5 Tropical fruits: a source of lipids

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5.1 Introduction

Approximately 40% of the earth's land mass is located in the tropics and it is here that most of the world's underdeveloped nations with their growing populations reside. The term tropical refers to the region between the tropics of Cancer and Capricorn or that region of the earth that lies between 23°27′ latitude north and south. The near constant warm temperature throughout the year is an important characteristic of the tropics. There is only a few degrees difference between the warmest and coldest months of the year and in fact the difference between day and night is greater than between winter and summer. The average temperature is about 27°C with very little variation in day length. The longest day is a little less than 13 h long. The subtropics encompasses the region from the tropics of Cancer and Capricorn to about 40° latitude north and south. The summers are hotter and the winters are cooler than in the tropics. The average temperature for the coldest month can approach 10°C. Generally, the humidity is lower and the difference in day length is greater than the tropics (Samson, 1986).

There are other more descriptive methods that are sometimes used to differentiate between tropical and subtropical plants. Plants that will not grow at temperatures below 5°C can be considered strictly tropical. In addition, those plants that are found in the temperature zone where coconut palms flourish are considered tropical while those found in the temperature zone where oranges thrive are considered subtropical (Popenoe, 1974).

Many countries located in the temperate zone have turned an envious eye to the tropics as a source of additional food resources. Because of improved transportation and preservation techniques, direct imports are a very convenient procedure for obtaining these food items. A second procedure that has been successfully implemented in a few cases is the transplantation of tropical plants for cultivation in northern regions with subtropical conditions such as Southern California and Florida. The banana and coconut are examples of fruits that have been exploited on a large scale. The avocado is gaining greater recognition as a food crop for export and the plant itself is being introduced into areas with more temperate climates.

B. S. Kamel et al. (eds.), *Technological Advances in Improved and Alternative Sources of Lipids*

The trends in global warming can have a direct impact on the cultivation of tropical fruits in the future. Most tropical fruits are killed by frost and even temperatures several degrees above zero can be damaging. Bananas will turn brown when exposed to temperatures below 12°C because the latex in the skin coagulates. Similar chilling injuries can occur to other sensitive tropical fruits such as soursop and sapodilla. Extremely high temperatures on the other hand can cause wilting, sun scald, necrotic spots and even death of plants. The fruits of northern climates (apples, pear, peach, cherry, etc.) require low temperatures in order to break the dormancy of the buds. An increase in global temperatures may have a profound effect on the types of fruit plants grown in the present day temperate zones.

Rainfall is another climatic variable that can have an enormous effect on the growth and production of tropical fruits. Rainfall is about 200 cm/year in the region 10° latitude on either side of the equator. Less then 100 mm/month rainfall is considered low in the tropics as evapotranspiration is usually 120–150 mm. However, more than 300 mm/month is not beneficial as the surplus cannot be stored in the soil and it encourages erosion and leaching. Ten well spaced showers of 10 mm will have greater benefits than one 100 mm downpour. Mangosteen, banana and papaya grow best with 100 mm or more of rainfall per month but there would be little problem if the level fell to 60 mm for a few months. Mango and cashew nut on the other hand need at least three dry months and not more than seven wet months to bloom and set fruits. Rambutan and durian need plenty of rain but can survive a few dry months. Dry months refer to the condition where transpiration exceeds precipitation. There are two wet and two dry seasons close to the equator. Near the 23rd parallel there is only one wet and one dry season. The closer one gets to the 23rd parallel, the longer the dry period lasts (Samson, 1986).

It is an unfortunate fact that many inhabitants of tropical countries suffer from lack of fresh fruits; and real starvation in densely populated hot regions such as India may be averted by the cultivation of high food value fruit trees such as avocado and mango on a large scale. The utilization of the fruit by-products such as kernel or seeds can also contribute a significant amount of edible oil and protein to the diets of native people. A number of research groups have begun a systematic search for new sources of fat and oils for supplementation of traditional oils or imported oils. These new and novel sources of oil may find uses not only for edible purposes but also for industrial raw material and as the base stock for cosmetic formulations.

Due to the scarcity of edible oil on the world market and the consequent high prices, many countries cannot afford the foreign exchange to purchase large quantities of this commodity. Therefore, many developing countries have initiated extensive research programs to identify new sources of oilseeds. In India for example, the seeds of *Hibiscus cannabinus* and *Hibiscus sabdariffa* of the Malvales family have been shown to contain 18–20% oil and work is in progress to render the dark colored crude oil safe for human comsumption (Mohiuddin and Zaidi, 1975).

An indigenous source of oil will reduce dependence on foreign supplies and at the same time stimulate a domestic industry. Some countries such as India are now in a position to export mango kernel oil. These new sources require only the collection of the fruit or fruit by-products and processing either by commercial procedures or utilizing village technology.

The need for new sources of oil and meal for human consumption and the possible discovery of novel oils with unique properties for use by the cosmetic and oleochemical industries has given the production and utilization of tropical fruits and fruit by-products renewed status.

5.2 Potential sources of fats and oils

A comprehensive listing of all tropical fruits that have been characterized for their lipid content and fatty acid composition would be impossible but Table 5.1 gives a reasonable overview of the potential for oil recovery from a wide variety of fruits harvested from lesser known tropical plants. The seed kernel is the main source of the oil and in some cases can be quite substantial. A few of these seeds contain over 60% fat.

The seed of *Couepia longipendula* contains 74.2% oil (Morton, 1987). This fruit is cultivated in Brazil and the kernel is consumed either raw, fried or roasted. The seeds are also sun dried and made into a special meal with manioc flour and sugar. The oil contains high levels of palmitic acid (25.2%) and oleic acid (26.5%) as well as the conjugated fatty acids, α-eleostearic (11.3%) and α-licanic acid (21.8%). Because of the presence of fatty acids with conjugated double bonds, the oil is recommended for industrial use only (Spitzer *et al.*, 1991b). *Acioa edulis* is another seed from the basin of the Rio Purus and the central Solimoes of Amazonia. The tree produces fruits with stones 9 cm long and 4.5 cm broad. The kernels are eaten raw by the natives or crushed and added to tapioca cakes. Like *Couepia longipendula*, the oil from this seed contains similar levels of palmitic, oleic and conjugated fatty acids, α-eleostearic acid (7.3%) and α-licanic acid (19%) (Spitzer *et al.*, 1991a).

The seed kernel of the chironji (*Buchanania lanzan* Anacardiaceae) a fruit found in India, Burma and Nepal contains 65.6% oil on a dry weight basis. The kernel oil is used as a substitute for olive and almond oils in India. The major fatty acids are oleic (63.2%), palmitic (33.8%) and stearic acid (2.0%) (Hemavathy and Prabhakar, 1988).

The seed of the Guindilla (*Valenzuela trinervis* Bert.) contains 67%

Table 5.1 Lipid levels in tropical and subtropical fruits

Scientific name	Fruit part	Lipid (%)	Reference
Banana	Dry peel	6.98	Chaudry and Farooqi (1970), Goldstein and Wick (1969)
Moringa peregrina (yassar)	Seed	27–54	Somalia *et al.* (1984)
Feronia elephantum Correa (wood apple)	Seed Pulp	34.0 1.5	Ramakrishna *et al.* (1979)
Buchanania lanzan Anacardiaceae (chironji)	Dry kernel	65.6	Hemavathy and Prabhakar (1988)
Cedrella odorata	Seed	18.0	Balogun and Fetuga (1985)
Lovoa trichilloides	Seed	25.9	Balogun and Fetuga (1985)
Khaya senegalensis	Seed	45.5	Balogun and Fetuga (1985)
Carapa procera	Seed	53.4	Balogun and Fetuga (1985)
Enthandrophragma angolense	Seed	52.0	Balogun and Fetuga (1985)
Azadirachta indica	Seed	17.4	Balogun and Fetuga (1985)
Terminalia catappa	Seed	40	Balogun and Fetuga (1985)
Valenzuela trinervis Bert. (guindilla)	Seed	67.0	Aguilera *et al.* (1986)
Hibiscus sabdariffa L. (roselle)	Seed Pulp	17–21 2.6	Al-Wandowi *et al.* (1984), Shoeb (1970), Mohiuddin and Zaidi (1975)
Trichilia emetica (mafura)	Kernel	55–65	Fupi and Mork (1982)
Carissa spinarum	Seed	22.4	Rao *et al.* (1984b)
Leucaena leucocephala Benth. (kubabul)	Seed	6.4	Rao *et al.* (1984b)
Physalis minima L.	Seed	40.0	Rao *et al.* (1984b)
Annona squamosa L. (custard or sugar apple)	Seed Pulp	18–26.5 0.1	Shoeb (1970), Ansari *et al.* (1985), Beerh *et al.* (1983), Rao *et al.* (1984a)
Annona muricata L. (guanabana or soursop)	Seed	23.9	Asenjo and Goyco (1943), Awan *et al.* (1980)
Hevea brasiliensis (para-rubber) toxic	Seed	50.2	Ravindran and Ravindran (1988)
Rhus coriara L. (sumach)	Seed	16.0	Erciyes *et al.* (1989)
Ecballium elaterium L. (squirting cucumber)	Seed	31.0	Erciyes *et al.* (1989)
Celtis australis L. (nettle tree)	Seed	48.0	Erciyes *et al.* (1989)
Gundelia tournel fortii L.	Seed	39.2	Erciyes *et al.* (1989)
Platonia insignis Mart. (balcuri)	Seed Pulp	65.0 2.0	Bentes *et al.* (1986)
Rheedia acuminata Planch (bacuripari)	Seed	15.5	Bentes *et al.* (1986)
Calodendrum capense L.f. Thunb	Kernel	60.0	Munavu (1983)
Hyoscyamus niger	Seed	28.4	Shoeb (1970)
Canarium schweinfurthii Engl. (aiele)	Pulp	40.0	Georges *et al.* (1992)
C. luzonicum	Kernel	68–74	Georges *et al.* (1992)
Buchanania lanzan	Seed	50.0	Sengupta and Roychoudhury (1977)
Lucuma caimito Roem (abio)	Seed	13.2	Schuch *et al.* (1984)
Acioa edulis (cotia chestnut)	Seed	73.6	Spitzer *et al.* (1991a)

Table 5.1 *Continued*

Scientific name	Fruit part	Lipid (%)	Reference
Couepia longipendula (castanha de galinha)	Seed	74.2	Spitzer *et al.* (1991b)
Brunfelsia americana	Seed	30.0	Daulatabad and Hosamani (1991)
Brachystegia nigerica (achi)	Seed	7.3	Obasi and Ndelle (1991)
Murraya koengii L.	Seed	4.4	Hemavathy (1991)
Azima tetracantha	Seed	12.0	Daulatabad *et al.* (1991)
Thevetia peruviana	Seed	41–72	Obasi *et al.* (1990)
Acacia arabica	Seed	5.2	Maity and Mandel (1990)
Actinodaphne hookeri (pisa)	Seed	37.4	Shah *et al.* (1983)
Madhuca butyraceae (phulwara)	Kernel	54.4	Shah *et al.* (1983)
Citrus sinensis (sweet orange)	Seed	39.8	Subrahmanyam and Achaya (1957a)
Tectona grandis (teak)	Kernel	40–45	Sabrahmanyam and Achaya (1957a)
Bactris gasipaes (pejibaya)		3.1–8.2	
Persea schiedpana (coyo)		5.6–7.6	Morton (1987)
Rheedia brasiliensis (bakupan)		8–9	Morton (1987)
Blighia sapida (akee)		18.8	Morton (1987)
Grewia subinaequalis (phalsa)	Seed	7.2	Morton (1987)

oil. The main fatty acids are oleic (62.3%), gadoleic (12.9%), linoleic (10.1%) and palmitic (9.6%). The protein content is 35% on an oil-free basis. The major drawback to this oil is the presence of toxic cyanolipids (Aguilera *et al.*, 1986).

Mufura oil is obtained from the seed of the mufura tree (*Trichilia emetica*) which grows in parts of East Africa as well as in some West African countries. The kernel of the seed contains 55–65% fat and 13% protein. Greater use of the oil and meal have been prevented by the presence of a strong bitter and emetic taste and also a brownish color in both oil and meal (Fupi and Mork, 1982).

Thevetia peruviana is a shrub that thrives in both arid and wet climates. The cultivar grown in Nigeria showed a seasonal variation on the yield and composition of the seed oil. Ripe and unripe seeds collected in December and February (dry season) gave average yields of 72% and 52%, respectively, and those from May and August (rainy season) gave 56% and 41%, respectively. The major fatty acids in oils from all seasons were oleic (30–44%), palmitic (15–30%), linoleate (10–19%) and stearic (4–16%). In August the unripe seed showed significant levels of shorter chain saturated fatty acids: lauric 18.6%, myristic 8.7%, capric 1.9% and caprylic 3.96%. This oil shows good potential for use as a pharmaceutical oil (Obasi *et al.*, 1990).

In the underdeveloped countries and in Nigeria especially, the search for novel and cheap sources of protein and oil for animal, human and industrial purposes is an ongoing activity. To achieve these goals, a screening program was carried out to assess the potential of 60 under-utilized wild seeds and nuts as potential alternative sources of protein and oil. Three members of the Meliaceae (*Khaya senegalensis*, *Carapa procera* and *Enthandrophragma angolense*) and one member of the Combretaceae families (*Terminalia catappa*) have seeds with oil contents over 40%. Based on fatty acid compositions of these oils, the utilization can be directed toward edible and industrial applications (Balogun and Fetuga, 1985).

The berry-like fruit of *Physalis minima* L. is found in India where it is used in Indian cookery. The seed contains 40% oil with a high linoleic acid content of 61.4% (Rao *et al.*, 1984b).

Four Turkish plant species were investigated by Erciyes *et al.* (1989) for their fruit seed oil as a possible resource for industrial raw material. They found that *Rhus coriaria* L. (Sicilian sumac) contains 16% oil in the kernels dry weight basis, *Ecballium elaterium* L. (squirting cucumber) 31% oil in seeds dry weight basis, *Celtis australis* L. (nettle tree or southern hackberry) 48% oil in dry kernels and *Gundelia tournefortii* L. 39% oil in dry achenes is a thistle-like stout perennial herb. All are rich in linoleic acid in the range 48–74%.

Buchanania latifolia grows in the dry deciduous forests throughout India. The seed yields 50% of a colorless oil. The seed kernels are eaten raw or roasted and form a substitute for almonds. The light yellow oil is used as a substitute for olive oil and almond oil. The major fatty acids are linoleic acid (53.7%) and palmitic acid (33.4%) (Sengupta and Roychoudhury, 1977). Other linoleic rich fats were investigated by Subrahmanyam and Achaya (1957a) in their search for new and potentially useful sources of fats. The four seed fats of Indian origin were sweet orange (*Citrus sinensis*) 39.8%, *Coffea arabica* 11.8%, *Coffea robusta* 10.0% and *Tectona gradis* 40–45%.

The oil content of four Egyptian citrus seeds revealed levels ranging from 40.2 to 45.4% for orange, mandarin, lime and grapefruit. Palmitic, oleic and linoleic acids were the major fatty acids in all oils. The lime oil content, however, showed unusually high levels of linolenic acid (42.2%) (Habib *et al.*, 1986).

The fruit pulp is normally a poor source of oil in most tropical fruits (Table 5.1). The noted exceptions are olive and avocado. The levels found in most fruit pulps range from a trace to 2%. Banana pulp contains 1.1% oil but the peel has four times as much at 6.9% (Goldstein and Wick, 1969). *Hibiscus sabdariffa* L. pulp has 2.6% fat, *Annona squamosa* L. has 0.1% fat *Platonia insignis* Mart has 2.0% and guava pulp about 0.5%.

One plant that produces a fruit with high fat levels in the pulp is

Canarium schweinfurthii Engl. (Burseraceae) (Georges *et al.*, 1992). This tree grows wild in Africa from Sierra Leone to Angola. In the Ivory Coast, it is found in the coastal forest and in the semi-forest areas of the interior. The tree produces a fruit similar in appearance to the olive. The fleshy pulp of the fruit is edible. On a dry matter basis, the fruit pulp contains 30–50% fat, 5.6% protein, 8.2% starch, 11.8% cellulose and 8.3% ash. Three types of fat are obtained from the fruit pulp depending on the degree of maturity. The liquid *Canarium* contained 89.4% oleic acid, the semi-solid fat contained 67.7% stearic and 30% linoleic acid and the solid fat contained the highest level of stearic acid at 84.0% with only 14.7% linoleic and 1.3% palmitic acid. The solid type *Canarium* fat has a melting point of 44°C, solidification point of 35.5°C and an iodine value of 36.

New oilseed and other oil-bearing crops need to be investigated for potential industrial uses. The industrial applications include oils for lubricants, surfactants, insulation, inks, varnishes and adhesives and possibly fuel. To be competitive, these crops must be high in oil content and grow on soils and in climates that are not suitable for normal farming. A survey of the fruits listed in Table 5.1 shows the presence of important fatty acids in very high amounts. For example, the fruits with high oleic acid content include guindilla (62.3%) (Aguilera *et al.*, 1986), roselle (66–77%) (Al-Wandowi *et al.*, 1984) and chufa (73%) (Linssen *et al.*, 1988).

Chufa is a small tuber that grows around the Mediterranean Sea. It tastes like almond or hazel nut and is called in some countries 'Earth-almond and Earthnut'. In Egypt, chufa is soaked overnight and consumed fresh. The most popular application is horchata de chufa, a milky looking extract sweetened with sugar and consumed as a refreshing beverage. Other applications are chufa flour and oil. The yield from oil-pressing of the chufa tuber is 45–55%. The fatty acid composition of chufa oil is very similar to olive oil (Linssen *et al.*, 1988).

Other important fatty acids include lauric acid and ricinoleic acids. The primary source of lauric acid is coconut and palm kernel oils although recently other plants have been shown to be potential new sources such as cuphea. The kernel oil from *Umbellularia californica* Nutt. collected from trees growing at the Royal Botanic Gardens, UK was characterized. The yield was 31% oil and the percentage lauric acid in the crude oil was 23%. These results were lower than those reported for trees growing in America. Differences in climate or the physiological state of the plant may have caused the differences. The yield from American grown kernels ranged from 43.3 to 64% and the percentage of lauric acid ranged from 58 to 70%.

The white crystalline material isolated from the seeds of *Umbellularia californica* consisted mainly of dilaurocaprin with smaller amounts of trilaurin and dicaprolaurin and a trace of tricaprin. The white material had a sharp melting point at 35°C (Reynolds *et al.*, 1991).

Azima tetracantha is a flowering shrub that grows in India with a seed oil content of 12% (Daulatabad *et al.*, 1991). Major fatty acids are linoleic (28.8%), linolenic acid (22%) and oleic acid (15.3%), with smaller amounts of palmitic (5.2%), myristic (4.2%), lauric (3.5%) and stearic (1.6%). This seed contains three unusual fatty acids: ricinoleic (9.8%), malvalic (4.0%) and sterculic (5.6%).

Brunfelsia americana is a free flowering shrub native to tropical America. The oil content of the seed is 30%. The major fatty acids are C18:2, C18:1, C16:0 and C18:0 at 58.8, 16.9, 9.7 and 5%, respectively (Daulatab and Hosamani, 1991; Daulatabad *et al.*, 1991). Fatty acids as reported in *Azima tetracantha* are found in this shrub: ricinoleic acid (5%), malvalic acid (1.1%) and sterculic acid (1.4%).

The *Annona squamosa* Linn. (Annonaceae) is a small tree native to tropical America and the East Indies. It is cultivated in India for its fruit. The seed contains 23% oil with 9.8% isoricinoleic acid. The major fatty acids are oleic (37%), palmitic (25.1%), linoleic (10.9%) and stearic acid (9.3%) (Ansari *et al.*, 1985).

5.3 Important sources of lipid

The range of extractable lipids from selected tropical and subtropical fruits are listed in Table 5.2. A detailed discussion of each fruit is given in this section.

5.3.1 Mango

The mango tree (*Mangifer indica*) is cultivated widely in many tropical and subtropical countries. The world production in 1978 was 13 million tonnes with India and Pakistan accounting for 9.0 and 0.6 million tonnes, respectively (Lakshiminayana *et al.*, 1983; Van Pee *et al.*, 1981). According to some estimates, the world exports of fresh mango are in the range of 15 000–20 000 tonnes per annum (Osman, 1981). In Bangladesh, the annual production of mangoes is about 500 thousand tonnes. Based on these numbers, the total annual production of mango fat could be over 10 000 tonnes. If properly collected and extracted, mango fat could be an abundant source of vegetable fat for developing countries (Ali *et al.*, 1985). About 4682 hectares were devoted to mango cultivation in Malaysia with a total production of about 11 000 tonnes (Augustin and Ling, 1987).

Mangos are also grown in the Philippines, Indonesia, Thailand, Burma, Sri Lanka, Northeast Australia, Zaire, Egypt, Israel, South Africa, Hawaii and the West Indies. It has been introduced to the Americas and

Table 5.2 Fat content of different parts of tropical fruits

Fruit	Part	Range of fat content	Reference
Avocado	Fruit Pulp Mesocarp	59 8–26 18–24	Abou-Aziz *et al.* (1973), Barua and Goswami (1981), Gaydou *et al.* (1987), Berry *et al.* (1978), Lewis *et al.* (1978), Frega *et al.* (1990)
Buffalo gourd	Seed Root	24–36 0.7–9.7	Vasconcellos and Berry (1982), Berry *et al.* (1976, 1978), Khoury *et al.* (1982), Vasconcellos *et al.* (1981), Scheerens and Berry (1986)
Durian	Aril Seed	3.8–5.2 0.5	Berry (1979, 1981)
Guava	Seed Pulp	9.4–10.1 0.6	Berry (1980), Beyers *et al.* (1979)
Jackfruit	Seed	6.1	Daulatabad and Mirajkar (1989)
Papaya	Seed Pulp Endosperm (dwb)	9.5–28.8 2.5 60.4	Chan *et al.* (1978), Subrahmanyam and Achaya (1957a), Marfo *et al.* (1986), Strocchi *et al.* (1977), Miralles (1983), Chan and Taniguchi (1985), Passera and Spettoli (1981)
Passion fruit	Seed	15–22	Assuncao *et al.* (1984), Gupta *et al.* (1983), Gaydou and Ramandelina (1983)
Tamarind	Seed Kernel	4.5–16.2 6–9	Marangoni *et al.* (1988), Morad *et al.* (1978), Andriamanantena *et al.* (1983), Pitke *et al.* (1977b)
Bread fruit	Seed Fruit	5.1–12.8 2.68–5.6	Achinewhu (1982)
Mango	Kernel Pulp	4–13 0.14–0.46	Lakshiminarayana (1980), Van Pee *et al.* (1981), Osman (1981), Hemavathy *et al.* (1987), Shah *et al.* (1983)
Okra	Seed Kernel	15–22 36.5	Rao *et al.* (1984b), Telek and Martin (1981)

is now being grown as a profitable crop in Florida, Mexico, Brazil and several other Latin American countries (Lakshiminarayana, 1980).

The dry mango stone consists of a 1:1 ratio of shell and kernel. Wide variations were found in the content, characteristics and composition of seed and fat of 43 varieties of mango fruit. The seed in fruit ranges between 3 and 25% and kernel in seed from 54 to 85% on an as is basis (Lakshminarayana *et al.*, 1983). The total lipid consists of 96.1% neutral and 3.9% polar lipids (2.9% glycolipids and 1.0% phospholipids) (Hemavathy *et al.*, 1987). The dry mango kernel from India contains 3.7–13% of a cream-colored oil with a melting point of 34–43°C and iodine value of 32–57. Its physical and chemical characteristics are very similar to that of cocoa butter.

The fruit is eaten fresh or processed into juice, jams and pickles. The mango kernel from 13 cultivars grown in Zaire, Africa, were analyzed for fatty acid composition (Table 5.3) and physico-chemical characteristics. Over 85% of the fatty acids are accounted for by oleic and stearic acids. The ratio of stearic/oleic varied from 0.56 to 0.97. The fatty acids incorporated in the *sn*-2 position were oleic and linoleic acids (Van Pee *et al.*, 1981).

The mango fruit in India has been cultivated for over 4000 years. In the Orient, it is called the 'King of the fruits'. There are 41 varieties of mango in India but only five are of commercial importance: Alphonso, Langra, Neelum, Totapuri and Rajapuri. Each variety has its own particular flavor and texture. The range in fatty acid composition is very similar to the mango grown in Zaire (Table 5.3).

Ten varieties of mango were collected from mango growers in Bangladesh and evaluated for variations in fat content and lipid class composition. Depending on climatic and soil conditions and the variations in varieties that grow in Bangladesh, the fat content of mango kernels varied from 7.1 to 10%, the hydrocarbon and sterol esters varied from 0.3 to 0.7%, triglycerides from 55.6 to 91.5%, partial glycerides from 2.3 to 4%, free fatty acids ranged between 3 and 37% as oleic, glycolipids were between 0.6 and 1.2% and phospholipids between 0.11 and 0.8%. The fatty acid composition of the triglyceride fraction is given in Table 5.3.

Two varieties of mango fruits (Taimur and Alphonse) found in Egypt were characterized by Abd El-Aal *et al.* (1987). The mango seeds represent up to 24% of the whole fruit and contained 9.7–10.8% edible fat. Low levels of hydrocyanic acid (0.04–0.05%) were detected in the kernel but the kernel lipids were found free of hydrocyanic acid. The major fatty

Table 5.3 Fatty acid composition and lipid levels in mango kernels

Fatty acid	Percent composition				
	Zaire[a]	India[b]	Bangladesh[c]	Malaysia[d]	Egypt[e]
Fat level	6.8–12.6	9.1–12.3	7.1–10.0	7.5–8.8	9.7–10.8
12:0	–	Trace–0.2	–	–	0.3–0.4
14:0	–	0.1–0.7	–	–	0.5
16:0	7.0–9.1	5.1–8.0	7.9–10.0	6.9–7.3	7.6–8.4
18:0	31.0–43.0	42.3–47.6	38.2–40.2	44.3–44.4	39.7–40.4
18:1	43.5–56.3	34.9–42.0	41.1–43.8	38.9–42.1	41.2–43.3
18:2	3.5–7.8	4.2–8.3	6.0–7.6	4.5–7.4	5.7–6.3
18:3	0.2–0.9	0.2–0.4	0.6–1.0	Trace–0.6	0.7–1.0
20:0	1.0–1.8	2.2–3.1	1.7–2.6	1.6–1.8	1.8–1.9

[a] Van Pee *et al.* (1981).
[b] Shah *et al.* (1983).
[c] Ali *et al.* (1985).
[d] Augustin and Ling (1987).
[e] Abd El-Aal *et al.* (1987).

acids are stearic and oleic acids with relatively high levels of linoleic acid (Table 5.3). These results are in agreement with previously published data.

5.3.1.1 Composition of pulp. The glyceride content and fatty acid composition of pulp from five commercial varieties of table ripe mangoes having wide differences in aroma and flavor were studied. The levels, however, were very low (0.14–0.46%) and do not represent a viable source of oil (Bandyopadhyay and Gholap, 1973).

5.3.1.2 Cocoa butter substitutes. Mango kernel oil can be used as a cocoa butter substitute or a partial replacer in the preparation of confectionery products. Moharram and Moustafa (1982) found that there were no differences in taste, texture and odor of butterscotch toffee when mango kernel oil was used in place of cocoa butter.

Cocoa butter is a unique naturally occurring fat containing mainly mono-unsaturated and di-unsaturated glycerides in which palmito-oleostearin constitutes a single dominant glyceride. Several workers have attempted to prepare cocoa butter like products from other fats that have some degree of resemblance to cocoa butter. The various methods tried include esterification (inter, trans, directed) hydrogenation and fractionation. All procedures attempted to produce a product with a melting point around 36°C and with properties of hardness and brittleness that are associated with cocoa butter. Fractionation was one of the better methods that was used to separate the glycerides into fractions with improved physical properties. These fractions could then be blended with natural cocoa butter without adversely affecting the original characteristics of the cocoa butter (Baliga and Shitole, 1981).

5.3.1.3 Glyceride structure. The major glycerides present in cocoa butter are the disaturated glycerides, oleopalmitostearin (52%) and oleodistearin (19%) while mango fats are high in di-unsaturated glycerides, stearodiolein (54%). Palmitic, stearic and arachidic acids were exclusively distributed among the *sn*-1 and *sn*-3 positions. Oleic acid represented 85–89% of the fatty acids at the *sn*-2 position (Van Pee *et al.*, 1980). The higher proportion of the major glyceride stearodiolein in mango fat is partially compensated for by the presence of the relatively high melting trisaturated glycerides, tristearin (5%) and palmitodistearin (9%) (Table 5.4).

The glyceride composition of mango fat reported by Baliga and Shitole (1981) showed that the proportion of disaturated to monosaturated glycerides is very low (0.4:1) compared to cocoa butter (3.7:1). Fractionation was therefore necessary in order to segregate a suitable fraction having properties similar to cocoa butter. The mango fat was successfully

Table 5.4 Fatty acid composition and glyceride structure

Fatty acid	Percent composition		
	Cocoa butter[a]	Mango fat[a]	Shea butter[b]
16:0	26.2	8.4	5.7
18:0	34.4	42.2	41.0
20:0	–	2.3	–
18:1	37.3	42.4	49.0
18:2	2.1	4.7	4.3
Glycerides			
SSS	2	14	–
SUS	77	24	–
SUU	21	61	–
UUU	–	1	–
SUS/SUU	3.7/1	0.4/1	–

[a] Baliga and Shitole (1981).
[b] Kamel and Kakuda (1992).

fractionated with acetone to produce a hard fraction. This fractionated mango fat was reported to be a good partial substitute for cocoa butter.

The fatty acid composition of mango kernel fat and the high levels of oleic and linoleic acids in the *sn*-2 position are very similar to that of shea butter (Barretdtet *et al.*, 1963). The fat from the kernel of (*Butyrospermum parkii*). Shea Butter is important commercially as an ingredient for the confectionery industry. From the study of Van Pee *et al.* (1981) it appears that mango kernel fat may be a good substitute for shea butter (Table 5.4).

5.3.2 Papaya

Papaya (*Carica papaya*) belongs to the family Caricacea which includes four genera and more than 20 species. The distribution can extend from latitude 32° north to 32° south where the weather is warm and humid and the elevation is less than 300 m above sea level. The fruit is commonly eaten fresh but can be cooked when immature or used in preserves, sauces or pies. The papaya in India is used in canning, candying and pickling as well as fresh consumption. It can be used as a source of papain for meat tenderizing and it is also an excellent source of vitamin C (Arriola *et al.*, 1980).

The projected production of papaya in Hawaii in 1980 was 40 000 tonnes per year. This volume of fruit will produce 11 000 tonnes of waste which is available for utilization. Seeds of Solo papaya obtained from the waste line of a papaya purée processing plant were air-dried and ground and extracted with diethyl ether. The seed accounts for about 14.3% of

Table 5.5 Fatty acid composition of papaya seed oil

Fatty acid	Percent composition						
	Hawaii[a]	India[b]	USA[b]	West Indies[b]	Nigeria[c]	Somalia[d]	Senegal[e]
Fat	9.5	24.9	–	–	28.3	25.5	28.8
12:0	0.13		–	–	0.01	0.15	1.2
14:0	0.16	0.2	–	4.6	0.04	0.44	1.0
16:0	15.1	17.2	12.0	13.0	16.6	16.0	16.1
16:1	–	1.3	–	–	–	0.72	0.5
18:0	3.6	3.6	5.5	1.8	1.9	5.5	3.1
18:1	71.6	77.3	80.0	80.6	79.1	73.0	71.4
18:2	7.7	0.4	2.2	–	2.6	3.9	5.3
18:3	0.6	–	–	–	–	–	0.4
20:0	0.87	–	0.3	–	–	0.64	0.5
22:0	0.22	–	–	–	–	0.14	–

[a] Chan *et al.* (1978).
[b] Subrahmanyam and Achaya (1957b).
[c] Marfo *et al.* (1986).
[d] Strocchi *et al.* (1977).
[e] Miralles (1983).

the weight of fresh papayas. The proximate composition of the papaya seed is 72% water, 9.5% fat, 8.4% protein, 9.4% total carbohydrate and 1.5% ash. On a dry weight basis, the fat content of the seed is 33% which is high compared to other fruit seeds. The ether extracted oil has a slightly green color with an iodine value of 74.8. The major fatty acids (Table 5.5) were oleic (71.6%), palmitic (15.1%), linoleic (7.7%) and stearic (3.6%). Only trace levels of lauric, myristic, arachidic, linolenic and behenic acids were found (Chan *et al.*, 1978).

The total lipid content of deseeded, frozen, lyophilized and powdered papaya fruits was found by Chan and Taniguchi (1985) to range from 1.7 to 2.5%. The total lipid levels were not greatly affected by stage of maturity but there was a general increase in unsaturation in the neutral, glycolipid and phospholipid fractions. They suggest that the increase in 16:1 and 18:3 fatty acids in the phospholipid fraction may be responsible for the increased resistance to chill injury observed in ripening papayas.

The results reported by Subrahmanyam and Achaya (1957b) showed that the papaya seed oil from India was slightly more saturated with about 4–5% more palmitic acid and only a trace of linoleic acid when compared to the American oil. Like olive oil, papaya seed oil is a good source of oleic acid with 77.3%.

Mature papaya fruits were collected from various locations in Nigeria. The testae were removed from the seeds before drying in an oven at 60°C. The seeds were ground into a powder for analysis. The proximate analysis showed 28.3% crude oil, 27.8% protein and 22.6% crude fiber (Marfo *et al.*, 1986).

The seeds from the papaya cultivated in Somalia account for about 16% of the fresh fruit weight. The air-dried seeds are soaked in water overnight to swell the membrane (sarcotesta) which can then be easily removed by hand to separate out the fleshy endosperm. The endosperm accounts for 43% of the dried seed. The endosperm and sarcotesta have different compositions with fat being the main component (60.4%) of the endosperm and crude fiber the major component of the sarcotesta. The level of fat in the endosperm is similar to that of sunflower, castor bean, sesame and coconut. The extracted oil is slightly green in color with 76% oleic and 15% palmitic as the major fatty acids. The fatty acid profile of Somalia seeds was similar to that of Hawaii grown papaya seeds (Chan *et al.*, 1978; Chan and Tang, 1979) but was lacking in lauric, myristic, arachidic and behenic acids (Passera and Spettoli, 1981).

Two samples of papaya oil extracted from dried papaya seed harvested in Somalia yielded 25–26% of an orange-yellow colored liquid with a smell of cress. The composition of fatty acid was similar to other reported values. The relatively high polyphenol content (2.5% in seed oil) gives the seed oil excellent stability to oxidation. The phosphatides are low while the carotenoids are significant (10 mg/100 g). Unlike the majority of vegetable oils, the terpenic alcohols constituted the most abundant fraction found in the unsaponifiable fraction (Strocchi *et al.*, 1977).

The fatty acid composition of the seed from papayas grown in Senegal was examined by Miralles (1983), in order to evaluate its potential as a new source of oil. The oil content and fatty acid composition are given in Table 5.5.

5.3.3 Avocado

Avocado (*Persea americana*) is a native of the highlands of Mexico and Central America. From here, the avocado spread to other regions of Central and South Amercia. It first appeared in Florida in 1833 and in California in 1856. Today, the avocado is grown in practically all tropical and subtropical countries of the world from a latitude of 40° north to 40° south. The production and export of high quality avocado fruit is concentrated in California, Florida, Israel and South Africa (Samson, 1986).

There are three primary races of avocado, Mexican, Guatemalan and West Indian. The cultivars of commercial importance are hybrids of these three races. The Mexican cultivars are well adapted to the cooler climates of tropical and subtropical areas. The West Indian cultivars are best adapted to the lowland tropical conditions of high temperatures and high humidity. The Guatemalan cultivars are intermediate between the Mexican and West Indian cultivars in climatic adaptation. Because of these differences, cultivars of the West Indian and Guatemalan races and their hybrids are grown in Florida, whereas cultivars of the Guatemalan and Mexican races and their hybrids are grown in California, Israel and South Africa (Ahmed and Barmore, 1980).

The olive and avocado are fruits with relatively high levels of fat in their pulp from which oil can be expressed. The fat content of avocados may range from 4 to 25% (Guillinta, 1974; Kawano *et al.*, 1976; Jacobsberg, 1988). Most other fruits have only 0.1–0.2% fat in their flesh on a wet weight basis. The large seed of the avocado contains less than 2% oil on a fresh basis and would not be economical for oil recovery (Haendler, 1965).

The avocado fruit grown in the north-eastern part of India has been analyzed for its chemical composition. The wet avocado pulp contained 25.1% total dry matter, 15.1% fat, 1.78% protein and 6% carbohydate (Barua and Goswami, 1981). Lewis *et al.* (1978) reported slightly higher oil yields (23.3–24.9%) from the ripe flesh of Fuerte type avocados grown in Australia. Similar results on oil yields were obtained by Frega *et al.* (1990) on varieties grown in Italy. The yields of pulp lipid from five avovado cultivars were: Fuerte (14.8%), Zutano (13.3%), Hass (11.2%), Lula (9.4%) and Bacon (8.7%) based on fresh material. The highest yields were reported by Aziz *et al.* (1975) on 15 Fuerte varieties of avocado treated with nitrogen fertilizer. The nitrogen fertilizer applications caused highly significant increases in fruit yields over control with average oil yields of 58.3–61.7%.

The fatty acid compositions of five cultivars grown in Italy are shown in Table 5.6. Palmitic acid was the major saturated fatty acid with only traces of stearic acid. Oleic acid, linoleic acid and palmitoleic acid were

Table 5.6 Fatty acid composition of avocado oil

Fatty acid	Percent composition		
	Italy[a] Cultivars[c]	Egypt[b]	
		Fuerte	Dueke
14:0	–	Trace	1.4
16:0	14.5–22.8	8.6	17.0
16:1	4.7–10.7	13.0	13.0
18:0	0.5–0.7	Trace	Trace
18:1 d9	42.9–61.7	41.9	47.2
18:1 d11	4.7–7.2	–	–
18:2	8.9–15.1	21.0	36.3
18:3	1.0–1.3	–	–

[a] Frega *et al.* (1990).
[b] Salem *et al.* (1976).
[c] Ranges for Bacon, Hass, Zutano, Lula and Fuerte cultivars.

the major unsaturated fatty acids. Measurable amounts (1–2%) of *cis*-vaccenic acid and linolenic acid were also found and Δ^5 avenasterol and β-sitosterol were the main constituents of the sterolic fraction (Frega *et al.*, 1990).

The gas chromatographic analysis of two varieties (Fuerte and Dueke) of avocado grown in Egypt revealed the following: the saturated fatty acids totaled 8.6% in Fuerte oil as against 18.4% in Dueke, the unsaturated acids were 91.3% and 81.4% in Fuerte and Dueke, repectively, myristic and stearic acids were found in small amounts and the palmitoleic acid content was the same in both varieties (Table 5.6).

5.3.3.1 Maturation. The mesocarps from four varieties of avocado were extracted for lipid and their fatty acid composition determined by gas chromatography. Four varieties (Lula, Bacon, Fuerte, Zutano) were grown under the same agroclimatic Mediterranean-like conditions and analyzed during the same growing season. The changes in lipid accumulation and fatty acid composition were followed from the 20th week after flowering (stage I) to 36 weeks after flowering (stage IV). Table 5.7 presents the average fatty acid composition of the four varieties at stage I to stage IV. The levels of all fatty acids decreased during the 20–36 weeks period except for oleic+*cis*-vaccenic acids which showed an increase. There were some significant differences between these results and those reported by Gaydou *et al.* (1987). The Lula variety in this study gave much lower palmitic and palmitoleic acids levels and approximately double the oleic acid levels than those reported by Gaydou *et al.* (1987). The cause for this difference could be the 3-week early harvest dates and variations in growing conditions. The sum of oleic and *cis*-vaccenic acids represents 57–70% of the fatty acids in stage I which increases to

Table 5.7 Fatty acid composition of avocado oils during maturation (weeks after flowering)

Fatty acids	Percent composition					
	12 weeks[a]	39 weeks[a]	20 weeks[b]	36 weeks[b]	4 weeks[c]	32 weeks[c]
12:0	–	–	–	–	1.0	Trace
14:0	–	–	–	–	2.2	0.15
16:0	22.4	25.6	12.9	9.0	22.2	14.4
16:1	5.4	12.0	2.5	1.8	5.9	13.3
18:0	0.9	0.7	0.7	0.5	2.1	Trace
18:1	42.2	45.6	64.5	77.1	9.8	62.6
18:2	22.2	15.2	12.2	8.5	40.1	9.5
18:3	3.3	0.7	1.9	0.9	10.4	Trace
Unknown	3.7	0.1	4.4	1.1	–	–

[a] Gaydou *et al.* (1987).
[b] Ratovohery *et al.* (1988).
[c] Abou-Aziz *et al.* (1973).

75–80% by stage IV. The unknown compound in the Fuerte variety showed the greatest drop from 8.8% at stage I to 2.4% at stage IV. The results presented suggest the use of fatty acid composition as a possible means to differentiate the various stages of fruit development (Ratovohery *et al.*, 1988).

The fatty acid composition of the oil from the Lula variety grown in Martinique was followed for 39 weeks. The lipid content increased steadily during the 12–39 weeks after flowering increasing from 2.7% to 18.5%. The fatty acid composition of mesocarp lipids did not show any significant changes between 16 and 39 weeks after flowering. There were, however, changes when compared to 12 weeks (Table 5.7). The levels of the unknown compound, linolenic and linoleic acids were higher and the content of palmitoleic acids was lower in the samples harvested 12 weeks after flowering (Gaydou *et al.*, 1987).

Changes in the lipid content and the fatty acid composition as a function of maturity were also studied by Abou-Aziz *et al.* (1973). The results of their study showed a similar increase in lipid content as the fruit matured. The percentages increased from 3.09 to 19% after 32 weeks for Fuerte and from 5.1% to 15.2% after 16 weeks for Dueke.

Lauric acid was only detected in the early stages and in small quantities (Table 5.7). In general, the percentage of the saturated acids was found to decrease as the fruit matured. In the first 4 weeks, the percentage of palmitic acid was 22.2% in Fuerte while at maturity the percentage was 14% (Abou-Aziz *et al.*, 1973). Oleic and palmitoleic acids were found to increase markedly with maturity while linoleic and linolenic acids decreased with maturity. Oleic acid was found to be the main acid at the maturity stage with 63% in Fuerte.

5.3.4 Buffalo gourd

The buffalo gourd (*Cucurbita foetidissima*) is found on the Chihuahuan Plateau of northern Mexico, New Mexico, Arizona and the coastal mountains of southern California. It has adapted well to the arid to semi-arid conditions of the western United States. Buffalo gourd is a perennial vine and produces a great many fruits. The fruits are round with a diameter of 5–7 cm. The fruit (pepos) were found to be 44% seeds and 56% pulp (Berry *et al.*, 1978). The number of seeds per fruit ranges from 200 to 300 with an average weight of 4 g per 100 seeds. This versatile plant is capable of producing a high quality oil from the seed, a good quality protein from the seed meal, starch from the roots, and because of its prolific vine growth, may have potential as an animal feed (Vasconcellos *et al.*, 1981).

The domestication of this plant is currently underway in Arizona. It may become a more profitable oilseed crop than sunflower in the high plains area of the south-western United States due to its potentially

Table 5.8 Fatty acid composition of buffalo gourd seed and root

Fatty acids	Percent composition		
	Seed[a] Arizona	Seed[b] Lebanon	Root[c] Arizona
14:0	Trace	Trace	1.6
16:0	6.6–24.4	9.3	21.8
18:0	1.2–10.2	2.1	3.0
18:1	10.0–31.6	25.0	3.8
18:2	39.3–77.2	63.6	24.8
18:3	–	Trace	43.6
Conjugated fatty acids			
Dienoics	1.9–2.8	–	–
Trienoics	0.0–0.10	–	–
Tetraenoics	–	–	–

[a] Vasconcellos *et al.* (1981).
[b] Khoury *et al.* (1982).
[c] Berry *et al.* (1978).

higher oil yield and greater drought tolerance (Gathman and Bemis, 1983). The physical and chemical properties of the seed oil from 15 genetically different selections were studied. The composition of the seed was 31.8–39.4% oil, 4.1–8.4% moisture and 49–66% protein in the defatted meal. The hexane extracted oil had a bland taste and odor with a dark reddish-brown to a light greenish-yellow color (Vasconcellos *et al.*, 1981).

The fatty acid composition of buffalo gourd seed oil (Table 5.8) from 15 genetically different selections showed a wide variation in levels suggesting the possibility of modification through plant breeding. The levels of linoleic acid averaged 61% and represents the predominate fatty acid. From UV spectra data, the conjugated fatty acid content was determined to be 2.3% which is about three times the levels found in cottonseed oil and about eight times the amount in soybean oil. The conjugated trienoic fatty acid levels were found to be 0.03%. Because of the low levels of these conjugated fatty acids there should not be a problem with the possible use of this oil for edible purposes (Vasconcellos *et al.*, 1981). The crude oil has a high carotenoid content of 100 mg/kg and the fiber content was 6.9%, an acceptable level for most monogastric animals (Berry *et al.*, 1976).

Berry *et al.* (1978) investigated the chemical composition of buffalo gourd root. The composition of the whole root on a dry weight basis was 10.9% protein, 9.7% lipid, 3.2% sugars, 54.5% starch and 4.8% lignin. The root oil is very different from the seed oil with the former containing a high level of linolenic acid (44%) (Table 5.8).

The phospholipid fraction comprised 2.9% of the crude oil. The composition is 55.8% PC, 18.7% PE, 17.2% PI, 2.8% LysoPC and 5.5% others (Scheerens and Berry, 1986). The composition is very similar to soybean lecithins and may indicate possible commercial uses. The fatty acid profile of isolated phospholipids revealed interesting contrasts to common patterns of the triglycerides fraction. Greater proportions of myristic and palmitic acids (7.4% and 21.45%) were found in the phospholipid fraction.

Feeding trials have shown that apparently buffalo gourd oil does not contain toxic substances that interfere with the growth rate of chicks (Khoury *et al.*, 1982). Similar studies on rats were conducted to evaluate the nutritional quality of the crude oil. When incorporated up to a level of 11% of the total diet in isocaloric and isonitrogenous diets, normal growth was observed for all oil levels. Buffalo gourd oil appears to be comparable to other commonly used vegetable oils with regard to its nutritional values (Vasconcellos *et al.*, 1981).

5.3.5 Okra

Okra (*Hibiscus esculentus* L.) can be found in the mild temperate, subtropical and tropical areas of the world. Okra is native to Africa but grows in Turkey, Greece, South America and the Middle East and is extensively cultivated in the southern United States. The tender pods are edible and have been used as an ingredient for pickles, soups and gravies.

Okra has not been cultivated as an oilseed crop mainly because of excessive seed loss that occurs when the mature pods ripen and shatter. Mechanical harvesting has only increased the losses and made the cultivation of okra uneconomical. There have been advances in this area, however, with the development of several shatter-proof varieties with higher seed yields and oil content. Seed yields of 1350–2250 kg/ha have been reported on rich delta soils in Louisiana, but in Texas only 740–1120 kg/ha of seed were harvested. However, when hand harvested in a small plot under the same conditions in Texas, a yield of 3144 kg/ha of seed was obtained (Telek and Martin, 1981).

Six varieties of okra were shown to have seed oil levels that ranged from 15.3 to 22%. The separated kernels contained 42–56% protein and a similar amount of oil (Telek and Martin, 1981). Rao *et al.* (1991) reported whole seeds and kernel contained 21% and 38.9% protein and 17.9% and 36.5% fat, respectively. A number of workers have determined the fatty acid composition of okra seed oil and the results are shown in Table 5.9. The three major fatty acids are linoleic, palmitic acid and oleic acid.

The glyceride structure of okra seed oil was studied by Crossley and Hilditch (1951). They found close similarities to cottonseed oil. The

Table 5.9 Fatty acid composition of okra seed oil

Fatty acid	Percent composition	
	India[a]	Puerto Rico[b]
14:0	–	0.12–0.24
16:0	23.5	30.2–33.7
16:1	Trace	0.14–0.56
17:0	–	0.24–0.64
18:0	4.3	3.28–4.0
18:1	28.9	17.8–29.3
18:2	42.4	31.5–42.1
18:3	–	0.24–1.42
19:0	–	Trace–1.12
Others	<0.9	

[a] Rao *et al.* (1991).
[b] Telik and Martin (1981).

composition of glycerides included about 40% saturated oleo-linoleins, 25% tri-unsaturated glycerides (oleo-dilinoleins), 10% saturated dilinoleins and 23% disaturated glycerides.

5.3.6 Passion fruit

The yellow and purple forms of the edible fruited species of passion fruit (*Passiflora edulis*) originated in South America. The yellow fruited form is adapted to lowland tropical conditions and the purple fruited form is more accustomed to subtropical conditions or to higher altitudes in the tropics. There are over 400 known species of *Passiflora* but approximately 50 or 60 bear edible fruits. In Hawaii and Fiji, the yellow passion is the basis of the entire passion fruit industry. In Australia, Ceylon, Africa and India, the purple passion fruit is of greater importance (Chan, 1980).

The oil from the seed is a by-product of the juice processing industry in many countries. The seed furnishes a pale yellow oil with an average yield of 20%. The four major fatty acids are palmitic, stearic, oleic and linoleic acids (Table 5.10) with a total unsaturation level of 89.8% (Assuncao *et al.*, 1984).

Gaydou and Ramandelina (1983) reported the oil content in two varieties of passion fruit seeds to range from 22.0 to 24.2%. The fatty acid compositions were comparable and linoleic acid was the major constituent. The results were similar to those reported by Assuncao *et al.* (1984) and Rojas (1981).

One set of results from Gupta *et al.* (1983) did not agree well with published data. The seed yielded 15% oil but the fatty acid profile showed a number of discrepancies. Palmitic was 3 times greater, stearic was 5 times greater and oleic was 1.5 times greater than the other

Table 5.10 Fatty acid composition of passion seed oil

Fatty acid	Percent of composition				
	P. edulis[a] flavicarpa	*P. edulis*[b] Sims	*P. edulis*[b] flavicarpa	*P. edulis*[c]	*P. edulis*[d]
12:0	–	0.2	Trace	–	0.4
14:0	–	Trace	0.1	Trace	0.8
16:0	8.0	11.5	9.9	9.8	34.9
16:1	–	0.4	0.4	0.50	19.4
18:0	2.2	2.2	2.2	2.4	11.0
18:1	12.6	18.2	19.8	16.1	30.2
18:1ω-7	–	–	1.9	–	–
18:2	77.2	66.4	64.4	70.6	3.3
18:3	–	0.8	1.0	0.51	–
20:0	–	0.2	–	–	–

[a] Assuncao *et al.* (1984).
[b] Gaydou and Ramandelina (1983).
[c] Rojas (1981).
[d] Gupta *et al.* (1983).

reported values. The most striking differences were the larger percentage of palmitoleic acid (19.4%) and very low levels of linoleic acid (3.3%). The discrepancy in composition could be a reflection of varietal differences but more likely an environmental effect caused by climate, soil and growing conditions.

5.3.7 Tamarind

Tamarind (*Tamarindus indica*) is a large evergreen tree that grows under tropical and subtropical conditions. The tree matures in 10–12 years and can live up to 200 years. The tamarind belongs to the Leguminosae family and bears flat pod-shaped fruit which on ripening yields an edible pulp. The flat, brown seeds are decorticated and the kernel ground into a powder, tamarind kernel powder (TKP), and is used in the textile industry and also in the food industries because of the polysaccharides which form jellies with sugar concentrates over a wide pH range.

A partial listing of fatty acid compositions and oil levels in tamarind seed and kernel are given in Table 5.11. The Indian tamarind yielded 7.4% oil and is unique in having substantial quantities of behenic and lignoceric acid. The other unusual occurrence in tamarind kernel oil is the presence of both long chain saturated fatty acids and linolenic acid (Pitke *et al.*, 1977b). Since it has a large proportion of saturated fatty acids and its melting point (10–12°C) is relatively high, it can be classed under the vegetable butter group.

The tamarind fruit from six different areas of Madagascar were ana-

Table 5.11 Fatty acid composition of tamarind seed and kernel oil

Fatty acid	Percent composition			
	India[a] kernel	Madagascar[b] kernel	Egypt[c] seed	Trinidad[d] seed
Lipid	7.4	6.8–9.0	16.2	4.5
12:0	Trace	–	28.2	–
14:0	Trace	0.2	0.4	0.2
16:0	14.8	14.9–19.4	10.2	7.8
16:1	–	0.3	Trace	–
18:0	5.9	6.2–7.0	Trace	4.1
18:1	27.0	15.3–26.3	24.3	17.3
18:2	7.5	36.0–48.6	34.2	56.1
18:3	5.6	Trace–0.2	–	1.1
20:0	4.5	2.3–3.3	2.7	1.9
22:0	12.2	3.1–4.8	–	3.0
22:1	–	–	–	0.12
24:0	22.3	3.9–8.0	–	–
24:4	–	–	–	5.6

[a] Pitke *et al.* (1977b).
[b] Andriamanantena *et al.* (1983).
[c] Morad *et al.* (1978).
[d] Marangoni *et al.* (1988).

lyzed for their fatty acid and sterol compositions by Andriamanantena *et al.* (1983). The TKP when extracted with hexane yielded 6.0–6.4% oil and when extracted with chloroform/methanol yielded 7.4–9.0% oil. The fatty acid profiles (Table 5.11) were different from the Indian sample especially in levels of linoleic, behenic, lignoceric acids. The protein level in the Malagasy tamarind kernel powder was low ranging from trace to 0.1%.

The tamarind fruit that is grown in upper Egypt is brewed into a popular soft drink. The oil yield and fatty acid composition were very different from the Indian tamarind. The seeds contain 16.25% oil with a composition that is high in linoleic, oleic and lauric acids (Table 5.11). Lesser amounts of stearic and linolenic were present. The tamarind seed meal was also low in protein (2.66%) compared to other oil seeds (cottonseed, peanut) but does contain a substantial amount of sugar (25.28%) which would give the meal a high caloric value if used as an animal feed (Morad *et al.*, 1978).

A study was done by Marangoni *et al.* (1988) on tamarind grown in Trinidad which was reported to be typical of the West Indies. The seeds were separated from the pulp, washed, air-dried and ground. The crude fat and crude protein of the ground seed were 4.5% and 15.5%, respectively. The protein levels in the Trinidad tamarind were much higher than the Egyptian or Malagasy varieties. The fatty acid composition showed higher levels of linoleic acid (56.1%), lower levels of palmitic acid (7.7%) and a new fatty acid 22:4 (5.6%) not reported by others.

Other seed oil components analyzed for were phospholipids, sterols and glycolipids. The analysis of the tamarind seed oil from India by Pitke *et al.* (1977a) revealed that PC and PE were the major phospholipids whereas PI and PA were found in relatively small amounts. The main sterols found in Malagsy tamarind kernel oil were beta-sitosterol, compesterol and stigmasterol (Andriamanantena *et al.*, 1983). Manila tamarind seeds (*Pithecellobium dulce*) has been analyzed for its glycolipid composition in the seed oil by Kulkarni *et al.* (1991). The total glycolipids were separated into monogalactosyldiglycerides, digalactosyldiglycerides, sterylgalactosides, acylated sterylgalactosides and unidentified components.

5.3.8 Guava

The seed fat of the guava fruit (*Psidium guajava*) can be found growing in the villages and towns of West Africa. The pear-shaped fruit contains numerous small seeds that are 2–3 mm in diameter. The fruit can be eaten fresh or made into guava jelly or extracted for its juice. The trees can be grown in orchards and with the commercial production of juice from the fruit, a reasonable supply of seeds is produced which normally goes to waste. The characterization of the seed oil has been investigated by Opute (1976). The dried seeds were extracted with chloroform/methanol and yielded 9.4% fat. The fatty acid composition of this lipid material showed an extremely high linoleic acid content (79.1%). The remaining fatty acids were under 10% (Table 5.12).

In India, the guava fruit is eaten raw, stewed in sugar syrup, made into jams, jellies and sometimes guava cheese. With the rapid growth of

Table 5.12 Fatty acid composition of Nigerian and Indian guava seed oil

Fatty acid	Percent composition	
	Nigeria[a]	India[b]
14:0	Trace	1.2
16:0	9.7	8.9
18:0	3.4	4.8
18:1	7.8	53.9
18:2	79.1	29.2
18:3	–	1.1

[a] Opute (1976).
[b] Subrahmanyam and Achaya (1957b).

the canning industry, the collection of the guava seed can be easily accomplished and the recovery of the seed oil is therefore an economic possibility. The variety of guava fruit grown in India has a significantly different fatty acid profile. The oil content of the seed (10.1%) was the same but the linoleic acid content was lower (29%) and the oleic acid levels higher (54%) than that grown in Nigeria (Subrahmanyam and Achaya, 1957b).

5.3.9 *Durian*

The durian (*Durio zibethinus*) is cultivated in Southeast Asia with major production in Malaysia, Indonesia, Thailand and the Philippines. The fruit is 15–20 cm long, slightly oval in shape with a greenish color and covered with short hexagonal woody spines. The fruit consists of five compartments and each compartment contains an oval mass of cream colored pulp with two or three seeds about the size of chestnuts. The pulp has a strong flavor and odor which are very repulsive to some people but very pleasant and enjoyable to others. Approximately 30 species belong to the genus *Durio*. In Thailand two durian cultivars are commercially available, Kan Yao (long stalk) and Mon Tong (golden pillow). The thick pudding-like texture of the aril contains 60% moisture, 2% protein, 1.2% fat and 36% carbohydrates. The carbohydrates include a mannan and erythrodextron (Martin *et al.*, 1980).

The range in fatty acid composition of the aril from four durian clones is given in Table 5.13. The oil is composed primarily of palmitic and oleic acids with a high linolenic acid content when compared to most fruit coat fats. The fat content of the wet aril ranged from 3.8 to 5.2% (Berry,

Table 5.13 Fatty acid composition of durian aril and seed oils

Fatty acid	Percent composition		
	Durian clones[a]	Durian aril[b]	Durian seed[b]
14:0	0.5–0.8	0.3–0.91	0.12
16:0	32.3–39.8	28.9–34.1	12.2
16:1	2.3–8.5	5.2–7.1	1.1
18:0	0.8–2.2	1.2	1.4
18:1	45.8–53.6	42.1–58.9	8.4
18:2	1.8–3.2	3.2–7.8	6.5
18:3	2.7–7.0	2.2–5.7	11.3
22:0	–	–	1.1
Dihydrosterculic	–	–	2.5
Malvalic	–	–	15.7
Sterculic	–	–	38.5

[a] Berry (1981).
[b] Berry (1980).

1981). The seed on a wet basis contained 0.5% fat. The fatty acid composition of the seed oil is given in Table 5.13. The seed oil contained an undesirable amount of cyclopropene fatty acids which are not completely removed by cooking. These compounds have been reported to produce skin irritation and shortness of breath. It has been suggested that these seed should not be consumed in large quantities (Berry, 1980).

5.3.10 Breadfruit

Breadfruit has several botanical names, the most common being *Artocarpus communis* and *Artocarpus altilis*. The breadfruit tree grows best near the equator at elevations below 610 m. The tree can reach a height of 15–18 m with a truck diameter of 1.2 m. There are two types of breadfruit, the seedless and seeded type. The fruit of the seedless type contains 70–80% starch, 3.4–5.9% protein and 3–6% fiber. Breadnut is one of several seeded types that has many seeds embedded in a highly fibrous pulp. The breadfruit seeds were investigated for their nutritive qualities by Achinewhu (1982). He reported the breadfruit seeds contained 11.9% crude fat and 16.4% crude protein in the defatted meal. Palmitic (19%), stearic (18%), oleic (25%) and linoleic (31%) account for over 90% of the total fatty acids. The seeds can be boiled and eaten like chestnuts. Another seeded breadfruit is found in many parts of Africa and is called the African breadfruit (*Treculia africana*). The fruit has small brownish seeds which when roasted produce a groundnut-like aroma. It appears that to improve the utilization and consumption of breadfruit, a systematic investigation on the cultivation, chemical composition of the fruit and food preservation aspect must be carried out.

5.3.11 Jackfruit

Jackfruit (*Artocarpus heterophyllus*) is a large tropical fruit with a spiny skin and large seeds embedded in a highly pectic pulp. The seed is rich in starch and can be eaten after roasting or boiling. The air-dried seeds yield up to 6.1% crude oil with petroleum ether extraction. The oil is negative to Halphen and picric acid tests indicating the absence of cyclopropenoid and epoxy fatty acids. The fatty acid analysis showed a high level of linoleic (40.2%) and palmitic (30.2%) acids with a significant amount of linolenic (9.4%) and ricinoleic acids (7.2%) (Daulatabad and Mirajkar, 1989).

5.4 Commercial and village processing

The commercial processing of fats and oil requires expensive and sophisticated equipment. At the village level, some of the basic steps in oil processing such as cleaning, cracking and cooking of oilseed could be done but the more specialized procedures such as flaking, solvent extraction, or deodorization would be difficult if not impossible to perform. The technological capabilities of each country will determine the extent and the degree of sophistication used for their oil processing. A two-level arrangement may be the best situation for some of the lesser developed countries. The first level will be in the villages where the most economical and feasible oil processing procedures will be installed. The products will be prepared for individual or village consumption. The overriding concern at this level is simplicity and convenience. The second level will require a central location where more specialized equipment can be used. These facilities can supply the country as a whole to reduce imports or support an export market.

The literature contains only a few examples of the types of procedures used or required for oil processing of tropical fruits and fruit by-products. *Moringa peregrina* locally called Yassar in Saudi Arabia contains seeds that have been used as a source of oil. At the village level, the oil is extracted by boiling the seeds with water and collecting the oil from the surface. The extracted oil is called Al-Yassar (Somali *et al.*, 1984).

Mafura oil is obtained from the seed of the mafura tree (*Trichilia emetica*) which grows in parts of East Africa as well as in some West African countries. The kernel of the seed contains 55–65% fat and 13% protein. Greater use of the oil and meal have been prevented by the presence of a strong bitter and emetic taste and also a brownish color in both oil and meal. Improved refining techniques have improved the organoleptic properties of the oil and meal. Presently, mafura nut oil is used for inferior quality soaps. The raw meal can be extracted with aqueous alcohol to give a debittered meal with a protein content of about 36%. The mafura oil can be improved by a four-step process involving degumming with acetic anhydride and water, neutralizatioan with NaOH, followed by repeated washing with NaOH, brine and water, bleaching and deodorization at 220–240°C for 3 h. These procedures, however, will require very expensive equipment. The natives have been extracting a light yellow oil from the whole nut without the above-mentioned problems. They are using a technique they developed on their own in Tanzania. The whole nut is boiled for 10–15 min, dried in the sun and then agitated in water until a clear yellow oil of good quality is produced. This oil is from the husk of the mafura nut and can be collected in yields of 35–45% (Fupi and Mork, 1982).

Okra seed can be ground in a home grinder and the ground seed can be sieved on a simple screen to partially separate the hull from the kernel. The resulting meal had about 33% protein and about the same percentage of oil. This okra seed meal can be used in baked products where it subtitutes for part of the flour and part of the oil. Pilot plant studies for the commercial processing of okra seed have also been investigated.

Fairly efficient separation of the hard hull and the kernels was achieved with cracking rollers set to 0.38 mm followed by screening on 16-mesh sieves. Various low-boiling aliphatic hydrocarbons were found to be effective in solvent extraction. The flavors of both the deodorized and hydrogenated products were good. Hydraulic extraction of okra seeds produced a much darker oil than that produced by solvent extraction (Telek and Martin, 1981).

In India, a specially adapted mechanical mango stone decorticator, a mechanical disintegrator, an expeller with a stack cooker and a fixed bed batch extractor were used for the processing of mango kernel fat and meal. The depulped mango stones were collected and washed in a current of water. The washed stones were air-dried and then decorticated in a mango stone decorticator. The kernels were separated from the shells by screens having holes big enough for the kernels but too small for the wing-like shells. The kernels are dried in the sun to a moisture level of about 10%. After decortication, there were two possible pathways. In one, the dried kernels are broken into smaller pieces in a mechanical disintegrator and the coarse kernel particles are extracted with normal hexane; in the other pathway, the kernel are mildly cooked and passed through an expeller, and the resulting cake-like material is extracted with normal hexane. The cooked material has some advantages in that the cake is much easier to extract than the hard kernel. For extraction of the kernel, the cake material was placed into a fixed bed cylindrical vessel and hexane was percolated through until the miscella was free of fat. The extracts were combined and the solvent distilled off. The crude fat was alkali refined and bleached with bleaching earth and activated carbon. The cake was air-dried and then heated under a partial vacuum at 60°C to remove the last traces of solvent (Char *et al.*, 1977).

Raie *et al.* (1981) describe a technique for extracting mango kernel fat on locally constructed equipment in Pakistan. The mango stones were freed from the fruit pulp and skin, washed to remove unwanted material and dried in the sun. A locally designed and manufactured disintegrator was used to crush the mango stones at a rate of 58 kg/h. The crushed mango kernels were next separated from the shells by a sieving vibrator. The pieces of kernels were powdered and extracted with hexane.

Vasconcellos and Berry (1982) studied the effects of refining, bleaching and deodorization on the quality of the seed oil of buffalo gourd. The most effective conditions were found to be a triple refining scheme using 16° Be for 15 min at 65°C, 20° Be NaOH at 80% maximum and 20° Be at maximum, bleaching at 105°C for 10 min and deodorization with 5% steam at 210°C for 120 min. The major fatty acids in the oil following the recommended processing conditions were: 11.9% palmitic, 3.5% stearic, 22.0% oleic and 61.0% linoleic. The conjugated unsaturated fatty acids were reduced to 1.59%.

5.5 Toxicology

Not all seed oils and meals can be used for human or animal consumption due to the presence of toxic or antinutritive substances. The seed kernel of the para rubber (*Hevea brasiliensis*) on a dry weight basis contains 50.2% crude fat but the seed kernel also contains toxic level of cyanide (164 mg/100 g dry weight). These levels, however, can be lowered by storage or cooking. Three months storage lowered the cyanide level to 4.2 mg/100 g and cooking the fresh kernel eliminated 93% of the initial cyanide content. The phytate P content (37.5% of total P) was high and may further aggravate the problem of low P and cause a severe Ca/P imbalance. Also with problems in collection and storage of rubber seeds, it was concluded that this source of oil and protein has little promise as a human food (Ravindran and Ravindran, 1988).

Soursop (*Annona muricata* L.) is among the four best known species of the genus *Annona*. It is being processed and marketed in the United States, Cuba, Philippines, Brazil and Venezuela. Soursop fruits are grown in the eastern and south-eastern parts of Nigeria. A palatable drink with good keeping qualities can be produced from the local fruits. The seed of the fruit contains 22.1% pale yellow oil and 21.4% protein. Since the oil was reported to be toxic and some studies have shown it to have insecticidal properties, further work is deemed necessary before it can be exploited for culinary purposes (Awan *et al.*, 1980).

The seeds of *Acacia arabica* were analyzed for composition and nutritional properties. The seed contains 5.2% oil and is rich in linoleic (39.2%) and oleic (32.8%) acids. Trace levels of epoxy and hydroxy fatty acids were also detected. When animals were fed 10% seed oil in their diet, they showed poor growth performance and low feed efficiency ratios. The digestibility of the seed oil was 90% compared to 94% for peanut oil. Because of the low oil content of the seed and inferior nutritive value of the seed oil, the seed of *A. arabica* was not considered a prime candidate for commercial exploitation as a source of dietary fat (Maity and Mandel, 1990).

The seed kernels of *Calodendrum capense* contain 60% oil. The fruits grow on a large deciduous tree which is widely distributed in East and Southern Africa. The kernel cake contains 37.6% protein, 2.3% crude fiber and 35% carbohydrates. The cake contains bitter limonoides which have hampered its use as an animal feed (Munavu, 1983). Mafura kernel oil also contains a bitter tasting compound with distinct emetic properties (Fupi and Mork, 1982). The seed of the Guindilla (*Valenzuela trinervis*) contains 67% oil. The major drawback to this oil is the presence of toxic cyanolipids (Aguilera *et al.*, 1986).

Benzylisothiocyanate (BITC) content in the seed oil of papaya was 0.56% (w/w) and the content of benzylglucosinolate in the defatted seed meal was 1.08% (w/w). The physiological effect of BITC on animals has not been clearly shown. Thus, feeding experiments are necessary for evaluation of those products as animal feed (Chan *et al.*, 1978; Passera and Spettoli, 1981; Marfo *et al.*, 1988). The presence of isothiocyanates in the oil of the papaya seed (0.03%) suggests that the thioglucosinolate present in the seed are being hydrolyzed by the enzyme thioglycosidase. The defatted seed meal on a dry basis contains 3% phytates, 10% glucosinolates and 6.3% tannins. The occurrence of these toxicants may limit the use of the papaya seed and its oil for animal or human consumption (Marfo *et al.*, 1986). The oils may, however, be useful as an industrial raw material.

The safety issue concerning the seed oil of okra has prompted a brõader screening for cyclopropenoid fatty acid content. Malvalic and sterculic acids are the only fatty acids known to contain a cyclopropene ring in their structure. The cyclopropenoid fatty acids have strong biological actions. Feeding 200 mg of sterculia foetida oil to sexually developing pullets resulted in retardation of comb development, enlargement of gall bladder and liver, retardation of ovary and oviduct development and consequent inhibition of egg production. Red okra and White Velvet contain 0.5–0.84% cyclopropenoid fatty acids. Some varieties from Ghana contain even higher levels ranging from 1.48% to 1.94% (Telek and Martin, 1981). On the positive side, feeding trials with Wistar strain weanling rats on a diet consisting of 10% okra oil in a casein-based diet showed hypocholesterolemic effects. The control group received a casein-based diet with groundnut oil as the fat source. The results showed that serum cholesterol, total lipid and triglycerides levels in the rats on the okra diet were lower than those consuming groundnut oil (Rao *et al.*, 1991).

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