Handbook of Mango Fruit

Production, Postharvest Science, Processing Technology and Nutrition



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WILEY Blackwell

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Preface

Mango is one of the most consumed fresh fruits in the world, with production occurring in more than one hundred countries. Global production of the fruit has more than doubled in the last three decades. There are over one thousand different varieties of mangoes, giving rise to various shapes, sizes, colors, textures and nutritional properties. The mango market and trade has grown considerably since the 1990s, with the two major import markets being the United States of America and European Union countries. Since the mango fruit has made its way into mainstream market outlets in most of the developed countries and is available year-round, it is no longer classified as exotic. The year-round availability of the fruit is attributed to several factors, including the fact that the fruit is grown under diverse climatic conditions, which allows harvesting throughout the year, and improvements in transportation, market access, pre-harvest production practices, and postharvest treatment allow the crop to be shipped long distances relatively free of any pests and diseases. Demand for mangoes is also on the rise, as more health conscious consumers incorporate the fruit into their diets, based on its nutritional value and unique flavor. Along with the increased consumption of this nutrient-rich fruit, the processed mango market has also seen similar growth, especially in fresh-cut fruit, juice and beverages, and shelf-stable dried products.

This book provides a contemporary source of information that brings together current knowledge and practices in the value-chain of mango production, postharvest handling, and processing. This value-chain approach to the topic is the unique feature of this book, with an in-depth coverage on a wide variety of pertinent topics: production, harvesting and GAPs, postharvest entomology and pathology, postharvest physiology and storage, packaging technologies, processing and processed products, innovative processing technologies, nutritional profile and health benefits, bioactive and phytochemical compounds, and value-added utilization of mango by-products. An experienced team of over 30 contributors from Asia, North America, and South America has contributed to this book. These contributors come from a field of diverse disciplines, including horticulture, crop sciences, plant pathology and entomology, food science and technology, food biochemistry, food engineering, nutritional sciences, and agricultural economics.

The editors acknowledge many individuals for their support from conception through to final development of this book. Foremost is our sincere thanks and gratitude to all authors for their contributions and for bearing with us during the review and finalization process of their chapters. We are grateful to our family members for their understanding and support, enabling us to complete this work. We dedicate this work to the

worthy contributions of the numerous researchers and students throughout the world, for their decades long devoted efforts to improve the quality and utilization of fresh mango and its processed products.

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Mango Production, Global Trade, Consumption Trends, and Postharvest Processing and Nutrition

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1.1 Introduction

In terms of production, mangoes, pineapples, papayas, and avocados are considered the major tropical fruits, while lychees, durian, rambutan, guavas, and passion fruits are among the minor ones. Out of global production of the major tropical fruits, mangoes accounted for more than half of the total production in 2012, followed at a distance by pineapples, papayas, and avocados, with shares of 28.36, 15.08, and 5.33%, respectively (FAO 2015). It is to be noted that the FAO reports mango, mangosteen, and guava production and trade as one aggregated category. There are over a thousand different varieties of mangoes, giving rise to various shapes, sizes, colors, texture, and nutritional properties. The fruit is considered to be one of the most consumed fresh fruits in the world, with production taking place in more than 100 countries. However, despite its nutritional value, popularity in developed countries, and tremendous potential for export revenues in many developing countries, only a relatively small portion of the produce enters into international trade; the bulk of production is consumed in the producing country. In 2013, for example, less than 4% of global mango production reached international markets. The USA and Europe are the leading importers of mangoes and have shown steady increases in the volume of fruit absorbed over the past few years.

In recent years, since the mango fruit has made its way into mainstream market outlets in most of the developed countries and is available all year round, it is no longer classified as exotic. The year-round availability of the fruit is attributed to several factors. These include the fact that the fruit is grown under diverse climatic conditions, which allows harvesting throughout the year, and improvements in transportation, market access, preharvest production practices, and postharvest treatment allow the crop to be shipped over long distances, while remaining relatively free of pests and diseases. Demand for the fruit is also on the rise, as more health conscious consumers incorporate the fruit in their diet based on its nutritional value.

Although mangoes no longer command the high prices associated with exotic fruits and with its past scarcity on the international market, prices have not declined substantially. A likely explanation for the relative buoyancy of prices is due to promotional and

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consumer educational activities, which have had the effect of increasing the overall demand for the fruit despite increases in supply. Notwithstanding, prices of the fruit vary considerably depending on variety, source of origin, and time of the year.

This chapter gives an overview of mango fruit world production, exports, and imports, consumption trends, postharvest storage, processing, nutritional quality, and food safety aspects.

1.2 Mango Production, Trade, and Consumption

1.2.1 Area Harvested and World Production

The global area of mangoes harvested in 2013 was 5.41 million hectares, an increase of about 52% as compared to that in 2000 (Figure 1.1). Given the expansion in the harvested area, global production of mangoes have also increased, growing from 24.71 million metric tons (MMT) in 2000 to 42.66 MMT in 2013, which represented an increase of about 73%. Since 2010, the area harvested and production have shown an increase of 8.95% and 14.62%, respectively. It is noted that the majority of the increase in production since 2010 has been due to corresponding increase in area harvested (52%) versus improvements in yield per unit area (14%).

Mangoes are grown under very diverse climatic conditions, in tropical and subtropical regions. Asia is the dominant producing region, with over 77.17%, based on the 2013 production figures, followed by the Americas and the Caribbean (12.22%), Africa (10.50%), and Oceania (0.11%) (FAO 2015). Because of the wide distribution of the growing regions, these fruits are produced in 115 countries, with the vast majority being developing economies. Table 1.1 shows the leading mango producing countries for selected years from 2000 to 2013. Although the fruit is produced in over 100 countries, the data provided in Table 1.1 indicate that the bulk of production is highly concentrated, with 10 countries accounting for 82.06% of the total production in 2013, and since 2000 this share has remained fairly stable at or above 80%. India is by far the

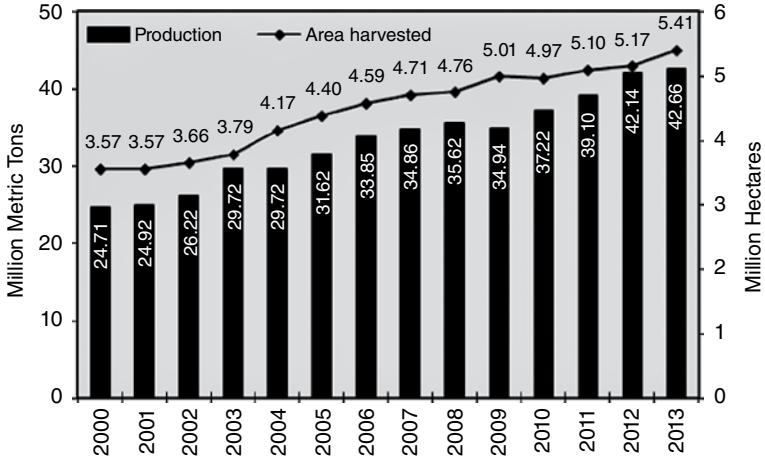

Figure 1.1 World mango production and area harvested (2000–2013). *Source:* FAO (2015).

Table 1.1 World's ten major mango[1] producing countries for selected years since 2000 (million metric tons).

					Percent Change	
Country	**2000**	**2005**	**2010**	**2013**	**2000–13**	**2010–13**
India	10.50	11.83	15.03	18.00	71.39	19.80
China	3.00	4.10	4.00	4.45	48.33	11.25
Thailand	1.62	1.80	2.55	3.14	93.57	23.18
Indonesia	0.88	1.41	1.29	2.06	134.99	59.92
Mexico	1.56	1.68	1.63	1.90	21.97	16.49
Pakistan	0.94	1.67	1.85	1.66	76.87	–10.13
Brazil	0.54	1.00	1.19	1.16	116.05	–2.24
Bangladesh	0.19	0.62	1.05	0.95	408.02	–9.34
Nigeria	0.73	0.73	0.85	0.85	16.44	0.00
Egypt	0.30	0.42	0.51	0.83	179.22	65.01
Others	*4.46*	*6.36*	*7.21*	*7.66*	71.51	6.24
World Total	24.72	31.63	37.14	42.67	72.61	14.87

[1]FAO reports mango, mangosteen, and guava data as one aggregated category.
Source: FAO (2015).

largest producer, accounting for 42.19% (18.00 MMT) of global output. Next are China and Thailand, with shares of 10.43% (4.45 MMT) and 7.36% (3.14 MMT), respectively. India's dominance as a producer is evident from the fact that in the top 10 producers, the rest of the 9 countries combined had a global share of 39.86%. Other important mango producing countries, with their share of world production include Indonesia (4.82%), Mexico (4.44%), Pakistan (3.89%), Brazil (2.73%), Bangladesh (2.23%), Nigeria (1.99%), and Egypt (1.96%).

1.2.2 Global trade – Exports and Imports

Despite the consistent growth in mango exports, the bulk of the production is still consumed in domestic markets. In 2013, only 1.65 MMT, or 3.85% of the global production, was exported, valued at about $1.69 billion (US dollars) (FAO 2016). Exports of mangoes showed a 165% increase over the 2000–2013 period, from 0.62 to 1.65 MMT. The situation was even more striking in value terms, with total exports increasing from US$ 386 million to US$ 1.69 billion over the same period, representing a 26% annual average growth rate. The higher growth rate observed for value of exports reflected a combination of increased demand for the mangoes as well as improvements in the quality of the fruit shipped. The leading mango exporting countries are shown in Table 1.2. The top 10 countries have an 85.24% share of global exports, with the top 3 countries (Mexico, India, and Thailand), accounting for 52% of the trade. Historically, Mexico and India have dominated the mango export market. However, over the 2000–2013 time period, the largest increase in exports was recorded by Thailand, from 8.76 thousand

Table 1.2 World's ten major mango[1] exporting countries for selected years since 2000 ('000' metric tons).

					Percent Change	
Country	**2000**	**2005**	**2010**	**2013**	**2000–13**	**2010–13**
Mexico	206.78	195.21	275.37	338.17	63.54	22.81
India	39.27	222.62	260.48	263.92	571.99	1.32
Thailand	8.76	1.52	144.57	252.90	2788.68	74.94
Peru	21.07	57.62	96.94	126.82	501.87	30.82
Brazil	67.17	113.88	124.38	122.18	81.89	–1.77
Netherlands	34.48	68.79	107.02	110.89	221.63	3.62
Pakistan	48.45	48.86	85.92	98.93	104.17	15.13
Ecuador	25.50	39.97	39.98	61.31	140.41	53.36
Yemen	3.57	11.64	20.37	35.25	886.87	73.03
Philippines	40.03	32.44	23.74	20.88	–47.84	–12.05
Others	126.73	149.65	170.70	216.95	71.19	27.10
World Total	621.82	942.19	1,349.46	1,648.19	165.06	22.14

[1]FAO reports mango, mangosteen, and guava data as one aggregated category.
Not in top-10: 2000, 2005 (Thailand, Yemen).
Source: FAO (2015).

metric tons (TMT) to 252.90 TMT in 2013, which represented a 29-fold increase. Other major mango exporting countries include Peru, The Netherlands (re-export), Pakistan, Ecuador, Yemen, and the Philippines.

It is noteworthy that three of the top five exporting countries, namely Mexico, Brazil, and Peru, are not in the top five mango producing countries, with Peru not even included in the top ten. This reflects the fact that these countries have made a conscious decision to target the international mango markets and, as mentioned earlier, have implemented programs and made high-cost investments in support of this decision. Overall, the noticeable rise in exports can be attributed to a combination of factors, including a conscious decision in many of the exporting countries to boost exports by improving cultural practices, such as paying more attention to phytosanitary conditions, investing in high technology production and marketing systems, and focusing exports on a few varieties that have the greatest international appeal.

With respect to imports, Table 1.3 lists the top 10 mango importing countries. As can be seen, world imports have grown by 91.23%, from 0.62 MMT in 2000 to 1.19 MMT in 2013; value-wise, this translates from US$ 513 million to US$ 1.65 billion, respectively (FAO 2015). Although over 150 countries import the fruit, the trade is dominated by a handful of countries, with the top three accounting for 52.92% of the volume traded in 2013. The USA is by far the largest importer, absorbing over a third of the trade (35.70%). Next in line is The Netherlands (12.36%), followed by Saudi Arabia (4.87%). The most popular varieties of mango traded are Tommy Atkins, Kent, Keitt, Haden, Francis, Ataulfo, Alphonso, Kesar, Edward, and Manila (NMB 2015). Other varieties which are gaining in importance in the trade include Sindhri, Badami, Glenn, Valencia Pride, and Nam Dok Mai.

Table 1.3 World's ten major mango[1] importing countries for selected years since 2000 ('000' metric tons).

					Percent Change	
Country	**2000**	**2005**	**2010**	**2013**	**2000–13**	**2010–13**
USA	235.08	260.84	320.59	424.45	80.56	32.40
Netherlands	61.86	98.04	142.55	146.99	137.63	3.12
Saudi Arabia	28.33	50.63	58.25	57.86	104.26	–0.67
United Kingdom	22.02	46.92	47.58	56.23	155.40	18.18
Germany	23.32	37.14	48.45	54.61	134.15	12.71
Malaysia	20.32	18.88	42.02	48.68	139.53	15.85
United Arab Emirates	38.90	31.62	46.49	48.00	23.40	3.24
France	26.26	34.94	32.27	35.15	33.85	8.94
Spain	9.19	13.72	32.23	27.79	202.49	–13.77
Belgium	16.12	12.20	16.42	26.43	64.00	61.01
Others	140.42	149.58	231.73	262.91	87.23	13.46
World Total	621.81	754.52	1018.57	1189.10	91.23	16.74

[1]FAO reports mango, mangosteen, and guava data as one aggregated category.
Not in top-10: 2000, 2005 (Belgium, Spain), 2010 (Belgium).
Source: FAO (2015).

1.2.3 US Production

The mango was successfully introduced into Miami, Florida, in 1863; the fruit was the focus of intense research that resulted in the development of many well-known cultivars such as Tommy Atkins, Haden, Keitt, and Kent. These cultivars are the most widely grown in the Western Hemisphere for export to the US market (Campbell and Zill 2009).

Despite its early involvement in mango production and cultivar development, the USA is not ranked among the top producers; because of climatic requirements, mango cultivation is restricted to specific regions of the US states of Florida, Hawaii, Texas, and California. Florida is the main mango producing state; in 2007, the planted area was about 490 hectares (408 bearing and 82 non-bearing hectares), but has since more than doubled to an estimated 1,042 hectares in 2012 (925 bearing and 117 non-bearing hectares) (USDA-NASS 2014).

1.2.4 US Imports and Exports

As noted earlier, the USA is the largest import market for mango, absorbing more than 32% of the global import trade in 2011. As can be seen in Figure 1.2, total mango imports (fresh and processed) increased by 74.34% from 305,918 metric tons (MT) in 2004 to 533,339 MT in 2014. Fresh mango imports accounted for 85% of the total imports, and grew at an annual rate of 5.3%, reaching 424,451 MT in 2013. Mexico is by far the largest supplier of fresh mangoes to the USA, with a market share of 65.58% for 2011–2013,

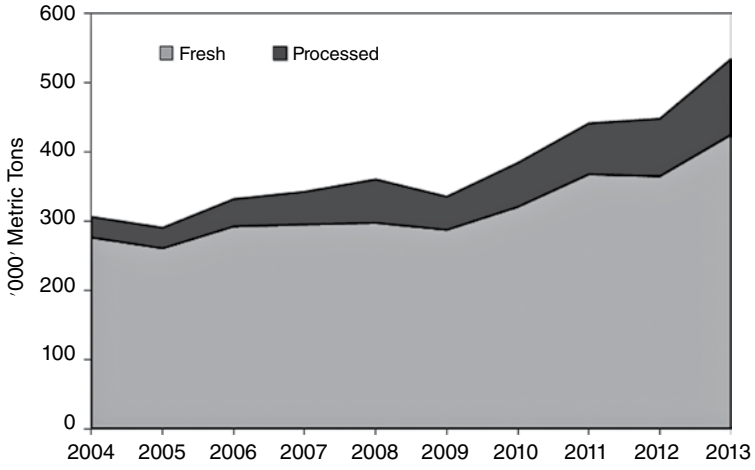

Figure 1.2 US fresh and frozen mango imports over ten year period (2004–2013). *Source:* USDA/FAS (2014).

followed by Ecuador (9.85%), Peru (9.77%), Brazil (6.31%), and Guatemala (4.46%) (Figure 1.3). Fresh mangoes are imported all year round; however, the peak of the importing season occurs during the summer months (June, July, and August). For 2011–2013, approximately 38% of the fresh fruit imports took place during these months (USDA/FAS 2014).

Data for US organic fresh mango imports are available since January 2013; this category represented about 28% of the total fresh mango imports for that year. Mexico and Peru are the main suppliers of organic mangoes to the US market, with a share of the fruit imports at 69% and 11.6%, respectively.

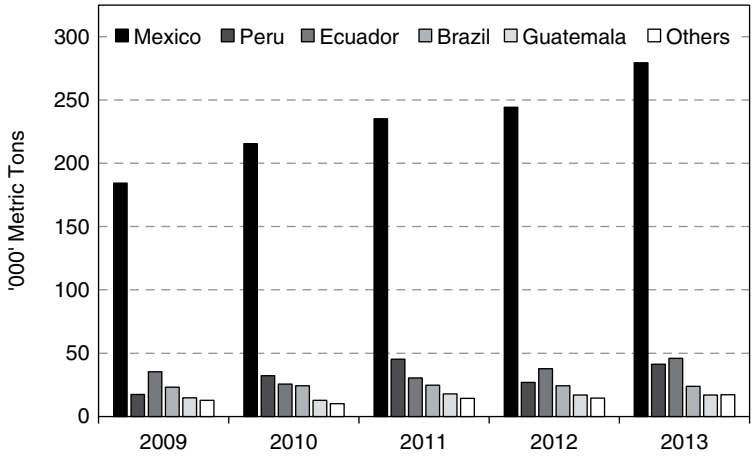

Figure 1.3 US total mango imports by country of origin, 2009–2013. *Source:* USDA-FAS (2014).

In 2013, total fresh mango imports were valued at $380.35 million; conventional fresh mango imports reached $279.65 million, while organic fresh mango imports totaled $100.7 million (USDA/FAS 2014). Imports of processed mangoes rose markedly (268%) over the period of 2004 to 2013, increasing from 29,573 MT to 108,887 MT. Within this category, frozen mango accounted for 52.75% during 2011–2013, followed by preserved mangoes (38.83%), and dried mangoes (7.77%), respectively. Frozen mangoes are marketed in the USA as concentrate, pulp, and chunks, which are used for toppings, baking, fruit salads, or snacks. Mexico and Peru are the main suppliers of frozen mango, with an import share of 70.91% and 26%, respectively (USDA-FAS 2014).

India, Thailand, and Pakistan are the more recent suppliers of fresh mangoes to the USA. In April 2007, after 18 years, the USA lifted its ban on the import of Indian mangoes, including the very popular Alphonso and Kessar varieties (USDA-APHIS 2007a). Indian mango exports to the USA have grown slightly, from 179 MT in 2007 to 275 MT in 2013; in the medium term, Indian mango exports are not expected to increase significantly, as they are not cost competitive. The average Indian mango import value in 2013 was $5.53 per kilogram (kg), which made them very expensive as compared to mango import values from Mexico ($0.87/kg) or Brazil ($1.30/kg) (USDA/FAS 2014). In July 2007, mangoes from Thailand were granted access to the US market when irradiated at low doses (USDA-APHIS 2007b). However, because the fruit is shipped by air, the cost increases significantly; the average import value for mangoes from Thailand in 2013 was $6.32/kg.

In August 2010, the USDA Animal and Plant Health Inspection Service (APHIS) formally allowed the import of Pakistani mangoes, particularly the Chaunsa variety, which rivals the Indian variety, Alphonso. It was ruled that the only authorized port of entry for Pakistani mangoes would be O'Hare International Airport in Chicago, Illinois. Furthermore, the fruit has to be irradiated in a facility at Sioux City, Iowa, before going to the market (USDA-APHIS 2011c). Because Pakistani fresh mangoes may only be imported via commercial air cargo carriers, it has served to increase the landed price and reduce its competitiveness. Most recently, approval has been given allowing imports of Australian mangoes, negotiated under the US–Australia Free Trade Agreement. Such US imports should not have a significant market impact, as Australian growers produced 45,000 metric tons (MT) of mangoes in 2012-13, with exports valued at about $13 million. Likewise, approval has been given for imports of mango from Jamaica. The annual quantity that Jamaica expects to export to the USA is about 261 MT, which represents less than 0.08% of US mango imports. As a consequence, US imports from Jamaica will not have any noticeable effect on the market (USDA-APHIS 2014).

Mangoes from Mexico, Central America, and South America are shipped to the USA at different times of the year, which means that fresh mangoes are available year round. For example, Mexican mangoes are shipped from late February until September; Peruvian mangoes are shipped from mid-November until April; Ecuadorian mangoes are shipped from late September until December; and Brazilian mangoes are shipped from late September until December. Compared with Mexican, Central American, and other South American mango exporters, Brazil has the costliest ocean freight to the USA, so it concentrates more on the European Union market.

Table 1.4 shows the annual average price of mango imports to the USA from selected countries during 2009–2013. The average annual import value has fluctuated from a low of $0.79/kg in 2010 to a high of $0.99/kg in 2013. Of the five countries shown in

Table 1.4 Average annual mango import values from the top five exporters to the US market, 2009–2013 (US $/kg).

Origin	2009	2010	2011	2012	2013
Mexico	0.68	0.75	0.71	0.79	0.87
Peru	1.27	0.91	0.99	1.23	0.98
Brazil	0.95	0.96	0.96	0.92	1.3
Ecuador	0.63	0.7	0.75	0.97	0.95
Guatemala	0.61	0.66	0.83	0.69	0.85
Average	*0.82*	*0.79*	*0.84*	*0.92*	*0.99*

Source: USDA-FAS (2014).

Table 1.4, Guatemala is the lowest-cost supplier of mangoes, while Peru appears to be the costliest supplier to the US market. Mexican mango import values have increased gradually during 2009 to 2013. The largest increase in per kg import value occurred in 2013, when it was $0.87/kg more than in 2012.

1.2.5 US Consumption

Several mango varieties are marketed in the USA, with the most popular being Tommy Atkins, Kent, Keitt, Haden, Ataulfo, Francis, and Francine. Per-capita consumption of mango has increased steadily from 0.92 kg in 2004 to 1.31 kg in 2013 (Figure 1.4), which is equivalent to a modest annual growth rate of 4.24% (USDA/ERS 2014). Consumption of mangoes in the USA is still low compared to other tropical and temperate fruits, such as pineapple (3.06 kg), bananas (12.77 kg), and apples (7.87 kg) (USDA/ERS 2014).

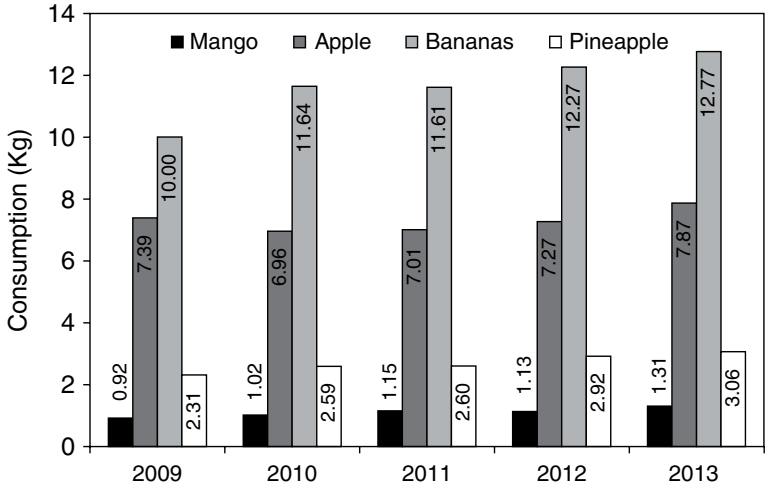

Figure 1.4 US per-capita consumption of selected fruits, 2009–2013. *Source:* USDA-ERS (2014).

Advertising and promotion programs established by agricultural commodity groups have played an important role in the increase in demand for these products. The National Mango Board (NMB), which was established in 2005 as a national promotion and research organization, with the mission to increase awareness and consumption of fresh mangoes in the USA, has been credited with much of the success with respect to rising per-capita consumption of the fruit. Price and product appearance are important attributes for consumers to decide on when purchasing fruit. The NMB conducted a study in 2011 to better understand the factors behind the decision to purchase mangoes. Findings indicated that US consumers ranked price (17.1%), ripeness (15.9%), and appearance (10.6%) as the three top reasons for purchasing mangoes (Ward 2011). This price sensitivity is not surprising given that the fruit competes with several other fruits and is not regarded as a staple. Ethnicity was the most important demographic factor influencing mango purchases; Asian consumers were the most likely ethnic group to buy the fruit, followed by African Americans, Hispanics, and whites, respectively. Finally, it was found that about 6% of the surveyed shoppers from all income levels were more likely to purchase mangoes; indicating that the effects of income on consumption of the fruit were minimal (Ward 2011).

1.2.6 European Union Market

European Union (EU) mango imports rose from 164,077 MT in 2004 to 260,845 MT in 2013, an increase of almost 60%. The more recent information by country within the EU shows that the top three mango import markets in 2011 were the United Kingdom and Germany (each with about 50,000 MT), and France (32,000 MT) (CBI 2014).

The most popular varieties sold are Tommy Atkins, Kent, Haden, and Keitt. Of these varieties, Haden commands the highest price, followed by Kent and Keitt traded at similar prices and then Tommy Atkins. Among the trade there is a definite preference for Tommy Atkins due to its ability to withstand long transportation and postharvest treatments, and its longer shelf life. At the same time, the organoleptic properties are considered by many buyers to be less desirable when compared to other varieties. The latter factor may explain the reason why some of the other varieties are gaining market shares at the expense of the Tommy Atkins (Pinheiro and Lopez 2012).

1.2.7 Market Outlook

Over the last decade, global production and trade of mangoes have increased substantially, with the growth in value exceeding that of quantity, suggesting that international demand outstripped that of supplies and/or increases in prices due to the general improvement in quality of fruit shipped. Despite the noticeable rise in volume of mangoes traded internationally and increased supplies in importing countries, prices in international markets have remained fairly competitive. As a response to these market opportunities, many governments of developing countries have taken steps to actively promote the production and trade of the fruit to increase their export earnings and improve socio-economic conditions in specific rural areas. Countries such as Mexico and Peru, for example, have significantly increased their export-oriented mango production based on a combination of government and private sector involvement. Because adjustments in output and changes in production areas take

years to respond to market signals, exporting countries might consider how they can join with agencies/organization in the importing countries to continue to grow the demand for mangoes and stave off downward price pressure.

Two recent developments are worth noting. The first is the rapid expansion in production and trade of organic versus conventionally produced fresh mangoes. As pointed out earlier, US imports of organic mangoes accounted for 28% of the total mango imports in 2013. This could imply that conventional fresh mango exports may have limited expansion opportunities in international markets due to health and environmental considerations becoming more important to consumers. The second development is the observable rise in the trade of processed mangoes. Unlike organic mangoes, processed mangoes represent a better market alternative for countries wishing to diversify their mango industry and add value to their exports. Processed mangoes, especially frozen mango exports, also have good prospects, since the product is ready to eat, and can be used in different culinary applications.

Although prospects for mangoes appear encouraging, it is worthwhile to sound a word of caution. Like most fruits, the demand for mangoes is elastic, meaning that the quantity demanded is responsive to a change in price. That is, an increase in price, in the absence of significant growth in the demand for the product, is likely to result in a decrease in the quantity consumed.

1.3 Postharvest Handling and Packaging

The ripening behavior and quality of mangoes are greatly influenced by the stage of harvest. The characteristic taste and flavor of the mango varieties cannot be attained unless the fruit is harvested at the appropriate stage of maturity. However, demand and marketing pressure often undermines this criterion and farmers go for pre-mature harvest followed by forced ripening using chemicals. The storage potential, marketable life, and quality of mango fruits depend on the stage of maturity at which it is harvested. Poor quality and uneven ripening are caused by early harvesting while late harvesting results in extremely poor shelf life (Narayana *et al*. 2012).

Fruit maturity is typically correlated with various physical characteristic like skin color, shape, size, and specific gravity. A number of chemical parameters are also used to assess maturity, which include total soluble solids (TSS), acidity, starch, phenolic compounds, and carotenoids. It is to be noted that the TSS, sugars, carotenoid pigments, and pH are directly proportional to fruit's specific gravity, both at harvest and during ripening (Narayana *et al*. 2012). Grading mangoes after harvest is important from a marketing point of view. Harvesting fruit at stages beyond mature green will reduce their shelf stability and shorten their fresh market life. The rate of respiration and ripening, development of pigments, flavor compounds, phenolic compounds, sugars, fruit quality, and postharvest diseases are all affected by handling procedures following harvest (Baldwin *et al*. 1999; Narayana *et al*. 2012; Roy and Joshi 1989).

Mango is a climacteric fruit that is harvested at a physiologically mature green stage and allowed to ripen for fresh market. The ripening of mango fruit involves many chemical and physiological changes as the climacteric peak of respiration is reached. Unripe fruits are characterized by their hard texture, high starch content,

low carotenoids, high organic acid concentrations, and subsequent low pH (Narayana *et al*. 2012). The postharvest losses in mangoes have been estimated to be in the range of 25–40% from harvesting until they reach consumers. The climacteric nature of mango makes it ripen quickly after harvest. Disease susceptibility, sensitivity to low storage temperatures, and perishability due to ripening and softening, are serious causes of postharvest losses in mango, limiting its handling, storage, and transport potential. Good handling practices during harvesting and postharvest stages can minimize mechanical damage and reduce subsequent wastage due to microbial attack (Narayana *et al*. 2012). Storage under ambient or higher refrigerated temperature leads to substantial postharvest losses, mainly due to moisture loss and/or microbial activity.

The postharvest shelf life of mangoes can be increased by using different storage and packaging techniques, such as:

- evaporative cool storage
- low temperature storage/cold storage
- modified atmosphere packaging (MAP)
- controlled atmosphere (CA) storage
- low pressure or hypobaric storage.

There are several ways of packaging mangoes using different types of packaging material. Depending on the cultivar to be packed, ventilated lugs, fiberboard boxes, and corrugated cartons of different dimensions have been used in India, Trinidad, Philippines, Florida, and Jamaica. Roy and Joshi (1989) reported that corrugated fiber board boxes with a ventilated partition were the best for transportation of "Alphonso" mangoes, because of less physiological loss in weight and low levels of spoilage and ripening.

Kader (2003) recommended maintaining cold chain through all marketing channels to maintain perishable commodities' quality and minimize postharvest losses:

- *Harvest*: Protect the product from the hot sun and transport quickly to the packinghouse;
- *Cooling*: Minimize delays before cooling and use efficient cooling techniques;
- *Temporary storage*: Store the product at its optimum temperature and practice "first-in-first-out" rotation, ship to market as soon as possible;
- *Transport to market*: Use refrigerated loading area, cool truck before loading, put insulating plastic strips inside door or reefer if the truck makes multiple stops, and avoid delays during transport;
- *Handling at retail market*: Use a refrigerated unloading area, monitor product temperature carefully, move product quickly to proper storage area, and display at proper temperature range;
- *Handling at destination*: Store in refrigerator at home or food service establishment.

Shelf life of mangoes can be extended significantly by implementing this cold chain concept. Continued technological developments in the future, to provide CA during transport and storage at reasonable cost (positive benefit/cost ratio), are essential to expanding their application on fresh tropical and subtropical fruits (Kader and Siddiq 2012).

1.4 Processed Products

The commonly processed mango products are puree/pulp, nectar, juice, juice concentrate, and dried/dehydrated mangoes (Figure 1.5). Besides these common products, there are a number of traditional products which are processed commercially in major mango producing countries, which include pickles, sweet or sour chutney (a tomato ketchup-type product), *amchoor* or dried powder, mango leather, and a variety of soft drinks and beverages (Siddiq *et al*. 2012). Ready-to-eat, fresh-cut products have been one of the fastest growing segments of the food industry in the USA in recent years. Mangoes, due to their unique flavor, are increasingly processed into fresh-cut or "minimally processed" products. Generally, fresh-cut mango products are consumed in the developed countries due to their higher prices. The other processed products are more popular in the countries where mangoes are a major fruit or in ethnic populations in North American and European countries.

Besides traditional processing technologies (canning, drying, juicing), research on the use of innovative technologies has been reported in the recent years. These technologies include high-pressure processing (HPP), pulsed electric field (PEF) processing, Ohmic heating, microwave heating, radio frequency heating, ultraviolet (UV) light, ionizing radiation, pulse light technology, ultrasound, and ozone treatments (Ahmed and Ozadali 2012). The quality preservation with respect to nutritional and sensory properties is higher when some of the non-thermal processing techniques are used. It is to be noted that most of the innovative technologies work reported in the literature is at research and development stages, with some technologies offering better commercialization potential than the others.

1.5 By-products from Processing Waste

Mango processing operations generate a substantial amount of waste while transforming raw fruits into finished products. For example, canning of mangoes is a major waste-generating operation, as shown in Table 1.5. Commercial processing of mango into juice, nectar, pulp, puree, fruit leather, and jam produces large quantities of waste (peels

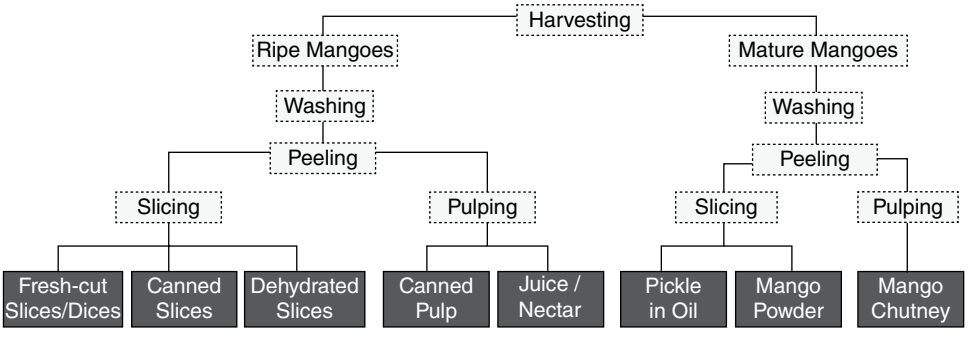

Figure 1.5 Commercial processing of different products from mangoes.

Table 1.5 Waste generation during typical mango canning operations.

Unit operations	Waste type
Washing	Wastewater, suspended solids, debris
Peeling	Solid pieces, wastewater
Pitting	Pits, Kernels
Cutting (slices, dices)	Solid pieces
Blanching	Wastewater, steam condensate
Filling and syruping	Syrup spillover
Thermal processing	Wastewater, steam condensate

and kernels). Fresh-cut processing, drying, and processing into other products also produces similar waste streams, with the exception of syrup in canning. In addition, a large number of non-marketable fruits are typically discarded, creating massive quantities of biowaste. Larrauri *et al.* (1996) reported that, depending on fruit and stone size, commercial processing results in 35–60% waste consisting of peel, kernel, and culled fruit. This waste contains significant amounts of nutrients and phytochemicals, which makes it suitable to be processed for value-added applications in functional foods and nutraceuticals.

Mango peel is rich in pectin, cellulose, hemicellulose, lipids, protein, polyphenols, and carotenoids, with excellent antioxidant and functional properties (Ajila *et al.* 2007). Mango peel flour has enormous potential as a functional ingredient in developing healthy food products such as noodles, bread, sponge cakes, biscuits, and other bakery products, besides using it in baby foods (Aziz *et al.* 2012). Mango contains various classes of polyphenols, carotenoids, and vitamins with different health-promoting properties, mainly antioxidant activity. Mango kernel is a rich source of gallic, ellagic, ferulic, and cinnamic acids, tannins, vanillin, coumarin, and mangiferrin, all having the potential to act as a source of natural antioxidants (Soong and Barlow 2006). Microwave assisted processes have been shown to produce extracts from mango seed with high antioxidant capacity (Dorta *et al.* 2012). Mango peel fibers with high hydration capacities have potential in dietary fiber-rich foods preparation (Koubala *et al.* 2013). Dried mango peel and kernel products can improve the nutritional, functional, and sensory properties, and oxidative stability of oil/oil-rich product (Abdalla *et al.* 2007); however, selection of a suitable drying method is important to ensure minimal quality losses.

Overall, mango processing wastes can be managed by adopting the following strategies:

- *Recovery:* waste utilization to produce by-products/co-products (e.g., non-fermented and fermented products);
- *Recycling:* the solid waste from processing contains nutrients that can be used for animal feed, as a source of energy in the form of biofuels, and for composting;
- *Disposal:* any leftover waste will need to be disposed of, which can be done without damaging the environment by incineration, land filling, etc.

1.6 Food Safety Considerations

In the last two decades, food safety has become the top-most concern of the fresh fruits industry, as well as different regulatory agencies (Kader and Siddiq 2012). The US Food and Drug Administration (FDA) published the *Guide to Minimize Microbial food Safety Hazards for Fresh Fruits and Vegetables* (Fan *et al.* 2009; Sapers 2005). This guide covers general principles, which prevent microbial contamination of fresh produce and recommends that efforts should be made to avoid food safety issues rather than focus on corrective actions alone. Paull and Lobo (2012) reported that the FDA has promulgated GMP regulations that apply to all food processing facilities, including fresh-cut operations and complements FDA's Current Good Manufacturing Practice regulations in *21 CFR 110*. Marketers and processors can benefit by following these guidelines, since mango fruit and fresh-cut mangoes are gaining popularity among consumers, especially in Europe and North America.

Sivakumar *et al.* (2011) suggested that food safety and quality maintenance of mangoes across supply chain channels depends on many factors, such as adequate orchard management practices, harvesting practices, packing operation, postharvest treatments, temperature management, transportation and storage conditions, and ripening at destination. Personnel working in the various fruit handling operations must be properly trained in good agricultural practices (GAPs). Moreover, development of the Hazard Analysis and Critical Control Points (HACCP) program is recommended with respect to mango handling and processing. Kader (2003) recommended maintaining cold chain throughout the food value chain.

1.7 Nutritional Profile

Mango, a flavorful and nutrient-rich fruit, is an excellent source of vitamins C and A, both important in human health. According to the NMB (2015), a one-cup serving of edible portion of mango has only 100 calories, and provides daily recommended allowance of 100% for vitamin C, 35% vitamin A, and 12% of daily fiber. Vitamin C, possessing antioxidant properties, promotes healthy immune function and collagen formation. Mango fruit has very low sodium (2 mg/100 g) and high potassium (156 mg/100 g) contents. Potassium, an important component of cell and body fluids, is helpful in controlling heart rate and blood pressure (Rudrappa 2015). Mango fruit is an excellent source of flavonoids, beta-carotene, and beta-cryptoxanthin. Consumption of natural fruits rich in carotenes is known to protect the body from lung and oral cavity cancers (Rudrappa 2015). Sivakumar *et al.* (2011) recommended including mango fruit and its processed products in the daily diet due to its health benefits, such as reduced risk of cardiac disease, anti-cancer, and anti-viral properties.

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