrigation, especially during the dry season (Ochse *et al*., 1961; Palma Gil *et al*., 1972; Vietmeyer *et al*., 1975). In the Philippines, fruiting trees may also be found where rainfall is not evenly distributed (Galang, 1955).

4.1.2 Temperature

Mangosteen thrives in the temperature range of 25-35°C when RH is over 80% (Bourdeaut and Moreuil, 1970) but a 20-25°C range is also acceptable for cultivation (Vietmeyer *et al*., 1975). Dede Juanda & Bambang Cahyono (2000) reported a suitable temperature range of 25-32°C but growth becomes affected when the temperature falls below 25°C. Temperatures below 5°C and above 38-40°C are lethal and since growth is slowed at temperatures 15-20°C, this is not recommended for cultivation.

4.1.3 Light

Shade is essential during the first 2-4 years of growth both in the nursery and during early field establishment (Nakasone and Paull, 1998). There are no reports of photoperiod response. The photosynthetic rate is steady over a 27-35°C temperature range, under 20-50% shade (Weibel *et al*., 1993). Dede Juanda & Bambang Cahyono (2000) reported the suitable sunlight intensity to be 40-70%. Foliage and fruit are susceptible to sunburn in direct sunlight (Verheij, 1992).

In Southeast Asia, shade is offered by other trees in the traditional mixed orchards and home gardens. In some plantings in Malaysia, alternate rows of *Indigofera* sp. have been grown to provide the necessary shade in the early years of establishment.

4.2 Soils

Mangosteen can grow successfully on a wide range of soils (Campbell, 1967; Almeyda and Martin, 1978). However, the tree is not adapted to limestone soils, sandy alluvial soils or sandy soils low in humus.

The best soils for mangosteen cultivation are porous, deep, wet but well-drained, slightly acid, clay loams rich in organic matter (Galang, 1955; Almeyda and Martin, 1978); Dede Juanda & Bambang Cahyono (2000). In spite of a relatively weak root system, the trees can tolerate heavy soils which impede water movement, provided that transpiration is limited by high humidity and shade. Under dry conditions, irrigation is needed, and thick mulches are very beneficial (Verheij, 1992).

Chapter 5. Properties

Each mangosteen fruit weighs approximately 55-75 g and contains 2-3 well-developed seeds.

5.1 Pulp (aril)

The quality of mangosteen fruit is affected by differences in climatic conditions (Popenoe, 1928). The analysis of ripe, edible aril is provided in Table 5-1. The analyses vary widely depending on the source.

The fruit has a high moisture content. The soft fruit aril, the edible portion, makes up about 25-30% of the fruit. Intengan *et al*. (1968) reported an average of 26% of the fruit as the edible portion. As dry matter, Nakasone and Paull (1998) reported that the aril constitutes 20%.

The data show that the aril contains a high percentage of carbohydrates, mostly in the form of sugars. The energy value of the aril is 340kJ/100g (Verheij, 1992). It is generally relatively low in minerals (Tongdee and Suwanagul, 1989) and vitamins, but calcium, phosphorus and ascorbic acid levels are comparatively high. A report of ascorbic acid at 66mg/100g by Yapwattanaphun *et al*. (2002) needs to be reconfirmed.

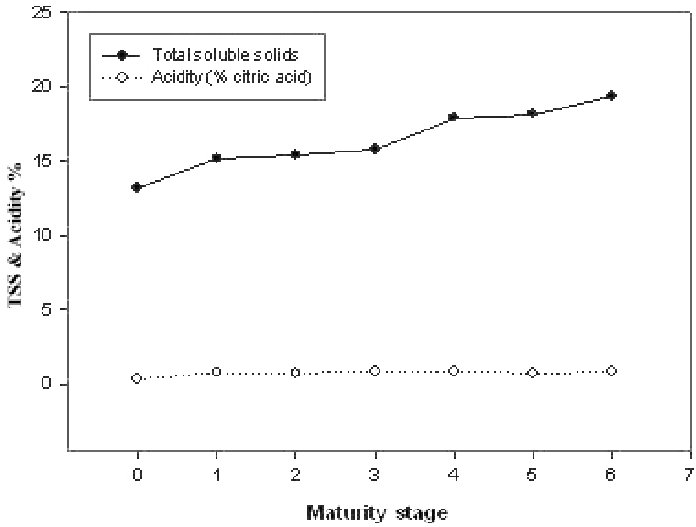
The percent total soluble solids range from approximately 13-20% depending on the maturity stage of the fruit. When immature the range is 13-15.2%, but when ripe it is about 18.3-19.0% (Tongdee, 1985; Nakasone and Paull, 1998) (Figure 5-1).

Table 5-1. Proximate analysis of 100 g of ripe mangosteen aril (adapted from Kanchanapom and Kanchanapom, 1998)

	Sources					Range or value
	1	2	3	4	5	
Moisture (%)	79.7	83.0	79.3	80.2-84.9	79.2	79.2-84.9
Calories	76.0	63.0	81.0	60-63	-	60-81
Protein (g,%)	0.7	0.6	0.5	0.5-0.6	0.5	0.5-0.7
Fat (%)	0.8	0.6	0.2	0.1-0.6	-	0.1-0.8
Carbohydrates (%)	18.6	15.6	19.2	14.3-15.6	19.8	14.3-19.8
Total sugar (%)					17.5	17.5
Reducing sugars (%)					4.3	4.3
Fibre (%)	1.3	5.1	0.5	5.0-5.1	0.3	0.3-5.1
Ash (%)	0.2	0.2	-	0.2-0.23	0.23	0.2-0.23
Calcium (%)	18.0	8.0	25.0	0.01-0.8	11.0	0.01-18.0
Phosphorous (%)	11.0	12.0	17.0	0.02-12.0	17.0	0.02-17.0
Iron (%)	0.3	0.8	0.9	0.2-0.8	0.9	0.2-0.9
Vitamin A (U.I.)	-	0.0	14.0	-	14.0	0-14.0
Thiamine (Vitamin B_2) %	0.06	0.03	0.09	0.03	0.09	0.03-0.09
Riboflavin (Vitamin B_2) %	0.01	0.0	0.06	-	0.06	0-0.06
Niacin (Vitamin B_5) %	0.04	0.0	0.1	-	0.1	0-0.1
Acid					0.49	0.49
Ascorbic acid (Vitamin C %)	2.0	2.0	66.0	1.0-2.0	66.0	1.0-66.0
Citric acid (g/100g)					0.63	0.63

Vitamin A values in international units; 1 I.U.=0.6mg beta carotene.

Sources: 1-Intengan *et al*. (1968), Coronel (1983), 2-Leung *et al*. (1952) and Dede Juanda & Bambang Cahyono (2000), 3-Dept. of Agric. Ext. (1990), 4-Morton (1987), 5-Poomipamorn and Kumkong (1997)



Maturity Stage: 0 = immature: yellow-white,
1-3 = mature where:
1 = green yellow with scattered pink spots,
2 = irregular pink-red and,
3 = uniform pink background;
4-5 = ripe for consumption where:
4 = red-reddish brown and,
5 = reddish purple.

Adapted from Tongdee (1985) and Nakasone and Paull (1998)

Figure 5-1. Mangosteen aril and total soluble solids (TSS) and acidity at different maturity stages

5.1.1 Flavour

The mangosteen aril possesses a delicate and unique flavour. MacLeod and Pieris (1982) analyzed the volatile compounds that contribute to the aroma, and detected about 52 compounds. Of these compounds, 28 were identified and are listed as in Table 5-2. Quantitatively, the major components were (Z)-hex-3-en-1-ol (27%), octane (15%), hexyl acetate (8%) and α-copaene (7%). The main contributors to mangosteen flavour are hexyl acetate, (Z)-hex-3-enyl acetate (cis-hex-3-enyl-acetate) and (Z)-hex-3-en-1-ol. Six sesquiterpenes were also identified.

Macheix *et al*. (1990) found that mangosteen contains the two anthocyanidins: cyanidin 3-sophoroside and cyanidin 3-glucoside.

This complex flavour pattern explains why processing for juice and other products do not necessarily maintain the delicate balance.

Table 5-2. Volatile flavour components of mangosteen aril (after Kanchanapom and Kanchanapom, 1998)

Alcohols
hexan-1-ol
(Z)-hex-3-en-1-ol
Aldehydes and ketones
Acetone
Benzaldehyde
Hexanal
(E)-hex-2-enal
2-furaldehyde
furfuryl methyl ketone
5-methyl-2-furaldehyde
Nonanal
Phenylacetaldehyde
Esters
hexyl acetate
(Z)-hex-3-enyl acetate
Hydrocarbons
ethyl cyclohexane
Heptane
Octane
Toluene
o-, m-, p-xylene
Terpenes
α-copaene
α-terpineol
Guaiene
Valencene
δ-cadinene
γ-cadinene
Miscellaneous
Dichloromethane
Pyridine

Source: MacLeod and Pieris (1982)

5.2 Seeds

The seeds possess a nutty flavour (Coronel, 1983). The seed is reported to contain about 30% oil (Pratt and Del Rosario, 1913). Xanthones, isolated from the fruit hulls and the edible arils and seeds of mangosteen, were tested for their antituberculosis potential. α- and β-mangostins and garcinone B exhibited strong inhibitory effect against *Mycobacterium tuberculosis* (Suksamrarn et al., 2003).

Like a few plant species which are known to accumulate triacylglycerols (TAGs) that are rich in stearic acid, *Garcinia* indica (kokum) has been reported to accumulate more than 30% stearate in its seed oil. Oils from these plants are solid or semi-solid at ambient temperature (Daniel et al., 2003). Thippeswamy & Raina (1991) also reported that *G. indica* accumulated very high levels (up to 56%) of stearic acid in its seed oil. Recently, the stearoyl-ACP thioesterase of *Garcinia mangostana* has been cloned and protein engineering of the thioesterase has been done (Hawkins & Kridl, 1998).

5.3 Wood

The heartwood of the trunk is dark brown and dense, coarse and very strong, and could be used in carpentry (Verheij, 1992).

Chapter 6. Uses

Mangosteen fruits are mostly eaten fresh as a dessert fruit. However it is a multipurpose tree and a wide range of uses have been recorded for all parts of the plant.

6.1 Food uses of fruits

There is some evidence that the taste of the fresh fruit is improved by chilling in a domestic refrigerator (Galang, 1955). Successful attempts to freeze whole fruits have made long-distance transport possible. Freezing is carried out quickly at low temperatures (-35°C) and frozen fruits maintained at -20°C; using this process fruit quality is maintained, the pulp is not discoloured, and the contribution of volatile substances to flavour remains more or less that of fresh fruits (Kanchanapom and Kanchanapom, 1998).

6.1.1 Processing of fruits

Canning of the pulp is not appealing because the pulp tends to lose its flavour in this process. However when processed with sugars a range of acceptable products are possible: canned mangosteen in heavy syrup, or as jam or crystallised (Singh, 1969; Kanchanapom and Kanchanapom 1998); boiled pulp and seed with sugar (Wester, 1920; Wester, 1921; Brown, 1954; Galang, 1955; Palma Gil *et al.*, 1972; Coronel, 1983; Kanchanapom and Kanchanapom, 1998); pulp preserved in brown sugar (Almeyda and Martin, 1976); syrup puree (Nuswamarhaeni *et al.*, 1989); toppings for ice cream or sherbet (Ochse *et al.*, 1961); a flavour for ice-cream or juice (Mohd Khalid and Rukayah, 1993) and wine.

It is reported that the pulp of immature fruit can be canned and the pulp of mature fruit could be dried successfully (Page, 1984). Fruits of *G. pedunculata* are cut into slices, dried and stored, and cooked in curries in India.

6.1.2 Other food uses

The acidic pulp of mangosteen has been reported as a substitute for tamarind (Cobley, 1956; Cox, 1976). In Sumatra, two species of *Garcinia*, namely *asam gelugor (G. atroviridis)* and *asam kandis (G. parvifolia)* are widely used as a substitute of tamarind. In Malaysia, tamarind and *asam gelugor*, too are widely used in food preparation.

Gamboge (*Garcinia cambogia*), an acid fruit commonly used in Sri Lanka and southern India, is used as a substitute for tamarind and limes as the acid ingredient in certain dishes. In the Malabar and Kankan coast of the Indian peninsula the fruit rind of *Garcinia cambogia* and *Garcinia indica* is used as a substitute for tamarind to impart flavor. Popularly known as Malabar tamarind, it is extensively used for culinary purposes, particularly in the preparation of fish curry.

Oil extracted from mangosteen seeds has been used frequently as a substitute for kokam butter (or Goa butter), used in confectionery and cooking as a substitute for ghee. Originally kokam butter was extracted from seeds of cultivated *G. indica,* but wild species are also exploited for the same purpose, such as *G. morella* in the evergreen forests of Assam and in the Khasi and Jaintia hills (Burkill, 1966; Dwivedi, 1993).

Seeds of *G. indica* are also gathered from the wild and there is a long tradition of their use to provide the sour taste to curries. Oil content is about 25% of the seeds but 44% of the kernels. Seeds are mixed with ash, dried and cleaned, decorticated by a wooden mallet and the fat recovered by water rendering. Sediment is removed by hot filtration and the resulting fat is white, hard and brittle. It is sold in the form of oblong balls. Refining of the fat is necessary to make vanaspati ghee. The fat is rich in combined stearic and oleic acid (Dwivedi, 1993).

6.2 Medicinal uses

Many traditional medicinal uses are reported for all parts of the mangosteen plant. A summary is shown in Table 6-1.

Table 6-1. The uses of the various parts of the mangosteen fruit and tree

Parts	Uses
Bark	Astringent for the cure of aphtha or thrush (Coronel, 1983)
Leaves	Astringent for the cure of aphtha or thrush (Coronel, 1983)
	Febrifuge (Coronel, 1983)
	Leaf infusion for the cure of wounds (Burkill, 1966)
Peel	Cure for diarrhoea and dysentry (Kanchanapom and Kanchanapom, 1998)

Parts	Uses
Pericarp (rind)	Cure for chronic intestinal catarrh (Coronel, 1983)
	Cure for dysentry and use as lotion (Burkill, 1966)
	Treatment of respiratory disorders (Wahyuono *et al*., 1999)
	Healing skin infections (Yaacob and Tindall, 1995; Ohizumi, 1998)
	Astringent (Pratt and del Rosario, 1913; MacMillan, 1956)
	Mangostin as an anti-bacterial agent (Mahabusrakum *et al*., 1983)
	Mangostin as an anti-inflammatory (Yapwattanaphum *et al*., 2002)
	Mangostin derivative found to be a central nervous system depressant (Yapwattanaphum *et al*., 2002)
	Relief of diarrhoea (Yaacob and Tindall, 1995)
Root	Medicine for menstruation (Burkill, 1966)

The active principles are mangostins and their derivatives, which are types of xanthones. Fruits also contain flavones and xanthones.

Dried fruit rind is used pharmaceutically as an astringent (Pratt and del Rosario, 1913). Du and Francis (1977) reported that mangosteen rind contains a substantial amount of red pigment. The major pigment is identified as cyanidin-3-sophoroside, while a minor pigment as cyanidin-3-glucoside (Kanchanapom and Kanchanapom, 1998). According to Mahabusrakum *et al*. (1983), the rind contains five polyoxygenated xanthones, including mangostin 4,β-mangostin, nor-mangostin and gartanin. These compounds are used in medicine and, to a certain extent, as anti-bacterial agents. The xanthone content in the rind and a number of other pharmaceutically-active compounds increase as fruit-ripening proceeds.

Mangostin, the major constituent of mangosteen rind, shows activity against the fungi *Trichophyton mentagrophytes*, *Microsporum gypseum* and *Epidermophyton floccosum* in a minimum concentration of 1 mg/ml for inhibition of growth, but it has no effect on *Candida albicans*. Investigations have resulted in the isolation of many other substances from mangosteen, other major components being β- and γ-mangostin, 1- and 3-isomangostin and gartanin. These substances have been investigated for their *in vitro* activities against *Staphylococcus aureus*, both normal and penicillin-resistant strains. The highest activity against both strains was found with mangostin. Mangostin, γ-mangostin and gartanin showed no activity against *Candida albicans* and *Cryptococcus neoformans*, but exhibited moderate activity against *Trichophyton mentagrophytes* and *Microsporum gypseum* (Mahabusarakam *et al*., 1983).

Mangostins depress the CNS system, are anti-inflammatory and antiulcer and raise blood pressure. Mangostins are also cardiotonic, antimicrobial and antihepatoxic whereas xanthones inhibit arthritis in rats (Asolkar *et al*., 1992).

All species of *Garcinia* impart good general health due to the presence of the antibiotic-like substances and, in India, *G. morella* is used for this purpose using extracts of seed coats (Keeler and Tu, 1983).

G. morella yields gamboge resin which is a strong purgative in veterinary medicine and gamboges from *G. hanburyi* is used similarly in Indo-China (Howes, 1949; Dastur, 1964).

6.2.1 Traditional preparations

As reported by Kanchanapom and Kanchanapom (1998) and Yaacob and Tindall (1995), mangosteen peel is used for relieving diarrhoea and dysentery when the well-dried rind is macerated or boiled with water and the infusion drunk, according to the following formulations.

For diarrhoea: Use the rind of a quarter of a fruit. Macerate with lime water (a saturated calcium hydroxide solution) or drinking water (Kanchanapom and Kanchanapom, 1998), then drink the extract.

For dysentery: Use the rind of a quarter of a fruit. Grill until burnt. Macerate with about half a glass of clear lime water or grind to a powder and dissolve in rice water or boiled water. Drink every two hours.

For skin infections: The mangosteen peel is also used for healing skin infections (Yaacob and Tindall, 1995). For the treatment of wounds, the fruit is dried and rubbed with a stone using water as a solvent (Yaacob and Tindall, 1995).

6.3 Resins

The yellow resin, gamboge, is present in bark resin and particularly in wild species such as *G. morella* and *G. hanburyi* in the latex. Gamboge is a solidified yellow resin used as a paint pigment and for colouring varnishes used for metal and lacquer work. *G. mangostana* will not replace the established sources.

6.4 Tannins and other uses

The rind is reported to contain 7-15% tannin and is used to tan leather and to dye fabric black (MacMillan, 1956; Coronel, 1983; Nakasone and Paull, 1998). It is also reported to be used as an ingredient in soap, shampoo and conditioner (Yapwattanaphun *et al*., 2002).

6.5 Wood

Non-bearing mangosteen trees provide timber for constructing furniture (Yapwattanaphun et al., 2002) and are used in carpentry (Nakasone and Paull, 1998). It is also used to make rice pounders (Verheij, 1992), fencing, handles for spears, and also employed in construction and cabinetwork (Morton, 1987). As yet, there are no published reports on the economic benefits from the timber of trees.

Chapter 7. Genetic Resources

Mangosteen produces apomictic seeds and it has been suggested that all mangosteen trees belong to a widespread single clone. As a result large germplasm collections have not been set up other than to maintain stock material.

Nonetheless recent research shows that variation does indeed exist within mangosteen and this raises questions about how it can be analysed, used and maintained as germplasm. In addition, there is the possibility of increasing variation in mangosteen. Both these courses of action would require the maintenance of new stocks in germplasm collections, rather like significant cultivars in past breeding programmes are maintained in genetic resources collections of field crops.

Cultivation of a perennial fruit tree crop like mangosteen will almost certainly require much more work on selection of rootstocks and grafting in attempts to overcome constraints to production, harvesting and seasonalities. Hence genetic resources activities will have to consider maintenance in collections or protected areas, of a range of wild materials.

This chapter discusses current genetic resources activities and the development of a strategic programme coupling enhanced research with targeted use and conservation of germplasm.

7.1 Current genetic resources activities

Only limited germplasm collections are held by different institutions. These are listed in Table 7-1. There has been little change over the past 30 years since the situation was assessed in Southeast Asia (Williams *et al*, 1975). The only country to consider wild species has been Malaysia, where a few samples are kept in cultivation and others identified and located in permanent plots in Forest Reserves. Further information on collecting and characterising materials of mangosteen can be found in IBPGR (1982), IBPGR (1986), IPGRI (2001) and IPGRI (2003).

Table 7-1. Existing holdings of mangosteen and related species in collections

Country	Institute	Species	Details	Reference
Brunei	Dept. of Agriculture	*G. mangostana*	*	
		Other species		
Indonesia	CRDB, Bogor	*G. mangostana*	*	Sastrapradja, 1975
Malaysia	MARDI Kluang	*G. mangostana*	**	See section 7.1.1
	MARDI Serdang	Wild species	Some samples	
	FRIM Kepong	Wild species	Data for forest reserves	Saw *et al.*, 1991
	ARC Tenom, Sabah	Wild species	Some samples	
Papua New Guinea	Lowlands Agriculture Experimental Station, Keravat	*G. mangostana*	<3	Coronel, 1983
Philippines	IPB/UPLB Los Baños	*G. mangostana*	**	Valmayor and Espino, 1975; Coronel, 1983
Thailand	Dept. Agric., Hort. Res. Centre, Chantaburi	*G. mangostana*	**	
	Faculty Natural Resources, Prince of Songkla Univ.	*G. mangostana*	*	
USA	Subtropical Hort. Res. Unit, USDA, Miami	*G. mangostana*	Few samples	GRIN database

* Samples to support local cultivation. ** Samples to support emerging commercial production.

7.1.1 Recent research on variation in mangosteen

In 1987, Idris and Rukayah reported on the occurrence of a male mangosteen. Richards (1990) considered that this could be a hybrid between a female mangosteen and either one of its parents, *G. malaccensis* or *G. hombroniana*. This has not been tested but the possibility exists that such chance variation occurs within the areas of distribution of the parents. There have been unsuccessful attempts to hybridise mangosteen with *G. hombroniana*, but on the whole Richards considers mangosteen to be substantially unhybridised. Both wild parents are facultative agamosperms. Both sporophytic agamospermy and gametophytic agamospermy, the former adventitious embryony and the latter mitotic diplospory, coexist and have evolved independently in the genus; however most wild species (other than *G. scortechinii*) are capable of sexual reproduction.

More recently another putative male mangosteen has been collected in Sabah (see Table 7-3). Research at MARDI, Malaysia, had noted regional variations in mangosteen especially in time to fruiting, growth rates and thickness of fruit rind. In 1991-1993 with the support of Greentech, Japan, MARDI initiated a major project to collect and study the genetic diversity of clones cultivated throughout Malaysia. Over 830 accessions were surveyed and collected from all states and over 10,000 samples were collected for propagation through seeds and/or scions. Difficulties in germinating seeds older than 7 days and poor results with cleft grafting onto 1-2 year rootstocks in shaded mist chambers, meant that much of the material did not grow. However, the accessions grown out in MARDI Kluang were recorded for distinct variation and 16 of the 830 accessions were identified as distinctively different (Table 7.2). The distinct characteristics are shown in Table 7-3. It took up to 10 years for the progeny to fruit and all the samples identified were from seed because grafted plants showed various physiological problems and no precocity as expected.

The National Plant Genetic Resources Laboratory at IPB, UPLB, the Philippines, has also collected germplasm of mangosteen and characterised it, especially for fruit parameters. This work has been carried out as an activity of UTFANET (Underutilized Tropical Fruits in Asia Network); see also chapter 8. For mangosteen this built on a specific project of IPGRI (formerly IBPGR): see Arora and Rao, 1992.

Table 7-2. The mangosteen germplasm accessions collected from states in Malaysia in 1991-1993 by MARDI

States	Code	Total Accessions Collected	No. Accessions with Distinct Variation	% Accessions Showing Variation
Johor	01	228	1	0.44
Perak	02	73	-	0
Kelantan	03	97	1	1.03
Terengganu	04	48	1	2.08
Pahang	05	34	2	5.88
Penang	06	63	-	0
Kedah	07	69	1	1.45
Perlis	08	10	-	0
Selangor	09	53	-	0
Negeri Sembilan	10	43	-	0
Melaka	11	23	-	0
Sabah	12	58	6	10.34
Sarawak	13	31	2	6.45
Total		**830**	**16**	

Table 7-3. The genetic variation found in 16 out of 830 mangosteen accessions collected from the MARDI-Greentech collection missions in 1991-93

States	Total Accessions Collected	No. Accessions with Distinct Variation	Plant or Fruit Characteristics[1] of Accessions with Distinct Variation	Collection Sites
Johor	228	1	Hard rind	Simpang Parit Pinang, Sg. Pinggan, Pontian
Kelantan	97	1	Small fruit size	Kg. Ragu, Manik Urai, Ulu Kelantan
Terengganu	48	1	Long fruit stalk	Kg. Lama, Besut
Pahang	34	2	Hardened aril	Kg. Baru, Ulu Checka, Jerantut
			Oblong fruit shape with pointed end	Kg. Paya Taram, Kerdau, Temerloh
Kedah	69	1	Seedless fruit with longer shelf-life	Kg. Yan Besar
Sabah	58	6	9-lobed fruit	Kg. Ulu Sipitang, Sipitang
			9-lobed fruit	Kg. Marintaman Lama Sipitang
			9-lobed fruit	Kg. Angan-Angan, Jalan Kemabang, Tenom
			Small fruit size	Kg. Marintaman Baru, Sipitang
			Big fruit size with very smooth rind surface and non-seasonal fruiting	Kg. Kelimau, Ranau
			Male plant	Dept. of Agriculture, Semporna
Sarawak	31	2	Early fruiting (4-5 years after planting)	Simpang Layan, Serian
			Non-seasonal fruiting	Lundu

[1]Gummosis was recorded only on 228 samples collected from the State of Johor, and found to occur in 35 of them (15.3%)

7.1.2 Variation in African *G. livingstonei*

Due to the wide variety of environments in which wild African mangosteen occurs, there appears to be great phenotypic variation. For instance, it can be a tree with one crown; the crown may be conical or spreading; and occasionally there are several trunks. It reproduces sexually and hence genetic variation is to be expected.

The ecological niches vary from scrub to a range of forest systems including riverine forests. It can also survive in coastal forests and in semi-arid conditions. It grows from sea level to 1,650m; appears to be hardy and survives well on rocky and sandy soils.

There has been no testing of the heritability of any major plant characteristics nor experimentation to see whether populations are genetically distinct for any useful characters. Such testing would enable the targeted selection of rootstocks to be used for mangosteen propagation.

7.1.3 Variation in other wild species

No up-to-date information or research is reported.

7.2 Strategic plan for genetic conservation

Where diverse material of mangosteen has been identified, e.g. in the MARDI project described above, it should be conserved until more is known about it. There is the possibility that long-established clonal material of the cultigen has diversified somewhat in diverse regions. If there is indeed any ecotypic differentiation it would be valuable to identify it and record such patterns of variation rather than simply evaluating for production characteristics. In addition, better evaluation of clone provenance selections in replicated trials using transplanting at different nurseries might identify additional genetic variation.

The known distinct types of mangosteen need to be identified as whether they are plastic responses, environmentally induced or genotypic and heritable.

The degree to which wild species will be needed for genetic conservation depends on the degree to which mangosteen will be grafted onto wild rootstocks and on any attempts at hybridisation to broaden the genetic base. Taxonomic review of the species, more information on their ecological tolerances and knowledge of their phenology is useful in order to develop a strategic plan.

In addition the recording of the distributions, types of populations and age ranges of wild species carried out by forest and forest conservation organisations should alert the user community to any potential threats to such species.

In conclusion, the development of a genetic conservation plan relies on targeted research in a number of areas and at present funding constraints hamper such work.

7.2.1 Storage of germplasm

Mangosteen seeds are recalcitrant i.e. they cannot retain viability when dried and subjected to low temperatures (Winters and Rodriguez-Colon, 1953; Chin, 1976). As a result plants will have to be conserved in field genebanks or in tissue culture genebanks. Due to the maintenance problems each accession will need to be justified and duplicated at an alternative location. The same will apply to wild species proved useful for rootstocks (Tixier, 1955).

Tissue culture of mangosteen is discussed in Chapter 9 under propagation. Normah (2000) has summarised recent work on slow growth in tissue culture for conservation purposes and indications that cryopreservation of tissue is possible. However, more research and development is required.

Chapter 8. Breeding and Improvement

The seed of mangosteen is an asexual propagule and hence it is thought that most trees belong to a single clone (Richards (1990). This means that there are no true varieties or cultivars of mangosteen. In view of this relative uniformity most research to improve production has been focused on propagation and management techniques rather than an attempt to breed new forms.

Nonetheless, Horn (1940b) reported a form cultivated in the Philippines locally called "Jolo", which possessed larger fruits than normal; the seeds were larger and the pulp more acid. Cadillat (1970) reported on a mangosteen from the Sulu Islands with a thicker fruit shell and acidic pulp but in this case taste was inferior. It is not known how much environmental differences were responsible for these forms nor for the differences in fruit parameters observed in recent germplasm collecting activities.

8.2 Recent developments

8.2.1 Mutation breeding

There have been few attempts to apply induced mutations in mangosteen. However, in Indonesia, Rostini *et al*. (2003) used gamma ray irradiation with 1 to 3 krad dosages to broaden the genetic variability of mangosteen to improve desired mangosteen traits. The results found that over 80% of seeds irradiated with 1 krad and 2 krad showed variations in growth rates, plant heights, leaf size, leaf colour, chlorophyll contents, number of lateral roots and root lengths.

8.2.2 Hybridisation

Mangosteen is self fertile but male sterile, and since it has many related species which are fully fertile, hybridisation may be possible, especially with closely related species such as *G. hombroniana*.

In Vietnam, recent advances in tissue culture of mangosteen have proved useful in embryo rescue from interspecific hybridisation (Sando, 2001). Now an assessment needs to be made of which species to use in making crosses.

8.2.3 Patterns of genetic diversity

As a spin off from tissue culture research, Te-Chato and Lim (2000) have looked at some wild species as well as mangosteen. The species were called locally chamuang, mahput, pawa and somkhag.

Based on flow cytometry, pawa was shown to have the smallest DNA content. Mahput has the highest DNA content, three times higher than that of pawa. It was also shown, from sequencing of genomic DNA using a specific primer, that mangosteen had the closest relation to pawa, followed by somkhang and mahput.

There is clearly a need to expand the genetic analyses using a wide variety of current techniques to help in identifying male parents for crossing, since mangosteen is female.

8.3 Other methods of improvement

Following early work on conservation by IBPGR, the precursor to IPGRI in the 1970s, a project by IPGRI in 1992 to promote the conservation and use of tropical fruit species in Asia (Arora and Rao, 1995), discussions with ICUC, FAO, CIRAD, ODA-UK (now DFID) and CSC resulted in a decision to form a network in Asia called UTFANET (Underutilized Tropical Fruits in Asia Network) involving 13 countries. This has stimulated work on propagation as well as management techniques such as promoting precocity of bearing, triggering synchronous flowering and increasing harvesting efficiency.

UTFANET identified the following areas of research (Dassanayake, 1996):

1. Shortening the vegetative period and reducing canopy size by either vegetative propagation using suitable rootstocks or by mutagenic treatment,

2. Better fruit handling procedures, to prevent gamboge discolouration, mechanical damage and postharvest losses.

8.1 Constraints to breeding

Breeding mangosteen has not been attractive as research work, since it requires a very long time before plants would go into bearing, and thus would involve long breeding cycles. Breeding to improve the quality of fruits as well as the yield would be a long process but there have been no attempts in that direction.

Mangosteen accessions available in different countries have not been well studied to unravel the genetic background of the species. Such study is needed to help in understanding the genetic diversity. This could provide clues for hybridisation and identify any important mutations. The limited research manpower and budgets available in countries in Asia pose constraints.

Chapter 9. Agronomy

9.1 Seedling establishment

9.1.1 Seed and seed germination

The best known and the most common practice for the propagation of mangosteen is through seed. Strictly defined, they are not true seeds (sexual embryos) but are adventitious embryos (asexual embryos), since there is no sexual fertilisation involved. Since the seeds are formed from nucellar tissue (asexual origin), they produce seedlings that are identical to the mother plant; they are apomictic and breed true to type (Galang, 1955; Campbell, 1967). There may be little variation in the resulting seedlings, and later in the fruits produced

There is a wide range of seed weights, from about 0.5g to 2.0g per seed. Those which are mature are usually in the weight range of 1.0-2.0g. Polyembryony is known to occur in mangosteen giving rise to up to three seedlings per seed. The phenomenon is reported to occur in as many as 11% of mangosteen (Wester, 1920, 1926).

Lim (1984) examined the embryology of mangosteen seeds and noted the development of endosperm from the primary endosperm nucleus, without fertilisation and also the late development of adventitious proembryos from the outer integument. The shape of the mature proembryo is subcyclindrical and tuberoid without any clear polarity and this was interpreted by Sprecher (1919) as a hypocotyl tubercle.

The germination of mangosteen seed is considered quite unique compared with seeds of other crop species (Vogel, 1980). During germination, swelling occurs at opposite ends of the seed, and a radical (root) and a plumule (shoot) emerge from these opposite ends. The radical dies when adventitious roots develop from the base of the plumule (Hume and Cobin, 1946; Chandler, 1958). Germination generally occurs in 14-21 days but this ranges from 10 to 54 days, depending on seed age and the growing medium. Seeds from the same plant often vary greatly in germination time in different years and seasons.

Seed handling techniques are important due to the short life of seeds. Any drying can drastically reduce germination and seeds generally lose viability in 3-5 days when removed from the fruit. When kept in the fruit, viability can be retained for 3-5 weeks (Chandler, 1958) but the resulting germination can be slower (Winters and Rodriguez-Colon, 1953).

Fresh seeds are covered by a very thin membrane, which is the only protection against desiccation. Seeds can be temporarily stored in moist charcoal, peat moss or coconut fibre (Gonzalez and Anoos, 1951; Winters and Rodriquez-Colon, 1953). In sealed tins with moistened charcoal, seeds survive for 3-5 weeks (Chandler, 1958).

The type of temporary storage, and the time after extraction from the fruit markedly affects germination (Figure 9-1).

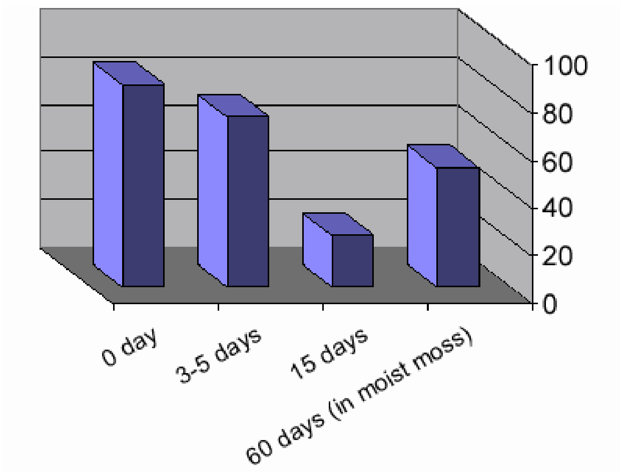


Figure 9-1. Germination rates (%) of mangosteen seeds recorded under different storage durations

Source: Gonzalez and Anoos (1951)

Normally, large (>1g in weight) plump and fully-developed seeds are chosen for planting. A number of studies have reported that large seeds are associated with higher viability and higher survival rates (Wester, 1916; Horn, 1940a; Hume and Cobin, 1946; see Table 9-1).

Table 9-1. Relation of seed size to germination, survival and subsequent growth of mangosteen in a shaded greenhouse

Weight Class (g)	Number of Seeds	Germination* (%)	Survival** (%)	Height (cm)
0.1	1	0	-	-
0.2	5	20	0	-
0.3	13	8	0	-
0.4	8	25	0	-
0.5	11	56	18	6.8
0.6	10	40	40	6.8
0.7	10	80	60	9.4
0.8	13	77	62	9.6
0.9	20	90	80	10.1
1.0	20	100	80	10.7
1.1	17	95	94	11.9
1.2	22	100	82	12.4
1.3	19	100	100	12.7
1.4	7	100	100	12.4
1.5	6	100	100	13.9
1.6	4	100	75	13.2
1.7	9	100	100	12.9
1.8	2	100	50	13.9
1.9	2	100	100	13.9
2.0	1	100	100	20.3

* Data taken 53 days after planting. ** Data taken 363 days after planting. Source: Hume and Cobin (1946)

Before sowing, seeds are normally pre-germinated. Fresh seeds are soaked for 12 hours in order to facilitate testa removal. Removing the testa by hand is delicate but is done in order to increase the percentage of germination. The removal of the testa also helps to produce more uniform seedlings. Seeds should be sown in a freely-draining medium, preferably under high humidity, and the seedbed should be properly shaded before the seedlings emerge.

Seeds are usually sown directly in individual polybags or pots (Havard Duclos, 1950). Various media may be used, including soil high in organic matter (Hume, 1947), or a peat-sand (1:1) mixture or a soil-sand (1:3) mixture. Other media with high moisture retention include shredded coconut fibres. If desired, growing media may be sterilised but this is not usually practiced.

When dealing with large numbers of seeds, sowing is usually in a seedbed (Plate 1). A typical seedbed may be made of wood or cement, and the sowing medium used can consist of a mixture of sand and soil in a 3:1 ratio by volume. The sowing medium should be deep, up to 1 m in depth. The medium needs to be moisture-retentive but well drained.

Seeds are planted 5-10 mm in depth and spaced 2-3 cm apart, if sown in a seedbed and are covered with sand. They are normally placed singly on the flat side in a horizontal position. Generally, it has been reported that sprouting occurs in 2-3 weeks and is complete in about 6 weeks. However, seeds may be sown in any position as germination still occurs when seeds are placed on their side or even upside down. Under such conditions, seeds will germinate in about 20-30 days after sowing (Padolina, 1931; Gonzalez and Anoos, 1951; Almeyda and Martin, 1978). By comparison, seeds which are sown without their testa removed require 4-5 weeks before they germinate, and the seedlings derived from such seeds are normally not uniform.

After emergence the seedlings have to be watered regularly. Seedlings show very slow growth (see section 9.1.3 below).

9.1.2 Other seed pre-treatments

Growth substances have been used to enhance germination. One such substance is 2,4-D. However, careful seed handling and sowing, as described above, means such treatments are not necessary.

9.1.3 Seedling growth

Under favourable conditions seedlings can grow up to 25 cm in a year (Verheij, 1992) but normally slow growth is seen in the early stages. The slow growth is attributed to the poor root development, especially the development of lateral roots.

Seedlings are kept in the nursery for about 2 years or until the first pair of side shoots have developed. An average height will then be about 25-30 cm. Some workers propose keeping seedlings in the nursery until they are 50-60 cm tall.

Seedlings need to be re-potted if kept in containers, or transplanted into nursery beds at a spacing of about 30-40 cm apart.

Mangosteen has a juvenile phase. Good growth of seedlings (especially leaf area) is promoted so that the juvenile phase is finished as quickly as possible; usually when the trunk has 16 pairs of laterals (Verheij, 1992) at about 5-7 years. Seedling growth can be promoted by the use of nitrogenous fertilisers. Also, studies have shown that seedlings watered with nutrient solution supplemented with yeast extract grew better within 10 months than similarly treated plants receiving no yeast extract (Horn, 1940a). As the seedlings grew older and leaf area increased, the growth stimulation by yeast extract was less. Growth of all seedlings grown in dead sphagnum moss watered with nutrient solution with or without yeast extract was better than growth in soil. Trials conducted at the Bureau of Plant Industry in Davao, Philippines, showed that the application of gibberellic acid could also accelerate the early growth of mangosteen seedlings.

In terms of vegetative growth, the young seedlings are reported to have a very large shoot-to-root ratio (6.24), and this ratio declines with age to a value of 4.94 at 24 months (Table 9.2), indicating the exceedingly slow growth of the seedlings.

Table 9-2. The shoot-to-root ratio of mangosteen seedlings up to 24 months

Seedling Age (months)	Shoot : Root Ratio
6	6.24
12	5.75
18	5.50
24	4. 94

Source: after Mohd Khalid and Rukayah (1993)

9.2 Vegetative propagation

Asexual propagation is currently limited and little used because plants propagated from seeds are usually more robust and reach fruiting earlier.

Many attempts to root cuttings and layering have failed (Gonzalez and Anoos, 1951; Campbell, 1967). This is not uncommon with local tropical fruits and emphasis is placed on inarching, a traditional method used in Southeast Asia. Inarching relies on using a different rootstock.

9.2.1 Rootstocks

There are several reports which indicate success with rootstocks of the genera *Garcinia*, *Platonia*, *Pentadesma* and *Clusia*; however, there has been no follow-up to confirm these findings. Inarching trials have shown that the mangosteen is not graft-compatible with plants belonging to the genera *Calophyllum*, *Cratoxylon* and *Rheedia* (Gonzalez and Anoos, 1951). Webster (1915a) obtained successful union by shield budding mangosteen on *Calophyllum inophyllum* (palomaria) and *G. venulosa* (gutagamba) using well matured but green and smooth, non-petioled budwood, but the bud was not able to sprout and was gradually callused over.

Most *Garcinia* species are not compatible with mangosteen. Of the Asian species of *Garcinia* used as rootstocks, only a few appear to be compatible with mangosteen. The percentage of union is very low (10% for *G. kydia* and 12% for *G. venulosa*). *G. lateriflora* and *G tinctoria* have shown, as have *G. hombroniana*, *G. livingstonei*, and *G. morella*, fairly successful results as rootstocks (Fairchild, 1915; Galang, 1955; Ochse *et al*., 1961). *G. speciosa* may be a potential rootstock according to research at the Prince of Songkla University, Thailand. There is no information to indicate that earlier or superior production can be achieved from grafted plants.

Attempts to graft mangosteen onto *G. malaccensis*, one of its other parents, have not been tried. Earlier reports of the use of African *G. livingstonei*, have not been followed up: here there are possibilities to extend mangosteen cultivation into drier and less shaded areas.

Grafting has been shown in other plant species to provide desirable characteristics such as precocity, dwarfness and plant architecture that promote economy for picking and pruning. The propagation of mangosteen could be considerably improved if a suitable and vigorous rootstock can be identified (Wester, 1926). Mangosteen seedlings themselves are not necessarily good rootstocks because of their slow growth (Winters, 1953). Several attempts have been made to identify other rootstocks that are fast growing and have vigorous root systems, but these attempts have generally failed because of incompatibility problems.

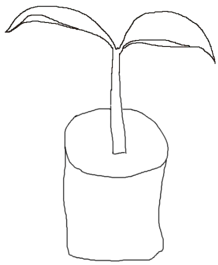
Mangosteen is compatible when grafted to itself but the resulting cleft grafted plants usually exhibit rather unique characteristics which are different from plants propagated from seeds. Grafted plants exhibit extremely stunted growth, usually together with non-upright shoot development. For as yet unknown reasons, cleft-grafted plants normally show a tendency to bend in a sideways direction when they grow, even observable at the nursery stage, and plants may need to be staked to keep them upright, especially when they grow taller. The bending becomes more pronounced if the scions used in cleft grafting are taken from side shoots instead of terminal shoots of the mother plant. However, at times, cleft-grafted plants can show precocity and come into first bearing very early. The first bearing sometimes occurs in saplings still at the nursery stage. When mangosteen is grafted onto mangosteen seedlings the best technique is cleft grafting and this is being used in Malaysia.

9.2.2 Cleft grafting

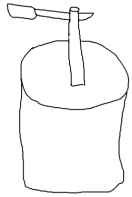
Cleft grafting is one of the oldest and most widely used methods of grafting (Figure 9-2 and Plates 2 and 3). In this technique, a healthy shoot is taken as the scion from a selected mother plant still in active growth, and is then is inserted into a healthy rootstock.

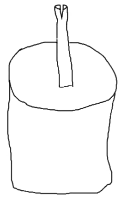
Healthy rootstocks of about 30-35 cm in height are preferred. Seeds for the rootstocks are usually obtained from selected plants with consistent fruit size and heavy bearing. These rootstocks are selected from plants which are propagated from seedlings and which are about 2 years of age. At this stage, the stem diameter of the rootstocks should be about the same size as that of the scion (1.6-2.0 cm), so that cambium tissue of each can match closely. In making a cleft graft, a heavy and sharp knife is used to cut off a two-leaf shoot at a right angle to the main stem of the rootstock, leaving a smooth and flat surface stub to be grafted. Then the knife is used to make a vertical split for a distance of about 2.0-2.5 cm down the middle of the stem, leaving a V-shaped opening for insertion of the scion. A good split should be right at the centre in order to permit a good placement of the scion for its subsequent growth.

A scion is normally obtained from a healthy terminal shoot; however, this may not be possible if large quantities of scions are required, so in such situations side shoots need to be used. A good scion is normally obtained from a shoot that has a semi-hardwood stem and is not too young (having two semi-hard leaves). The stem diameter of the scion is properly selected so that it approximately matches the stem diameter of the rootstock. The size of the scion should be 6-12 cm long. The basal end of the scion is cut into a gently sloping wedge about 2 cm long. The scion is inserted into the V-shaped opening in the rootstock. The pressure of the split rootstock will now be exerted on the scion, and thus ensure that the cambium abuts the cambium of the scion on the wedge. However, it is not necessary that the end of the wedge comes to the end point of the split in the rootstock.

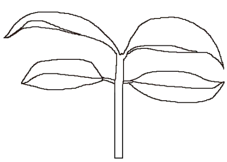


Step 1. A rootstock at 2-leaf stage (about 30-35 cm high, 2 years old) is chosen from seedling propagated from seeds.

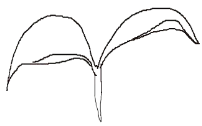




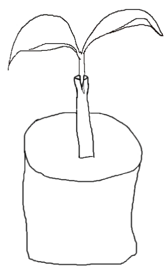
Step 2. The shoot is cut off at a right angle leaving a smooth and flat surface stub. Then a vertical cut (2.0-2.5 cm) is made down the middle of the stub to make a V-shaped opening for the scion.



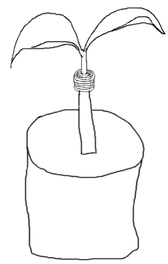
Step 3. A scion (about 6-12 cm) is obtained from another plant, with stem size approx. matching that of the rootstock.



Step 4. The basal end of the scion is cut into a gently sloping wedge about 2 cm long.



Step 5. The scion is inserted onto the opening in the rootstock.



Step 6. The completed graft is then wrapped with parafilm and later the plant is covered with clear plastic and placed under shade or in a mist chamber.

Figure 9-2. Cleft grafting in mangosteen

The completed graft is wrapped with a parafilm, and the newly grafted plant is sprayed with water to keep it moist. Afterwards, the plant is covered completely with clear plastic and placed under 75% shade in order to maintain a high percent relative humidity. After a young shoot emerges, the clear plastic bag may be removed (about one month after grafting). Alternatively, the grafted plant may be placed in a mist chamber, the wrapping of the plant with a clear plastic becoming unnecessary.

9.3 Tissue culture

Tissue culture is a tool to grow a whole plant from a single cell or tissue under aseptic conditions. It is grown on a synthetic medium in a suitable container under a controlled environment. Tissue culture strategies which can be used for to *in vitro* conservation of tropical fruits crops have been described by Sahijram and Rajasekharan (1998). It has been extensively used for many different species, including mangosteen. Alang and Normah (1991) reviewed the use of *in vitro* techniques for propagation of mangosteen. Tissue culture has potential for use in mangosteen for: (i) conservation of germplasm (see chapter 7), and (ii) micropropagation of planting materials, (iii) *in vitro* mutagenesis breeding (see chapter 8). It can also be used as assessment of diversity.

Plate 1. Mangosteen leaves, immature and ripe fruits showing the aril and seeds (DOA, Sabah).

Plate 2. Mangosteen young fruit (Beaufort, Sabah).

Plate 3. Mangosteen seedlings growing in a nursery cement seedbed (MARDI).

Plate 4. A typical mist chamber used for vegetative propagation of mangosteen to maintain high humidity for newly grafted plants (MARDI).

Plate 5. Mangosteen leaves attacked by leaf miners (MARDI).

Plate 6. Gummosis in mangosteen in both young and ripe fruits (MARDI).

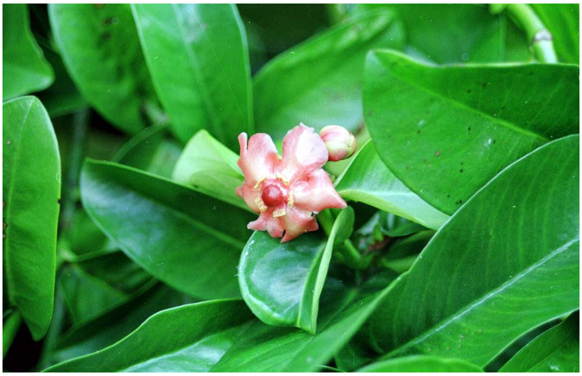


Plate 7. *G. dulcis* flowers (ARC, Tenom, Sabah).

Plate 8. *G. dulcis* immature fruits (ARC, Tenom, Sabah).

Plate 9. *G. dulcis*, cut, ripe fruit showing seed (ARC, Tenom, Sabah).

Plate 10. *G. cambogia*, locally called gourhaka, immature and ripe fruits on a tree (DOA, Sabah).

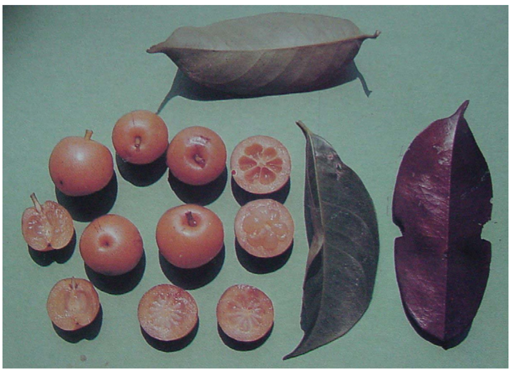


Plate 11. *G. parvifolia*, locally called kandis asam, leaves, ripe fruits yellow in colour showing the aril and rind (DOA, Sabah).

Plate 12. *G. parvifolia*, locally called kundong, ripe fruits red in colour showing the aril and rind (DOA, Sarawak).

Plate 13. *G. nitida*, locally called kandis, ripe fruits on a tree (DOA, Sarawak).

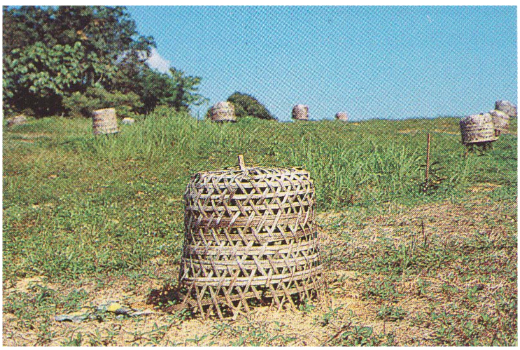


Plate 14. Young mangosteen plants provided with the required shade in the field using bamboo baskets (MARDI).

Plate 15. A drip irrigation system used to provide water for mangosteen.

Plate 16. A vegetatively propagated mangosteen plant which has been derived from cleft grafting (MARDI).

Plate 17. A vegetatively propagated mangosteen plant which has been derived from top grafting (MARDI).

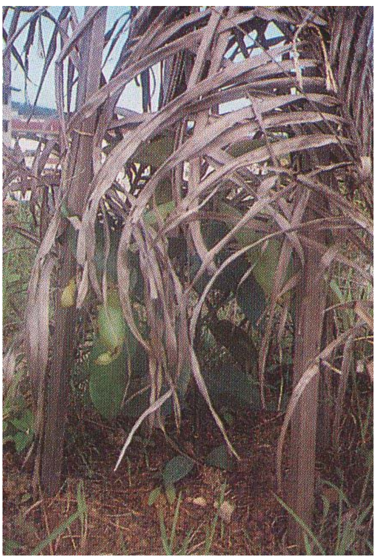


Plate 18. A young mangosteen plant provided with the required shade using coconut fronds (MARDI).

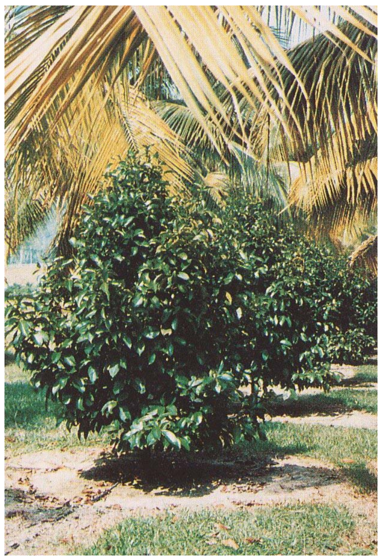


Plate 19. Mangosteen plants grown under coconut plants to take advantage of the natural shade (MARDI).

Plate 20. Ripe mangosteen fruits showing damage from the fruit borer (MARDI).

Plate 21. A long net used to collect the fruit to avoid it falling to the ground.

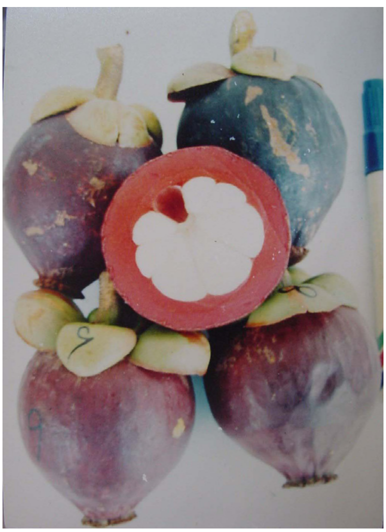


Plate 22. Fruits of a rare variety 'Mesta' with one showing the juicy cream white aril, taken from a tree in Temerloh, Peninsular Malaysia.

Plate 23. Mangosteen cultivated from seed with irrigation facilities (MARDI).

Bruise injury | Fruit cracking | Translucent flesh | Flesh collapse

Plate 24. A chart showing skin or fruit blemishes and defects in mangosteen developed in Australia.

No No Yes Yes Yes No

Plate 25. Suggested mangosteen harvesting stages used in Australia.

Several authors have reported successes in *in vitro* propagation of mangosteen (Goh *et al*., 1988, 1990, 1994, 1997; Te-Chato *et al*., 1999, 2000; Normah *et al*., 1992, 1995; Ferwerda, 2003). Multiple shoot formation has been obtained from segmented seeds, juvenile leaf segments, root segments, shoot tip and nodal and internodal explants (Goh *et al*., 1990, 1994; Normah *et al*., 1992).

Goh *et al*. (1988) experimented to determine the optimum conditions for *in vitro* growth and multiplication of mangosteen, using explants from both aseptically germinated seedlings and from field-grown plants, using various parts of the plant. Proliferating shoots were obtained from cotyledon segments of mangosteen cultured on modified Murashige and Skoog (MS) medium with 6-benzylaminopurine (BAP). Juvenile leaf segments produced adventitious buds on an alternative medium, Woody Plant Medium (WPM). Shoot tip, nodal and internodal explants produced multiple axillary and adventitious buds. Root segments, in contrast, gave few buds. The shoots were rooted with indolebutyric acid (IBA) treatment.

9.3.1 Leaf explants

Further work by Goh and coworkers was on direct regeneration of shoot buds, without the intermediate callus phase, from leaf segments cultured *in vitro* (Goh *et al*., 1990). Explants were taken from very young leaves (7-9 days old), still purple-red in colour and older leaves which had turned green, of 1 to 3-year-old seedlings and 16 year-old mature fruiting trees of mangosteen. They were cultured on 50 ml modified MS medium, with macronutrients at half strength, 20 gl^{-1} sucrose, 8 gl^{-1} agar. Cultures were maintained at 26±2°C, 12 h day photoperiod, 20 $\mu Em^{-2}s^{-1}$ light intensity. Exposure to light enhanced shoot bud production but there was no significant difference between 12 and 16 h daylight. BAP was effective in inducing shoot bud formation from leaves. The optimal level of BAP for shoot bud development from seedling leaf explants was 5 mgl^{-1}. At higher concentrations shoot buds were clustered and stunted. Explants from very young leaves from mature trees, taken when the leaves were 2-3 cm long, also produced shoot buds on this medium. However a higher percentage of shoot bud development was observed in leaf explants from seedlings rather than from mature trees, although similar in morphology. Buds were also produced in 3-4 weeks from seedling explants compared to 9 weeks in mature tree explants.

The frequency of bud formation was also decreased in explants of older leaves. Secondary shoot buds also developed on leaves of cultured epiphyllous shoots from both seedlings and mature trees. Shoots from leaves of seedlings and mature trees,, were then successfully rooted with an auxin treatment, IBA 20 mgl^{-1} for one week, when they measured more than 2 cm. Cultures of seedling leaves could be maintained indefinitely, useful for increased micropropagation, as there would be no need to return to the original explants.

Goh *et al.* (1994) developed and improved procedures for direct shoot bud regeneration from young leaves. Regeneration was achieved by culturing 3 mm transverse sections of about 10-day-old leaves on WPM with 20µM 6-benzyladenine (BA), 20 gl^{-1} sucrose and 2.5 gl^{-1} Phytagel. A wound response in the presence of BA at the time of culture was found to be essential for shoot bud induction. Explant size, concentration of BA in the medium, timing of addition of BA to the medium as well as the time of wounding of explant significantly influenced shoot bud regeneration. Leaves from field-grown seedlings produced an average of 45 shoot buds per leaf after 50 days of culture compared with 8 shoot buds per leaf from shoots maintained *in vitro*. Regeneration of shoots (5-6 mm tall) excised from the explants required BA (5 µM) for further growth. Rooting was induced with IBA when the shoots reached 10-15 mm in size and were established in vermiculite/sand mixture in pots.

9.3.2 Seed explants

Normah *et al.* (1995) studied the factors affecting *in vitro* shoot proliferation and *ex vitro* establishment of mangosteen using seed explants. Seed explants are useful because *Garcinia* seeds are formed apomictically and are thus homogenous. A maximum mean number of 16.5 shoots per explant was obtained from cultures after 2-3 weeks on MS medium supplemented with 40 mM BA, and 2.5 mM α-naphthaleneacetic acid (NAA), 20 gl^{-1} sucrose, 7 gl^{-1} Bacto agar, and kept at 30°C under an 8h photoperiod with 25 $mmolm^{-2}s^{-1}$ light intensity. Cultures on the same medium but supplemented with activated charcoal produced fewer shoots, but the growth of these shoots was more organised and 75% rooting was obtained. WPM was found to be a less suitable medium for shoot proliferation from seed. Buds formed a week later on WPM than MS, and were fewer in number. However those which formed buds also produced roots. They were established in media containing vermiculite : soil 1:1, sand : soil 1:1, vermiculite : sand 1:1 and sand : soil :

organic material 3:2:1 which gave the best survival rate (98%). These plants were then successfully transplanted in the field.

In contrast Fewerda *et al*. (2003) developed a simple and efficient protocol for the *in vitro* propagation of mangosteen using WPM. This involves a two-step culture system which allows for rapid clonal propagation at times when seeds are scarce. Seeds aseptically dissected from fruits were cultured in tubes containing 1.8 g vermiculite (used as a solid substrate) and 10.2 ml liquid WPM for germination. The cultures were maintained under 25 mmol $m^{-2}s^{-1}$, 24-26°C, and a 16/8 h photoperiod, cooler and longer light period than Normah *et al* (1995). The seedlings were cut into two segments, one containing the apical bud and a portion of the stem, and the other containing the remaining stem and root system. The top portions were more effective in producing plantlets.

Segmented seeds from immature fruits have been found to produce more shoots than seeds from mature fruits (Normah *et al*., 1992).N

9.3.3 Regulation of bud regeneration

Goh *et al*. (1997) studied the role of ethylene in the regulation of shoot bud regeneration from leaf explants by culturing leaf segments (2 mm) on WPM supplemented with BA (20 µM), ethylene inhibitors $AgNO_3$, aminoethoxyvinylglycine (AVG) or ethylene precursor 1-aminocyclopropane-1-carboxylic acid (ACC), under aerated or airtight conditions, where cultures were sealed with rubber septa stoppers. In aerated cultures, the first emergence of shoot buds occurred on midribs of the leaf segments within 18 days of incubation and 92% of the explants regenerated buds by day 42. In airtight cultures a large accumulation of ethylene, callus production and a marked delay of at least 12 days in shoot bud regeneration was observed. The addition of ACC to the culture medium also dramatically delayed shoot regeneration and enhanced callus proliferation. Under airtight conditions, both $AgNO_3$ and AVG were effective in preventing the delay of shoot regeneration and callus formation; however, only AVG suppressed ethylene production. Ethylene or ethylene inhibitors did not affect the percentage of regenerating explants after 49 days of culture. As ethylene only delayed the emergence of shoot buds, it is presumed to regulate some of the early developmental stages associated with shoot bud regeneration in mangosteen leaf explants.

Huang *et al*. (2000) investigated tissue culture parameters in *Garcinia* and revealed that no auxin supplementation was necessary for bud primordium differentiation in explants from cotyledons or for proliferation of regenerated shoots. The optimum N^6-benzyladenine concentration for primordium differentiation was 4.4 µM, and for shoot proliferation was 13.3 µM. Continuous culturing in an 8-hour photoperiod at 30°C resulted in degeneration of shoots; in contrast, a 16 hour photoperiod at 26°C regime enabled the sustained regeneration of shoots.

9.3.4 Multiplication of plantlets in vitro

Te-Chato *et al*. (1999) successfully induced nodular callus at a high frequency on very young laminae taken from *in vitro* grown plants. The optimal medium was MS supplemented with 2.22 µM BA, 2.25 µM thidiazuron (TDZ), 500 mg l^{-1} polyvinylpyrrolidone (PVP 360 000) l^{-1} and 3% sucrose. A multiplication rate of 2-3 was obtained by subculture of the nodular callus at 3 to 4-week intervals. Plantlet regeneration from the nodules was achieved by transfer to other media, WPM with 500 mg l^{-1} PVP, 0.4 µM BA, 3% sucrose, overlain with half strength MS with 0.32 µM NAA, 0.13 µM BA and 3% sucrose. Shoots were rooted by wounding at the base, dipping in 4.4 mM IBA solution and culturing on WPM with 1.11 µM BA, 0.25% activated charcoal, 34.5 µM phloroglucinol (PG) and 3% sucrose. Te-Chato *et al*. (2000) developed a four-step procedure for plant regeneration from leaf explants excised from *in vitro*-grown plantlets.

9.3.5 Further work

Work on *in vitro* propagation techniques using seed and other explants is still being carried out, for example in the Philippines and Vietnam (UTFANET, 2003). Despite the success of *in vitro* micropropagation, as yet, data are lacking to compare the performance, including fruit bearing, of tissue-cultured-derived plants with those that are produced from seeds. The work will include preliminary information on precocity of tissue-cultured mangosteen. Few such plants at University Kebangsaan of Malaysia Normah have gone into bearing.

9.4 Establishment in the field

It is rare that seeds are sown directly in the field, although in home gardens this is sometimes practiced; more often seedlings are transplanted.

The sections below outline the best-known methods of preparation of site, planting and maintenance of seedlings or young grafted plants.

9.4.1 Land preparation for orchards

If access to equipment is available necessary, new land clearing can be done by using a bulldozer to remove large plants together with their roots. The use of a bulldozer can cause soil compaction and subsequent deep ploughing needs to be carried out after the land clearing. Under average soil conditions, one round of disc ploughing (or deep ripping) followed by rotavation is sufficient to attain the desired soil tilth.

Despite the fact that mangosteen seedlings need a lot of moisture, they are, however, sensitive to water-logging. Therefore attention has to be paid to drainage.

High rates of organic matter in the soil are recommended, and practices normally follow recommendations for other crops (Marshall and Marshall, 1983). Organic matter may be incorporated into the planting sites 6-9 months prior to planting.

In planting an orchard it is necessary to remember that the mature trees will require space of 40 to $80m^2$ per tree.

9.4.2 Transplanting

Seedlings are ready for transplanting into the field when they are about 2 years old. Planting holes are dug with a minimum size of 60 x 60 x 60 cm. In some commercial operations larger holes are dug about a month before transplanting (1.2 x 1.3m). Organic matter can be mixed with the topsoil and used for filling the planting hole around the seedling. Addition of phosphate (e.g. Christmas Island Rock Phosphate at 100g/hole) is recommended. Wooden sticks are used to support the seedlings in the initial stages.

Seedlings in polybags or with a large root ball from the nursery are transplanted with as little disturbance as possible to the root system. Mangosteen seedlings have a long delicate tap root and a poor lateral root system. Many failures of seedlings can be related to damage of the tap root when transplanting. It is also recommended, but seldom practiced, that leaves of seedlings are pruned in half to avoid undue damage to leaves (Horn, 1940a). Failures are also due to over-exposure of seedlings to direct sun during transplanting (Ochse et al., 1961).

Shade has to be provided quickly and is critical during the first two years of establishment. Mangosteen plants require about 30-50% shade to protect them from the hot sun and avoid leaf scorching (MOA, 2002). Shade can be provided using bamboo baskets which are perched upside down on a tripod above the seedlings (Plate 4). The shade enclosure should be 1.2-2m above ground level. The baskets can provide the required shade for about two years since they last that long. Other materials such as coconut leaves, oil palm fronds, banana leaves or grasses may also be used to provide shade for the seedlings (Plate 5). Alternatively, shading can be achieved with mixed stands, with crops such as banana, plantain, rambutan, durian and coconut, at least 1.5m from the mangosteen. Mangosteen orchards flourish very well under coconut (Plate 6). In areas with a pronounced dry season, it is a good practice to always grow mangosteen under partial shade.

Shade is maintained up to 2-4 years and is then is gradually reduced to allow full sun exposure (Fairchild, 1915; Hume, 1947; Gonzalez and Anoos, 1951; Almeyda and Martin, 1978). However, in some climatic conditions e.g. in Mindanao, Philippines, well-established mangosteen can be grown in the open without any shade. When considering an orchard it is best to check the local practice for shading.

Seedlings which are transplanted also require mulching. Mulching should be done right after transplanting. A heavy mulch around the plant is a good alternative to weed control. The mulch is applied 30 cm from the base of the trunk up to the spread of the canopy (Hume, 1947). During any dry season, the area around the base of the plant should be covered with mulch to keep the soil continuously moist (Fairchild, 1915; Hume, 1947; Almeyda and Martin, 1978). Empty oil palm fruit bunches, coconut husks and dried grasses are useful mulches. Cover crops (*Crotalaria sp.*, cowpea, tropical kudzu, etc.) have also been found to help.

9.4.2.1 Spacing

In mixed orchards with other fruits, such as durian, rambutan or coconut, an area of 40-80m^2 is allowed per mangosteen plant and they are planted at 8-10m spacing (110-140 plants/ha). A spacing of 11-12m is recommended if equipment access is required.

In commercial cultivation, square planting is recommended for mangosteen, and the planting density depends on the type of planting materials used, soil depth and quality, topography, and irrigation. The planting distance for mangosteen seedlings propagated from seed is recommended at 7 x 7m, giving a total of 200 plants per hectare. Other planting distances of 6m in a row and 6-8m between rows are also used, giving a total of 280 plants per hectare.

9.4.2.2 Time of planting

Field planting should be done at the onset of the wet or rainy season. This avoids damage since seedlings are sensitive to dry conditions. Also at this time there is no need for supplementary watering.

9.4.2.3 Weeding new plantings

The exceedingly slow growth makes the seedlings very vulnerable and they can be quickly overtaken by weeds, hence weeding is necessary. A general maintenance programme such as weed slashing and/or use of contact herbicides may be implemented after 2 years. If mulching has been successfully carried out around the base of the plant, circle weeding may not be necessary.

As the shade provided may hide weeds, regular checks are needed. During early growth, weeds around the plant trunk should be removed, taking care not to damage the young plants. For mature plants, weeds can be controlled by spraying paraquat at 1.0 kg/ha or glufosinate ammonium at 0.5 kg/ha (MOA, 2002).

9.5 Management of orchards

9.5.1 Pruning

Mangosteen usually ends its juvenile stage when the trunk has 16 pairs of laterals and it then grows into a pyramidal crown. Until then no pruning is needed except to remove broken or dead branches.

Trees produce periodic flushes of shoot growth, up to 6 per year when vegetative and only 1 or 2 per year when bearing. No pruning should be done when there are flowers, fruits or flushes of shoot growth.

Regular corrective pruning to remove suckers at the base of the main trunk, odd upright growing branches and small inside (inner) branches is a good practice (Fairchild, 1915; Hume, 1947). Because of the height of the mature tree and the fact that fruits are borne singly, thus making harvesting difficult, it has been suggested that pruning may be useful to head back the plant to a height of 8-10m allowing greater expansion of lateral branches. Alternatively, the use of dwarfing rootstocks has also been suggested.

In Thailand, for mangosteen plants which are reported to take 12-20 years to fruit, small inner branches are pruned from old, unproductive plants to stimulate bearing.

9.5.2 Fertilisers

Mangosteen plants have been found to respond well to manuring (Galang, 1955), and dilute organic fertilisers which can be absorbed slowly are also found desirable (Hume, 1947). In India, growers were reported to give each plant regular feeding with well-rotted manure (45-90 kg) and peanut meal (4.5-6.8 kg) every year. Likewise, application of a nitrogenous fertiliser produces faster vegetative growth of the plants (Ochse *et al.*, 1961; Palma Gil *et al.*, 1972). Fertilisers can be applied in a ring around the base at the edge of the canopy. There is a dearth of exact information on fertilisers for mangosteen, however, the following general recommendations are suggested: 50-100g ammonium sulphate is applied a month after planting and again at the end of the rainy season or 6 months after planting. During subsequent years of vegetative growth, the amount of fertiliser is gradually increased. When the plants start fruiting, 500g of complete fertiliser high in N and K is applied, once at the onset and another at the end of the rainy season, or every 6 months. The amount of fertiliser is gradually increased every year as the plants grow bigger and as fruit production increases. Fully grown plants should receive at least 2 kg of complete fertiliser a year. Dolomite is applied at the rate of 0.2 kg per plant per year of age with no increase after year 15. Chicken manure may also be applied at the rate of 2 kg per plant per year, and this is thought to improve vigour.

9.5.2.1 Fertiliser practices of different institutions

Kanchanapom and Kanchanapom (1998) in Thailand suggested the schedule shown in Table 9-3. For trees 15 years or older, half is applied when vegetative growth is being stimulated after fruit harvest and the remainder is applied 2-5 weeks after anthesis.

Table 9-3. A fertiliser schedule for mangosteen (Thailand) (Kanchanapom and Kanchanapom, 1998)

Tree Age (year)	Manure/Fertliser	Rate per Plant (per year)
Young plants	Organic manure	
1-15 years	Dolomite, N, P, K	200g, 70g, 6g, 50g
>15 years	10:10:19 (N:P:K)	2-7 kg

Another such programme is given in Table 9-4.

Table 9-4. An alternative fertiliser schedule for mangosteen (Thailand)

Tree Age (year)	Nutrient Requirements	Fertiliser Rate (kg/plant)	No. of Applications per Year
0	CIRP, Organic manure	100g/hole, 10g/hole	Once at planting
2-3	15:15:15 (N:P:K)	0.2	3
4-5	15:15:15 (N:P:K)	0.3	3
6 onwards	12:12:17:2+TE (N:P:K:Mg)	0.5	3

NPKMg (15:15:15:2)

The programme for mangosteen recommended by Malaysian Agricultural Research and Development Institute (MARDI) is given in the Table 9-5.

Table 9-5. Fertiliser schedule for mangosteen as recommended by MARDI (Malaysia)

Plant Age (years)	Compound Fertiliser	Amount/Plant/Year (kg)	Frequency per Year
1	15:15:15	0.5	3
2	15:15:15	1.0	3
3	12:12:17:2	1.5	3
4	12:12:17:2	2.0	3
5	12:12:17:2	2.5	3
6	12:12:17:2	3.0	3
7	12:12:17:2	4.0	3
8	12:12:17:2	5.0	3
>8	12:12:17:2	6.0	3

NPKMg + trace elements (12:12:17:2).
Source: MOA (2002)

A more refined fertiliser schedule for mangosteen cultivation in Malaysia has been recommended by the Ministry of Agriculture of Malaysia and this is given in Table 9-6. The first four years in the field the plants require high nitrogen. In the fifth year, high potassium is required for flowering and subsequent fruiting. Fertilisers are normally applied either by broadcasting or applying in narrow bands around the periphery of the canopy at the base of the plant.

Table 9-6. Fertiliser schedule for mangosteen as recommended by Ministry of Agriculture of Malaysia

Stage/Plant Age (year)	Fertiliser Type	Rate per Plant (kg/year)	Frequency per Year
At planting	Organic manure, CIRP	10g/hole, 100g/hole	Once at planting
1	NPKMg (15:15:15:2)	0.2	3
2	NPKMg (15:15:15:2)	0.3	3
3	NPKMg (15:15:15:2)	0.5	3
4	NPKMg (15:15:15:2)	0.6	3
5	NPKMg + trace elements (12:12:17:2)	1.0	3
6	NPKMg + trace elements (12:12:17:2)	1.5	3
>7	NPKMg + trace elements (12:12:17:2)	2.0	3

Source: MOA (2002)

The fertiliser schedule that was used at Kamerunga Horticultural Research Station (now closed), Cairns, Australia is given in Table 9-7. Micronutrients were applied, particularly for zinc and iron. Prior to first harvest, the total fertiliser was applied in four parts in August, December, February and April.

Table 9-7. Fertiliser schedule formerly practised for mangosteen at Kamerunga Horticultural Research Station, Australia

Age of Plant (years)	Fertliser per Plant per Year (g) (N:P:K)
1-2	70:6:50
2-4	210:18:150
4-6	350:30:250
6-8	490:42:350
8-10	630:54:450
Bearing plants	700:60:500

Source: Chay-Prove (2004)

The fertiliser schedule that is recommended in Indonesia is given in Table 9-8 (Dede Juanda & Bambang Cahyono, 2000).

Table 9-8. A fertiliser schedule for mangosteen in Indonesia

Age of Plant	Type of fertilizer / manure			
	Urea g/yr	Superphosphates g/yr	KCl g/yr	Manure kg/yr
At planting	-	-	-	20
6 months after planting	125	83.5	41.5	-
1 year after planting	250	83.5	166.5	40
2 years after planting	375	125	250	40
3 years after planting	500	166.5	333.5	40
4 years after planting	750	3000	2250	40

9.5.3 Irrigation

Mangosteen is sensitive to environments which are either too wet or too dry. Where the area does not have a rainfall which is evenly distributed throughout the year, an irrigation system is strongly recommended to supply water during the dry months.

Mangosteen plants benefit from supplementary irrigation, even if they are planted in rather wet areas. The mangosteen root system lacks root hairs (Hume, 1947); consequently, there is poor contact with the soil for efficient water absorption. For this reason, the plant requires a constant and abundant supply of water in the soil (Fairchild, 1915; Hume, 1947; Gonzalez and Anoos, 1951 and Ochse *et al*., 1961; Almeyda and Martin, 1978). However, at the seedling stage, standing water can kill the plants (Popenoe, 1928). The large requirement for water is indicated naturally by some of the most fruitful mangosteen plants being found to grow on banks of streams, lakes, ponds or canals where the roots are almost constantly wet (Popenoe, 1928).

The correct choice of irrigation system is essential because an unsuitable system can lead to soil erosion, water logging, and also increase the cost of production. Some irrigation systems such as drip irrigation, trickle irrigation or microsprinklers may be ideal depending on soil type, topography, water source, planting distance and cost.

The drip irrigation system delivers water directly to the root zone of the plants through a network of tubing. The main advantage of this system is the saving of water since water loss due to evaporation is minimal compared to other irrigation systems.

At present specific amounts of water requirement at different stages of plant growth have yet to be established. Practices are noted below:

At nursery stage

Seedlings in polybags are watered twice a day, once in the morning and once in the evening. It is important, that the soil mixture used in the polybag is not too compact since water logging or ponding can occur.

At field establishment

If transplanting is not carried out during the onset of the rainy season, an irrigation system is necessary to avoid transplanting shock. However continuous watering should be avoided because too much water can cause stunted growth.

Fruiting and flowering

Dry conditions just before and during flowering may be desirable to induce a good fruit set. Artificially, a continuous dry period of 15-30 days (to limit apical bud growth) followed by two heavy watering, spaced 7 days apart, can be imposed on plants to induce flowering. Regular watering is then required during fruit growth and development, at least at 80-85% of pan evaporation (Kanchanapom and Kanchanapom, 1998) (Figure 9-3). An insufficient amount of water can severely slow down fruit development. Excessive water tends to result in plants forming new shoots. Plants which form new shoots during fruiting result in the fruits becoming small or aborted.

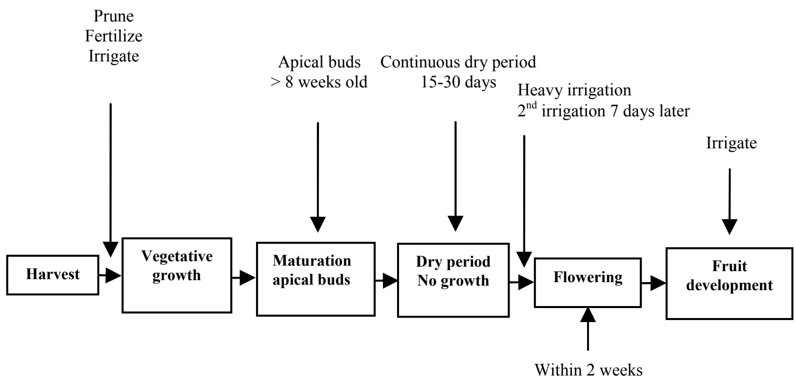


Figure 9-3. Steps required to induce flowering in mangosteen in Thailand

Source: after Salakpetch (1996)

9.7 Pest and diseases

Mangosteen does not appear to suffer from serious attacks of major pests and diseases (Hume, 1947). The ones widely recognised are shown in Table 9-9. Further details are provided below.

9.7.1 Pests

Only a few insect pests have been reported, possibly due to the bitter sap of the mangosteen. The major insect pests are leaf eaters (*Stictoptera* sp.) which feed on young leaves and shoots, the leaf miner (*Phyllocnictis citrella*) which bores into the leaves (Plate 9), and beetles which lay eggs on the fruit and the larvae feed on the flesh and seeds. Fruit borers (*Curcalilio* sp.) are also notable in the district of Mantin, Negeri Sembilan, Malaysia (Plate 11).

In the Philippines, the tussock caterpillar (*Eupterote favia*) feeds on the leaves; the coconut scale (*Aspidiotus destructor*) forms colonies underneath the leaves causing yellowing in patches and impairing plant growth (Gabriel, 1975).

Isolated cases of infestation by mites and mealy bugs have also been reported. Mites can attack the fruit surface, deface the fruits with small bites and scratches, and make it unattractive for market.

Caterpillars and grasshoppers can cause some leaf damage. A leaf-eating caterpillar in India may be the same as that which attacks new shoots in the Philippines and which has been identified as *Orgyra* sp. of the tussock moth family Lymantridae. Caterpillars of various species may damage young shoots and leaves and capsids can defoliate plants (Galang 1955).

Ants nesting in trees can damage growing tips. A small ant, *Myrnelachista ramulorum*, in Puerto Rico, tunnels into the trunk and branches, and damages the new growth.

Table 9-9. Major pests and diseases of mangosteen and their control

Pests	**Damage**	**Control**
Leaf eater, *Stictoptera* sp. (Noctuidae)	Larval stage eats young leaves and shoots. Often occurs in nursery. If the population is high, the plant will become bald.	Spray with systemic insecticide such as dimethoate and methamidophos. Spray at interval of two weeks.
Leaf miner, *Phyllocnictis citrella* (Lyontiidae)	The larvae often found on young shoots. Larval stage makes tunnels in the epidermis. Adult a moth.	If the infestation is not serious the insect can be controlled by biological agents. If the damage level is high control can be carried out by spraying with methidithion, abamectin and fenthion.
Fruit borer, *Curculio* sp. (Curculionidae)	Larval stage attacks fruit from mature to ripe stage. Borer eats the mesocarp, aril and seed. Each fruit can harbour up to 8 larvae. Larvae move out of fruit into soil and pupate later becoming adult beetles.	No control recommendation available. Destroy all affected fruits to reduce the beetle population in the field.
Diseases	**Damage**	**Control**
Stem canker, *Zignoella garcineae*	The disease attacks branches and stems. The leaves become wilted and drop causing the	Plants attacked by this fungus must be completely eradicated, infected parts should be burned to stop the

	plant to die. Stems become cankerous.	spread of the disease.
Sooty mould, *Corticum salmonicolor*	Attacks branches, causing leaves to wilt, dry and die. Affected areas turn pink.	Improving aeration and sunlight penetration by pruning overlapping branches will reduce infection. Scrape and paint affected part with Tridemorth (Calicin).

Source: Mohd. Khalid and Rukayah (1993)

A caterpillar that causes extensive damage to young leaves of mangosteen plants in Hawaii has been identified as *Stictoptera cuculioides* (Lepidoptera:Noctuidae), formerly called *S. subobliqua*. This noctuid moth was first described in Sri Lanka and has been reported in India, Thailand, Singapore, Malaysia, Papua New Guinea and Guam. In addition to mangosteen (*Garcinia mangostana*), *S. cuculioides* feeds on related latex-bearing plants of the Guttiferae.

The caterpillar feeds upon emerging leaves and shoot tips of the host plant, causing extensive defoliation of new flushes. It has nocturnal feeding behaviour. Pupation occurs in the soil. The pupa (cocoon) is dark brown, 1.3-1.6 cm long, and 0.6 cm wide. The adult moth is brown but can vary in colour tone and pattern. The adult male appears to have a more ornate wing pattern and a larger abdomen compared to the female. Previous reports indicate that the larval stage averages 15 days and pupation lasts 10-12 days.

Growers should monitor new flushes as they emerge for evidence of feeding damage. Insecticides containing *Bacillus thuringiensis* are effective in controlling leaf-eating caterpillars, including *S. cuculioides*. Azadirachtin extract from neem plants is reported to provide effective control in Thailand.

9.7.2 Diseases

Two widespread diseases; stem canker and sooty mould are itemised in Table 9-9. In addition the following are reported.

Thread blight, caused by *Pellicularia koleroga*, has been recorded in Puerto Rico, USA and elsewhere under conditions of excess shade and humidity (Roger, 1951). The smaller stems are first attacked and the disease becomes severe when it attacks the leaves, forming a whitish film over the blade. The leaves turn clear brown and then darken before abscising. Removal of some shade and the application of Bordeaux mixture or other copper fungicides may be used to control the disease.

Fungal leaf spot diseases caused by species of *Pestalotia* and *Leptostoma* can cause minor damage (Roger, 1951; Su 1933).

Occasionally, anthracnose and bacterial leaf sheath disease have been recorded. Control is possible with common fungicides.

Botryodiplodia theobromae, a fruit rot, does not attack trees but can be a problem for post harvest decay.

9.7.3 Physiological problems

A major physiological disorder called "gummosis" is found on mangosteen. This is evidenced by the oozing of latex onto fruit surfaces and branches (Plate 10). Gamboge, or resin, found as yellow spots on the fruit skin, frequently spoils fruits. Gummosis also occurs inside the fruit. If gamboge infiltrates the white fruit segments, these turn translucent, and fruits harden and the flesh tastes bitter. Mangosteen produced in Honduras often has crystal-like "stones" in the flesh and they may render the fruit completely inedible. In most instances gummosis is the result of physical injury. Physical damage to the latex vessels can be caused by sucking insects (capsids), force of storms or strong winds and rough harvesting and handling. Fruit-cracking may occur because of excessive absorption of moisture after drought. In cracked fruits the flesh will be swollen and mushy. Fruits exposed to strong sun may also exude latex.

9.7.4 Wind damage

Trees are not particularly subject to wind damage but injury to leaves and fruits from strong winds may become serious enough to justify the need to plant a windbreak around an orchard (Hume, 1947; Galang, 1955; Ochse *et al*., 1961). In the Philippines, rows of ipil-ipil or agoho (*Leucaena* sp.) are planted, properly pruned and maintained, in order to provide sufficient wind protection (Coronel, 1983).

When cultivating mangosteen, wind breaks and shade providers can be considered together (see section 4.3).

Chapter 10. Harvest and Postharvest Handling

10.1 Fruit maturation

Mangosteen trees are slow to come into bearing. They usually produce their first fruits 10-15 or more years after planting (Hume, 1947; Gonzalez and Anoos, 1951; Ochse *et al.*, 1961). Bearing age under good care can be 7-9 years after planting (Fairchild, 1915; Galang, 1955; Ochse *et al.*, 1961; Palma *et al.*, 1972; Almeyda and Martin, 1978). In Davao, the Philippines, plants planted under coconuts are reported to bear fruits in 4 years.

Mangosteen is a seasonal fruit. It takes about 5-6 months from flowering to fruit ripening (Palma Gil *et al.*, 1972). The fruiting season in the Philippines is from June to December (Galang, 1955). The production seasons in Malaysia are shown in Figure 10-1. The fruit is usually available in Malaysia during June to August and December to February. In lowland areas of Sri Lanka, the harvest is from May to July or in highland areas September to October. In Sri Lanka, plants have been reported to produce 2 crops a year: a light crop in January from flowers produced in August and a heavy crop in July and August from flowers produced in January (Fairchild, 1915; Popenoe, 1928). In Puerto Rico the harvest period is July and August for unshaded trees or November to December if shaded (Almeyda and Martin, 1976). However, depending on zone, weather conditions and farm management practices, fruiting season can begin four to six weeks earlier. In Los Baños, Laguna, USA, plants start to flower in April (Gonzalez and Anoos, 1951).

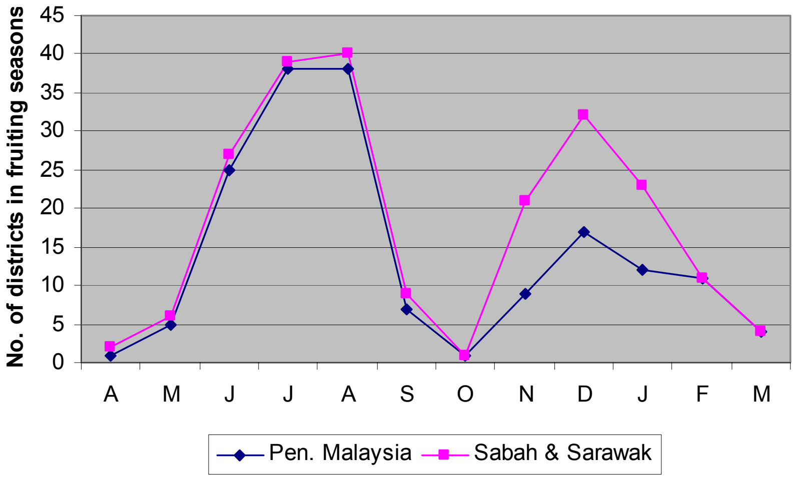


Figure 10-1. Production seasons of mangosteen in Malaysia

Source: after Mohd. Khalid and Rukayah (1993), Anon. (1988)

Generally, the fruits of mangosteen take 5 to 6 months to mature from fruit set. Poonnachit *et al*. (1992) reported that fruit development takes 100-120 days from anthesis and up to 180 days in cooler areas or at higher elevations. The pattern of fruit growth follows a sigmoid curve. Initially, fruit growth is dominated by the pericarp, with aril dry matter not increasing until 20 days from anthesis and then continuing throughout the fruit development (Figure 10-2). At 13 weeks the fruit shows the highest percentages of pulp, rind, sugar and acid: 29.37%, 69.14%, 18% and 0.49%, respectively (Kanchanapom and Kanchanapom, 1998).

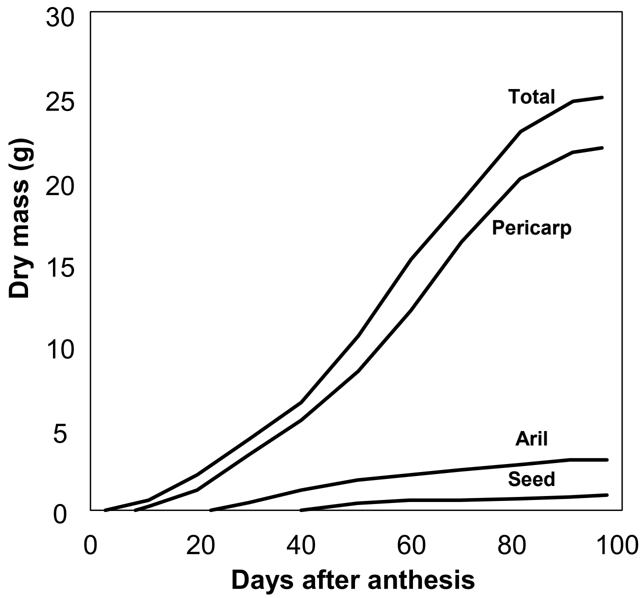


Figure 10-2. Mangosteen fruit total dry mass, pericarp, aril and seed increase during growth

Source: Poonnachit *et al.* (1992)

10.2 Harvesting Methods

Fruits ripen over a 6-12 week period and picking is done by hand every 2-3 days. Only the fruits that have turned purplish violet are picked. During harvesting, the fruits should be handled carefully especially if the fruits are to be shipped long distances, to prevent damage (Vietmeyer *et al.*, 1975). Hand-picking is desirable since the pericarp, which is still slightly soft, is subject to injury from falling. An alternative method, if handpicking is not practical, is to use a long pole with a hook and a basket at the end to catch the fruits.

Mangosteen fruits are produced singly at the end of the branchlets, and usually do not mature and ripen uniformly. The fruit ripens over a period of 6-12 weeks, and each tree will bear coexisting generations of fruit, resulting from successive generations of flowers. Therefore, not all the fruits will reach maturity or ripen at the same time. The intervals between harvests should not be too long to avoid the fruits from becoming overripe. Harvesting should be performed every second or third day to obtain top quality fruit with the degree of ripeness demanded by the market. Thus, the harvesting of a single tree may take from 40 to 60 days in the ripening season. This makes harvesting difficult, slow and the costs of labour may be high. The high cost of picking appears to be a major constraint for the commercialisation of the crop (Cox, 1976).

Traditionally, mangosteen fruit is harvested using a variety of methods, ranging from striking the tree with wooden sticks, or shaking the branches so that fruits fall, to using special hooks for detaching the fruits, which then fall onto specially prepared surfaces such as netting, piles of grass or other soft materials spread out beneath the trees to reduce damage. These methods are time-consuming (Kanchanapom and Kanchanapom, 1998). If unpicked, overripe fruits eventually drop to the ground. Bamboo poles can be used to knock the fruits to the ground. This latter method of harvesting is cheap but results in a very high percentage of injured fruits. The percentage of injured fruits can be as high as 90%. Bamboo poles with a V-shaped cut at the top which can hold a single fruit are also used in Malaysia (MOA, 2002).

Harvesting is also done by climbing the tree or using a hydraulic platform and picking the fruits individually (Coronel, 1983). In Thai orchards, youngsters climb the trees to pick the fruit (Cox, 1976).

Improved tools and techniques have been developed for harvesting. A long harvesting pole with a net is more practical for commercial use. The net is shaped like a funnel and the mouth supported by a stiff iron ring. A prong is attached to the ring and this can be used as a hook for grasping the fruit. The fruit is positioned into the net and plucked by pushing the pole. The fruit then falls into the net. Harvesting is usually done by individually plucking each fruit, or three to five fruits can be collected in the net before they are brought down. This method allows rapid collection of fruits with little damage, (only about 1%). The harvesting pole attached to a bag or a net is generally considered the best currently available method of harvesting. Nevertheless, the cost of harvest labour remains high. In Thailand, harvesting cost is estimated at 1 baht (USD 0.05) per kg or 50 baht (USD 2.00) per person per day for harvesting mangosteen (Kanchanapom and Kanchanapom, 1998).

Harvesting in early morning or late afternoon, when the weather is cool, is recommended. The aim is to dispatch the fruits to market in the best possible condition.

Fruits should be handled carefully during harvest. It is essential to avoid dropping harvested fruits or causing mechanical injury which bruises the skin of the fruits. A 20 cm drop can cause significant damage to the pulp; it deteriorates and changes colour from white to brown. Such fruits often exude latex through the fractured skin. A common symptom of such damage is a hardened rind and hard, translucent pulp. The fruit quality is compromised, and such fruits will not fetch a good price.

10.2.1 Maturity index

A fully mature fruit is identified by the occurrence of red lines appearing on the outer surface of the rind. The number of lines, so-called "bloodlines", increases as the fruit matures. Alternatively, the maturity of the fruit can be gauged by the way in which the fruit separates from the peduncle stalk. Fully mature fruits, when picked, will detach cleanly from the point of stalk attachment. After picking, metabolism continues within the fruits. The following changes generally occur in the mature fruits after harvesting (Kanchanapom and Kanchanapom, 1998):

1st day:	Mature fruit ready for harvesting
2nd day:	Fruit has bloodlines
3rd day:	Fruit begins to develop colour
4th day:	Fruit begins to change to pink
5th day:	Fruit is red
6th day:	Fruit is dark red
7th day:	Fruit is red-purple
8th day:	Fruit is black
14th day:	Fruit begins to rot

At present, there is no standard or uniform maturity index that is universally used. Countries such as Malaysia, Thailand and Australia have developed their own maturity indices for harvesting to meet various marketing purposes. Although their maturity indices have been developed independently, they are similar (see sections 10.1.2 - 10.1.3).

Fruits are at the edible, ripe stage when the skin has darkened to a reddish-purple, no latex remains in the skin, and the flesh segments separate easily from the skin (Tongdee and Suwanagul, 1989), and soluble solids content ranges from 17 to 20% and titratable acidity ranges from 0.7 to 0.8% (pH = 4.5 to 5.0) (Kader, 2002).

10.2.2 Malaysia

Ripeness is judged by the full development of colour and the softening of the fruits, since colour is considered the easiest criterion in the identification of maturity (Mohd Khalid and Rukayah, 1993). MARDI has developed a colour index ranked 0 to 5. Fruits with colour indices 1 to 3 can be harvested for export market, and for fruits to be consumed immediately colour indices 4 to 5 are used. The colour indices developed by MARDI are described in Table 10-1.

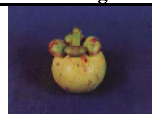
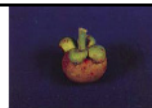
Table 10-1. Mangosteen colour indices developed by MARDI

Colour Index	Stage of Maturity and Suitability
0	The fruit is greenish-yellow with traces of red. The rind contains yellow latex. At this stage the pulp and the rind are not separable. The fruit will develop poor flavour even if the colour finally changes to colour index 5.
1	The fruit is reddish-yellow with patches of red. The yellow latex is slightly reduced. The pulp and rind are still not separable. The fruit can be consumed 3-4 days after harvesting at this stage. This is the earliest stage to harvest for export.
2	The fruit turns reddish with patches of bright red. Yellow latex is still present in the rind. The rind and pulp can be separated. This stage is suitable to harvest for export.
3	The fruit is dark brown. Yellow latex is still present in the rind. This stage is suitable for consumption. For export, the fruit should be harvested no later than this stage.
4	The fruit is purplish-red. No latex is now present in the rind. The rind and pulp can be easily separated. The fruit is suitable for consumption, and the pulp quality is good.
5	The fruit is dark-purple to black. No latex is now present in the rind. The rind and pulp can be easily separated. The fruit has excellent pulp quality for consumption.

Source: Mohd. Khalid and Rukayah (1993)

More recently, a new maturity index has been developed and the colour changes are classified into six stages (Table 10.2).

Table 10-2. Mangosteen maturity indices developed in Malaysia

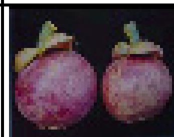
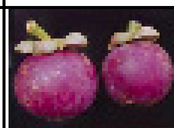
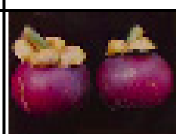
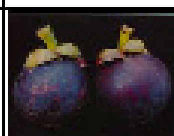
Stage	Skin Colour Change	Suitability	Fruit and Half Fruit Showing Colour Change
0	This fruit is yellowish green with red patches. At this stage the pulp and the rind are not separable.	The fruit, if harvested at this stage, would develop a poor flavour.	
1	The fruit is pale yellow or green, with pink spots scattered over part of the skin.	The quality of the pulp is still low.	
2	The fruit has a light yellow-pink colour with pink patches scattered all over the skin. The rind and pulp can be separated.	Fruit harvested at this stage will give a good quality flavour.	
3	The fruit is evenly pink in colour. The patches of pink seen in stage 2 enlarge and merge so as to become congruent. The pulp can be separated from the rind.	Fruit at this stage is suitable for export.	
4	The fruit colour is now red or brownish red. Separation of the rind and pulp is easy.	The fruit is also suitable for export.	
5	The fruit is red-purple in colour. No gum is present in the rind. The pulp and rind are readily separated.	The fruit is suitable for consumption.	
6	The fruit is now purple, dark purple or black. The rind contains no gum. Pulp and rind are readily separated.	The fruit is suitable for consumption.	

Source: MOA (2002)

10.2.3 Australia

In Australia, fruits are hand-picked and the optimum harvest time is when 25% of the fruit skin has developed a purple colour. At this stage the skin is resistant to mechanical damage during handling but will develop an appealing purple colour within 1-2 days of harvest and retain a relatively long shelf-life. Since the fruits on a tree ripen over a 2-month period, frequent harvests are required (Chacko *et al*., 1995).

Table 10-3. Harvesting maturity indices used by growers in Australia

Harvesting Maturity Stage	Colour Index	Other Characteristics	Acceptability **	Fruit Showing the Colour
Stage 1	Pale yellow-green, 150D @ L^* 93.25, C^* 25.21, H° 109 #	pH=3.9, rind thickness mm = 9.0, Brix % <12, firmness index=7.9	Not acceptable	
Stage 2	Botchy pink, 63C @ L^* 68.21, C^* 37.16, H° 1.4 #	pH=3.3, rind thickness mm = 7.7, Brix % <14, firmness index=6	Not acceptable	
Stage 3	Pinkish red, 63B @ L^* 41.54, C^* 46.12, H° 1.5 #	pH=3.2, rind thickness mm = 7.4, Brix % >16, firmness index=5	Acceptable	
Stage 4	Maroon-red, 64A @ L^* 54.71, C^* 50.33, H° 3.5 #	pH=3.2, rind thickness mm = 7.2, Brix % >16, firmness index=5	Acceptable	
Stage 5	Dark maroon-violet, 81A @ L^* 44.39, C^* 55.70, H° 324 #	pH=3.2, rind thickness mm = 7.0, Brix % >16, firmness index=5	Acceptable	
Stage 6	Violet-black, 83A @ L^* 31.76, C^* 28.60, H° 324 #	pH=3.6, rind thickness mm = 6.8, Brix % <14, firmness index=5	Not acceptable	

@ Royal Horticultural Society Colour Chart, # Minolta Chroma Meter CR-300, L^* Lightness, C^* Chroma, H° Hue, ** Suggested Harvesting Stages.

Source: Lim *et al*., (1998)
A Mangosteen Quality Standards chart prepared recently by staff from the Northern Territory Department of Primary Industries and Fisheries and sponsored by several grower groups is available at the Centre for Wet Tropics Agriculture (Chay-Prove, 2004). The chart shows the suggested harvesting stages for mangosteen, fruit packing methods, storage conditions as well as skin/fruit blemishes and defects. For immediate consumption, the fruit should be harvested at colour index 5 (dark maroon violet) (Table 10.3). When picked at colour index 3-4, the skin is still resistant to mechanical damage during handling and at the same time develops the desirable maroon violet colour. Fruits harvested at the appropriate stage, so-called red stage, have a shelf-life of 2-3 weeks at ambient or room temperature. After that period the shell hardens and it is difficult to open the fruit.

10.2.4 Thailand

Kanchanapom and Kanchanapom (1998) reported that the earliest mangosteen fruits can be harvested after fruit set is 11-12 weeks (77-84 days). The colour changes in skin colour are divided into six stages (Table 10-4).

Table 10-4. Mangosteen colour stages

Colour Stage	Description
0	The fruit is of an even white-yellow colour or white-yellow with light green patches or grey spots. Copious amounts of yellow gum occur in the rind. At this stage the pulp and the rind are not separable. If the fruit is harvested at this stage, even though subsequent colour changes up to stage 6 occur, the flavour will be poor.
1	The fruit is pale yellow or green, with pink spots scattered over part of the skin. Gum is still plentiful in the rind, and pulp and rind still cannot be separated. Even though colour changes to stage 6 will occur in fruit harvested at this stage, flavour will be poor.
2	The fruit has a light yellow-pink colour. There are patches of pink scattered all over. A moderate amount of gum is present in the rind. The rind and pulp can be separated, but only with difficulty. This is the earliest stage at which fruit may be harvested to give a good quality product.
3	The fruit is evenly pink. The patches of pink seen in stage 2 enlarge and merge so as to become congruent. Little to very little gum is present in the rind and it is now moderately easy to separate pulp from rind. The fruit is suitable for harvest for export.

4	The fruit is now red or brown-red, sometimes with purple patches. Very little to no gum is now present in the rind. Separation of rind and pulp is easy. The fruits is suitable for harvest for export. The fruit is now almost ready for consumption.
5	The fruit is red-purple in colour. No gum is present in the rind, and pulp and rind are readily separated. The fruit is suitable for consumption.
6	The colour is now purple, dark purple or black with or without purple coloration remaining. The rind contains no gum. Pulp and rind are readily separated. The fruit is suitable for consumption.

Source: Kanchanapom and Kanchanapom (1998)

The maturity indices have been further developed to include aril acidity and total soluble solids at different stages (10-5). Fruits are not harvested before the pericarp develops a light greenish yellow colour, with distinct irregular pink red spots over the entire fruit (stage 1). Fruits with less colour development have excessive latex exudation at the peduncle and have inferior flavour when they do darken to full purple stage in about 5 days.

Tongdee (1985) studied the relationship between aril acidity and total soluble solids at different maturity stages during ripening which took place over 6-12 weeks, as illustrated in Figure 10-3. The amount of latex declines with maturity, while total soluble solids increased after stage 1 and acidity remained constant (Nakasone and Paull, 1998).

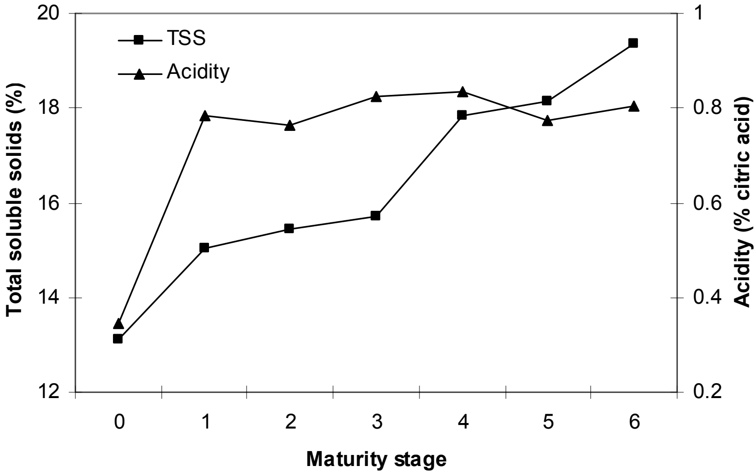


Figure 10-3. Mangosteen aril acidity and total soluble solids at different maturity stages (see section 10.1.3)

Source: Tongdee (1985)

Table 10-5. Mangosteen maturity indices developed in Thailand

Stage	Pericarp Colour	Detachment Force (kg)	Latex	Seed&Aril	Final EatingFlavour	Fruit TSS*
0	Yellowish white	2.20	Severe	Not separable	Inferior	15.2
1	Light greenish yellow with scattered pink spots	2.09	Severe	Not separable	Inferior	-
2	Irregular pink red	1.19	Moderate	Difficult	Minimum stage	16.0
3	Uniform pink background	1.24	Slight	Moderate	Export	-
4	Red-reddish brown	1.32	None	Readily	Export	17.7
5	Reddish purple	1.32	None	Easy	Eating stage	18.3
6	Dark purple, slight red colouration	1.32	None	Easy	Eating	-
7	Dark purple-black	1.32	None	Easy	Eating	-

* Total Soluble Solids.

Source: after Tongdee and Suwanagul (1989), Nakasone and Paull (1998)

10.3 Yield

Under optimum conditions in Malaysia, mangosteen trees begin to fruit 6-8 years after planting. The yield varies from tree to tree and from season to season. The first crop may yield 100-300 fruits per tree, and about 500 in a fully grown tree. The yield steadily increases up to 1,000-2,000 fruits per tree in the 10-20th years of cropping.

In Thailand, the average yield in 1987 was 4.5t/ha. For an estimated mean weight of 75g per fruit and 150 trees/ha, this equals 400 fruits per tree.

Trees in two small orchards in the Nilgiri hills in southern India produced on average of 360 fruits per year over a period of 18 years, the best trees yielding consistently up to 500 fruits per year (Verheij, 1992).

In Australia, yields are variable, and about 400-900 fruits can be harvested from each mature tree (Chay-Prove, 2004). Older trees (45 years) can yield 3,000 fruits per tree and then decline in yield (Kanchanapom and Kanchanapom, 1998).

In Indonesia, the yield increases from average of 10-20 fruits per tree after the 5th year to more than 1,000 fruits per tree after the 15th year as shown in Table 10-6 (Dede Juanda & Bambang Cahyono, 2000).

Table 10-6. Production of mangosteen fruits according to age of tree in Indonesia

Age of tree	Number of fruits produced per year
5 years	10–20
6 years	40–60
7 years	70–90
8 years	100–150
9 years	200-300
10 years	350–500
15 years onwards	1000–1500

Normally, the mangosteen tree is little disturbed by harvesting, but careful attention to its condition and care after harvest is important to ensure better yields and improved quality of fruit the following year.

The trees tend to bear in alternate years (Vietmeyer, 1975). An estimated light crop is 100 fruits per plant while a heavy crop is 500-600 or more fruits per plant (Fairchild, 1915; Popenoe, 1928; Galang, 1955). Yields of 200-800 fruits per full grown plant have been reported in places with good soils and up to 2,000 fruits/tree have been noted. Average crops to aim for are 400-700 fruits/tree. At, 15 trees/ha this will result in over 4,500 kg + fruits/ha

10.4 Postharvest handling

Mangosteen fruits may have various degrees of injury as a result of harvesting and in field handling before the fruits reach the packing house. Such injury should be minimised in subsequent handling, including long distance transportation, to avoid further damage and loss in quality. A compression force of 3-4 kg causes little or no damage to the fruit. At 5 kg or more, the pericarp collapses in the more mature fruit. Mechanical damage in mangosteen is reduced by careful handling avoiding any compression (Tongdee and Suwanakul, 1989). In many parts of Southeast Asia the fruits are taken to market in baskets, and also in long bundles of about two dozen fruits strung together, or by cart (Verheij, 1992).

The quality types of fruit can be described as follows (Kanchanapom & Kanchanapom, 1998):

1. Small-sized fruits, averaging about 16-18 fruits per kg or smaller. They are suitable for domestic consumption.
2. Skin of the fruit is rough. Fruits bear signs of insect damage such as by fire aphid and red mite.
3. Frequent insect infestation, around and under the sepals. Such infestation can lead to black mould.
4. Skin broken with gum flowing out giving a soiled appearance.
5. Hard rind and rotten pulp.
6. Bruised, translucent pulp.

Market experts emphasise that growers must understand how to harvest, pack, store, and transport their fruits so the consumers will receive a product of high quality. Therefore, growers, shippers, carriers, and receivers should be familiar with quality standards and strive to reduce postharvest losses for such highly perishable, high-value fruits as mangosteen. The quality of the fruits required by the markets can be described (Kanchanapom and Kanchanapom, 1998) as:

- Large size - 100g per fruit or 8-10 fruits per kg (some countries require fruit of 200g)
- Skin of the fruit clean, no markings from disease or insect damage, skin naturally smooth
- Rind of medium thickness, not hard and the pulp pale white, soft and appealing
- No sign of gum from the rind or rough skin
- No sign of bruising or rotten pulp

Misshapen and damaged fruits should be removed. Burst latex vessels cause yellow dried latex on the fruit skin which should be scraped off and the fruit then washed with a soft brush. Fruits are graded for size. Some Thai growers/exporters coat cleaned fruits with lacquer, giving fruit skin damaged by thrips prior to harvest a more attractive appearance (Nakasone and Paull, 1998).

The key to the establishment of any fruit industry for export is through the increase in production of consistently high quality fruits (MOA, 2002). It should be realised that the type or quality of produce that is satisfactory for local market may not necessarily be acceptable for the export market.

10.4.1 Packing house operations

Harvested fruits are transported to the packing house to prepare the fruits before being transported to either the local or export market. A packing house can be a simple shed constructed from locally available materials or a complex with sophisticated facilities. It must be provided with all the basic necessities required for pre-and post-packing operations. A chart showing the typical packing house operations is shown in Figure 10-4 (modified after Mohd Khalid and Rukayah, 1993 and MOA, 2002):

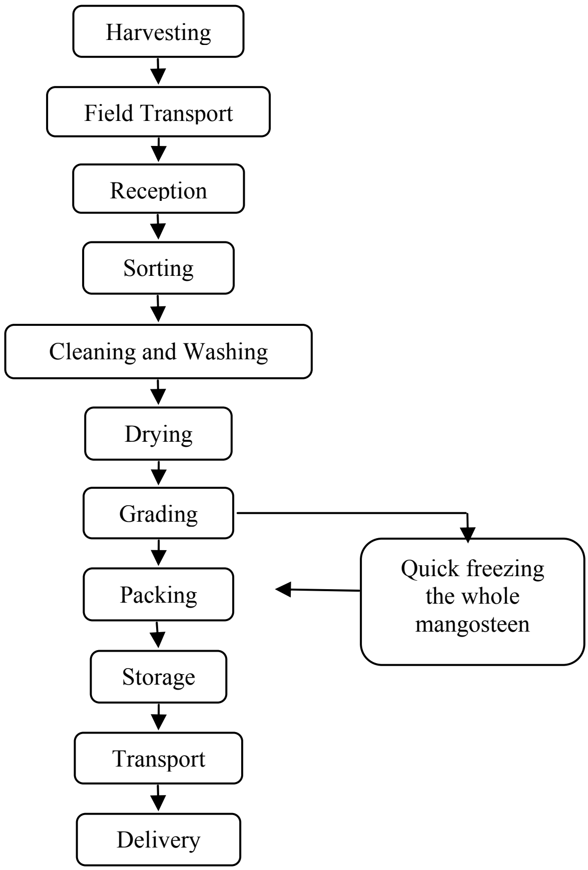


Figure 10-4. A chart showing postharvest handling operations in a typical packing house

Source: Kanchanapom and Kanchanapom (1998)

Reception:

The fruits arrive at the packing house. They are labelled to identify source and date of arrival, checked for quantity or weight delivered and acknowledged by receipt to the supplier.

Sorting:

A preliminary sorting of fruits should remove unmarketable fruits (immature, over mature and damaged fruits) and foreign matter.

Cleaning and washing:

The fruits are cleaned with care since damage to the skin will promote early decay. Washing is required to remove any latex stains acquired from injuries caused during harvesting.

Drying:

The washed fruits are spread out in a single layer on racks, in the shade but exposed to good ventilation to aid rapid drying.

Grading:

The fruits are sorted according to quality and size before being packed. The scope of these operations depends on the market.

Packing:

The selected fruits should be packed in a corrugated fibreboard carton with good ventilation and of the dimension agreed by the importing countries.

Storage:

For fresh markets a cool room with temperature of 5°C and relative humidity of 85% can be used for storage of mangosteen. At this temperature mangosteen can be kept up to 4 weeks. The thick fruit wall hardens as the fruit ripens and during storage at low temperatures (<10°C). Storage at 8-10°C is recommended for long-term (up to 8 weeks) storage. Precooling of tray packs is useful (Augustin and Azudin, 1986).

10.5 Storage

Kanchanapom and Kanchanapom (1998) have described several measures which can be used to preserve the flavour, namely:

1. Packaging

After harvest, the fruit should be handled and packed with special care. Fruit skins should be cleaned of any adhering gum and the area below the sepals checked for insect (black ant) infestation. Any insects should be removed by blowing or gentle brushing. Similarly coloured and sized fruit should then be selected and each wrapped in white tissue paper or foam mesh. The fruit should be placed in a corrugated cardboard box, size 25 x 37.5 x 7.5 cm, with 6 holes in each side for ventilation. Each box should contain about 24 fruits and weigh approximately 2.5 kg.

Another method is to place the fruit on a foam tray sized 13 x 13 cm, which can hold four fruits. The tray is covered with PVC film and placed in a box of size 25 x 37.5 x 7.5 cm with 6 trays to each box. There are many types of containers varying in size, strength and cost. One of the major problems resulting in quality loss of the commodities is due to incorrect packing practice and unsuitable containers. Wrapping of each fruit individually in plastic or PVC has no advantage since the fruit heats up rapidly, hastening maturity and subsequently rotting.

2. Measurement of respiration rate and ethylene production

The mangosteen has a climacteric respiration pattern which shows the characteristic changes after harvesting. The fruit produces carbon dioxide CO_2 and ethylene C_2H_4 at rates of 10.95ml/hr and 29.72µl/hr, respectively, at a temperature of 25°C. The heat produced by this respiration is about 2,405 BTU/t/day (Kosiyachinda, 1987). Temperature and RH of the storage room are prime factors affecting the shelf-life of mangosteen. Suitable storage conditions for mangosteen reported by many researchers are in the range of 4-13°C at 85-90% RH depending on the stage of ripening, harvesting method and transportation (Martin, 1980; Augustin and Azudin, 1986; Kosiyachinda and Tansiriyakul, 1988). Limited studies on modified atmosphere to prolong storage life indicated that CO_2 treatment of mangosteen during storage can extend the storage life without affecting eating quality.

3. Cold storage treatment

Mangosteen fruits have a storage and marketable life of not more than one week under tropical ambient conditions (Kosiyachinda, 1987). At low temperatures (9-12°C), mangosteen may have a storage life of up to four weeks (Martin, 1980). At present, the best method for fruit storage is by keeping the fruit under refrigeration.

Fruits that have been harvested at a stage suitable for export can be kept the longest under storage. The optimum temperature of the cold room for storage is 2°C. At this temperature, fruits can be kept for 42 days. However, the optimum storage period at this temperature is from 1-21 days after harvest. Fruits kept in a cold room should be sealed in airtight plastic bags. During this time, fruits maintain initial quality and are suitable for consumption. Storage for longer periods will cause the rind to harden and change colour.

In Australia, fruits are cleaned in water and graded according to fruit weight: >100g, 75-100g and <75g. For export markets, Thailand growers wrap each fruit in tissue paper and pack them into cardboard carton. Each box has ventilation holes and contains 24-30 fruits. Storage at 13°C is suitable for maintaining a high standard of quality, and the ideal transit temperature range is 13-25°C. Experiments have shown that fruits can be stored for 7 weeks at 4.5°C and 85-90% RH, but hardening of the pericarp under such conditions causes a reduction in fruit quality (Chacko *et al.*, 1995). The packaging and storage requirements recommended for mangosteen cold storage are shown in Table 10-7

Table 10-7. Packaging and storage requirements recommended for mangosteen cold storage in Australia

Packaging	More than 95g/fruit
	No blemish or defect
	Uniform colour darker than pinkish red in stage 3
	No visible insect/chemical/fungal deposits on fruit
Storage	5°C at RH >85% for up to 4 weeks, or
	-18°C or -27°C for up to 16 months

Source: Lim *et al.*(1998)

Detailed recommendations for maintaining postharvest quality have been given by Kader (2002), and Paull and Ketsa (2000), in Table 10-8.

Table 10-8. Recommendations for maintaining postharvest quality

Recommendations by Kader (2002)	**Recommendations by Paull and Ketsa (2000)**
Optimum Temperature: 13 ± 1°C (56 ± 2°F), storage potential = 2-4 weeks, depending on cultivar and ripeness stage.	*Grades, Sizes and Packaging:* There are no US or international standards. Fruits are graded by size and colour. They are normally sold in single-layer, fibreboard carton of 2.25 kg (5lb) with padding, or sometimes in trays with fruit individually wrapped to prevent injury (20 to 24 fruits per tray). In Southeast Asia, fruits are sold in baskets or strung in bundles of from 10 to 25 fruits.
Optimum Relative Humidity: 90-95%	*Pre-cooling Conditions:* Room-cooling is normally used (Augustin and Azudin, 1986).
Rates of Respiration: 6-10ml CO_2/kg/hr at 20°C (68°F); climacteric respiratory pattern. To calculate heat production multiply ml CO_2/kg/hr by 440 to get Btu/ton/day or by 122 to get kcal/metric ton/day.	*Optimum Storage Conditions:* Recommendations vary from 3.9 to 5.6°C (39 to 42°F) with 85 to 90% RH for 7 weeks (Pantastico, 1975) to 13.3°C (56°F) with 85 to 90% RH for 14 to 25 days. Storage at 4°C (39.2°F) or 8°C (46.4°F) can lead to significant hardening of the skin (Augustin and Azudin, 1986), although the flesh may still be acceptable after 44 days. Current practice is to store fruit at 12 to 14°C (54 to 57°F) giving storage-life of about 20 days without chilling injury. Application of surface coatings reduces weight loss (Choehom, 1997).
Rates of Ethylene Production: 3-30µl C_2H_4/kg/hr at 20°C (68°F).	*Controlled Atmospheres (CA) Considerations:* An atmosphere of 5% O_2 + 5% CO_2 has been used for 1 month (Yahia, 1998) and resulted in best overall retention of peel appearance and internal quality (Rattanachinnakorn *et al.*, 1996). Holding fruit in polyethylene film bags reduces weight loss and disease (Daryono and Sabari, 1986). However, it is not clear if the

Recommendations by Kader (2002)	**Recommendations by Paull and Ketsa (2000)**
	effects are due to the prevention of water loss or to the modified atmospheres in the bags.
Responses to Ethylene: Exposure to 100ppm ethylene for 24 hours at 20°C (68°F) accelerates ripening (colour change to dark purple and softening of the pulp).	*Retail Outlet Display Considerations:* Display in over-wrapped trays or in closed, styrene, clam-shell containers with no perforations at 10 to 14°C (50 to 57°F). Do not mist.
Responses to Controlled Atmospheres (CA): Limited published information indicates a useful CA of 5% O_2 + 5 to 10% CO_2 for up to 4 weeks.	*Chilling Sensitivity:* Storage at <10°C (50°F) leads to rapid hardening and darkening of the pericarp when fruits are returned to ambient temperature (Uthairatanakij and Ketsa, 1995; Choehom, 1997).
Translucent Flesh: Symptoms are internal and include flesh changes from white to translucent and textural changes from soft to firm and crisp. This disorder may result from mechanical injuries, nutrient imbalance, and/or excessive water uptake into the flesh.	*Ethylene Production and Sensitivity:* Mangosteen is a climacteric fruit. Ethylene production is about 29μL/kg/h. The respiratory peak occurs sooner when fruits are treated with ethylene. Ethylene treatment triggers autocatalytic ethylene production (Noichinda, 1992).
Physiological Disorders: *Chilling Injury:* Symptoms include darkening and hardening of the skin and increased susceptibility to decay when the fruit is moved to higher temperatures following storage at less than 10°C (50°F) for longer than 15 days or at 5°C (41°F) for more than 5 days.	*Respiration Rate:* 21mg (12μL) CO_2/kg/h at 25°C. Heat production is 4,620 BTU/ton/day (1,281 kcal/ton/day).
Rind Hardening: Mechanical damage (compression or impact bruising) to the fruit during harvesting and handling often results in hardening of the rind, which may be combined with hardening and translucency of the pulp (one or more segments).	*Physiological Disorders:* Fruit damage during harvesting and marketing can affect >20% of fruit. The gamboge disorder occurs where latex seeps into the flesh (aril) turning it yellow and giving it a bitter taste. The gamboge also moves onto the outer surface of the fruit. This is a preharvest disorder of unknown cause that makes it difficult to separate the aril from the surrounding tissue,

Recommendations by Kader (2002)	**Recommendations by Paull and Ketsa (2000)**
	even in ripe fruit; it causes hardening of the pericarp. This should not be confused with impact injury that leads to hardening of the pericarp at the point of impact and aril collapse, dehydration, pink colour development, or browning (Tongdee and Suwanagul, 1989). A drop of 10 cm can cause slight pericarp damage, indicated as hardening at the point of impact within 24h. Higher drops causing significantly greater damage and often lead to downgrading of the fruit (Tongdee and Suwanagul, 1989; Ketsa and Atantee, 1998). Another disorder of mangosteen fruit is translucent aril (nue-kaew) believed to be induced by heavy rain during fruit growth and development, even if just before harvest (Laywisakul, 1994). The specific gravity of fruit with translucent aril is >1.0, while that of normal aril is <1.0. This allows separation of fruit by floating them in water (Podee, 1998). Fruits with translucent aril have lower SSC and TA than normal fruit (Pankasemsuk *et al*., 1996).
Pathological Disorders: Decay may be caused by *Botryodiplodia theobromae*, *Diplodia* spp., *Pestalotia flagisettula*, *Phomopsis* spp., or *Rhizopus* spp.	*Postharvest Pathology: Botryodiplodia theobromae*, *Diplodia* spp., *Pestalotia flagisettula*, *Phomopsis* spp., and *Rhizopus* spp. have been reported; they harden the skin and decay the aril.
	Quarantine Issues: Mangosteen is a fruit fly host. Irradiation has potential for disinfestation. Alternatively, harvested fruits are carefully cut open and the aril inspected; fruits are then frozen whole and shipped.

Chapter 11. Processing

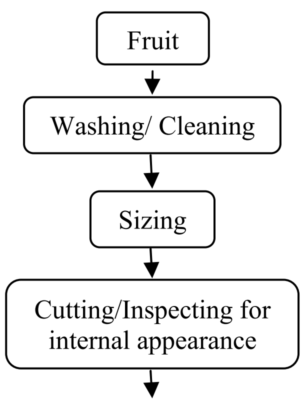
Besides fresh consumption, mangosteen pulp can be converted into processed forms such as jam, frozen mangosteen and canned mangosteen in heavy syrup. Unfortunately, the delicate mangosteen flavour is usually lost in canning. The production of these processed products is currently limited due to non-uniform size of fruits and lack of consistent quality.

Kanchanapom and Kanchanapom (1998) described the ways in which fruits can be processed and these are described in this chapter.

11.1 Freezing of whole mangosteen

The freezing of mangosteen is normally carried out at very low temperatures in order to maintain the quality of the fruit; this is called the quick freezing process. The freezing process is aimed not only at retarding microbial growth but also at inactivating various chemical reactions especially enzymatic browning. In addition, freezing can maintain flavour and volatile substances in the product at similar levels to the fresh fruit.

At present, frozen mangosteen is commercially available. Fruits used in the operation are sorted for size, maturity and defects. The size required is 80g or more per fruit or 8-12 fruits per kg. The fruit should be mature, reddish purple in colour, completely free of scratches and damage, and the fresh pulp must be pearl white and have the desired flavour. The steps involved in the process of freezing of whole mangosteen are shown in Figure 11-1.



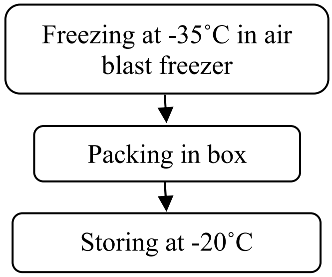


Figure 11-1. A flowchart showing the steps involved in the process of freezing of whole mangosteen

Source: Kanchanapom and Kanchanapom (1998)

No treatment is applied before the freezing process. After cutting, the fruit is put in a freezer within five minutes. A quick operation is used in order to prevent pulp discolouration, but the method requires highly skilled workers and is labour intensive.

Several compounds have been used as anti-browning agents to keep the fruit looking fresh, such as sulphites, citric acid and ascorbic acid. Since the use of sulphites in fresh fruits and vegetables has been banned, the best alternative is the use of citric acid and ascorbic acid. Studies on the prevention of browning in production of frozen mangosteen were carried out by soaking mangosteen prior to freezing in mixed solutions of calcium chloride (0-0.25% w/v) and citric acid (0-0.5% w/v), with or without ascorbic acid (0-0.53% w/v). The most acceptable product was obtained by soaking for one minute in a solution of 0.25% (w/v) calcium chloride and 0.5% (w/v) citric acid. The pulp had snowy white segments with a sour-sweet taste and ice cream-like texture. Sophanodora and Sripongpunkul (1990) found that the best quality of frozen mangosteen was produced from good quality fruits with optimum ripeness at the fifth stage.

11.2 Semi-individual quick frozen fruit (Semi-IQF)

Freezing whole fruits requires high quality fruits. Since more than 50% of the total fruits harvested could not meet the standard, the application of the semi-individual quick freezing method is an alternative for developing a new product. The steps involved in the process of semi-IQF of mangosteen are shown in (Figure 11-2).

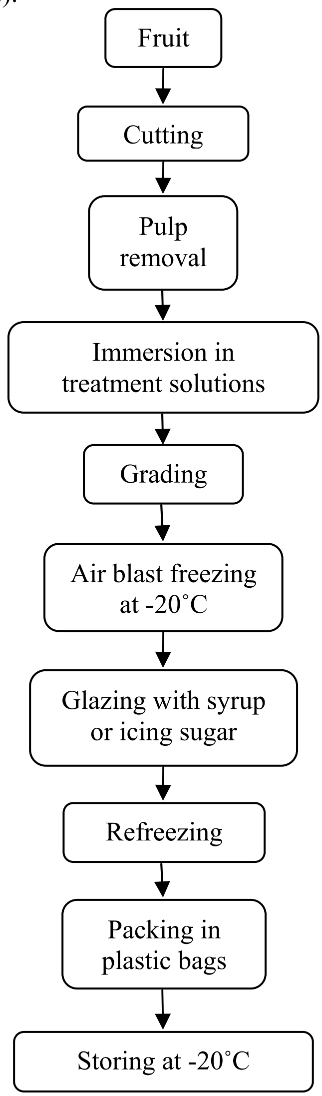


Figure 11-2. A flowchart showing the steps involved in the process of semi-individual quick freezing of mangosteen

Source: Kanchanapom and Kanchanapom (1998)

11.3 Canning of fruit

Fruits have been canned for export marketing. The fruit required for canning is of a small size, about 40g per fruit or 23-25 fruits per kg, and the fruit colour should be of maturity stage 3, 4 or 5. Fruits can either be canned as whole or separated segments. The drained weight is about 280 to 340g. The steps involved in the process of canning of mangosteen are shown in the following flowchart (Figure 11-3).

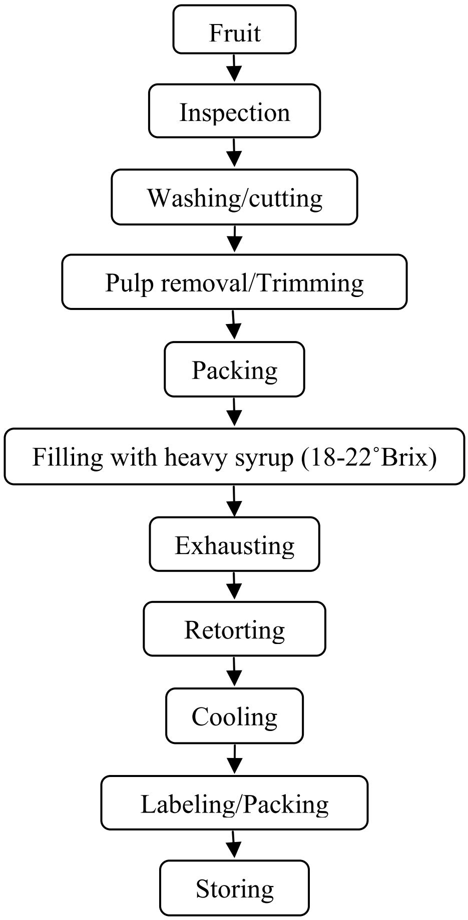


Figure 11-3. A flowchart showing the steps involved in the process of canning of mangosteen

Source: Kanchanapom and Kanchanapom (1998)

11.4 Intermediate moisture mangosteen fruit

The pulp and seed of mangosteen, when boiled with sugar, make an excellent preserve which can be used as topping for ice cream or sherbet. In the Sulu Islands, the pulp has been preserved in brown sugar (Almeyda and Martin, 1976). The addition of sugar almost masks the flavour. The intermediate moisture product has been developed to conserve the flavour by immersing the fruit in a 70° Brix sucrose solution to reduce the weight by 50%, and further drying using vacuum or hot air dehydration to about 2% moisture (Moy *et al*., 1978). Different osmotic solutions such as glucose, fructose and commercial syrups have been used (Lerici *et al*., 1985). The osmotic syrups can be reconcentrated and reused for osmotic water removal through at least five complete cycles without adversely affecting the fruit being concentrated (Bolin *et al*., 1983). The steps involved in the process of producing intermediate product of mangosteen are shown (Figure 11-4).

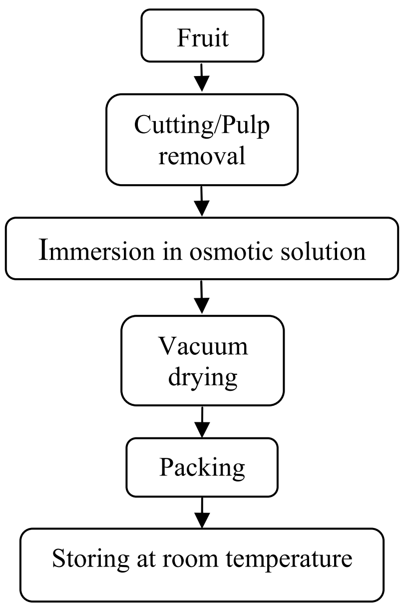


Figure 11-4. A flowchart showing the steps involved in the process of producing intermediate product of mangosteen

Source: Kanchanapom and Kanchanapom (1998)

11.5 Other processed products of mangosteen

Apart from being processed as industrial products, mangosteen fruits offer a number of possibilities for home-made products. If the market price of fresh mangosteen is too low, or when the quality of the fruits is such that they can no longer be kept before deteriorating, it may be advantageous to process the fruits into products, which will not only keep longer but may also sell at a higher price. In Thailand, the popular processed products of mangosteen include: (a) preserved mangosteen, (b) compressed mangosteen, (c) mangosteen jam and (d) crystallised mangosteen (Kanchanapom and Kanchanapom, 1998).

a) Preserved mangosteen

Ingredients:

50 mangosteen fruits
2 cups of granulated sugar

Directions: Mix the peeled mangosteen into the sugar and place in a brass frying pan. Using low heat, stir until liquid issues from the fruit. Gradually increase the heat and continue mixing until the seeds become brittle. Keep in a tightly sealed container. Preserved mangosteen can be kept for a long time before eating.

b) Compressed mangosteen

Directions: Pare mangosteen fruit and remove the pulp from the peel using a stainless steel or wooden fork, so that the fruit flavour is not tainted by metal. Take care not to separate the segments. Place in a jar. Prepare syrup from 1 cup of granulated sugar and 1 cup of water and pour onto the mangosteen. Place the jar in a pan of water and boil gently as follows:

Large jar	- 20 minutes
Medium-sized jar	- 15 minutes
Small jar	- 10 minutes

c) Mangosteen jam

Ingredients:

Finely shredded mangosteen pulp	- 2 cups
Water	- 1 cup
Granulated sugar	- 2 cups
Water	- ½ cup
Lime juice	- 1½ tablespoons

Directions: Heat the sugar with half a cup of water until dissolved and filter the syrup through a fine cloth. Mix the mangosteen with 1 cup of water. Stir while heating until soft. Add syrup and lime juice and stir until thickened and the mangosteen turns clear. Prepare a jar for keeping the jam by immersing in boiling water for 5 minutes and then placing upside down over low heat until dry. Pour in the jam while still hot and close the lid tightly.

d) Crystallised mangosteen

This mangosteen product is popular in the south of Thailand. It is prepared from fruits collected at the bloodline stage, they are peeled under clear lime water, crystallised and then skewered onto wooden sticks.

Chapter 12. Economics and Marketing

Figures for production costs and returns as net benefit are not available. Few typical examples re provided by Dassanayake (1996) in a report to UTFANET and by Dede Juanda & Bambang ahyono (2000), showing the long time span needed for financial return (Tables 12-1 & 12-2).

Table 12-1. Returns from mangosteen plantings in Sri Lanka

	Years					
	1	**2-7**	**8-10**	**11-14**	**15-20**	**21-30**
Total Cost (Rs)	28440	14185	9170	13770	25570	34870
No. of Fruits			6000	25000	80000	125000
Gross Income (Rs)			12000	50000	160000	250000
Net Benefit (Rs)	-28440	-14185	2830	36230	134430	215130

Source: Crop Enterprise Budgets, Division of Agriculture, Economics and Planning, Peradeniya, Sri Lanka, May, 1992 (pp. 17)

Table 12-2. Returns from one hectare of mangosteen planting in Indonesia (x 1000)*

	Years					
	1	**2-4**	**5-8**	**9-14**	**15-20**	**21-25**
Total Cost (Rp)	43135	13606	32087	26288	27968	25124
No. of Fruits			23290	69870	69870	58225
Gross Income (Rp)			58225	174675	174675	145562
Net Benefit (Rp)	-43135	-13606	26138	148387	146707	120438

* Fruiting starts after year 6; average yield of 935 fruits per tree; crop stand of 137 trees per ha; ex-farm rice of Rp 2,500 per fruit; BEP (production) = 108.4 t; BEP (price) = Rp 1,164; B/C ratio = 2.15; ROI = 434.3%; IRR = 53.4%.

Source: Dede Juanda, Js. and Bambang Cahyono. (2000).

The lack of relevant economics data is due to the fact that most current mangosteen production is from a few trees in mixed cropping systems or in home gardens. This is well illustrated in dela Cruz *et al.* (2003) which summarises a survey of farmers in Quezon Province, Philippines.

However, a detailed analysis of the economics of production has been carried out in Malaysia, and the costs broken down into those associated with development, operating and maintenance and crop production. These are described in detail in section 12.1 below.

12.1 Economics of production

12.1.1 Development costs

All development costs are expenditures on physical assets. These include land development costs, cost of building, facilities, vehicles, tools and other infrastructure. Replacement of capital equipment is made at various times during the life of the project. Details of the items that make up the capital costs are listed in Table 12-3.

Table 12-3. Estimated capital costs for a 10 ha mangosteen farm

Items	Capital Item	Cost (USD)
1	Land premium @ USD263/ha	2632
2	Land survey @ USD132	132
3	Land clearing @ USD724	7237
4	Farm road @ USD263/ha	2632
5	Farm drainage @ USD263/ha	2632
6	Land fencing @ USD263/ha	2632
7	Store building @ USD53/m²	5263
8	Pick-up van @ USD11,842/unit	11842
9	Motorcycle @ USD1,053/unit	1053
10	Water pump @ USD1,579/unit	1579
11	Equipment @ USD1,316	1316
12	Shed @ USD263	263
13	Contingency 5%	1961
Total		**41171**

Source: after MOA (2002)

12.1.2 Operating and maintenance costs

Operating and maintenance costs include land and vehicle maintenance, management expenses and utilities. Quit rent, road, drainage and fencing maintenance are the items included in land maintenance and amount to the sum of USD 1,684 per year.

Vehicle maintenance includes the cost of oil and fuel, insurance and road tax and repairs. The maintenance cost of a pick-up van and motorcycles is estimated at USD 1,579 per year. The farm operator (manager) is allocated USD 263 per month to manage the farm (Table 12-4).

Table 12-4. Estimated operating and maintenance costs for a 10 ha mangosteen farm

No.	Item	Yearly Cost (USD)
1	Land maintenance	
	Quit rent	895
	Road maintenance	263
	Drainage maintenance	263
	Fencing maintenance	263
2	Vehicle maintenance	
	Petrol	526
	Insurance	316
	Road tax	79
	Breakdown repair	658
3	Management salary	3158
Total		**6421**

Source: after MOA (2002)

12.1.3 Crop production costs

The estimated crop production costs are shown in Table 12-5. They include variable field costs. The establishment costs include the cost of land preparation, digging and basal fertiliser application, materials and labour needed for planting and replacement cost for any dead plants. The variable field costs include the cost of materials and labour for pest control, fertiliser application, weed control and harvesting of the fruits. This assumes that all field activities are contracted out.

Table 12-5. Crop production costs (in USD) from year 0 to 4 for 10 ha

Item/Year	0	1	2	3	4
Land preparation	1316				
Digging holes	526				
Planting materials	1895				
Basal fertilisers	816				
Planting	632				
Shading	1579				
Fertiliser		274	547	821	1095

Item/Year	0	1	2	3	4
Fertiliser applications	526	211	211	211	211
Pesticides		53	53	53	53
Pesticide applications		211	211	211	211
Herbicides		132	132	132	132
Herbicide applications		316	316	316	316
Total	**7289**	**1195**	**1468**	**1742**	**2016**

Source: after MOA (2002)

Land preparation is carried out during year 0 and transplanting of the mangosteen seedlings will be carried out subsequently during the onset of the rainy season. The cost of land preparation is assumed at USD 132 per ha. Planting holes are dug at a cost of USD 0.26 per hole and planting of the seedlings at USD 0.26 per plant. Bamboo baskets are needed to shade the seedlings. Fertiliser application, weed control, pest and disease control, mulching, harvesting and infield transportation of fruits are estimated to cost USD 0.79 per plant.

The harvesting cost is a major component of the total cost of mangosteen cultivation. To produce good quality fruits, the fruits have to be harvested individually by hand picking or by using a harvesting pole with a net to catch the fruit. The cost of harvesting is assumed at USD 0.013 per fruit. When the orchard produces marketable quantities of fruit, the harvesting costs constitute more than 50% of the variable field costs. Harvested fruits are put into bamboo baskets which hold 50 kg of fruits and cost USD 0.79 each.

12.1.4 Cash-flow analysis

For the cash-flow projection, it is assumed that there is no stock maintained and no debtor or creditor. From very simple cash-flow projection, it is expected that USD 104,092 would be required to implement the concern. The capital establishment cost is about USD 10,526 per hectare. The average requirement of the capital over the first 7 years of the project life (i.e. before production commences) is USD 15,000 per year. Positive cash flow can only be expected from year 12. Once the orchard starts to produce in marketable quantities, positive cash flow can be expected to increase from USD 17,058 in year 12 to USD 100,111in year 32 to year 35.

Normally price, cost and yield vary from place to place and from time to time. They are dependent upon the environment and other economic factors. Prices are determined by product supply and demand. The sensitivity analysis of profitability is conducted with a 25% decrease and increase in ex-farm price.

At the price of USD 526/ton, the Net Present Value (NPV) at a discount rate of 10% gives a positive value of USD 57,461 which indicates that the farm project is viable. The Internal Rate of Return (IRR) is 13% which can be considered as fairly reasonable for an agricultural project. The payback period is 16 years (see Table 12-6).

When the average price of mangosteen drops to USD 395/ton ex-farm, the NPV is negative indicating that the project is not viable. The IRR is 9% which is less than the cost of capital, and the payback period increases to 19 years. When the average price of mangosteen increases to USD 658/ton ex-farm, the NPV increases to USD 131,675, the IRR increases to 15% and the payback period reduces to 15 years. Hence, profitability of mangosteen cultivation is sensitive to price changes.

The long period until financial return of mangosteen cultivation tends to discourage investors to venture into commercial production. However, fairly satisfactory returns can be earned at an average price of USD 526.30/ton ex-farm provided the farm is well managed and yields are maintained as projected (Table 12-6).

Table 12-6. Summary of financial analysis at 10% discount rate

Selling Price	Net Present Value	Internal Rate of Return	Payback Period
1. USD 395/t	USD 16,752	9%	19 years
2. USD 526/t	USD 57,461	13%	16 years
3. USD 658/t	USD 131,675	15%	15 years

Source: after MOA (2002)

12.2 Marketing

The seasonal production of mangosteen is marketed for a period of six to ten weeks. Such short and abrupt supply often leads to wide price fluctuations with higher prices at the start and end of the season, and lower prices at mid-season due to greater quantities that are available at this time and/or a drop in the quality of the fruits. The seasonal nature of the crop and the fact that currently, it is mainly grown by smallholders has led to a number of constraints in marketing. One of them is a production shortfall.

12.2.1 Domestic and regional marketing

The predominance of smallholders in mangosteen production has led to irregular supply of fruits, which renders organised marketing impossible. There is non-standardisation of product quality and grades, which makes exporting the fruits difficult. As such, mangosteen is mainly sold in small quantities at fruit stalls and by the roadsides.

In Malaysia, the domestic market for mangosteen has been increasing due to an increase in per capita income. With anticipation of an increase in total consumption due to the recognition of the need for a healthy lifestyle as well as to meet the needs of a growing affluent population, the domestic market for mangosteen is expected to grow further.

Tourism also affects the demand for mangosteen. In areas where tourism is popular e.g. Sri Lanka, Malaysia, Thailand and elsewhere, hoteliers serve mangosteen to their clients in many different forms.

In fact, production of quality fruits has not kept pace both with domestic and export markets. A number of indicators reflect this situation including the rise in price and stable production trend over the last few years. An analysis of the consumption pattern indicates a lowering per capita over the last ten years (Figure 12-1). This is mainly due to the high prices of fruit that make them rather expensive for ordinary consumption. If the production could be increased, resulting in lower prices, the per capita consumption of the fruits would be higher in the future.

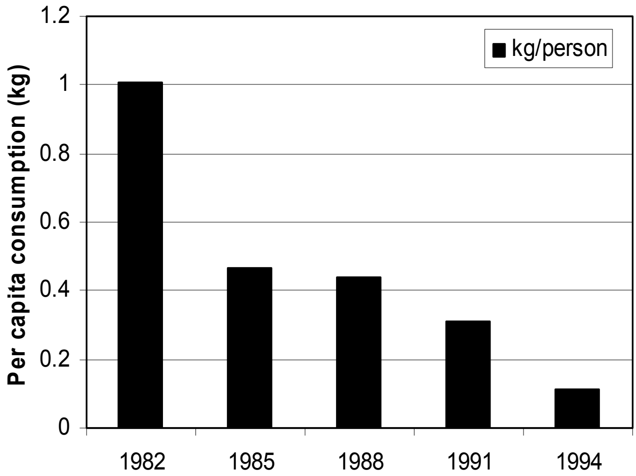


Figure 12-1. Per capita consumption of mangosteen in Malaysia

Source: MOA (2002)

Singapore

Singapore will remain a major market for mangosteen. More than 90% of Malaysian mangosteen export goes to Singapore. By reason of geographical proximity, a good network of transport and a 3 million consumer population with a relatively high purchasing power makes Singapore an attractive market outlet. However, the Singapore market is not only very quality conscious but price conscious as well. Therefore in order to export to Singapore mangosteen producers should ensure that their fruits are of good quality and certainly free from pesticide residue. The price should also be competitive especially against fruits from temperate countries as well as mangosteen from other ASEAN countries such as Thailand and Indonesia. For the potential exporters of mangosteen, the best strategy for the Singapore market will be to move away from price competition and to reposition it in the higher end of the market. This will be through improving quality, product presentation and creating a distinctive identity and by dealing with major fruit distributors there in order to achieve economy of scale and price competitiveness.

Hong Kong, China

Hong Kong is the second most important export destination for Malaysian mangosteen, after Singapore. Like Singapore, a six million population with high purchasing power and a free trade with a non-tariff barrier makes Hong Kong an attractive market outlet for fruits such as mangosteen.

The major setback in this market is the system of consignment sales. Presently, the potential buyer will indicate a price to the exporter. If he decides to export to Hong Kong, the importer will then pay the exporter based on the prevailing selling price. Therefore, the potential exporter of mangosteen to Hong Kong has to decide whether to accept this system of sales. This system can negate profitable export earnings and be a disincentive to marketing in Hong Kong.

Other markets

Apart from the above markets, countries of the Middle East, South Korea, Japan and Taiwan-China are potential markets of mangosteen due to a receptive clientele with high purchasing power.

There is also the possibility of import substitution for some of the imported fruits to Malaysia. The import of fresh fruits is still very high, and made up mostly of apples, oranges, grape and pears. Local mangosteen producers are encouraged so that the price of mangosteen is comparable or even lower than that of imported fruits.

12.2.2 International marketing

Mangosteen is constrained by availability of good quality fruit throughout the year. For instance, Europe holds promise for mangosteen but for it to be successful, the fruit should be exported in large volumes for mass distribution so that its prices could be cheaper in order to compete effectively with other tropical fruits. To date, volumes exported have been relatively small e.g. 50-60 t per season from Sri Lanka (Dassanayake, 1996).

Presently, the main export markets for mangosteen are still largely confined to regional markets such as Singapore, Hong Kong and other East Asian countries. For mangosteen to succeed as a prime export crop, numerous constraints in production, grading and marketing technologies need to be addressed.

Chapter13. Conclusion and Future Impacts

13.1 Potential

For some national economies, tropical fruits, including mangosteen, can become large export-income earners. At present, mangosteen cultivation is mainly found in home gardens or orchards. Commercial cultivation for mangosteen as a monocrop is limited; in many instances, mangosteen is mostly intercropped with other fruit types. Despite the many limitations and constraints in growing mangosteen, many growers, particularly in Thailand, Malaysia, the Philippines and Indonesia, continue to grow the crop.

Mangosteen has tremendous economic potential because of its great demand both in the domestic and export markets. While the major producing countries are continuously expanding its planting and pursuing research and development activities on mangosteen, several international organizations are also engaged in the research and development of the crop.

For the full potential of mangosteen to be realized, the development of mangosteen may be supported and promoted by large scale commercial production with good management and investment. Commercial orchards of mangosteen require technology inputs to the production, postharvest, processing, including grading, packaging, cold storage equipment, and marketing systems.

13.2 Constraints to commercial cultivation

To promote commercial cultivation in any national economic efforts would require considerable amount of resources ranging from manpower, investments to marketing strategies. At present, the limited volume of production assures a high price in the market. In the export trade, non-overlapping harvesting seasons in producing countries ensure availability of supply. Some of the major constraints to efficient commercial-scale production, quality improvement and marketing of mangosteen include but are not limited to the following:

1. Mangosteen is very slow growing and has a long juvenile period. This is the key constraint which needs to be urgently addressed. A long period of 10 or more years until fruit production should be reduced first by biologists and agriculture scientists in order to attract entrepreneurs to venture into mangosteen cultivation.
2. The knowledge and ability of human resources in adopting new or better technology is a constraint, in particular the transfer of information and technology to growers.
3. Mangosteen market situation and trade are increasingly dependent on discerning consumer behaviour.
4. The international market requires standardised high quality products. To achieve this, it is imperative that collaboration on facilities and human resource development, quality assurance, standardisation and certification, long distance transport and quarantine requirements be improved further.
5. In terms of crop physiology and husbandry, mangosteen shows strict climatic requirements, short viability of seeds, absence of rapid methods of propagation, slow plant growth and delayed precocity of trees.
6. Although asexual propagation by grafting has been practically established for its propagation, and its advantage in significantly reducing the juvenile period has been demonstrated, there are only few growers who take up the use of such grafted planting materials because of the much slower growth than seedlings and the plants remain extremely dwarfed (Namuco 1999).
7. Information on crop cultural management are still lacking, while the crop is known to be critical in its requirement for shading, nutrition, irrigation, and pruning.
8. Few growers are commercially engaged in mangosteen cultivation because of inadequate information on the economics, production, post-production techniques and marketing.
9. In many producing countries, mangosteen trees are already old, and this situation necessitates new plantings to be undertaken to replace unproductive trees (Frohmader 1993).

13.3 Research gaps and needs

In general, research and development efforts should be aimed at improving plant growth and development, shortening the juvenile period, increasing yield and improving fruit quality (Namuco 1999), while at the same time, properly addressing the problems associated with increasing production area and yields, as discussed below.

13.3.1 Varietal improvement

Mangosteen is clearly demonstrated to have low genetic diversity. Germplasm collection and conservation efforts carried out have offered opportunities to broaden its present genepool. Selection for outstanding clones from existing seedling populations have yielded very little opportunity or success. To develop new clones, non-conventional crop improvement strategies may need to be undertaken to bring about variability, and also make it possible to select for new genotypes. It has been suggested to cross mangosteen with other *Garcinia* species (Richards 1990) to produce hybrids, with acceptable fruits with fewer cultural problems, and this is a possible means of development.

13.3.2 Taxonomic status

Research on rootstocks for the cultigen mangosteen has in the past been haphazard. Mission-oriented research, such as improvement of mangosteen through hybridisation is limited because the patterns of variation in the wild species have not been outlined. These constraints relate directly to the lack of a good taxonomic framework for the many wild species. It is urgent that a review of the Asian species is conducted in the near future.

13.3.3 Propagation and nursery management

Mangosteen is mainly propagated through seeds. The present practice of using seeds as planting material results in a long juvenile period. Asexual methods for production of planting materials, including tissue-derived materials, are rarely practiced. Although asexual propagation by grafting has been successfully demonstrated to shorten the juvenile period, the resulting the growth of grafted plants is much slower than normal. The method produces dwarf plants, which in turn causes yield to be very low. Results on the performance of mangosteen derived from planting materials other than from seeds are still inconclusive.

The use of related species has also shown limited opportunity for further expansion. While mangosteen has been reported to be graft compatible with other *Garcinia* species such as *G. kydia*, *G. venulosa* and *G. morella*, growth of grafted materials is extremely slow. Research should be conducted to accelerate seedling growth, for example by using growth regulators, fertilization and irrigation. No comprehensive study had been done to evaluate the potential of the trees until maturity.

13.3.4 Orchard establishment

Mangosteen is known to be adapted to ecological conditions of moist soils, good rainfall and high humidity. Therefore, cultivation of mangosteen is best in specific ecological regions to improve performance and increase yield. Besides these large scale requirements, shade is a very important requirement, and is essential during the crop's early establishment period.

Very little information is known about the performance of mangosteen as a major component of multiple cropping systems. Studies addressing phenology, adaptation and yield performance in such systems should be pursued.

13.3.5 Fertilizer application

It is generally known that mangosteen responds favourably to fertilizer application. Fertilizer application technology based on tissue and soil analysis should be developed. In addition, the use of organic fertilizers and mycorrhizal fungus should be examined (Namuco 1999).

13.3.6 Irrigation

Appropriate irrigation technology must be developed in order to optimize production and extend the fruiting season. By controlling water availability to the crop by appropriate irrigation technology, this may shorten the harvesting period, thus reducing harvesting costs, by triggering synchronous flowering (Verheij 1991).

13.3.7 Post-harvest handling

Mangosteen fruits stored at low temperatures result in hardening of the pericarp. This condition reduces acceptability of the fruits due to difficulty in opening them. Crystallization of pulp and presence of yellow latex in mangosteen fruit when harvested need to be studied to address these problems. Other postharvest handling studies would include food processing for development of new products.

13.3.8 Economics and Marketing

R&D in economics and marketing need to be improved as it has been neglected so far. The principal objectives of the R&D are to collect and analyze the information on the production and marketing of mangosteen locally, regionally, and where relevant, internationally. There should also be studies or review on existing incentives and constraints that influence private sector participation, its macroeconomics, and also the longer-term market outlook for mangosteen production.

13.3.9 UTFANET - Networking for research and development

The effective implementation of UTFANET will promote collaborative research on key areas. Such R&D areas should be identified based on priorities of the region with individual countries taking lead roles in areas where they have comparative advantages. UTFANET will also further extend the necessary platforms and opportunities for the researchers and scientists in relevant countries to collaborate with existing networks and institutions like IPGRI, PROSEA and ICRAF in the conduct of documentation and dissemination, R & D and training activities.

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Appendix A. Institutions and specialists engaged in *Garcinia mangostana* research and development

Institution	Specialist
Subtropical Horticultural Research Unit-USDA 13601 Old Cutler Road Miami, FL 33158, USA	Raymond Schnell (curator)
Horticulture Research Centre Malaysian Agricultural Research and Development Institute P. O. Box 12301 50774 Kuala Lumpur, Malaysia	Masri Muhamad Melor Rejab
College of Agriculture University of the Philippines, Los Banos College, Laguna, Philippines	Felipe S. dela Cruz, Jr. Roberto Coronel Lizada M.C.C. Esguerra E.B.
Plant Tissue Culture Laboratory School of Biological Sciences The National University of Singapore Lower Kent Ridge Road, Singapore 119260	Chong Jin Goh Chiang Shiong Loh
Commonwealth Scientific and Industrial Research Organisation Division of Horticulture Private Mail Bag 44 Winnellie, N.T. 0821, Australia	J. Wiebel E. K. Chacko
Institute of Botany Academia Sinica Nankang, Taipei, Taiwan, China	Huang-Li Chun Huang-Bau Liang Wang-Chiu Hui Kuo-Ching I
Faculty of Natural Resources Department of Plant Science Prince of Songkla University Hat Yai 90112, Thailand	Sompong-Te-chato Mongkol-Lim Te-Chato S

School of BioScience and Biotechnology Faculty of Science and Technology Universiti Kebangsaan Malaysia 43600 UKM, Bangi, Selangor, Malaysia	Normah Mohd Nor Mohamad, O.
Department of Horticulture Faculty of Agriculture Kasetsart University, Bangkok 10900 Thailand	Yapwattanaphun C
Taman Buah Mekarsari Citeuremp, Jakarta, Indonesia	Muhammad Reza Tirtawi- nata
Pusat Kajian Buah-Buahan Tropika, LPPM IPB Kampus IPB Baranangsiang, Jl. Raya Pajajaran - Bogor 16144, Indonesia	-
Balai Penelitian Tanaman Buah Jl. Raya Solok - Aripan Km. 8, Kotak Pos No. 5 Solok, Sumatera Barat	rif@padang.wasantara.net.id

Appendix B. Institutions with *Garcinia mangostana* germplasm collections

Institution	Accessions
Estacao Experimental de Fruiticultura Tropical – EPABA Conceicao Do Almeida, Bahia, Brazil	*Garcinia* spp. (2)
Centro Agronomico Tropical de Investigacion y Ensenanza Apdo. 74 7170 Turrialba, Costa Rica	*G. mangostana* (2) *G. tinctoria* (5)
Institut de Recherche Sur Les Fruits et Agrumes – CIRAD Stat. de Neufchateau-Sainte Marie F-97130 Capesterre Belle-Eau, Guadeloupe, France	*G. mangostana* (2) *G. xanthochymus* (1)
National Biological Institute P. O. Box 110 Jalan Raya Juanda 18 Bogor, Indonesia	Several specimens of wild species
Taman Buah Mekasari Citeureup, Jakarta Indonesia	*G. mangostana* 300 individual productive trees of which 90% originated from seedlings and 10% from grafting. Some wild species
Balai Penelitian Tanaman Buah Jl. Raya Solok - Aripan Km. 8, Kotak Pos No. 5 Solok, Sumatera Barat	*Garcinia* spp.
Malaysian Agricultural Research and Development Institute P. O. Box 12301 50774 Kuala Lumpur, Malaysia	*Garcinia* spp.

Agriculture Research Centre, Lagud Seberang Tenom, Sabah, Malaysia	*Garcinia* spp.
Department of Agriculture, Semenggok Sarawak, Malaysia	*Garcinia* spp.
Direccion Estatal de Agricultura Estado de Tabasco 86400 Huimanguillo, Tab. Mexico	*G. mangostana* (4)
Lowlands Agriculture Experimental Station Dept. of Primary Industry P. O. Keravat Keravat, East New Britain Province, Papua New Guinea	*Garcinia* spp. (3)
Chiayi Agricultural Experiment Station Tari 2, Ming-Cheng Road 60014 Chia-Yi, Taiwan	*G. dulcis* (1) *G. hombroniana* (1) *G. mangostana* (1) *G. xanthochymus* (1)
Plew Horticultural Experimental Station Chantaburi Province, Thailand	*G. mangostana* (440 from Thailand)
Prince of Songkhla University Faculty of Natural Resources Songkhla 90112 Haadyai, Thailand	*G. atroviridis* (3) *G. dulcis* (1) *G. mangostana* (59 all from Southern Thailand) *G. prainiana* (4) *G. speciosa* (1) *G. xanthochymus* (1)
Subtropical Horticultural Research Unit-USDA 13601 Old Cutler Road Miami, FL 33158, USA	*Garcinia* spp. (11 species, 25 accessions)

Glossary

A

acute - terminating with a sharp or well defined angle.

acuminate - the shape of a tip or base of a leaf or perianth segment where the part tapers gradually and usually in a concave manner.

adventitious - describes an organ growing where it is not normally expected.

agamospermy - apogamy where the sexual union is not complete, yet the embryo is produced from the inside layer of the female gametophyte.

allotetraploid - having 4 genomes with 2 sets (rarely 1) coming from a different species than the others.

alternate - describes leaves that are not opposite to each other on the axis, but arranged singly and at different heights.

androecium - all the male reproductive organs of a flower; the stamens. *cf. gynoecium.*

anterior - front; on the front side; away from the axis.

anther - the pollen-bearing (terminal) part of the male organs (stamen), borne at the top of a stalk (filament).

anthesis - flower bud opening; strictly, the time of expansion of a flower when pollination takes place, but often used to designate the flowering period; the act of flower bud opening.

apex - the tip of an organ, the growing point.

apical - pertaining to the apex.

apogamy - the formation of a sporophyte from a gametophyte by asexual means.

apomictic - a plant that reproduces without fertilisation.

aril - a fleshy or sometimes hairy appendage or outer covering of a seed.

asexual - lacking sexual characteristics, or when referring to reproduction, occurring without the fusion of egg and sperm.

axil - the upper angle formed by the union of a leaf with the stem.

axillary - pertaining to the organs in the axil, e.g. buds flowers or inflorescence.

axis - the main or central stem of a herbaceous plant or of an inflorescence.

B

budding - method of propagating woody plants. A cutting of one variety, called the scion with buds attached, is joined onto another related species or variety called the rootstock. As the plant grows, the two parts graft together to form one plant.

C

calyx - the outer whorl of floral envelopes composed of the sepals.

clone - a group of plants that have arisen by vegetative reproduction from a single parent, and which therefore all have identical genetic material.

connate - united or joined; in particular, said of like or similar structures joined as one body or organ.

coriaceous - of leathery texture.

cotyledon - seed leaf; the primary leaf or leaves in the embryo.

cross pollination - the transfer of pollen from the anther of the flower of one plant to the flowers of a different plant.

cultivar a race or variety of a plant that has been created or selected intentionally and maintained through cultivation.

cuspidate - with an apex abruptly and sharply constricted into an elongated, sharp-pointed tip.

D

diploid - having two sets of chromosomes.

dioecious - having male (staminate) and female (pistillate) flowers on different plants.

E

ecospecies - a taxonomic species described in terms of its ecological characteristics.

ecotype - a subdivision of an ecospecies that survives as a distinct population through environmental selection and isolation; comparable to a taxonomic species.

elliptic - oval in outline.

epiphyllous - growing on a leaf, usually through vegetative reproduction.

explant - a plant part aseptically excised and prepared for culture in a culture medium.

F

facultative - capable of functioning under varying environmental conditions.

fasicle - a condensed or close cluster.

G

gametophyte - that part of a plant which bears the gametes or sexual cells.

genotype - the genetic constitution of an organism, acquired from its parents and available for transmission to its offspring.

genus - a group of related species, the taxonomic category ranking above a species and below a family.

glabrous - not hairy.

glandular - bearing glands.

globose - globe-shaped.

grafting - a method of propagation, by inserting a section of one plant, usually a shoot, into another, so that they can grow together into a single plant.

H

hybrid - a cross-breed of two species, usually having some characteristics of both parents.

hypocotyl - the axis of an embryo below the cotyledons which on seed germination develops into the radicle.

hypogynous - situated on the receptacle beneath the ovary and free from it and from the calyx, having the petals and stamens so situated.

I

interspecific - refers to hybrids between two separate species of the same genus.

M

meiosis - cell division, the nuclear division that halves the chromosome number.

-merous - a suffix preceded by an Arabic number or numeric prefix indicating how many of each part a flower possesses.

micropropagation - propagation of plants through tissue culture.

mitosis - cell division in which the number of chromosomes in the daughter cells is the same as that of the parent cell.

mitotic diplospory - during reproduction, the mother cell does not enter meiosis and undergoes only mitotic divisions without a reduction of the genome.

O

obovate - inverted ovate; egg-shaped, with the broadest part above.

P

panicle - a loose irregularly compound inflorescence with pedicellate flowers.

pedicel - a tiny stalk; the support of a single flower.

pericarp - (*syn.* fruit wall) the wall of the matured ovary.

petiolate - having a petiole.

petiole - the stalk of a leaf that attaches it to the stem.

phenology - the science of the relations between and periodic biological phenomena

phenotype - the morphological, physiological, behavioural, and other outwardly recognisable forms of an organism that develop through the interaction of genes and environment.

plumule - the bud or growing point of the embryo.

polyploidy - having more than two sets of chromosomes.

propagate - to produce new plants, either by vegetative means involving the rooting or grafting of pieces of a plant, or sexually by sowing seeds.

R

radiate - spreading from or arranged around a common centre.

radicle - the portion of the embryo below the cotyledons that will form the roots.

resinous - coated with a sticky gum or resin.

receptacle - the more or less expanded or produced portion of an axis which bears the organs of flower or the collected flowers of a head.

rootstock - the root system and lower portion of a woody plant to which a graft of a more desirable plant is attached.

S

scion - a cutting from the upper portion of a plant that is grafted onto the rootstock of another plant, usually a related species.

self fertile - able to be pollinated by its own flower.

sepal - a division of a calyx; one of the outermost circles of modified leaves surrounding the reproductive organs of the flower.

sessile - without a stalk.

sheath - a tubular envelop.

sporophyte - the spore-bearing part or generation.

stamen - one of the male pollen-bearing organs of the flower.

staminode - a sterile stamen, or any structure without anther corresponding to a stamen.

stigma - that part of a pistil through which fertilisation by the pollen is effected.

stipule - an appendage at the base of a petiole, often appearing in pairs, one on each side, as in roses.

style - the usually attenuated portion of the pistil connecting the stigma and ovary.

T

tetraploid - having 4 sets of chromosomes (twice the normal number of chromosomes).

Index