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Potential for novel food products from agroforestry trees: a review

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Abstract

The domestication of trees for agroforestry approaches to poverty alleviation and environmental rehabilitation in the tropics depends on the expansion of the market demand for non-timber forest products. This paper reviews published data on the nutritive values of the flesh, kernels and seedoils of the seventeen fruit tree species that have been identified, in four ecoregions of the tropics, by subsistence farmers as their top priorities for domestication. In some species, genetic variation in nutritive value has been reported, but in most species there is still inadequate information on which to base programmes for the genetic improvement of these species. Farmers and agroforesters have identified many of the biological constraints relevant to their viewpoint on production, but there is a need for inputs from the food industry into the identification of the desirable traits and characteristics of potentially novel food products. This paper calls for greater collaboration between agroforesters and the food industry in the effort to promote the domestication and commercialization of under-utilized tree products.

1. Introduction

New initiatives in agroforestry are seeking to promote poverty alleviation and environmental rehabilitation in Developing Countries, through the integration of indigenous trees, whose products have traditionally been gathered from natural forests, into tropical farming systems (ICRAF, 1997). This is being done in order to provide marketable products from farms that will generate cash for resource-poor rural and peri-urban households. One important component of this approach is the domestication of the local tree species that have commercial potential in local, regional or even international markets (Leakey and Simons, 1998). Consequently, in collaboration with ICRAF (International Centre for Research in Agroforestry), farmers in four ecoregions of the tropics (the humid and dry zones of West Africa, Amazonia, and southern Africa) have identified their priority indigenous trees for 'domestication', from among the many that have been, and are still being, used traditionally, to provide people's needs for food and nutritional security (Fig. 1). For most of these hitherto wild species, little attention has been made to seek market opportunities for the products within the international food industry, although in some instances research has been carried out to assess their food value and potential for domestication. To meet the objective of market creation and expansion, it is important to identify potential market niches and then to determine whether there are important product characteristics, which should be improved through genetic selection. While some traits that are relatively easy to identify do benefit the farmer, there are undoubtedly others that are important to the food industry, but that require more sophisticated evaluation in collaboration with the private sector. This review seeks to draw together, in priority order for each region, all the existing information on the characteristics of the products from the tree species that farmers have identified as being their preferred choice for domestication.

2. Humid lowlands of West Africa

2.1. Irvingia gabonensis *(O'Rorke) Baill. and related species (Bush Mango or Dika Nut)*

This fruit is like that of a small, cultivated Mango in appearance (Fig. 2) but the two are unrelated. The pulp of this fruit is eaten fresh and the kernel of the nut is a food additive. The flesh is juicy and varies between sweet

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and bitter. The sweeter form is generally considered to be *I. gabonensis* var. *gabonensis*, while the bitter form is var. *excelsa*, now called *Irvingia wombolu*. Trees are being selected for the sweetness of their fruits, fruit size, colour and other desirable traits (Ladipo et al., 1996), but not, so far, for any kernel traits. The pulp can be used for the preparation of juice, jelly and jam. The extraction rate of juice from the fruit pulp was 75% and the sugar concentration of this juice is comparable with pineapples and oranges (Akubor, 1996), but with a higher ascorbic acid content (67 mg 100 ml^{-1}). This concentration of ascorbic acid is also nearly three times that of *Dacryodes edulis* and *Chrysophyllum albidum* (Achinewhu, 1983). These fruits are therefore a good local source of vitamin C.

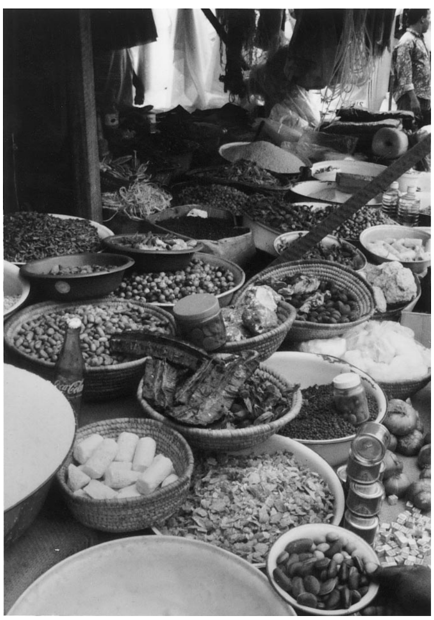

Fig. 1. Tree products on a market stall in Kumba, Cameroon.

Evaluation of the wine-making potential of the juice (Akubor, 1996), showed that wine produced after 28 days fermentation had 8.12% alcohol content. Sensory evaluation showed no significant difference in colour, mouthfeel, sweetness, flavour and general acceptability from a German reference wine.

A study of fruit-ripening and storage (Joseph and Aworh, 1991) has shown that fruits harvested at the mature green stage and ripened at 26–29°C were preferred to tree-ripened fruits in colour and texture, although they were both comparable in composition. Fruits held at 12–15°C developed symptoms of chilling injury. In a separate study (Aina, 1990), ripening fruits were found to increase in soluble solids and carotenoid content, decrease in acidity and to undergo starch hydrolysis.

The most important product from these species (especially *I. wombolu*) is, however, the kernel of the nut, which is extracted, dried and can be stored for long periods (Fig. 3). These kernels are traded on both a local and a regional scale in West Africa (£1–£3 kg^{-1} depending on season). Uzo (1980) considered that the fruits from a single tree could generate income of US$300 per annum. The composition of *I. gabonensis* var. *excelsa* (now *I. wombolu*) kernels at 88.1% dry matter has been reported by Ejiofor et al. (1987) to be 51.3% fat, 26.0% total carbohydrate, 2.5% ash, 7.4% crude protein, 0.9% crude fibre, 9.2 mg 100 g^{-1} vitamin C and 0.6 mg 100 g^{-1} vitamin A.

Other reports (e.g. Oke and Umoh, 1978) have quoted values of 54–67%, and even 72%, for fat content and 38.8% for carbohydrate (Ejiofor, in press). Okolo (in press) reports that the fat has an absence of volatile oils, a melting point at 37–42°C, saponification value of 233–250 and an iodine value of 2–9. He also quotes reports from 1929–39, that the myristic acid and lauric acid contents of *Irvingia* kernels vary depending on the source of the fruits (Nigeria: 50.6 and 38.8%; Sierra Leone: 33.5 and 58.6%, respectively). Unpublished data (Hellyer, 1997) show myristic acid and lauric acid values

Fig. 2. Fresh fruits of *Irvingia gabonensis* in southern Cameroon. Note variation in colour and size.

Fig. 3. Prepared and unprepared kernels of *Irvingia gabonensis* in Cameroon.

of 39.2 and 51.1% from *I. wombolu* kernels from Cameroon. The amino acid composition of kernels has been reported by Amubode and Fetuga (1984).

A comparison of kernel composition between *I. gabonensis* and *I. wombolu* has shown that *I. wombolu* has less fat, more crude protein, less crude fibre and less vitamin C than *I. gabonensis* (Ejiofor et al., 1987). The fat from *I. wombolu* has lower iodine and saponification values (Joseph, 1995).

Kernels are processed by grinding and separating the residue from the fat. The residue is used as a food additive to thicken soups and stews, as it produces a viscous consistency when added a few minutes before serving. A rheological study of the polysaccharides in dika nut found that the variation of 'zero-shear' specific viscosity was broadly similar to the general form of disordered polysaccharides, although with some specific attributes consistent with it having a compact molecular geometry rather than a 'random coil' conformation (Ndjouenkeu et al., 1996). Joseph (1995) reports that the viscosity of mucilaginous solutions is lower at high temperatures and at high shear rates, making it appropriate as a thickening agent. The residue can be made into cubes/pellets with enhanced storage life (Ejiofor et al., 1987). Okolo (in press) has calculated that a pilot plant, with a capacity of 100 kg per hour, would require 256 tonnes of kernels per year. Calculated on crude protein basis, Dika nut meal shows comparatively better water and fat absorption properties than raw soy meal and hence it may have useful applications in processed foods, such as bakery products and minced meat formations (Giami et al., 1994).

2.2. *Dacryodes edulis* (G. Don) H.J. Lam and related species (African Plum, African Pear or Safoutier)

A recent workshop in Cameroon (Kengue and Nya-Ngatchou, 1994) reviewed knowledge of this species in view of new initiatives for its domestication. The flesh of the fruit has good nutritional value and has been reported by Umoro Umoti and Okiy (1987) to contain, as a percentage of dry matter (dm), 31.9% oil, 25.9% protein, 17.9% fibre. The main fatty acids in the lipid fraction are palmitic acid (36.5%), oleic acid (33.9%) and linoleic acid (24%), giving a profile similar to palm oil (*Elaeis guineensis*). The main essential amino acids are leucine (9.57%) and lysine (6.3%), while others are glutamic (17.0%), aspartic acids (15.1%) and alanine (7.7%). The ascorbic acid content of the flesh is 24.5 mg 100 g^{-1}, but this is lost by some forms of cooking (Achinewhu, 1983). Many of the nutrients are, however, in the skin of the fruit, which is usually discarded.

The seeds of *D. edulis* are usually discarded, but analysis shows them to have considerable nutritional value and a lack of toxins that makes them at least useful as a supplement to animal feed (Obasi and Okolie, 1993).

A small survey of three markets in Yaoundé (Leakey and Ladipo, 1996) determined that there was 4- to 5-fold variation between fruitlots in fruit weight, pulp:seed ratio and price per kilogram of pulp (Fig. 4). While large fruits with a high pulp:seed ratio were usually highly priced it was clear that some small fruits also commanded a high price, presumably because flavour, quality and other variables were important in the market place. Although Leakey and Ladipo (1996) report continuous variation in fruit size, pulp:seed ratio and other fruit characteristics, between different fruitlots of different origins, Youmbi et al. (1989) indicate that there are two morphological types in markets in Cameroon: a large fruit with a large seed and a small (short) fruit with a well developed mesocarp. They further indicate that these two types vary in their chemical composition, with the large type characterized by a higher lipid content in the mesocarp than in the seed, and the converse in small fruits. Non-structural carbohydrates are higher in the seed than in the mesocarp of both types. The further characterization of these differences is important in the domestication of the species and their orientation to different markets. In this regard, Okafor (1983) defined two varieties (*D. edulis* var. *edulis* and *D. edulis* var. *parvicarpa*) on the basis of the relationship between their longitudinal and mid transverse circumferences.

Tests have determined that storage life of fruits can be prolonged beyond 8 days by refrigeration (Emebiri and Nwufo, 1990). At 15°C, storage life was 2 weeks, although some fruit types did deteriorate over this period. The causes of this variation in storage life need to be determined. A palm oil dip, or enclosure in a polythene bag, enhanced storage life at 15°C. At 5°C, susceptible fruit types remained firm, but they deteriorated before Day 25. The apparent genetic variation in shelf-life is a trait that should be included in the selection of cultivars.

Fig. 4. Fruits of *Dacryodes edulis* from Yaoundé market. Note variations in colour, size and price.

2.3. Ricinodendron heudelottii *(Baill.) Heckel (Peanut Tree, Essessang or Nyangsang)*

The kernels of the nut are widely traded in Cameroon and used as a flavouring in food dishes with the oil used in cooking (Fig. 5). The paste of ground kernels is said to have a better taste than groundnut sauce (Ndoye, 1995). However, remarkably little is known about the products of this species. In the Ivory Coast the kernels are used as a condiment (Téhé, 1986). The nutritive value of kernels is recorded in Pélé and Berre (1967), but the data have not been seen by the author. Kapseu (in press), however, reports that the polyunsaturated acids are high (79.4%) and that the unsaponifiable matter is low (1.6%). The kernels can be stored for long periods.

2.4. Chrysophyllum albidum *G. Don (White or African Star-apple)*

Achinewhu (1983) has reported that fruit pulp (Fig. 6) contains 21.8 mg 100 g^{-1} ascorbic acid, while the skin contains 75 mg 100 g^{-1}, while Edem et al. (1984) report

Fig. 5. Kernels from the fruits of *Ricinodendron heudelottii*.

Fig. 6. Fruits of *Chrysophyllum albidum* from Nigeria (Photo by D.O. Ladipo).

446 and 239 mg 100 g^{-1} for pulp and skin, respectively. The latter authors also indicate that proximate analysis of fruit pulp was protein (8.8%), lipid (15.1%), ash (3.4%), carbohydrate (68.7%) and crude fibre (4.0%), with only minor differences between pulp and skin. With the exception of calcium (100 vs 250 mg 100 g^{-1}) and iron (10 vs 200 mg 100 g^{-1}) in pulp and skin, respectively, the mineral contents of these components of the fruit were also very similar. According to Achinewhu (1983), the levels of toxic substances in both the mesocarp and the pericarp were low, although the juice was highly acidic. Edem et al. (1984), on the other hand, identified high levels of tannins in pulp (627 mg 100 g^{-1}) and lower levels in peel (264 mg 100 g^{-1}). Fruit storage was best at 10°C while, for the kernel, the traditional method of storing in layers of red clay was best.

The juice of fruits has potential as an ingredient of soft drinks and can be fermented for wine or other alcohol production (Ajewole and Adeyeye, 1991).

The seeds of this species are not particularly rich in lipids (3.2%), but linoleic (38.4%) and oleic (29.6%) acids are the main fatty acids present (Essien et al., 1995). Ajewole and Adeyeye (1991) have, however, reported higher lipid content (16.6%) and confirmed that unsaturated fatty acids are the main components of the oil (74%) and hence desirable in the context of heart disease risk reduction. The residual cake also has potential for animal feed.

2.5. Garcinia kola *Heckel and related species (Bitter Cola)*

The flesh of the fruit is edible and has medicinal uses (Fig. 7). Comparison of the nutritive value of the pericarp and mesocarp of fresh fruits from Nigeria (Dosunmu and Johnson, 1995) shows that crude protein was higher in the mesocarp than in the pericarp (7.8% vs 3.9%), while the pericarp was richer in crude fibre (16.5% vs 13.9%) and macro elements (e.g. K: 990 vs

Fig. 7. Flowers and fruits of *Garcinia kola* in Cameroon.

499; Fe: 150 vs 4.2; Ca 200 vs 100 mg 100 g^{-1}). The mesocarp was richer in N (1248 vs 624 mg 100 g^{-1}) and P (720 vs 520 mg 100 g^{-1}). The mesocarp was also richer in crude lipid (8.7 vs 6.9%) and ascorbic acid (127 vs 93 mg 100 g^{-1}).

The kernels of the nuts are widely traded and eaten as a stimulant (Fig. 8). Unsaturated fatty acids (linoleic acid: 40.5%, oleic acid: 30.8%) are the main components of the lipids (4.5%) found in the seeds of this species (Essien et al., 1995; Omode et al., 1995). The low kernel oil content of this species, however, probably eliminates it as a commercial source of oil (Foma and Abdala, 1985).

The chemical, brewing and anti-microbial properties of *Garcinia kola* seeds have been compared with hops in lager beer brewing, because of their similarity in flavour and greater availability in West Africa (Aniche and Uwakwe, 1990). Treatment of *G. kola* with methanolic lead acetate produced a yellow precipitate from which organic acids (alpha acids) were confirmed by thin-layer chromatography. Hops, however, had a higher concentration of organic acids than *G. kola*. Laboratory brewing trials with both products gave beers with similar chemical properties. Organoleptically, *G. kola* beer was as acceptable to tasters as hopped beer, but with an improved bitterness. *G. kola* and hop extracts exerted similar anti-microbial effects on two beer spoilage microorganisms (*Candida vini* and *Lactobacillus delbruckii*).

The products of three *Garcinia* species (*G. kola* = 36%), are widely used in Ghana and 70% of this use is as chewing sticks. These are bought in urban markets as an alternative to toothpaste and brush (Adu-Tutu et al., 1979). The good dental health is attributed to these chewing sticks, despite the shortage of dentists (1 per 150 000 people) by comparison with the UK (1 per 3000 people), although it has to be remembered that there are also dietary differences between these countries.

Fig. 8. Kernels from the nuts of *Garcinia kola*.

3. Semi-arid lowlands of West Africa

3.1. *Adansonia digitata* Linn. (Baobab)

The young tender leaves of Baobab are used as green or dried vegetables (Fig. 9), rich in vitamin A and calcium; while the white powdery pulp of the fruit capsule is extracted and used as a flavouring in a variety of cool and hot drinks. The fruit are rich in pectins and have a vitamin C content of 169 mg 100 g^{-1} (Agbessi Dos-Santos, 1987), at least ten-fold greater than that of oranges (Booth and Wickens, 1988). The seed kernels contain 12–15% edible oils, more protein than groundnuts and are rich in lysine, thiamine, calcium and iron (Booth and Wickens, 1988).

In the Sahel four types of Baobab are recognized. They are Black-bark, Red-bark, Grey-bark and Dark-leaf. The Dark-leaf Baobab is preferred for use as a leafy vegetable, while the Black- and Red-bark Baobabs are preferred for their fruits (Fig. 10). Baobab leaf is an excellent source of calcium, iron, potassium, magnesium, manganese, molybdenum, phosphorus, and zinc (Yazzie et al., 1994), and has an amino acid composition that compares favourably with that of an 'ideal' protein. Dried leaves are rich in β carotene (Nordeide et al., 1996). The leaves also contain an important amount of mucilage (Gaiwe et al., 1989).

Recently, Sidibé et al. (1996) assessed the tree-to-tree variation in vitamin C content of fruits from the Black-, Red- and Grey-bark types in 2–3 trees from 4–5 villages in three areas of Mali spanning a range of rainfall zones (450–500 mm; 600–700 mm; 750–850 mm). The vitamin C content varied 3-fold between trees, but there were no

Fig. 9. Dried and ground leaves of *Adansonia digitata* in Mali (Photo by J. Baxter).

Fig. 10. Fruits of *Adansonia digitata* in Malawi.

consistent differences in vitamin C content between zones or tree types. The powders from fruits are added to drinks and to gruel as it cools after cooking, so preserving the vitamins. Healthy, non-smoking adults need 23 g per day of Baobab powder to meet their vitamin C requirements, while convalescents or nursing mothers require 90 g.

In Senegal, Becker (1983) reported that fruit with 91.3% dry matter contained 73.7% carbohydrates, 8.9% fibre, 0.2% fat, 2.7% crude protein and 209 mg per 100 g vitamin C.

In Malawi, fruit pulp of Baobab, at 86.8% dry matter, was found to contain: 79.4% total carbohydrate, 8.3% fibre, 4.3% fat and 3.1% crude protein, and high levels of several minerals, including 28.4 mg g^{-1} K and 1156 μg g^{-1} Ca (Saka et al., 1994). Ascorbic acid content was 179 mg per 100 g fresh weight (fw) (Saka, 1995). Proximate analysis of the seed kernel at 92.12% dry matter indicated that it was 29.6% fat, 28.7% crude protein and 7.3% crude fibre, while K and Ca are 1186 and 456 mg per 100 g, respectively. Fatty acid composition was 31.7% oleic acid, 30.8% palmitic acid and 25.2% linoleic acid.

In Nigeria, similar results were obtained (Odetokun, 1996), although carbohydrate contents were lower and protein content higher than in Malawi. Carbohydrates were higher in the pulp than in the seed and *vice versa* for protein. Eromosele et al. (1991) observed that fruits were rich in Mg (209 mg 100 g^{-1}) and ascorbic acid (337 mg 100 g^{-1}).

Traditionally, Boabab seeds and pulp are sundried, roasted or fermented to extend shelflife and enhance nutritive value. When fruits from Maiduguri (Nigeria) were treated experimentally (Obizoba and Amaechi, 1993), it was found that fermentation for six days was better than roasting with regard to the value of crude protein (36.4 vs 32.7%), fat (34.1 vs 32.0%) and carbohydrate (30.0 vs 23.5%).

Fruit pulp and aqueous extracts stored over a period of 8 months, with and without sodium metabisulphite, were found to deteriorate rapidly during periods of high humidity, unless treated with an antioxidant (Ibiyemi et al., 1988). Storage of pulp was also prolonged by use of airtight containers, while juice could be stored at 10°C.

3.2. *Vitellaria paradoxa* Gaertn. syn. *Butyrospermum paradoxum* (Sheanut or Karité)

This tree is one of the most common components of the Sahelian Parklands and occurs over very large areas of Africa. The nuts (Fig. 11) are used for oil extraction for cooking, soap and cosmetics. Nut production is about 3–6 kg of dry kernels per tree, but varies considerably between trees and years (Hilal, 1993; Boffa et al., 1996). One hundred kilograms of fruits give about 10 kg of dried kernels. These will yield about 5 kg of butter, with an oil content of 46.3–51.6% (33% non-saturated and 67% saturated).

After removing the fruit pulp, the seeds are dipped in boiling water, dried or smoked and stored. After shelling and grounding, the butter is extracted. The wet extraction process uses either boiling water or churning in cold water. The dry method uses heat and pressing. Another method uses organic solvents. The butter itself consists of a saponifiable fraction, containing triglycerides rich in vitamin F, and an unsaponifiable fraction, consisting of karitens, triterpenic alcohols, phytosterols and vitamins A, D and E, which give the butter its cosmetic hydrating, protecting, revitalizing and curative qualities (Hilal, 1993).

Many analyses have been done of Shea butter (see Booth and Wickens, 1988), but according to Sawadogo and Bezard (1982), it contains 45.6% oleic acid and 44.3% stearic acid. Oleic acid was found preferentially esterified in the 2-position (60%). The total triacylglycerols were fractionated and the fractions were analysed for fatty acid and triglyceride compositions: the mono-unsaturated fraction accounted for 50% and the di-monounsaturated fraction for 27.3% of the fat. The proportion of 30 possible isomers could be determined.

Fig. 11. Fruit, nut and exposed kernel of *Vitellaria paradoxa* in Mali.

Only 11 isomers could be found at over 1%. Two isomers accounted for 60% of the shea butter.

According to Badifu (1989), the non-polar lipid components of shea butter were sterols, diglycerides, free fatty acids and triglycerides. The main components of non-polar lipids were triglycerides. The major fatty acids of the triglyceride were stearic acid (about 46%) and oleic acid (about 41%). Others present in relatively small quantities were 4% palmitic, 7% linoleic and 1% linolenic acids. The free sterols were 11% campesterol, 20% stigmasterol and 68% beta-sitosterol. The polar lipid components in phospholipids were phosphatidylcholine (lecithin), phosphatidylserine and phosphatidylethanolamine (cephalin). The glycolipid component was digalactosyldiglyceride and the main sugar moieties were galactose (about 32%) and glucose (about 66%). The predominant fatty acids in phospho- and glycolipids were stearic (36 to 50%), oleic (41 to 50%), and linoleic (6 to 11%).

Chavelier (1943), however, reports that, of the glycerides, 7.0% are saturated (tributyrine 3.1%, dibutyrostearirine 3.1%, arachidodipalmitine 1.0%), while 93% were non-saturated (dipalmitsoleine 19%, dibutyrsoleine 54%, and palmitodioleine 19%).

After refining, traditionally prepared Shea butter is tasteless and odourless. It has been sold as baking fat, margarine and other fatty spreads and finds increasing use in edible products (Booth and Wickens, 1988). The fat is useful in patisserie and confectionery, the latex in the fat giving pliability to the dough. It is also used to formulate a cocoa butter substitute, which is unnoticeable in the final product.

Trees of *V. paradoxa* also produce a latex which can be tapped. No literature has been found giving the properties of this latex.

3.3. Parkia biglobosa *(Jacq.) R. Br. ex G. Don (Néré or Locust Bean)*

The seeds of Néré are fermented to make Soumbala or Dawadawa, a black, strong-smelling, flavoursome, tasty, proteinaceous food that is eaten for 50–90% of the year (Fig. 12). This keeps without further treatment for long periods and is eaten in small quantities with sorghum or millet dumplings or porridge (Booth and Wickens, 1988). It is rich in protein (40%), lipids (35%), linoleic acid and vitamin B_2 (0.4-0.9 mg per 100 g) and widely traded in urban markets. Soumbala is deficient in the amino acids methionine, cystine and tryptophan, like other legume seeds, but the cereals in the diet compensate for this deficiency.

The yellow, floury pulp around the seeds in the seedpod is a high energy food with up to 60% sugar (20% reducing sugars and 10–24% sucrose) and 291 mg vitamin C per 100 g of dry matter (Campbell-Platt, 1980). This pulp can be eaten raw, pressed into a cake or made into a refreshing drink with water, or fermented into an alcoholic beverage. The pods and leaves can also be eaten. Dried flour, unlike dried fermented seeds were rich in α and β carotene (Nordeide et al., 1996).

3.4. Tamarindus indica *Linn. (Tamarind)*

Tamarind products are highly developed and widely used in Asia and so far little used in Africa, (Fig. 13). In India and Thailand especially, cultivars are grown and the food industry is active. Tamarind gum (or hydrocolloid) is a polysaccharide polymer (D-galactose, D-xylose and D-glucose) obtained from the endosperm of the seeds. It is extracted, purified and refined and used as a thickening, stabilizing and gelling agent in foods, especially in Japan where Dainippon Pharmaceutical Co conducted two years of feeding toxicity tests

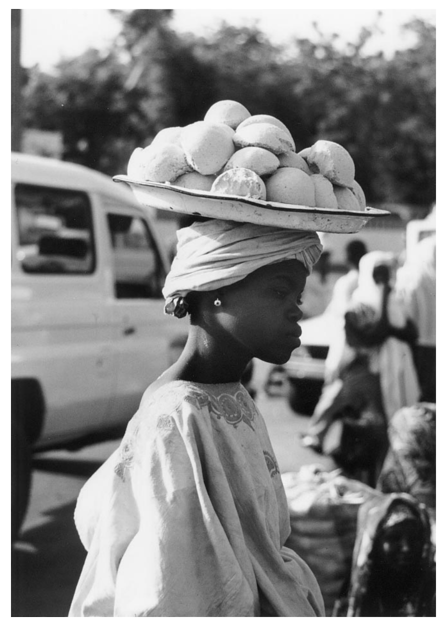

Fig. 12. Soumbala made from *Parkia biglobosa* fruits in Mali (Photo by J. Baxter).

Fig. 13. Syrup and jam made from fruits of *Tamarindus indica*.

(Glicksman, 1986). In India it is the chief acidifying agent in curries, chutneys, and sauces. The gum can also be used as a binder in pharmaceutical tablets, as a humectant and emulsifier (Hulse, 1996). Proximate analysis of seed kernels shows that 65.1–72.2% is non-fibre carbohydrate, 15.4–22.7% is protein, 3.9–7.4% is oil and 0.7–8.2% is crude fibre.

Two main products are used by the food industry: (i) Tamarind kernel powder (TKP), which contains about 50% gum and (ii) Tamarind gum polysaccharide (TGP), the purified product that is virtually 100% pure. These two products have different specifications (see Glicksman, 1986) and uses. TKP hydrates quickly in cold water, but reaches maximum viscosity if heated for 20–30 min. TGP is more soluble but still requires some heat. A typical 1.5% gum solution will yield a viscosity of 500–800 cps at 25°C. TGP has excellent stability over a range of pH, with electrolytes (e.g. 20% salt) and at temperatures below 65°C and degrades rapidly at higher temperatures and low pH. TSP has the ability to form gels in the presence of sugar or alcohol and can be used to form pectin-like gels in jams, jellies and other preserves (Glicksman, 1986). The xyloglucan from tamarind seeds offers no chemical advantage over guar gum as a viscosifier, but tamarind flour is cheaper, indicating that a bioprocess to upgrade the tamarind polysaccharide might be commercially viable (Reid and Edwards, 1995).

In Nigeria, fruits have been analysed for their ascorbic acid content (Eromosele et al., 1991), but found not to be particularly rich in this vitamin.

In Malawi, tamarind fruits with 73.1% dry matter were found to contain: 85.0% total carbohydrate, 5.9% fibre, 1.6% fat, 4.1% crude protein (Saka et al., 1994). Ascorbic acid content is 19.7 mg per 100 g fresh weight (Saka, 1995), but α and β carotene are absent from both dried leaves and dried fruits (Nordeide et al., 1996).

3.5. *Zizyphus mauritiana Lam. (Jujube or Ber)*

The fruits of Jujube are one of the best edible wild fruits and some cultivars are planted. The fruits, which vary in size, are sweet and rather dry with a comparatively large stone and the larger fruits are often eaten raw (Booth and Wickens, 1988). The fruits are also boiled with rice and millet and stewed or baked. Alternatively they are made into jellies, jams, chutneys or pickles. They can also be candied or sun-dried.

Great variation has been recorded in the fruit's nutritional value (Becker, 1983; Geurts, 1982), but they are generally rich in sugars (5.4–23%), vitamin C (96–500 mg 100 g^{-1}), vitamin A and carotene (21–81 mg 100 g^{-1}). Eromosele et al. (1991) have reported that the fruits are rich in Ca (712.5 mg 100 g^{-1}) and Mg (227 mg 100 g^{-1}).

The potential of these fruits is virtually untapped in Africa, but is commercially exploited in India and Pakistan where cultivars are well developed–see also section below on this species under southern Africa.

4. Southern African plateau–Miombo woodlands

4.1. *Sclerocarya birrea (A. Rich) Hochst. (Marula)*

The products of this pan-African, dry forest tree (fruit, nuts, oils, juice, gums, etc.) have been extensively characterized in South Africa and the findings reviewed by Weinert et al. (1990). The fruits and nuts, in particular, have considerable commercial value. The fruits (Fig. 14), which vary 30-fold in their reported flesh:stone ratio, are described as having exotic flavour and high nutritive value (e.g. vitamin C is 2–3 times that of orange), with a few trees yielding 1.5 tonnes of fruit per tree. The strong aroma of the fruits has also been characterized by freon 11 or 12 extraction and over 100 components have been identified.

The nuts too have been described as a delicacy and yield an oil with a quality (fatty acid composition) comparable with olive oil, but with a stability that is 10 times greater. This stability is explained in terms of its tocopherol/sterol composition (Δ^5-Avenasterol and α-tocopherol). The amino acid content, with the exception of lysine which is deficient, has been likened to human milk and whole hens' eggs. It has been concluded that the oil could be of value to the food industry where it could be used as a coating of dried fruit, as a frying oil or as a substitute for high-oleic safflower oil in baby foods.

Proximate analyses performed on fruits from different areas of southern Africa reveal some variation that may be either genetic or environmental. The causes of this variation need to be investigated as genetic variation of this magnitude would be of importance to domestication programmes. Similarly the ascorbic acid content of Marula fruits in Nigeria (403 mg 100 g^{-1}) has been reported to be twice that found in Botswana, although it is said to vary considerably depending on the stage of ripening, being highest in ripe fruits (Eromosele et al., 1991).

Fig. 14. Fruits and leaves from *Sclerocarya birrea*.

The gum of Marula is acidic and has a low intrinsic viscosity, low molecular weight and high methoxyl content. The main sugar in the gum is galactose (63%), without any rhamnose (Weinert et al., 1990).

White edible flesh surrounds a large nut, which contains three edible kernels. The nut represents about 50% of the weight of the fruit (Taylor and Kwerepe, 1995). In some trees the fruit pulp is sweet and in others very sour. Fruits are rich in vitamin C (194 mg per 100 g at 85% moisture). They are very popular in Botswana and are used to make a local beer. They can vary between 10.4 and 16.0 degrees Brix (sweetness). In South Africa, the Mitsubishi Corporation have also brewed a beer 'Afreeka' which has been undergoing market trials in UK in 1997. Also in South Africa, the internationally popular liqueur, 'Amarula', is marketed by Distillers Corporation. In Zambia a wine, 'Marulam', is also marketed commercially (Fig. 15). A pasteurised juice has also been marketed in Botswana and early 'browning' problems overcome (Taylor and Kwerepe, 1995). Juice flavour has been evaluated by a tasting panel, who quantified 19 characteristics of flavour, odour, mouthfeel and aftertaste. The prominent trait identified was sourness although one of five juices was much sweeter than the others (Schäfer and McGill, 1986). General experience suggests that there is considerable variation between trees within the species in sweetness, and that trees from drier environments are sweeter than from wetter areas. Numerous small enterprises in the countries of southern Africa produce Marula jam and jellies.

The nut kernels are nutritious and widely eaten. Kernel oil is also highly prized both for cooking and for cosmetics. At 96% dry matter, the kernel is 57.3% fat, 28.3% protein, 3.7% carbohydrate and 2.9% fibre (Taylor and Kwerepe, 1995) and rich in phosphorus and magnesium. Ogbobe (1992) has, however, reported from Nigeria, that the kernels contain 11% crude oil, 17.2% carbohydrate, 37% crude protein, 3% fibre and 1% saponins. He also reported that the oil contains nine fatty acids of which palmitic, stearic and arachidonic acids are the most dominant.

Fig. 15. 'Amarula' liqueur and 'Marulam' wine made from fruits of *Sclerocarya birrea*.

Marula fruits fall from the tree before they are ripe, while still green, and turn yellow as they ripen on the ground. After gathering, the ripening process in storage involves concurrent changes in pH, total acids and total soluble solids. The process reaches a climax after seven days (Weinert et al., 1990). Fallen fruit have a storage life of 14 days at 12.8°C. After 21 days, 89% of fruits have rotted. There are contradictory results from low temperature storage, with one report that fruits can be kept for 16 days at 4°C and another indicating that temperatures of 9°C cause damage.

Figures about the current level of production seem to be unavailable, but in 1985 it was estimated that 600 tonnes of juice were processed in South Africa. Since then there has been the introduction of several alcoholic beverages onto the international market, suggesting that the current figure must now be considerably higher. It is assumed that further growth is constrained by the fact that harvesting is restricted to the collection of fruits from wild trees, although domestication programmes have been initiated in South Africa, Botswana and Malawi.

Much research has been done on juice, extraction, product characterization and processing (see Weinert et al., 1990). Variation in total soluble solids of puree and juices varied between 7.5° Brix and 15.5° Brix over three seasons, the lower value coinciding with a drought and the higher value with a wet year. Total titratable acidity was similarly affected, altering the sugar:acid ratio, an index for sensory quality in fruit juices. Sensory characteristics have also been evaluated by 14 descriptor terms; including odour, flavour, mouthfeel, aftertaste, etc. The combination of these traits and those of yield are currently being used in South Africa to register cultivars for testing horticulturally for commercial fruit production.

4.2. Uapaca kirkiana *Muell. Arg. (Masuku or Mahobohobo)*

The fleshy pulp of the Masuku fruit (Fig. 16) is eaten fresh or processed into a variety of products: juices, squashes, wines, sweet beer, porridge, jams and cakes (Ngulube, 1995). In Zambia, popular brands of wine are 'Masau' and 'Mulunguzi'. They are produced commercially and sold in supermarkets. A beer called 'Napolo Ukana' and a gin called 'Kachasu' are produced.

In Zambia the fruits of Masuku are mostly (80%) cream coloured, but others are rufous (18%) and a few

Fig. 16. Fruits growing on *Uapaca kirkiana* in Zimbabwe.

brown (2%) (Mwamba, 1995), with trees bearing cream-coloured fruits having the greatest fruit load. The pulp forms only about 45% of the fruit, the skin being 38% and the seed 17%.

In Malawi, Uapaca fruits with 27.4% dry matter were found to contain: 86.5% total carbohydrate, 8.4% fibre, 1.1% fat and 1.8% crude protein (Saka et al. 1994). Ascorbic acid content is 16.8 mg per 100 g fresh weight (Saka, 1995).

The total free sugar content of Masuku fruit juice from Zambia is 8.5% (Sufi and Kaputo, 1977) as determined by paper chromatography and confirmed by ultra violet absorption spectrophotometry. It contains glucose (4.1%), fructose (2.7%), sucrose (1.5%) and xylose (0.2%).

4.3. Zizyphus mauritiana *Lam. (Jujube or Ber)*

In Malawi, Zizyphus fruits at 14.8% dry matter were found to contain: 73.0% total carbohydrate, 3.4% fibre, 9.5% fat, 4.1% crude protein (Saka et al., 1994). Ascorbic acid content is 13.6 mg per 100 g fresh weight (Saka, 1995).

See also section above on Jujube in the Semi-arid Lowlands of West Africa.

4.4. Vangueria infausta *Burch. (Wild Medlar)*

Vangueria fruits in Malawi have been found to contain at 26.5% dry matter; 78.1% total carbohydrate, 10.2% fibre, 2.6% fat, 5.7% crude protein (Saka et al., 1994). Ascorbic acid content is 16.8 mg per 100 g fresh weight (Saka, 1995). In Botswana, an ascorbic acid content of 4.7 mg per 100 g has been reported for fruits with 64.4% moisture.

4.5. Azanza garckeana *(F. Hoffm.) Exell and Hillcoat (Snotapple)*

In Malawi, Azanza fruit pulp at 52.8% dry matter was found to contain: 35.2% total carbohydrate, 45.3% fibre, 1.1% fat, 12.0% crude protein (Saka et al., 1994). Ascorbic acid content was 20.5 mg per 100 g fresh weight (Saka, 1995).

5. Western Amazonia

5.1. Inga edulis *Mart. (Inga or Guaba)*

The pulp around the seeds in the pod (Fig. 17) is sweet and tender and is widely marketed and eaten as a fresh fruit in Amazonia (Villachica, 1996). There is great variability within the species and potential to create cultivars, but there is not much published information on the nutritional aspects of these fruit. The pulp, which is over 80% water, is rich in carbohydrates and has high energy value. The nutritive value of fresh pulp is low, as reported by Villachica (1996). The fruits, which can normally be kept for only 3–4 days, can be stored in a refrigerator for three weeks. The embryos of this and other *Inga* species are cooked and are more nutritious than the fruit pulp (Pennington and Robinson, in press). Boiled embryos of *Inga ilta*, for example, contain 57.7% moisture, 13.5% protein, 0.2% fat, 1.2% crude protein, 23.2% starch and 4.2% soluble carbohydrates. The cooking probably degrades trypsin inhibitors and enhances palatability.

5.2. Bactris gasipaes *H.B.K. (Peach Palm or Pejibaye)*

The two major products from Peach Palm are the fruit (mesocarp) and the 'heart of palm' (Figs. 18 and 19), although the oil, wood and fibre are also valuable. The main markets for the fruit are as a delicacy for direct human consumption, as an animal feed, and as a starchy ingredient in bread and cakes. The fruit of Peach Palm, which vary in flavour and texture, are always eaten cooked as boiling breaks down a trypsin inhibitor that would otherwise have negative effects on human/animal growth. Considerable variation has,

Fig. 17. Exposed seeds and pulp in pods of *Inga edulis*.

Fig. 18. Fruits of *Bactris gasipaes.*

Fig. 19. Stems of *Bactris gasipaes* being prepared as 'Heart of palm'.

Fig. 20. Bottled fruits and canned 'Heart of palm' from *Bactris gasipaes.*

however, been reported in the presence of this inhibitor among different samples. Fruits are already marketed in jars and cans and can also be sold dehydrated.

Domestication of Peach Palm towards the different products and uses has arisen from farmer selection within Amerindian communities in tropical America (Clement, 1988). Consequently, eight or nine landraces can be identified, which are suited for different uses. Classification is based on fruit size (Clement, 1990): small fruits are generally more oily and fibrous (two landraces described); large fruits are starchy, low in oil and have a high pulp:seed ratio (2–3 landraces). The last four landraces are intermediate in size.

Proximate analysis of mesocarp samples have not taken into account the differences between landraces, but big variation has been reported (see review by Clement, 1990); for example, oil (8.3–23.0%, with one sample of 61.7%), protein (6.1–9.8%, with one sample of 17.5%), N-free extract (59.5–79.9%), fibre (2.8–9.3%). Analyses of the composition of mesocarp protein have shown that all the essential amino acids are present, although at lower levels than in maize. Arginine (7.3–9.2%) and glutamic acid (4.7–6.3%) are the most abundant. The mesocarp is frequently extremely rich in β-carotene, although there is big variation in the presence of this pro-vitamin (Arkcoll and Aguiar, 1984).

Mesocarp oil quality has been studied in more detail than protein quality (e.g. Silva and Amelotti, 1983) and it contains both saturated (29.6–46.3%) and unsaturated (53.3–69.9%) fatty acids, with palmitic acid (29.6–44.8%) and oleic acid (41.0–50.3%) the most abundant respectively. It seems that the triglyceride structure is extremely variable, even within samples. This should allow opportunities for genetic selection at the clonal level. A study of the tocopherols and tocotrienols showed a strong predominance of α-tocopherol (Lubrano et al., 1994). Although the more primitive landraces are apparently rich in oil, there is a problem of extraction as the oil, starch and water form an emulsion that has to be solvent-extracted (Clement and Arkcoll, 1985).

As an animal ration, Peach Palm fruit flour can substitute for maize, sorghum or wheat and has been widely tested as a meal for chickens, usually as a partial substitute for cereals (e.g. 50%), especially for older birds (Clement, 1990). For pigs, silaging of fruits has been reported to be an excellent means of storing the fruits, which may also be acceptable to cattle. Animal feeds would usually be based on the starchy fruit varieties with low oil content.

Peach Palm flour has also been used in bread baking and at 10% substitution for wheat gives dough with excellent baking quality (Tracy, 1996), slightly less protein, more energy (from the oil) and more vitamin A (β-carotene). The flour can also be used in cakes.

Palmito or Heart of Palm is already grown commercially with more than 2000 ha in Costa Rica by 1990. It is, however, in competition with palmito of Acai (*Euterpe oleracea*), that has lower overheads as it is exploiting natural populations, but has lower quality control. Processing technology has been developed in Costa Rica and Brazil (Fig. 20). Uses, such as deep fried chips, are also being found for some of the residue from palmito preparation.

6. Conclusions

Farmers working with ICRAF throughout the tropics have identified the indigenous trees that they would like to see domesticated. They have also identified the traits which, from their perspective, should be improved. For example they would like to see the trees coming into production at an earlier age, the length of the productive season increased, the tree height reduced and, of course, the yield and quality of the products increased. The success of this initiative to domesticate fruit trees is, however, closely linked to commercial (Leakey and Izac, 1996), economic and policy issues (Cannell, 1989; Leakey and Tomich, 1999), but overridingly there is the need to develop and expand markets to provide the incentive to plant and manage trees in farmland. It is therefore important to examine what is known about the products and to identify ways in which they could be utilized and improved.

This review has indicated that there have been a few studies to characterize the products with commercial potential from the farmer-identified priority species. Very few of these, however, have looked at the range and origin of intraspecific genetic variation and the opportunities it presents to improve the yield and quality of the products. Furthermore, few if any of these studies have made any recommendations as to which components of the products should be improved to enhance their value to the food industry. Agroforestry researchers working in tree domestication need information from members of the food industry about the traits that they would like to see improved by genetic selection. The need is for information about characteristics that would make the products more competitive in the market, ensure their certification as a food additive, or enhance either processing or storage. Clearly, dialogue and collaboration between agroforestry researchers and food scientists is needed to ensure that progress towards tree domestication is coordinated and steered in a direction that is most likely to result in a significant adoption of novel products by the food industry.

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