1. Introduction

Mango is one of the oldest and most important fruits (Fig. 1). It is the second most important tropical fruit crop in the world, after banana with a total production of about 25.1 MMT (million metric tons)\textsuperscript{11}. Mango has been cultivated in India for more than 4000 years, and today its culture is extended in more than 80 countries in tropical and sub-tropical regions. Some of the most important producers include India (11.5 MMT), China (3.2 MMT), Mexico (1.5 MMT), Thailand (1.4 MMT), Pakistan (0.90 MMT), The Philippines (0.88 MMT), Nigeria (0.73 MMT) and Brazil (0.54 MMT) (FAO, 2003) (Fig. 2. Table 1). Mango trade is becoming increasingly important in recent years. About a decade ago, the mango was an exotic, rare fruit in many countries especially in Europe and in North America. Nowadays, mango is commonly marketed in most countries. Mango is the fastest growing fruit in terms of consumption in the USA market; there has been about 10\% yearly increase in mango import volumes in the US market in the last two decades. Mango consumption is increasing in the world, as the fruit is becoming more available in the world market, due to improved pre-harvest and postharvest handling techniques, including available quarantine treatments, an increase in sea transport and in the use of modified (MA) and controlled atmospheres (CA). Great variety of mango types are available in the market including different colors (green, yellow, colored), shapes, and flavors. Although production, yield, and quality of mango fruit have improved significantly in the last years, several problems are still facing this fruit. Chilling susceptibility and infestation with diseases and insects, and thus short postharvest life limit the trade of mango fruit in distant markets.

Figure 1. Mango fruit in the market.

Figure 2. Most important mango producing countries and their share.
Table 1. Mango producing countries and their producing period.

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<th>Country / month</th>
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2. Nutritive Value

Mango fruit (Fig. 3) is a rich source of vitamin C (ascorbic acid). Vitamin B1 (thiamine) in 2 mango cultivars was found to be 35-60 mg/100g and vitamin B2 (riboflavin) in 3 cultivars to be 45-55 µg/100 g. Folic acid in green mangoes was found to be 36 g/100 g. The mango fruit is also a rich source of carotenoids, some of which are pro-vitamin A. ß-carotene (all-trans), ß-cryptoxthanin (all-trans and cis), zeaxanthin (all-trans), luteoxanthin isomers, violaxanthin (all-trans and cis) and neoxanthin (all-trans and cis) were identified in mangoes. Ripe mangoes were found to be ten times richer in carotene than partially ripe fruit, while unripe green mangoes contain only trace amounts. Mango peel is a good source of tropical fruit fiber, and its fiber had higher antioxidant activity (67.6%) and glucose retardation index (21.5%) values than lemon fiber.

Unfortunately large portion of the mango fruit is usually not used, although contain significant nutritional components. For example, total waste in several cultivars grown in Mexico (Corazon, Hayden, Crillo, Reina de Mexico, La Paz, San Felipe) averaged from 40 to 60% of the fruit, and was higher in the smaller fruited cultivars such as ‘Corazon’ and ‘Crillo’. Total sugar content of peel ranged from 3.14% (San Felipe) to 55.3% (Reina de Mexico), and crude fiber from 7.2% (La Paz) to 17.9% (San Felipe). Maximum protein content was 11% (San Felipe) and fat content was 4.7% (La Paz).

Mango peel dietary fibre contained high amounts of total extractable polyphenols (70 g/kg) and soluble dietary fibre (281 g/kg) and had a high water-holding capacity (11.4 g/g dry matter), which indicates that mango peel is a good source of tropical fruit fibre. Mango seed kernel is also a good source of nutrients for humans and animal feed. Mango seed kernel contains about 44% moisture, 2.8-6.0% proteins, 4-13% fat, 33% carbohydrates, 2.0-19.3% crude fiber, 2% ash, and 0.4% tannins. The seed kernel fat contains high amount of stearic (ca 46%) and oleic (40%) acids, while palmitic, linoleic, arachidonic and behenic acids are present in small quantities (<7%). Of the inorganic ions detected, potassium (365 mg/100 g), phosphorus (140 mg/100g), magnesium (100 mg/100g) and calcium (49 mg/100g) were present in high levels, while iron, sodium, manganese and zinc were present at low levels (<11%).

3. Cultivars and Characteristics

Mango cultivars (Table 2) are many and commonly classified into two groups depending on their ability to reproduce from seeds to monoembryonic and polyembryonic. Monoembryonic cultivars are hybrid in origin and must be reproduced by asexual propagation. Polyembryonic cultivars are those where many embryos may develop from diploid parent nucellar tissue after fertilization of the egg cell.

Since only one embryo is of hybrid origin in these polyembryonic types, seedlings are usually identical to the tree from which the fruit is harvested. Polyembryonic cultivars are mostly of Philippine or Indochinese origin. Pandey listed 793 mango cultivars from all over the world. There are more than a thousand cultivars in India, but only about 25 to 40 cultivars are grown commercially. In the region of ASEAN (Philippines, Malaysia, Indonesia, Singapore, Thailand) there are over 500 cultivars. In Hawaii, Piere and Haden are the most important commercial cultivars. In Florida, an important collection of mango germplasm exists, but Tommy Atkins is the most important commercial cultivar. In Mexico, Manila, Ataulfo, Kent, Haden, and Tommy Atkins are the most important commercial cultivars. In South Africa, Zill, Kent and Haden are the most important grown cultivars. The ‘Common’ and ‘Kensington Pride’ are produced in Australia and ‘Fiji’, ‘Peach’, ‘Jarra’, ‘Parrot’ and ‘Kerosene’ are produced in Fiji. The most important Egyptian commercial cultivars include Alphons, Ewais, Hindy Sinnara, Mabrouka, Misk, Pairi, Sukkary, Taimour and Zebda.

Mango cultivars can be classified into 3 classes according to skin color upon ripening: red, yellow and green. There are
several yellow-skinned cultivars such as Carabao, Ataulfo and Manila among many others. Several cultivars grown in Asia and Africa remain green-skin after maturation.

Table 2. Important mango cultivars in the world.

<table>
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<tr>
<th>Country</th>
<th>Cultivar</th>
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<tbody>
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<td>Australia</td>
<td>Kensington Pride, R2E2, Keitt, Irwin, Haden, Kent</td>
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<tr>
<td>Brasil</td>
<td>Haden, Keitt, Palmer, Tommy Atkins</td>
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<td>Costa Rica</td>
<td>Haden, Irwin, Keitt, Tommy Atkins</td>
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<tr>
<td>Egypt</td>
<td>Alphonso, Ewais, Hindy Sinnara, Mabrouka, Misk, Pairi, Sukkary, Taimour, Zebda</td>
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<tr>
<td>USA, Florida</td>
<td>Tommy Atkins, Keitt</td>
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<tr>
<td>USA, Hawaii</td>
<td>Pierie, Haden</td>
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<tr>
<td>Fiji</td>
<td>Fiji, Peach, Jarra, Parrot, Kerosene</td>
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<tr>
<td>Philippines</td>
<td>Carabao, Pico</td>
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<tr>
<td>Guatemala</td>
<td>Tommy Atkins, Haden, Zill, Ataulfo</td>
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<tr>
<td>India</td>
<td>Alphonso, Banganapalli, Bombay Green, Chausa, Dashehari, Fazli, Fernandin, Himsagar, Kalapadi, Kesar, Langra, Malda, Mankurad, Mulgoa, Neelum, Pairi, Rumani, Suvanarekha, Totapuri, Vanraj, Zardalu Híbridos: Amrapali, Arka Anmol, Arka Aruna, Arka Punnet, Mallika, Manjeera, Ratna, Sindhu</td>
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<td>Indonesia</td>
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<td>Golek, Arumanis, Tok Boon, Kuala Selangor, Maha 65</td>
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<td>Ataulfo, Haden, Keitt, Kent, Manila, Tommy Atkins, Criollo (varios tipos)</td>
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<td>Apple Mango</td>
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<td>South Africa</td>
<td>Haden, Heidi, Keitt, Kent, Sensation, Tommy Atkins, Zill</td>
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<td>Venezuela</td>
<td>Haden, Keitt, Tommy Atkins</td>
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4. Fruit Physiology

4.1. Fruit growth and development

Fruit set in mango occurs when the conditions for cross pollination are favorable. After the initial enlargement of the ovary, the endosperm in the mango seed appears in a free nuclear condition and the embryo sac will be made up entirely of endosperm. The endosperm engulfs the nucleus during development, which itself is later consumed by the embryo.

After setting, mango fruit takes approximately 3 months to reach maturity with marginal varietal. There are large differences in size, shape, appearance and physiological characteristics. For example, the average weight of different mango fruit cultivars ranges between less than 80 to more than 800 g.

The growth pattern in the drupaceous mango fruit after fertilization follows a pattern of a single sigmoid curve, and consists of rapid cellular growth for about 3 weeks, followed by cell enlargement for the subsequent 4 weeks.

Changes associated with mango fruit ripening include: 1) skin color changes from green to yellow in some cultivars, 2) flesh color changes from greenish yellow to yellow to orange, in all cultivars, 3) decrease in chlorophyll and increase in carotenoid contents, 4) decrease in flesh firmness and increased juiciness, 5) starch is converted into sugars, 6) increase in soluble solids content, 7) decreased titratable acidity, 8) increase in characteristic aroma volatiles, 9) carbon dioxide production rate increases from 40-50 to 160-200 mg/kg.hr at 20°C and ethylene production rate increases from 0.2-0.4 to 2-4 µl/kg.hr at 20°C.

4.2. Factors affecting fruit growth and development

Many factors, especially environmental conditions, can influence the development of mango and therefore influence its quality. The same cultivar can attain different characteristics in different growing conditions. Even in the same region, the different environmental conditions during different years can affect maturity and quality of the fruit. For example, growers in the Philippines are accustomed to harvest mango after 100-110 days from induction during April to June, but fruit picked in January to March is done after 120-125 days.
Light is important for photosynthesis. However, the most important effect of light on the fruit is on the development of anthocyanin pigments responsible for colors. The intensity of light in a specific region will determine the quality of the fruit from the standpoint of color. The differences in light intensity between mango growing regions can produce fruits of different colors.

Temperature is a very important factor that influence fruit maturity and quality. Temperature can influence not only the suitability of the growing region for mango cultivation, but also the harvest period and the quality of the fruit. The minimum temperature (base temperature) at which mango will not develop normally is reported to be 17.9°C. Heat units, which are calculated from the sum of the temperature units (degree days) in excess of the base temperature over the growing season, was calculated in some countries for mango. In the Philippines it has been found that ‘Carabao’ mango in different regions reaches maturity after 1000 heat units, even though this is reached at different periods in different regions.

The amount and distribution of rainfall not only determines the suitability of the region for mango growing but also influence the maturation and quality of the fruit. Mango growing is generally successful when the annual rainfall ranges between 75-350 cm per year, and that there is no water-logging and the rain does not fall during flowering, fruit set and fruit development. Rain before harvest and high humidity can increase disease levels, fruit susceptibility to heat and to brush damage and reduce storage life.

Mango trees, especially young trees, need an adequate supply of nutrients for an adequate rapid growth, flowering, and fruiting. Excess application of nitrogen can adversely affect the color of mature fruit. The addition of potash to trees with excess nitrogen can improve the color and flavor of the fruit. Potash deficiency is associated with small fruit of poor quality, and high potash levels are associated with an increase in physiological breakdown of the fruit. However, this problem has also been attributed to calcium deficiency. The high potash level can result in a lack of balance between potassium and calcium in the tree and in the fruit. The requirement of mango for phosphorus is usually low, and the deficiency for such element is usually uncommon. Deficiency of boron and calcium adversely affect the keeping quality of mango fruit. Nutrient imbalance can cause the development of fruit disorders such as internal breakdown.

Low preharvest calcium levels in fruit adversely affect the keeping quality and increase the incidence of postharvest disorders in cold-stored fruit. Fruit of ‘Dashehari’ trees sprayed before harvest with 2 consecutive treatments of calcium chloride (0.6% calcium) showed higher calcium level in the peel and flesh, a lower cumulative physiological loss in weight and reduced respiratory rate. Boron deficiency affected the keeping quality of cold-stored ‘Tommy Atkins’ mangoes. Heavy rain occurring late during fruit development can release soil nitrogen previously unavailable to trees due to low moisture content, adversely affecting fruit quality. Nutrient imbalance is known to increase the incidence of disorders such as internal breakdown.

Mango growing is ideal when at least 4 months of dry weather occur between flowering and harvest. In this period and in the other period where rainfall is not possible, irrigation is needed. Prolonged moisture stress can result in late flowering and small fruits. Irrigation frequency significantly affect postharvest diseases and disorders.

Insects and diseases result in loss of yield and deterioration of quality, and thus adequate control is essential. Preharvest pesticide application can contribute significantly to yield, but may adversely influence quality from the standpoint of residue content. Integrated pest management (IPM) strategies are essential to control pests, but at the same time reduce the use of pesticides. Prediction of diseases, based on the monitoring of environmental conditions, can reduce significantly the use of pesticides. Biological control is becoming important in reducing insect and disease population, and thus in reducing the use of pesticides.

Preharvest application of ethephon (2-chloroethylphosphonic acid) at 50-200 ppm applied in ‘Carabao’ mango at 78 days from induction, and fruit harvested one week later increased soluble solids content and decreased acidity.

Application of gibberellic acid (GA3) as a foliar spray (100-300 mg/L) prior to harvest retarded ripening of mango fruits for up to six days of storage at ambient temperature. Fruits treated with GA3 had lower levels of soluble solids, lower solids to acid ratio, lower total carotenoids and lower peroxidase and amylase activities at harvest, and higher acidity, ascorbic acid and chlorophyll levels in the peel.

Treatment with calcium nitrate and calcium chloride (0.6-2.0%) delayed ripening after harvest, lowered weight loss and reduced respiration rates.

4.3. Ripening physiology

Mango is a climacteric fruit, exhibiting a climacteric type of respiration and an increase in ethylene production. Respiration patterns and ripening behaviour vary among the different cultivars, the climatic conditions and the geographical location where the fruit is grown. Respiration is very high after fruit set and then declines and maintains low until the fruit starts to
mature. The rise in respiration and ethylene production (during the rise in the climacteric) is related to fruit maturation and ripening. The respiratory peak in ‘Alphonso’ mangoes was observed after five days from harvest, and fruits ripen withing seven or eight days, while in ‘Kent’ and ‘Haden’ mangoes the peak was observed at the ninth and eleventh days respectively, and in ‘Pairi’ mangoes on the ninth day after harvest. However, these differences should be considered normal due to difference in location, climatic conditions and orchard and trees conditions. Respiration (consumption of oxygen and/or production of carbon dioxide) and ethylene production can serve as excellent maturity indices. However, their determination is usually destructive, and in addition they need expensive techniques done by qualified personnel. Being a climacteric fruit, mango can be ripened after harvest if picked at physiological maturity.

Ethylene production in unripe mango fruit is very low (less than 1 nl/g/h). It decreases as the fruit matures, then becomes undetectable and reappears upon ripening. The small amount of ethylene present in the fruit at harvest is sufficient to initiate ripening. It has been reported that the threshold concentration to cause a physiological effect in ‘Keitt’ mango is 0.04-0.4 ppm.

Several changes occur during the maturation and ripening of mango fruits, and some of those are used as maturity indices. All metabolic changes mentioned are part of the natural senescence of the fruit. This is an irreversible process that contribute to losses of organelles, chemical constituents, and thus the quality and postharvest life of the fruit. Natural senescence is aggravated and promoted by factors such as ethylene, mechanical injury and high temperature. This process can be delayed by lower temperature, elimination of mechanical damage and reducing of ethylene production.

Pulp firmness is an important attribute for the evaluation of fruit maturity, resistance to transport and storage, and also as a quality characteristic. Fruit softening and cell wall changes are of the principal changes associated with fruit ripening. Fruit texture changes are due to changes in cell wall and pectic substances in the middle lamella, although changes have been detected among different cultivars. Softening of mango fruit is characterized by an increase in the solubility of cell wall pectins. In general, water-soluble polysaccharides increase during ripening, but in ‘Keitt’ mangoes water-soluble and alkali-soluble pectins decline, and ammonium oxalate-soluble pectins increase as the fruit became soft. Some postharvest treatments such as refrigeration, packaging and coating, and modified atmospheres retard mango fruit softening. Calcium application in ‘Haden’ mangoes by infiltration or dipping extend their storage life by one week.

The loss of green color is one of the most obvious signs of fruit ripening in many mango cultivars. The development of the optimum skin color is very important for fruit quality, since that it is an important factor by which most consumers define mango quality. Some mango cultivars do not change their green color. In many mango cultivars the skin color changes from dark green to olive-green, sometimes reddish, orange-yellow or yellowish hues appear from the base color, depending on the cultivar. Some cultivars also develop reddish blush, which has been attributed to anthocyanins. Color changes in mango fruit are due to the disappearance of chlorophyll and the appearance of other pigments. Chloroplasts are transformed to chromoplasts containing yellow or red pigments. In the yellow cultivars, carotenoids and xanthophylls are the predominant pigments. Peel color is not an adequate maturity index, since that when the change occur the fruit is already soft.

Mango fruit pulp contains high concentration of carotenoids (up to 9 mg/100 g), and so it usually develops an intense yellow to orange color, and therefore mango is a good source of vitamin A. The pulp carotenoid level varies among the different cultivars.

Sugar changes are important for organoleptic attributes in the fruit. Fruit flavor is mostly a balance between its content of sugars, acids and aromatic volatiles. Sugar changes (increase) is the most pronounced during fruit ripening and is the most important for better mango flavor (sweetness). Starch content increases during fruit development but it is hydrolyzed to simple sugars during ripening. Ripe mango contains up to 10-20% of total sugars (fresh weight basis), depending on the cultivar and the stage of ripening. At the beginning of the ripening stage most of the sugar content is usually in the reducing state, while when the fruit is completely ripe, sugars are usually mostly non-reducing (about 17%) than reducing (3%). The high activities of both sucrose synthase (EC 2.4.1.13) and invertase (EC 3.2.1.26) in the mesocarp during ripening are indicative of active sucrose metabolism.

Organic acids are important for respiratory activity and as a constituent of flavor. During maturation and ripening, mango fruit suffers a substantial loss in organic acids, indicated through changes in titratable acidity. The predominant acids in mango fruit are citric, succinic, malic and tartaric acids; being citric acid the highest concentration and tartaric acid being the lowest in concentration.

Volatile constituents are important for the aroma, and thus for the organoleptic quality of the fruit. As in all types of fruits, ripe mango contains many volatiles, but several of them are not odor-active and do not contribute significantly to the aroma. There has been several research studies determining the types of volatiles of mango, but none determined their aromatic activity. Some reports indicated that the predominant volatiles in some cultivars are monoterprenes as well as lactones and some fatty acids, however there is no indication of the presence of a single flavor impact component. Some
mango cultivars possess a peach-like flavor that may be related to the presence of lactones. In almost all fruits, aromatic volatiles are commonly produced at later stages of ripening.

5. Physiological Disorders

Mango fruit is susceptible to various physiological disorders which influence fruit quality. These disorders are either induced or inherent, and several of them become apparent during fruit ripening. Chilling injury is an induced disorder. Examples of inherent physiological disorders include the “spongy stem-end” in ‘Kensington’, “soft nose” in ‘Florida’ mangoes and “internal breakdown”, “spongy tissue” or “soft nose” in Indian ‘Alphonso’ mangoes. Inherent physiological disorders are unpredicted, and most are caused by preharvest factors.

5.1. Biennial bearing

Biennial or alternate bearing is a major problem in several mango growing regions, especially in Asia and Africa. This disorder, which results in significant reduction in yield, is less of a problem in regions where humidity is relatively high with lower temperatures. This problem has been attributed to several factors such as genetic, physiological, environment and nutritional. However, the problem is augmented by the poor handling of the tree, especially the lack of adequate pruning and inappropriate fertilizer programs.

5.2. Internal breakdown

This is characterized by a breakdown in the flesh on the ventral side and toward the apex of the fruit. In ‘Haden’ mango, there is a yellowing of the green skin at the apex, which becomes soft. The tissue becomes spongy and grayish black at the advanced stage of the disorder. “Spongy tissue” is described as white sponge-like corky tissue, slightly desiccated in nature, in the pulp between the skin and the stone of the ripe fruit. In rare cases, when injury can be seen from outside, the skin turns brownish-black, forming a flat external depression. Commonly, the pulp remain unripe because of the unhydrolyzed starch. In some cases mechanically injured fruits develop spongy-like symptoms, where the exocarp may or may not be injured. These symptoms can be differentiated from the natural spongy tissue symptoms by the papery-white dead tissue developed in the pulp and on the stones and the absence of any browning reaction around the damaged tissue. The cause of this disorder is not completely known. The tissue becomes soft or spongy, with or without off-flavor, and the disorder commences from the stone and spreads toward the periphery. In severe cases, the whole fleshy tissue becomes too soft, resembling bacterial rot. X-ray photograph and x-ray images of fruits having spongy tissue show dark grey patches corresponding to internal cavities, in contrast to light grey areas of healthy tissue.

Low calcium in the fruit from the site prone to soft-nose was suggested as a possible contribution factor to the initiation of this disorder. Calcium and magnesium content in the disordered ‘Kent’ fruits was lower than the content in the healthy fruit of the same cultivar. However, levels in the less susceptible ‘Beverly’ fruits were as low as the disordered ‘Kent’ fruits at the same site. The inner flesh of the distal region of the fruit, the location at which the soft-nose disorder develops, was found to have the lowest calcium concentration in the whole fruit.

The earlier harvesting of the fruit and its subsequent ripening with ethylene was reported to reduce the incidence of spongy tissue disorder in ‘Alphonso’ mangoes.

5.3. Chilling injury

Chilling injury (CI) has been reported to occur in mango fruit at temperatures below about 10-13°C, although some cultivars (Dasheri, Langara) were reported to be safely stored at 7-8°C for up to 25 days. There are several variabilities in the susceptibility of the different mango cultivars to CI. Ripe fruit can be stored/transported at lower temperatures than those of green fruit. Symptoms in mango fruit, which may not be developed until the fruit is held in room temperature for 1-2 days, were described as discolored and pitted areas on the surface followed by irregular ripening with poor color and increased susceptibility to microbial spoilage.
5.4. Heat injury

Vapor heat disinfestation treatment in which seed surface temperature was held at 47°C for 15 min. increased the severity of lenticel spotting and skin browning in ‘Kensington’ mangoes from 2 production zones stored at 10°C for 5 days followed by 22°C for 5 days. Both secondary disease incidence and level of injury increased in ‘Kensington’ mangoes treated with hot water or vapor heat to a fruit core temperature of 47°C with increasing time from 7.5 to 30 min.

5.5. Blacktip

The ‘black tip’ disorder is characterized by yellowing of tissues at the distal end of the fruit, and the color intensifies into brown and finally black, the mesocarp and seed being unaffected. This usually follows with the appearance of grey spots of indefinite outline in the etiolated tissue, turn brown and coalesce, and the entire fruit tip turns brownish-black. This disorder was reported to be caused by the emanation of gases from brick kiln fumes, such as sulphur dioxide, ethylene and carbon monoxide. A spray of 1% borax at the time of fruit set, followed by two more sprays at 10-day intervals, or spray of washing soda (0.5%) and caustic soda (0.8%) can be useful in controlling the disorder.

6. Postharvest Decay

Decay is one of the most important causes of postharvest losses in mango, and the major problem during storage and marketing. Mango fruit is infested by several diseases, but the most important ones are anthracnose caused by Gloeosporium gloeosporioides (Penz.), stem-end rot caused by Gloeosporium mangiferae or Diplodia natalensis (P. Evans), and the soft brown rot caused by Hendersonia creberrima (Syd.). Other mango fruit diseases, which are usually of regional significance, include alternaria rot, soft brown rot, bacterial soft rot, grey mould and mucor rot. The rapid ripening of mango fruit and their poor tolerance to low temperature encourage the development of postharvest diseases and to limit storage life.

6.1. Anthracnose

Anthracnose is the most serious disease in most mango growing regions, especially those with high rainfall and humidity. This disease is caused by Colletotrichum gloeosporioides (Penz) Sacc., Glomerella cingulata (Stonem), Spauld & V. Schrenk conidial state, and to a lesser extent by Colletotrichum acutatum Simmonds. Infection can be on the fruit, but can also on blossoms, leaves, twigs and young branches. Infection of fruit by C. gloeosporioides occurs prior to harvest from waterborne conidia spread from dead twigs and leaves. In addition to attack through the wounds, the organism could penetrate the fruit through the cuticle and natural openings on the fruit surface. In the fruit, the infection is latent and starts to develop as the fruit advances in its stage of ripening. C. gloeosporioides causes large, spreading lesions on the surface of the fruit that takes the form of dark sunken patches up to 20 mm wide, at any point on the fruit surface.

6.2. Stem-end rot

Stem-end rot is second to anthracnose in importance in many mango growing regions. It has been attributed to be caused by Lasiodiplodia theobromae (Pat.) Griff and Maubl (syn. Botryodiplodia theobromae Pat.) alone. However, L. theobromae, Phomopsis mangiferae Ahmad and Dotiorella dominicana (Sacc.) Petr. And Syd. were reported to cause stem-end rot in Australia, Thailand and Malaysia. The disease usually starts at the stem-end of the fruit but the fungi can also attack any part of the fruit, especially that which becomes injured during harvesting or handling. Endophytic colonization of the inflorescence and pedicel tissue was found to be the primary route of infection of fruit that develop stem-end rot during ripening. Storage at 30°C favoured the infection by L. theobromae over that by D. dominicana as the cause of stem-end rot, and the reverse occurred at 25°C and lower, which explains the possible different causes of the disease in tropical and in sub-tropical growing areas. Infection can be reduced leaving a pedicel of about 1-2 cm.
6.3. Alternaria rot

*Alternaria* rot, which is caused by *Alternaria alternata*, can cause serious losses when anthracnose and stem end rot are absent or well controlled. *Alternaria* rot is only a problem during storage of mango for 3 weeks or more. *A. alternata* infects mangoes through the lenticels and penetrates the fruit, resulting in darkening of the intercellular spaces and cell collapse. The symptoms of this disease consist of either small black spots (0.5-1.0 mm in diameter) with dark center and diffusive borders, or dark leticels. At least 350 h of RH over 80% were reported to be needed for a significant incidence of quiescent infections of *A. alternata* to establish during development. After infection in the orchard, the hyphae remain latent until the fruit ripens, and then develop intercellularly. The quiescent periods in mangoes inoculated with *Alternaria tenuis* Nees, *C. gloeosprioides* and *L. theobromae* were 14, three, and four days, respectively, indicating that alternaria rot appeared later than anthracnose.

6.4. Black-mold rot

Black mold, which is caused by *Aspergillus niger* and other *Aspergillus* spp. can a serious postharvest disease in mango fruit exposed to high temperatures and rough handling. The affected fruits show yellowing at the base, and develop irregular, greyish spots which coalesce into dark brown or black lesions, and the mesocarp or the diseased area becomes depressed and soft.

6.5. Other diseases

Other diseases that can attack the mango fruit in postharvest include *Rhizopus* (caused by *Rizopus oryzae*), scab and sooty mold (caused by *Cannodium mangiferae*). *Rhizopus* is usually a result of mechanical injury. *Botryodiplodia theobromae* is able to proliferate on green, unripe as well as ripe fruit, but needs mechanical injury for infection. This pathogen can cause total spoilage of the fruit within 48 h, and can increase the rate of respiration, and inhibits the development of respiratory climacteric peak.

6.6. Control

Several measures before and after harvest are needed to reduce postharvest disease incidence and to minimize losses. Chemical control before and after harvest is still been used. However some chemicals are not allowed anymore such as the case of benomyl in the USA. Alternative treatments, such as heat, are been looked at again. Harvesting at the appropriate stage, careful harvesting and handling to reduce mechanical injury, avoidance of latex staining and heat stress are needed to reduce disease infection and fruit losses.

6.6.1. Chemical treatments

Decay control is accomplished with an adequate preharvest and postharvest integrated program. In postharvest, washing water usually contain about 100 ppm of sodium hypochlorite. It also can contain fungicides depending on the extent of the problem. Careful handling of the fruit, elimination of mechanical injury, rapid cooling, maintenance of low (optimum) temperature and maintenance of hygienic conditions are essential for decay control.

Several pesticides are applied to mango in pre- and postharvest for control of diseases. Benomyl (0.1%), TBZ (0.08%) or captan (0.135%), especially applied in hot water after harvest, were found to be effective for control of anthracnose. Benomyl has been withdrawn from use in postharvest in the USA. Field sprays of the benzimidazole fungicides, such as benomyl, for the control of anthracnose has been reported to become less effective in Florida and Thailand, and strains of *C. gloesporioides* and *L. theobromae* resistant to benzimidazole fungicides have been isolated from mango fruit. Maximum residues for prochloraz permitted in some countries are presented in Table 3.
6.6.2. Heat

Hot water treatments for decay control can be used with or without fungicides. These treatments consist of temperatures of 48-55°C for 3 to 15 minutes, depending on the variety and the extent of the problem. ‘Haden’ and ‘Tommy Atkins’ mangoes are treated for about 3 minutes. The treatment is applied right after receiving and washing of the fruit in ambient water. Immediately after hot water treatment, fruit should be cooled in ambient or cold water. Hot water temperature should be controlled and water should be circulating to maintain temperature uniformity.

Hot water is more effective for the control of anthracnose than for stem end rot (or soft brown rot), and *Alternaria* rot. Shorter treatments are sufficient for anthracnose (about 3 minutes), while stem-end rot usually needs longer treatments (7 minutes or more).

Hot water can contribute to increased skin damage. Less mature fruit and those susceptible to hot water injury (such as ‘Zill’ and ‘Irwin’) are exposed to lower temperatures (48-50°C) than mature fruit and those less susceptible cultivars which can be exposed to higher (50-55°C) temperatures.

When hot water treatment is done as dipping, the tank should be made of a material that do not react with any of the chemical material. The tank should be resistant to corrosion and easily cleaned. These tanks are usually made of fiberglass, plastic, stainless steel or steel with a protected cover. Hot water tanks are of different sizes. They should be built from material that will not corrode rapidly (stainless steel and fiberglass are commonly used). Tanks should be equipped with temperature devices, and water should circulate to result in a uniform temperature. Tanks should be equipped with filters to avoid accumulation of soil, debris, etc. Exposing of mango fruit to hot, dirty latex-contaminated water can increase the incidence of phytotoxicity and lenticel damage.

Vapour heat treatment used for the oriental fruit fly control in ‘Carabao’ mangoes consisting of heating the fruit core to 46°C for 10 min. 34 was found to significantly reduce the incidence of anthracnose and stem-end rot without delaying the onset of decay 10.

Heat treatments, either hot air or hot water, are very preferable for being non-chemical treatments. They can delay ripening and senescence when used adequately (and thus delay the development of diseases), they can increase the resistance of the fruit to CI, and thus are looked at as excellent alternatives for pesticide treatments.

6.6.3. Biological control

Antifungal resorcinols, present in the peel of mango fruit, interfere with the development of anthracnose and *Alternaria* rot. *Bacillus licheniformis* (Weigmann) Chester was found to be more effective in reducing fruit diseases than chemical treatments. Postharvest dip application in *Bacillus licheniformis* (isolates B250 and B251) effectively controlled anthracnose and stem-end rot and B251 effectively controlled soft brown rot 23.

6.6.4. Irradiation

Irradiation was tried for diseases control in mango. A dosis of 1000 Gy was suggested for the control of anthracnose. Severity of anthracnose caused by *Colletotrichum gloeosporioides* Penz., was reduced in ‘Keitt’ mangoes exposed to 500 Gy or higher, and the severity of stem-end rot caused by *Diplodia natalensis* P. Evans or *Phomopsis citri* Fawe., was reduced in ‘Tommy Atkins’ mangoes exposed to 1500 Gy, but not to 750 Gy.
6.6.5. Ultraviolet radiation

UV-C treatment of ‘Tommy Atkins’ mangoes for 10 min. was reported to be effective in suppressing decay, and increasing the levels of putrescine and spermidine. One-minute exposure to short-wave infrared radiation followed by a 20-s prochloraz dip (81 g a.i/100 l) was reported to effectively control anthracnose and soft brown rot.

6.6.6. Combined treatments

Immersion of ‘Kensington Pride’ mangoes in hot water (52°C for 5 min.) plus benomyl (benlate 50 WP 1g/l) provided good control of stem-end rot following inoculation with either Dottiarella dominicana Petrak or Lasiodiplodia theobromae (Pat.) Griff. & Maubl. during storage for 14 days at 25-30°C. Long-term controlled atmosphere storage (5% O₂, 2% CO₂, at 13 °C for 26 days) followed by air storage for 11 days at 20°C of ‘Kensington Pride’ mangoes treated with hot benomyl followed by prochloraz provided effective control of stem-end rot and anthracnose. A. alternata and dendritic spot were also controlled by hot benomyl followed by prochloraz.

7. Insects

7.1. Mango insect pests

Mango pests include internal pulp feeders such as fruit fly immatures, seed pests such as mango weevil, and external pests such as scales, mealybugs, thrips and mites. Of the 260 species of insects and mites reported to have been recorded as minor and major pests of mango, 87 are fruit feeders. The three to four key pests, including fruit flies, seed weevils, tree borers and mango hoppers require annual control measures, while secondary pests generally occur at subeconomic levels, and can become serious pests as a result of changes in cultural practices and mango cultivars or because of indiscriminate use of insecticides against a particular pest. Only fruit flies, seed weevils and lepidopterous larvae actually penetrate the fruit pulp and seed, while other pests such as Othreis materna (L.), Gonodonta pyrgo (Cram.), G. clotilda (Stoll) and Leptoglossus stigma (Herbest) often extends only into the pulp of ripening mangoes. External pests pose a risk because they may be present on the fruit surface as hitchhikers, but they can be detected visually by inspectors and removed before the fruits are shipped. Immature mango seed weevils (Cryptoryynchus mangiferi F.) occur in mango seed, but not in the flesh, and are difficult to control without damaging the market quality of the treated fruit. A related weevil (Sternochetus gravis F., sy. S. frigidus F.) occurs in rainfall regions in India and Southeast Asia, and causes severe damage to the fruit pulp.

7.1.1. Fruit flies

Fruit flies of the family Tephritidae are considered the most important insect pest risk carried by exported fruits worldwide. White and Elson-Harris (1992) reported 48 species of fruit flies attacking mango and a related species (M. foetida), including eight species of the genera Anastrepha, 30 species of the genera Bactrocera, seven species of the genera Ceratitis, two species of the genera Dirioxa and one species of the genera Toxo-trypana. Eggs of fruit flies are deposited under the peel, and larvae feed and tunnel through the pulp tissue. The commonly quarantine pests in mango (depending on the country and region) include:

1. Cryptoryynchus mangiferi (Fabricius)
2. Coleoptera: Curculionidae
3. Mediterranean fruit fly (Ceratitis capitata Wiedemann)
4. Mexican fruit fly (Anastrepha ludens Loey)
5. West Indian fruit fly (Anastrepha obliqua Macquart)
6. Caribbean fruit fly (Anastrepha suspensa Loey)
7. Oriental fruit fly (Deus dorsalis)
8. Melon fruit fly (D. cucurbitae)
9. Queensland fruit fly (Bactrocera tryoni)
10. Stone-nut weevil (Sternochetus mangiferi)
11. Mango weevil (Cryptoryynchus mangiferi)
Significant losses occur in mango worldwide due to infestation with fruit flies belonging to the family Tephritidae. In addition, fruit flies have tremendous impact on the restriction of international trade, and therefore quarantine procedures have to be practiced to limit their distribution. Fruit flies are widespread. Seven *Ceratitis* spp. have been reported to attack mango fruits. The Mediterranean fruit fly (*Ceratitis capitata* Wiedeman) is a common polyphagous pest, established in 95 countries, and considered the most destructive among the many fruit flies. Other species of this insect such as *C. rosa* and *C. cosyra* are known to attack mango in Africa. *Anastrepha* spp. are endemic to the western hemisphere, extending from the southern USA to northern Argentina including the Caribbean Islands. Eight *Anastrepha* species have been reported to attack mango, and the Caribbean fruit fly (*A. suspensa*) is considered as a threat in Florida. The West Indian fruit fly (*A. obliqua*) has been reported to be the most common fruit fly pest when compared with other neotropical species. In the majority of *Anastrepha* species, the female deposit their eggs (15-19 eggs per *A. ludens* female) in either the epicarp or mesocarp of ripening fruit, either singly or in clusters depending on the species. Larvae pass through three instars before emerging from the fruit and burrowing into the ground to pupate. Eggs incubation of *A. ludens* in mango was reported to require 3.8 days, larval development requires 14.2 days and pupal development requires 14.2 days at 27±2°C. Cultivars vary in their resistant to *Anastrepha* spp. Mango fruit contains resin ducts located in the exocarp which confer protection against two types of movement in the exocarp; the vertical movement of the ovipositor and larval movement.

The oriental fruit fly (*Dacus dorsalis* Hendel) and the melon fruit fly (*D. cucurbitae*, Coquillett) (Diptera: Tephritidae) were reported to infest ‘Nang Klangwan’ mangoes in Thailand. Queensland (*B. tryoni* Froggatt) and the Mediterranean fruit flies are the dominant fruit flies of mangoes in Australia. The stone/nut weevil (*Sternocetus mangiferae* Fabr.) is also an important mango pest in India, Bangladesh, Cambodia, Indonesia, Japan, Malaysia, Mauritius, Mozambique, New Caledonia, Pakistan, Philippines, South Africa, Sri Lanka, Tanzania, Thailand, Uganda, USA, Vietnam, Wallis Island and Zanzibar. However, this pest is not considered serious because only small portions of a few fruit are damaged by the adult weevil while emerging from the pupae by boring out through the pulp. Therefore, several countries require quarantine systems for this insect. *Dacus dorsalis* Hendel (Oriental fruit fly), *Dacus zonatus*, *Dacus correctus*, *Anastrepha ludens*, *Anastrepha obliqua* are others of the most common fruit flies that attack the mango fruit.

*Bactrocera* spp. are pests of major importance in the eastern hemisphere. The common species reported on mango include the Queensland fruit fly (*B. tryoni* Froggatt), oriental fruit fly (*B. dorsalis* Hendel), *B. zonata* (Saunders), *B. neobumeralis* (Hardy), *B. jarvisi* (Tryon) and *B. frauenfeldi* (Schiner). The oriental fruit fly (*Bactocera dorsalis*) is one of the most serious pests in some countries (such as India).

Monitoring of fruit flies is very important. Dropped fruits in the orchard need to be collected and destroyed weekly since the larvae of fruit flies emerge from these fruits and pupate in the soil. Preharvest control is normally done by weekly application of a toxic bait consisting of a mixture of insecticide plus an attractant and water. The bait treatments commonly used for mango are mercaptobutoxin plus protein hydrolysate, or trichlorfon and protein hydrolysate. The toxic bait is applied to a portion on only one side of the tree in a form of large droplets at a rate of about 250-1000 ml/tree, depending on tree size. Baiting should be applied before the fruit start coloring, and a 10 days safety period must elapse between the time of final application and harvesting.

### 7.1.2. Mango weevils

Mango is the only known host for the mango weevil (*Cryptorrhynchus mangiferae* F.). This pest is found throughout all the mango growing regions, except in North and South America, and the Caribbean. Therefore, the weevil is a quarantine pest. The weevil is primarily a pest of the seed with one seed supporting up to five larvae, although occasionally it may be found in the fruit flesh. Mango seed weevil (*Sternocetus mangiferae* F.) (Coleoptera: Curculionidae) is an important limiting factor for the international trade of mango and prevents the export of fresh fruit into areas uninfested with this
pest. The flesh of ripe fruit is damaged when adults emerge from the seeds, and weevil-damaged seeds may limit plant propagation in nurseries and orchards. Pre-mature fruit drop may be caused by severe weevil infestation. The mango seed weevil is present in South and Southeast Asia, Australia, in tropical Pacific Islands, and in parts of Africa. The Americas were believed to be free of the mango weevil, although its presence was reported in the southern Caribbean region.

### 7.2. Insect control treatments

Integrated pest management strategies adequately control orchard pests while reducing reliance on pesticides. Measures to control insects include preharvest and postharvest programs. Preharvest programs include cultural practices, traps, chemical treatments and use of sterilized insects.

Preharvest chemical control has been achieved using organophosphates and hydrolyzed albumen. This is usually based on baited traps and the appearance of the first trapped males. The chemical control agents are dimethoate (0.1%) and fenthion (15%). The bait spray is based on Neziman (1:1 protein hydrolysate: malathion 4 L in water). Weekly application of malathion is commonly used. For example, adult fruit flies can be controlled by bait sprays of carbaryl (0.2%) + protein hydrolysate (0.1%) or molasses starting at preoviposition stage (2 weeks after fruit set), repeated after 21 days. The use of hang traps (about 10 traps for each hectare of orchard) containing 100-ml emulsion of methyl euginol (0.1%) and malathion (1%) during fruit development is another used control method. The use of poison bait containing mercaptotiothion, trichlorfotm or protein hydrolyzate was practiced against fruit flies. Removal of fallen fruits is important to prevent the build-up of insect populations.

Postharvest treatments include the use of chemicals or high temperatures. Acceptable quarantine treatments that disinfest mangoes include vapor heat, hot air and hot water immersion. Phytosanitary requirements of mango in some countries are presented in Table 4 and disinfestation treatments for insect control approved in Japan and USA in Table 5.

Table 4. Phytosanitary requirements of mango in some countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Phytosanitary requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Approved treatment for fruit fly, area free of <em>Sternochetus gravis</em> F.</td>
</tr>
<tr>
<td>Canada</td>
<td>No phytosanitary certificate required</td>
</tr>
<tr>
<td>European Community</td>
<td>Phytosanitary certificate required</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>No restrictions</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Phytosanitary certificate required, area free of Queensland and Mediterranean fruit fly</td>
</tr>
<tr>
<td>Japan</td>
<td>Phytosanitary certificate required, disinfection schedule approved for nominated mango</td>
</tr>
<tr>
<td></td>
<td>cultivar and fruit fly species</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Must be free of seed weevil on inspection</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Phytosanitary certificate required, disinfection approved for nominated mango cultivars</td>
</tr>
<tr>
<td></td>
<td>and fruit fly species</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>Phytosanitary certificate required, require destructive test of 2% of consignment for seed</td>
</tr>
<tr>
<td>Singapore</td>
<td>No restrictions</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>Phytosanitary certificate required, destructive test of 2% of consignment for seed weevil</td>
</tr>
<tr>
<td>USA</td>
<td>Phytosanitary certificate required, disinfection schedule approved for nominated mango</td>
</tr>
<tr>
<td></td>
<td>cultivars and fruit fly species</td>
</tr>
</tbody>
</table>

#### 7.2.1. Chemical control

Chemical control of the Midterranean fruit fly has been achieved by applying organophosphates and hydrolysed albumen. Chemical application is based on monitoring by Trimedlure-baited traps and the appearance of the first trapped males. The chemical control agents are dimethoate (1%) and fenthion (0.15%). The bait spray is based on Neziman (1:1 protein hydrolysate: malathion 4 L of water). *Anastrepha* flies are susceptible to most insecticides. In Mexico, control starts when the fruit is 85 days old and is suspended 2 weeks before harvest.

Fumigation with ethylene dibromide (EDB) has been a traditional treatment for fruit fly disinfestation. The protocol requires fumigation with 16 to 35 g/m³ for 2 hrs at 21 to 26°C. However, this treatment is no longer registered for use in the USA, Mexico, Japan and other countries. Until 1994, mango shipped to New Zealand from Australia, Cook Islands and the Philippines were disinfested of fruit fly by treatment with 33, 29 or 22 g m⁻³ EDB at 10-15, 15.5-19.5 or 20°C or
above, respectively. This treatment was banned in 1994. Mangoes shipped to Australia from countries where fruit flies occur were fumigated with EDB at 16-35 g m\(^{-3}\) for 2 h at 21-26°C or above, depending on the country of origin and how the fruit is packed.

Table 5. Disinfestation treatments for insect control approved for mango in Japan and USA.

<table>
<thead>
<tr>
<th>Importing country</th>
<th>Exporting country (mango cultivar)</th>
<th>Required treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>Australia (Kensington)</td>
<td>VHT (46.5°C, 15 min., Qu, Me)</td>
</tr>
<tr>
<td></td>
<td>Philippines (Carabao)</td>
<td>VHT (46°C, 10 min., Or, Me)</td>
</tr>
<tr>
<td></td>
<td>Taiwan (Irwin, Haden)</td>
<td>VHT (46.5°C, 30 min., Or, Me)</td>
</tr>
<tr>
<td></td>
<td>Thailand (Nang Klang Wun)</td>
<td>VHT (46.5°C, 10 min., Or, Me)</td>
</tr>
<tr>
<td></td>
<td>Thailand (Nam Doc Maii, Pimsen Dang, Rad)</td>
<td>VHT (47°C, 10 min, Or, Me)</td>
</tr>
<tr>
<td>USA</td>
<td>Mexico, Central America north and including Costa Rica (flat, elongated cultivars)</td>
<td>HW (46.1°C, &lt; 375g: 65 min., 375-570g: 75 min.)</td>
</tr>
<tr>
<td></td>
<td>Mexico, Central America north and including Costa Rica (rounded cultivars)</td>
<td>HW (46.1°C, &lt; 500g: 75 min., 500-700 g: 90 min.)</td>
</tr>
<tr>
<td></td>
<td>Puerto Rico, US Virgin Islands, West Indies (excluding Aruba, Bonaire, Curacao, Margarita, Tortuga or Trinidad and Tobago)</td>
<td>Flat, elongated cultivars: HW 46.1°C, &lt; 400 g: 65 min., 400-570 g: 75 min. Rounded cultivars: &lt; 500 g: 75 min., 500-700 g: 90 min.</td>
</tr>
<tr>
<td></td>
<td>Panama, South America, West Indies localities excluded the mentioned above</td>
<td>Flat, elongated cultivars: &lt;375 g: 65 min., 375-570 g: 75 min. Rounded cultivars: &lt;425 g: 75 min., 425-650 g: 90 min.</td>
</tr>
<tr>
<td></td>
<td>Taiwan</td>
<td>VHT (46.5°C, 30 min.)</td>
</tr>
</tbody>
</table>

Me: Mediterranean fruit fly, Or: Oriental fruit fly, Qu: Queensland fruit fly, HW: Hot water treatment, VHT: vapor heat treatment

7.2.2. Heat treatments

Heat treatments have been reported to delay ripening, control insects and diseases, and to ameliorate CI in several horticultural crops. Hot water immersion is an efficient treatment for mango disinfection of fruit flies. The use of hot water immersion has intensified after the Environmental Protection Agency (EPA) initiated actions in 1986 to eliminate the use of EDB due to health concerns. Animal and Plant Health Inspection Service approved a hot water immersion quarantine treatment that destroys immature tephritidae in mangoes. Hot water treatments are used in several countries as quarantine treatments for mango and papaya fruits. For example, mangoes exported to the USA, Japan, New Zealand and some countries in South America from Mexico, the Caribbean, Peru, etc, are treated with hot water immersion at a temperature of 46.1 to 46.5°C for 65 to 90 minutes, depending on fruit weight. Large commercial hot water treatment facilities are installed in several countries such as Mexico, Brasil, Venezuela, Costa Rica and Peru.

Hot water treated fruit must be kept in screened areas to prevent re-infestation. Hot water immersion can damage the quality of mango fruit.

![Figure 5. Commercial hot water treatment facility.](image)

Vapor heat raises the temperature of mangoes when air saturated with water vapor is heated between 40 and 50°C. In this treatment heat is applied directly to the fruit surface by condensation of water vapor on the fruit. Vapor heat treatments have been used to disinfect mangoes of fruit flies. The vapor heat treatment for mangoes from Mexico is the same as that required for grapefruit, oranges and tangerines, while the vapor heat treatment required for mangoes from Taiwan consists
of raising the fruit pulp temperature to 46.6°C and maintaining it for 20 minutes. Mango fruit from the Philippines and Thailand are required to be treated with vapor heat at 46 (Philippines) and 46.5°C (Thailand) and held at the respective temperature for 10 min. New Zealand requires mango from Thailand to be vapor heat treated for fruit infestation by heating the fruit until seed surface temperature is 46.5°C, and then held at that temperature for 10 min. A vapor heat treatment schedule has been approved for use against the Queensland fruit fly (B. tryoni) in ‘Kensington’ mangoes from Australia to Japan, where the pulp temperature is raised to 46.5°C and held at that temperature for 10 min. A vapor heat treatment was also approved as a quarantine treatment for Mexican fruit fly (A. ludens) and other Anastrepha species in ‘Manila’ and for mangoes from Taiwan infested with oriental fruit fly for import into the USA. A vapor heat treatment was developed in Taiwan to disinfest mangoes against the melon fly and the oriental fruit fly. In this treatment, infested mangoes were exposed to vapor at 47.5°C until the center pulp reaches 46.5°C and remains there for 45 min.

Forced hot-air quarantine treatments were developed to disinfect mangoes of Caribbean fruit fly (A. suspensa) or West Indian fruit fly (A. obliqua Macquart). A mean center pulp temperature of over 47°C killed all stages of the West Indian fruit fly in Mexican-grown mangoes treated with hot air. A mean center pulp temperature of over 46°C killed all stages of the Caribbean fruit fly in Florida-grown mangoes treated with hot air. These treatments consist of heating the fruit with 48.0±0.3°C air for 160-220 minutes until the fruit seed surface temperature reaches 46.1°C or above to disinfect the fruit of Caribbean fruit fly, or with 50°C air for 133 or more minutes until the seed surface temperature is 48°C to disinfect the fruit of West Indian fruit fly. The conditioned air is forced over the surface of the fruit and slowly heats the pulp. Condensation is not formed, and relative humidity is usually maintained at about 50%.

Mango is susceptible to heat injury, although more tolerant than many other fruits. Small fruits are usually more susceptible to heat than large fruits, and therefore pretreatment size/weight grading is needed to insure that fruit is of uniform size. Preconditioning fruit can reduce damage significantly. Hot water treatment has been found to cause more internal and external injury than vapour heat. Hot water treatment injuries were reported to include rupturing of the cuticle, hollow cavities in the mesocarp, starch deposits, thickened cell walls and possible disruption enzymes involved in carbohydrate metabolism. Vapour-heat treatment in ‘Carabao’ mangoes caused internal breakdown in the inner mesocarp of the ripe fruit, presence of white, starchy and tough lesions and development of fermented odor.

7.2.3. Controlled atmospheres (CA)

Mango fruit is tolerant to insecticidal atmospheres (atmospheres with <1% O₂ and/or ≥50% CO₂) ‘Keitt’ mango fruit tolerated up to 5 days in atmosphere containing as low as 0.2% O₂ and as high as 79% CO₂, at 20°C. However, Bender and Brecht reported symptoms of CO₂ injury and abnormal color development in ‘Kent’ and ‘Tommy Atkins’ mangoes exposed to 50% and 70% CO₂. Insecticidal CA (≤0.5% O₂ or ≥50% CO₂ at 43°C was effective in controlling eggs and larvae of A. ludens and A. obliqua.

7.2.4. Irradiation

Irradiation involves the use of ionizing energy such as gamma rays, x-rays, electrons and microwaves. The use of irradiation for fresh horticultural crops at a maximum dose of 1.0 kilogray (KGy) was approved by the U.S. Food and Drug Administration for purposes of quarantine treatment and decay control. Mainland USA has begun to use irradiation as a quarantine treatment for some fruits imported from Hawaii since April 1995 and remains the only country using irradiation as a quarantine treatment, although on a very limited basis. However, several problems are still facing the application of this treatment. Irradiation is unique among quarantine treatments in that it is the only treatment used which does not cause acute mortality; instead, insects are prevented from maturing or are sterilized. Irradiation dosage that kill insects and eradicate diseases can also damage the fruit. Mango fruits may suffer from dosis as low as 150 Gy when applied on a commercial scale where much of the fruit load may receive dosis more than 300 Gy. The fact that insects are still alive for some time after irradiation has been one of the major obstacles to its commercial application.

Irradiation has been considered safe by the World Health Organization (WHO), Food and Agriculture Organization (FAO) and the International Atomic Energy Agency.
7.2.5. Biological control

Several parasitoids (Opioe fullawayi Silvistri, O. bumilis Silvestri, O. kraussi Fullavai, O. tryoni Cameron, O. bellus Gahan) have been reported parazitizing C. capitata. The most important parasitoids collected from C. capitata in Hawaii were O. vandenboschi, O. oophilus and B. longicaudatus). Both classical biological control and repeated augmentative releases of mass-reared parasitoids have been used to supress Anastrepha population. Parasitoid species such as Diachasmimorpha longicaudata, Doryctobracon crawfordi, Ganapis pelleranoi, Biosteres vandenboschi and Aceratoneuromya indica have been released in USA, Mexico, Costa Rica, Brazil and Peru for the control of A. suspensa, A. ludens and A. fraterculus. The mango seed weevil is thought to have few natural enemies. Parasitoides are unknown, probably because of the concealed nature of most of its life stages, and adults are thought to be susceptible to predation by ants, rodents, lizards and birds 14.

7.2.6. Combined treatments

Treatments with CA in combination with heat have been effective in causing the in vitro and the in vivo mortality of Anstrepha ludens and A. obliqua in ‘Manila’ mangoes 36, 37, 73, 74. ‘Manila’ mangoes treated with 50% CO₂ and 0% O₂ at 40 to 49°C and 50% RH for 160 min. and then stored at 10°C and 85% RH for up to 20 days 36, 37 showed no sign of injury in treatments at less than 44°C, but injury occurred at 44°C and increased with increased temperature.

Eggs and larvae of Mediterranean fruit fly, oriental fruit fly and melon fruit fly were reported to be killed in mangoes immersed in water at 46.3°C for 120 min. and then fumigated with EDB 40. All oriental fruit fly and melon fruit fly larvae in Taiwan-grown mangoes were killed when fruit were immersed in water at 48-50°C for 120 min., hydro-cooled, dried and cooled and then fumigated with EDB 29.

8. Harvest and Postharvest Handling

8.1. Harvest maturity/maturity indices

Mango quality at arrival, especially in import markets, vary widely among different lots. This is due to the absence of adequate maturity/harvesting indices. The supply of high-quality fruit requires the selection of uniformly ripened fruits. Therefore, the selection of adequate maturity indices is very important. The frequent need to transport fruit over long-distances has necessitated harvesting mango fruit at less-than-optimal maturity, which has resulted in poor quality fruit entering the market. Maturity at harvest determines both the postharvest life of the fruit and its quality. Fruit harvested before optimum maturity will either never ripen or never reach optimum quality. Mangoes harvested at the mature and half-mature stages ripen to good-quality fruit while immature fruits do not ripen normally. Fruits harvested after optimum maturity will have a shorter postharvest life. Fruits harvested medium-ripe or ripe and stored for short period showed lower contents of sugar and carotenoids. Physiological maturity in climacteric fruits is the stage at which the fruit can continue its processes of ripening and can reach its optimum eating quality off the tree. Fruit harvested before reaching physiological maturity will not ripen off the tree or will ripen with very poor quality.

The development and especially the use of standardized and adequate maturity indices has been a major problem in almost all the mango growing regions. In several countries, such as Egypt, India and Bangladesh, mango is considered ready for harvest when the fruit start dropping naturally from the tree. This method is not adequate since that mango fruit at this stage is overripe, easily injured during harvesting, and will have a very short postharvest life. Fruit harvested at this stage and dropped on the ground (as it is practiced in some countries in Asia and Africa) damages the fruit very drastically.

Maturity indices should comply with several requirements, including: 1) easy de determine, 2) not influenced by environmental conditions, 3) should relate to maturity and quality of the fruit, 4) be as objective as possible, 5) be preferably non-destructive.

The time of harvest should be determined according to its purpose. Generally, tree-ripe fruits attain much better quality than fruits harvested less ripe and ripened off the tree. However, tree-ripe fruits will not withstand prolonged storage and transport periods. Therefore, it is recommended that fruit destined for local market (immediate consumption) and for processing should be harvested at later stages of ripening than fruits intended for storage or to be transported to distant markets. Mango fruits should be harvested after they reach physiological maturity and before they are overripe.

It is important to define at least two sets of maturity indices: 1) maturity indices for fruits harvested when ripe and intended for immediate consumption in nearby markets or for processing (late harvest); 2) maturity indices for fruits
harvested when physiologically mature and intended for storage or transport to distant markets (such as export markets) (early harvest).

Several maturity indices have been suggested for different cultivars, but little efforts have been made to determine indices that have practical significance. Many physical, subjective attributes are used by mango growers as an indication for maturity changes such as fruit shape, size, color, appearance of powdery material or ‘bloom’ on the surface of the fruit, the appearance of plant sap on the surface, changes of the color of the stem, etc. The most important of these factors which is used in several regions, is the position of shoulders in relation to the position of the stem end of the fruit. The rise of the shoulders above the stem end is an indication of maturity. The maturity of fruit has also been correlated with various chemical characteristics such as soluble solids, titratable acidity, sugar to acid ratio, starch and specific gravity. Many attributes have been tested to determine maturity indices in fruits and vegetables. Several methods are been used to establish maturity indices in different mango growing regions, including: 1) computation (days from flowering, days from fruit set), 2) softness of cheeks, 3) peel color, 4) pulp color, 5) development of shoulders, 6) specific gravity, 7) starch content, 8) dry matter and 9) °Brix.

Several of these factors have commercial applications only for a specific types of harvest (early or late) and for specific cultivars. Some of these factors are only applicable for fruit that have reached an advanced degree of ripeness. There is no single index that can be used successfully to select mango with uniform maturity.

There are many factors that can influence the maturity and quality of the fruit. Fruit on the same tree may vary significantly in maturity due to uneven or prolonged flowering. In addition, variation in maturity between fruit can also be influenced by where fruit hang on the tree. In the southern hemisphere, fruit on the northern side were reported to mature more quickly than fruit on the southern side. These, in addition to the great diversity of cultivars grown in the world, makes maturity at harvest very much dependent on cultivar, region, environmental conditions, type and purpose of market, etc.

In some countries such as Egypt, fruit is considered ready for harvest when it drops on the ground. This is a very erroneous measure of fruit maturity and harvesting time. Dropped fruit are over mature and will not withstand handling and storage or transport.

8.1.1. Fruit age

Generally, harvest maturity in mango is reached in about 12 to 16 weeks after fruit set depending on cultivar. Computing the age of the fruit is one of the simplest factors that can be used for harvest. This factor is used in Asia (ASEAN region). This has been calculated from full bloom and fruit set, and recommendations were made as to the minimum age at harvest for different cultivars at different regions. Table 6 contains examples of the use of computation in different countries in ASEAN.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Age (days)</th>
<th>Computation</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arumanis</td>
<td>90</td>
<td>Full bloom</td>
<td>Indonesia</td>
</tr>
<tr>
<td>Arumanis</td>
<td>91</td>
<td>Fruit set</td>
<td>Malaysia</td>
</tr>
<tr>
<td>Blencong</td>
<td>86</td>
<td>First bloom</td>
<td>Indonesia</td>
</tr>
<tr>
<td>Carabao</td>
<td>84</td>
<td>Full bloom</td>
<td>Philippines</td>
</tr>
<tr>
<td>Carabao</td>
<td>116</td>
<td>Flower</td>
<td>Philippines</td>
</tr>
<tr>
<td>Cempora</td>
<td>101</td>
<td>First bloom</td>
<td>Indonesia</td>
</tr>
<tr>
<td>Golek</td>
<td>78</td>
<td>Full bloom</td>
<td>Indonesia</td>
</tr>
<tr>
<td>Golek</td>
<td>84</td>
<td>Fruit set</td>
<td>Malaysia</td>
</tr>
<tr>
<td>Kam Daeng</td>
<td>71</td>
<td>Full bloom</td>
<td>Thailand</td>
</tr>
<tr>
<td>Malgoa</td>
<td>108</td>
<td>First bloom</td>
<td>Indonesia</td>
</tr>
<tr>
<td>Malgoa</td>
<td>112</td>
<td>Fruit set</td>
<td>Malaysia</td>
</tr>
<tr>
<td>Nam Dorkmai</td>
<td>100</td>
<td>Full bloom</td>
<td>Thailand</td>
</tr>
<tr>
<td>Nam Dorkmai</td>
<td>102</td>
<td>Full bloom</td>
<td>Philippines</td>
</tr>
<tr>
<td>Nam Dorkmai</td>
<td>93</td>
<td>Fruit set</td>
<td>Thailand</td>
</tr>
<tr>
<td>Nang Klarngwun</td>
<td>115</td>
<td>Full bloom</td>
<td>Thailand</td>
</tr>
<tr>
<td>Tok Boon</td>
<td>105</td>
<td>Fruit set</td>
<td>Malaysia</td>
</tr>
<tr>
<td>Tongdum</td>
<td>102</td>
<td>Full bloom</td>
<td>Thailand</td>
</tr>
<tr>
<td>Yampulu</td>
<td>101</td>
<td>First bloom</td>
<td>Indonesia</td>
</tr>
</tbody>
</table>

Table 6. Examples of the use of computation at different countries in ASEAN.
It is clear from Table 6 that minimum age differs, even for the same cultivar grown in different regions, due mainly to pre-harvest factors such as environmental conditions. In addition, the use of terms such as first bloom, full bloom and fruit set is not very standardized. “Full bloom” is most recommended since that it is the most easily standardized.

8.1.2. Shape

On the basis of shape and form, external four maturity stages can defined during mango fruit development: 1) shoulders in line with the stem end and green olive color, 2) shoulders outgrowing the stem end and olive-green color, 3) shoulders outgrowing the stem end and light color, 4) flesh becoming soft and blush developing. Fruits are recommended to be harvested at stages 3 and 4. However, the change in the shape of the shoulder may not apply to all cultivars.

8.1.3. Specific gravity

As mango fruit matures it accumulates dry matter and thus become denser. Therefore, specific gravity (volume-weight relationship) may have some value as a maturity index. Specific gravity changes are rapid in young fruits and slow as maturity is reached. It has been suggested that uniform ripening and good storage quality can result from picking fruits having specific gravities between 1.01 and 1.015. Specific gravity usually changes, although slightly (0.97 to 1.04), which in some cases makes it to be not very reliable as a maturity index. In addition, the pattern of specific gravity in mango fruit can vary from year to year.

8.1.4. Soluble solids and titratable acidity

During maturation, soluble solids increase and titratable acidity decreases. However, there is no major use of this attribute as a maturity index for mango yet. In several cultivars, changes were either inconsistent or small enough to be used as a commercial maturity index.

8.1.5. Texture

Ripening in mango fruit is associated with loss of firmness, although no definite commercial application is widely used.

8.1.6. External (skin) and internal (pulp) color

Skin color is variable for the different cultivars. Yellow cultivars develop their skin color somewhat uniformly, however cultivars with red blush are not uniform in their skin color development. In addition, some cultivars do not change their green color upon ripening. Even in yellow cultivars, when the skin color changes the fruit is usually advanced in maturity. Fruit position on the tree can affect peel color development. Nitrogen fertilization significantly affects the development of yellow and red colors. Therefore, skin or peel color is not an optimum maturity index for many mango cultivars. On the other hand, in most mango cultivars pulp color changes are somewhat uniform when fruit advances in maturity. Unfortunately this is a destructive index, but more consistent and more utilized than skin color change. Pulp color is commonly used as a maturity index in several mango growing regions.

8.1.7. Non-destructive objective techniques

Some non-destructive methods were tried to study the maturity of fruits. Near-infrared (NIR) technology is a non-destructive method for analyzing the ingredients of organic products, and therefore it is implemented in the food industry both in laboratories and on-line production processes 46. In mango fruit, NIR was tested to assess dry matter in ‘Kensington’ mangoes 13, and to establish relationships between reflectance spectra and quality parameters in ‘Tommy Atkins’ mangoes 39.
8.1.8. Combined factors

Due to differences among mango types, diversity of cultivars, and diversity of production conditions, there is no consensus on maturity indices. It is important that maturity indices are established for cultivar, growing region and purpose of harvest. Mango fruit transported to distant markets by sea should be harvested firm and without any sign of color change. The fruit should be picked, treated, packed and shipped while still green and with a firm texture, and should arrive at the retail market more yellow or red than green but still firm. It is necessary that several indices are used together to make a better decision. For example in Australia flesh color is combined with skin color and dry matter content. In Mexico flesh color is combined with fruit shape (shoulder development).

Experience with the cultivar and growing condition is very important to determine the ideal maturity index or indices to use, optimum maturity stage and the optimum harvesting time. Easy-to-assess harvest indices relying on visual attributes are needed. Conditions that are usually applied for mango varieties such as ‘Haden’, ‘Tommy Atkins’ and similar varieties include: A) completely mature: formed shoulder, a depression around the peduncle, firm, and green color, B) immature: shoulders in line with peduncle, firm and green color.

8.2. Quality indices and grade standards

The mango should be uniform in size and shape, with no scars or other surface defects such as scuffing or evidence of bruising. High quality mango at destination should have appealing color and shape, firm texture, tender flesh, with sweet taste and highly aromatic. Fiber content should be minimal. Acceptable quality for characteristics for ‘Tommy Atkins’ mangoes were considered as pulp rupture force of 0.5-1.0 kg, greater than 9.5% soluble solids, pH 4.0 and pulp and peel colour score of 3.0. Pulp rupture force value of less than 0.5 kg were indicative of over-ripe fruit.

Mango fruit are susceptible to physical damage during all the postharvest handling chain. The types of physical damage that can occur in mango include scuffing, compression, vibration and impact bruising. Scuffing occurs when fruit surfaces are abraded by stems of other fruits, the sides of rough or dirty picking containers, dirty packing line conveyers and worn or stiff packing line brushes. Mangoes can also suffer vibration bruising in transit when individual fruit are allowed to rub against each other. Careful handling should be maintained to reduce all forms of physical injury.

The Organization for Economic Co-operation and Development provides guidelines in defining international marketing requirements. Minimum requirements for fruit intended for the international market should be intact, firm, fresh in appearance, sound, clean, free from black stains and bruising, free from damage caused by low temperature, free from pests and pest damage, carefully picked at the stage that allow transport and handling and continuation of the ripening process so as to arrive in a satisfactory condition at its destination. Class standards are defined as “extra”, “good quality” (class I) and “marketable” (class II). Fruit sizes defined are A: 200-350 g, B: 351-550 g, and C: 551-800 g. The maximum permissible differences allowed within each size groups are 75, 100, and 125 g, respectively.

Mango for export market must comply with requirements of consumers and with quality standards of the importing market in terms of size, color, appearance, absence of defects, ripening stage, uniformity, absence of insects and diseases, phytosanitary regulations, etc. The fruit must arrive to the market at an optimum ripening stage that can allow reasonable shelf life for retail marketing. Depending on the importing market, the mango may need to be subjected to a legal disinfection treatment. The only insect disinfection treatment accepted by most importing countries is the use of heat treatments.

Import markets have established quality standards. The three important quality standards developed are:
3. Europe. UN/ECE standard FFV-45. Concerning the marketing and commercial quality control of Mangoes.

Generally, import markets require that mango at arrival be: 1) physiologically mature, 2) 30 to 50% development of color, 3) in the case of red cultivars, a significant amount of red area being developed in the fruit shoulder, 4) fruit being firm, 5) a minimum of 10% sugar; 6) uniform shape, 7) free from diseases, insects, latex stains, soil burns and mechanical injury, 8) meeting specific size and weight requirements.

Prices in import markets are usually set on the basis of 1) the presence of red color, red varieties are usually more expensive than yellow varieties; 2) maturity stage, over mature fruits are less desirable; 3) uniformity, fruits should be very uniform in size, weight and color; 4) absence of diseases and defects.

Regarding the uniformity of fruits, which is a very important characteristic, a package with a capacity of 4 kg, for example, should contain: 1) 6 fruits of 666 g each, 2) 8 fruits of 500 g each, 3) 10 fruits of 400 g each, 4) 12 fruits of 330 g each, 5) 14 fruits of 290 g each.
An export plan should be prepared for each market, and should include:

1. Fruit must be screened in the field to insure export quality. This operation can be done by the exporter or by agents working for the exporter association. This way exported fruit is assured to be of high quality and suitable for export market.

2. Development of a registry for each shipment. A detailed historical registry of fruit is needed and it should include all aspects of the operation such as origin of fruit, date of harvest, date and hour of packing, special treatments applied. This registry will help identify the cause of problems that appear during marketing.

3. Inspection. All packed fruit should be inspected (fruit and package) before leaving the packinghouse to assure their quality. It is important that all information should be printed adequately on the package. Fruits should be taken off the package and inspected individually and its grade be specified according to a set of standards. The sample size is established by the International Standardization Office (ISO874-1980) according to Table 7. Some importing countries allow inspection at the exporting site (packinghouse). This is the case, for example in Mexico for fruits exported to USA and Japan. Official inspectors (through agreement between the US Department of Agriculture and the Mexican Secretary of Agriculture) assure that phytosanitary regulations are adequately applied and fruit is strictly secured from re-infestation. Quality Inspection can be done either at the export site, at the port of exit or at the port of entry.

4. Specifications of export mango. These are set according to the requirements and the standards of the importing country. Some of the general specifications for the markets in England, Europe, and Canada are as follow: a) varieties, most popular varieties are ‘Tommy Atkins’, ‘Haden’, ‘Keitt’, and ‘Kent’; b) color, skin color needed should be partly red with green and yellow, pulp color needed should be yellow to orange; c) appearance, size and ripening should be uniform, fruit should be free of defects such as mechanical damage, decay, insect damage, etc.; d) size, size requirements for ‘Haden’ and ‘Tommy Atkins’ are as follows:

<table>
<thead>
<tr>
<th>Total number of packages</th>
<th>Packages to be sampled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 100</td>
<td>5</td>
</tr>
<tr>
<td>101 to 300</td>
<td>7</td>
</tr>
<tr>
<td>301 to 500</td>
<td>9</td>
</tr>
<tr>
<td>501 to 1,000</td>
<td>10</td>
</tr>
<tr>
<td>More than 1,000</td>
<td>15 (minimum)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>‘Haden’</th>
<th>‘Tommy Atkins’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum weight</td>
<td>300 g</td>
<td>350 g</td>
</tr>
<tr>
<td>Minimum longitude</td>
<td>9.0 cm</td>
<td>10 cm</td>
</tr>
<tr>
<td>Minimum width</td>
<td>8.0 cm</td>
<td>9.0 cm</td>
</tr>
<tr>
<td>Minimum thickness</td>
<td>8.0 cm</td>
<td>9.0 cm</td>
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</tbody>
</table>

e) conditions, fruit should not show latex staining, mechanical cuts, or insect and disease damage; f.) phytosanitary regulations.

Disinfestation treatments for fruit flies are not needed for the EC despite the large production of temperate fruit in regions free of fruit fly. Fly infestation has never perceived as a threat because freezing winter temperatures throughout much of the region effectively prevent establishment of the insects. Canada also does not require fruit fly disinfection of tropical products for the same reason. The USA requires that mango be disinfested using treatments such as vapor heat, hot air or hot water.

It is important to note that prior approval to import is required by some countries. These import permits may cover multiple importations but usually require renewal every 3-12 months. Phytosanitary certificates must be issued by a government agent based on an agreement commonly done between export and import countries. Consignments that found to contain quarantinable pests will be rejected, and will either be regressed or destroyed.

### 8.3. Establishment of a quality control system

Due to the market competition it is essential to develop a quality control system following the standards established by the
Maturity indices should be developed and a harvesting system should be established. Each packer/producer/exporter should make sure that maturity indices and harvest techniques used in his establishment be the ideal. A “seal of quality” should be established, indicating the certification of the fruit. A certification team (technicians) should be trained and used to establish the system. These “quality promoters” will be the responsible agents to certificate the fruit received in the packinghouse/market, decide its grade, price and whether it is adequate for export or not. Not all fruit will pass through the system, nor all producers and probably not all exporters will be part of this system. However the “seal of quality” should be the factor that distinguish between “certified” and “not certified” fruits. Producers/exporters associated with the system should be the only who receive the service of certification, and thus the “seal of quality”. Mango with the ‘seal of quality” should be promoted and distinguished. The “seal of quality” should be awarded when: a) The quality control is done by an inspector approved by the association, and the inspection follows the “quality manual” developed by the association. b) An initial visit is done to the establishment to install the procedure of the quality control system. c) Random visits should be done to the establishment to monitor the process.

8.4. Bagging

Individual bagging is used in some regions to protect fruit from insects and diseases. Bagging of developing fruit can reduce or eliminate disease infection or fruit fly infestation, but can favor the proliferation of scale or mealybugs. Fruits are commonly bagged at 55-60 days from full bloom or after the period of heavy fruit drop, but fruit can also be bagged earlier if early floral induction has occurred. Bagging decreases the incidence of insects, anthracnose and stem-end rot, and thus affects fruit quality and may also affect fruit maturity. In Taiwan bagging is commonly practiced to prevent oriental fruit fly damage 30 to 45 days before harvest. Two types of paper bags are used, white and black. The white bags are used on red cultivars, such as ‘Irwin’, while the black bags are used on cultivars whose skin color remain green such as in the case of ‘Jinhwung’.

8.5. Harvesting

Harvesting should be done by experienced pickers. The quality of the picked fruit will be greatly influenced by the ability of the picker to choose adequate (mature) fruit and by the method of picking used. Fruits will not mature at the same time, and therefore they should be picked at different intervals, especially when harvesting is done at earlier stages of maturity. Repeated harvest of the same tree should be carried out to ensure that only mature fruit is picked each time. In young trees, and in the lower part of old, vigorous trees, picking is done by hand. However, in higher branches some harvesting aids are needed to assist in picking. Several devices are used in different regions, most commonly is a half-elliptical basket attached to a long pole adapted with a severing blade or scissor. The upper end of these baskets usually contains a heavy gauge looped wire or a scissor controlled by the picker to facilitate the separation of the fruit. The basket should be big enough to hold a maximum of 3-5 fruits, so that fruits will not be injured neither mechanically nor by the latex. Baskets should be made of a material (like cotton) that facilitates its cleaning. It is important that these devices be designed so that about 2 cm of the peduncle of the fruit remains attached after harvest. It is preferable that picking be done by hand whenever possible. Ladders or three-wheeled motorized picking platforms (known in some parts as cherry pickers) are employed in some regions to pick fruits from tall trees. Fruits are cut by the blade and fall into the bag. When the bag is full with 3-6 mangoes, the pole is lowered and the fruit is transferred to baskets, buckets or crates.

Mechanical aid harvesting is used in some places, such as in Australia. In the system used in Australia, fruit are commonly pulled from the tree using hocks that separate the fruit from the panicle flush with the fruit. The spurt sap is allowed to squirt away from the fruit while it is falling. Fruit is then caught on suspended plastic tarpaulins that are constantly being sprayed with water and a detergent solution. The solution coats the fruit as they roll down the tarpaulin protecting the fruit from the sap. With mechanical aid harvesting in N. Queensland, picking costs, sap burn and bruising have been reduced very significantly. Sap burn has been reduced from 25-35% to 3% and bruising in ‘Kensington Pride’.
has been reduced down to 3%. The process involves hand removal of the fruit and lands on a catching platform from where it is washed by sprays of water and detergent which protects the fruit from sap burn. The stem is then trimmed by hand and fruits are accumulated in bins or lug boxes. In Australia, one machine is needed per 40,000 trays harvested, and picking rates of 700-1300 kg/ha is possible with a harvest aid machine using a nine person team. Hedge rows no taller than about 3.5 m are best suited for the use of mechanical harvesting catching platforms.

It is very important that care should be taken to reduce mechanical injury. In some countries in Africa and Asia, a pole is used to cut the fruit and let it drop on the ground where it is collected either immediately or even sometimes after few days. This practice causes major injury and fruit losses. Branches should not be vigorously shaken, and fruit should not be allowed to drop on the ground. Mechanical injury during harvest is, unfortunately, common and causes major quantitative and qualitative losses.

Harvesting date should be chosen very carefully so that: 1) fruit arrival to the market should be during the time of peak demand and highest price (usually the start of the week); 2) to maximize the chance of early sale and to minimize loading wait at the shipping port.

The hour of harvest should be selected carefully. One should weigh the benefits or not of picking in the coolest hour of the day. From the standpoint of field heat, respiration and heat damage, the fruit should be harvested the earliest/coolest hours of the day. Harvesting during warm hours will increase fruit deterioration, increase the need of fast cooling, increase energy requirement for cooling and negatively affect workers comfort. Latex flow can be higher in the coldest (earliest) hour of the day.

Fruits should never be dropped on the ground. Contact of the fruit with the soil and soil-born diseases should be avoided all the time. Rough harvesting increases fruit bruising, disease infection, quality deterioration, losses and reduce profits.

8.6. Transport and handling at the packinghouse

Harvested fruit should be transported to the packinghouse or to the market as soon as possible. Exposure to the sun in the field, at the road, in the packinghouse or in the market should be avoided. Fruit should be transported with care so that mechanical injury is minimal. Drivers should follow smooth roads, vehicles tires should be correctly inflated and vehicle suspension should be in good conditions.

At the packinghouse, if fruit need to wait before packing, they have to be set in the shed and be protected from the sun, high temperature, wind, rain, etc. Fruit should be packed within no more than 3-4 hours from arrival. It is preferable that the peduncle be cut at this point to leave about 0.5 cm. Samples should be taken to evaluate quality of the fruit. This inspection point is very important to determine the condition of the fruit, determine acceptance, the suitability for a determined market, the treatments that the fruit should receive in the packinghouse, decide the price on bases of quality evaluation, etc. If an infestation quarantine treatment is needed, a sample should be evaluated for the presence of insects.

It is recommended that fruit be received in water and transported on a roller conveyer to the other steps of the packinghouse. Water can contain up to 200 ppm chlorine and fruit should be exposed for 3-5 seconds. Chlorine is degraded easily and thus its concentration should be monitored regularly. Fruit should be dried by air fan and/or using brushes. The packing line should be designed so that it can be comfortable for workers and do not injure the fruit. Light and temperature should be controlled adequately.

There are many types of designs of packing lines and packinghouses, some are very simple while others are computerized. However, the most important consideration is that the packing line should not be complicated, should not damage the fruit and the process should be clean and organized. The line should be designed so that the process is logical, continuous and synchronized.

8.7. Washing

Washing of fruit is usually done immediately after arrival to the packinghouse. This is commonly done before hot water or fungicide treatments. Detergents and sanitizers are commonly added to washing water, however some of them may cause fruit damage or may promote early fruit disease expression.

8.8. Latex staining and control

When a mango fruit is detached from its stalk, or when the skin of an unripe fruit is cut, a transparent liquid oozes out. The
sap contained in the fruit is under a considerable pressure. When the pedicel is broken the sap is exuded towards the fruit skin. Latex (sap), with low pH and high oil content exudates can stain the fruit, burn the skin and reduces its quality. Latex exudates prevent the development of ideal fruit color. It has been reported that skin damage by sap burn is particularly severe with ‘Kensington’ and less serious in Florida cultivars. The oil component of the latex of the Thai cultivars was found to be much lower than that in ‘Kensington’. The problem is aggravated if the fruit is picked in the early morning, and the peduncle is completely detached. It is recommended that fruit be picked after about 9:00 AM when the fruit is less turgid and latex flow is minimal. In addition, it is important that at least a 2 cm of peduncle be kept attached upon cutting of the fruit. High nitrogen content in the fruit has been associated with more severe latex burn. Areas of skin damaged by latex may develop bacterial or fungal legions. Latex-burned skin can be invaded with Aspergillus spp., especially in hot conditions.

The susceptibility of mango to latex staining depends on several factors such as cultivar, maturity stage at harvest, time of harvest, growing region, season, age of tree, among others. The flow and volume of latex is related to: 1) Maturity. Immature fruit usually produce more latex. 2) Hour of the day. The flow of latex is higher during the morning than during the afternoon due to fruit turgidity. 3) Rain. The flow of latex increases immediately after rainfall due to increased turgidity of the fruit.

It is recommended that fruit be harvested with 2 cm pedicel attached and re-trimmed to 0.5 cm at the packinghouse. Latex commonly do not exude from the longer pedicel because there is no continuity between the fruit and the pedicel resin ducts. The pedicels should be cut at the packinghouse before packaging, because they can break again causing the flow of latex which can increase disease infection.

Mango latex is known to cause an allergic dermatitis. Patients were presented with urticaria and eczematous rash following exposure to mangoes. Patch testing with diluted sap, crushed leaf, crushed stem and fruit skin was strongly positive. Harvesting and packinghouse personnel should avoid being in contact with the latex. Workers who are allergic to mango latex should be assigned to other duties.

Several strategies have been suggested to combat the problem of latex including harvesting of the fruit with the pedicel attached, inversion of the fruit to allow the sap to drain and until the pedicel dries, the use of detergents and emulsions which reduce the effects of the sap. Some of the suggested methods include:

1. Desaping in a 1% solution of calcium hydroxide. This is not used commercially.
2. Washing fruit in 1% aluminum potassium sulfate.
3. Applying surface coating to fruit prior to eliminating the latex (de-saping). This method is not used commercially.
4. Trimming and de-saping at the packinghouse followed by inversion on a stationary rack or a roller-conveyor running below water or water and detergent sprays for 20 minutes. This has been used in Australia. Hand-picked mango fruit in Australia are picked with approximately 10-mm of the fruit stalk still attached, to prevent from spurting out of the cut end of the fruit. The fruit are then placed in filed crates and taken to the packing shed for desapping. Desapping (or bleeding) is done by breaking the fruit stalk off flush with the fruit, while holding the fruit in such a position that the spurt of the sap is directed away from the fruit. The fruit is then placed stem down on the racks for 20-30 min. to allow the ooze sap to cease flowing. During this period the fruit is usually sprayed with detergent and water.
5. Inversion in the soil at a shady spot immediately after harvest for 30 minutes. Soil bleeding, which is commonly used in some countries like Egypt, causes a significant increase in the incidence and an earlier appearance of stem-end rot, resulting from soil-borne inoculum.

8.9. Sizing

Fruit should be selected, and only good quality fruit should be packed. The purpose of this step is to sort fruit into uniform categories (according to size, shape, color and absence of defects), and to divert low quality fruit to another use such as low quality market or processing. Fruit can be classified to different grades according to the requirements of the market. Defected fruit should be eliminated. This is done manually by trained persons. This area should be designed to be comfortable in relation to height of selection tables, lights and temperature.

The purpose of sizing is to categorize fruits into different and uniform groups on the basis of size or weight. Mango fruit can be classified manually, but uniformity will be much better when sizing is done mechanically either by size or weight according to the requirements of the importing market. Sizing can be done by using divergent arms, where the distance is minimal at the beginning and increases continuously. Distances between arms are adjustable so that fruit sizes can be modified depending on the cultivar and the requirement of the market. Small fruits are dropped at the beginning and biggest fruits are dropped at the end.
Mango can also be classified by weight. These sizers consist of plates controlled electronically. Each plate carries one fruit. When the fruit is dropped in the sizing plate, its weight is recorded, and the fruit will be dropped automatically in the packing band where its size corresponds.

Quality grading of mango fruit is usually done by manual inspection and observation of individual fruits by trained persons. Fruits are classified according to uniformity, maturity stage, color, absence of injuries and defects, latex stain, disease and insect infestation.

8.10. Quarantine treatments

In case that fruit is to be shipped to a market that restricts the entry of certain insects and requires a quarantine treatment, fruit should be treated with a legal system established through an agreement between exported and imported authorities.

Handling of the fruit should follow a protocol of the quarantine system. The protocol usually defines preharvest treatments and precautions, restrictions of type of fruit that can be treated and fields where fruit for treatment can be harvested, traps for insects in the field, integrated preharvest treatments and control systems, etc.

At arrival to the packinghouse, fruit that has been harvested according to the quarantine protocol should be sampled to assure the absence of insects. Fruits found to be infested should not be treated nor packed. In addition, it is common that quarantine protocols require that export be prevented from fields that produce infested fruits, until the infestation is corrected.

Quarantine systems using fumigants such as ethylene dibromide (EDB) and methyl bromide (MB) are not acceptable by most importing countries. The quarantine system commonly used for mango in many countries is the use of hot water or vapor heat.

8.10.1. Hot air

Vapor heat was approved in Japan in 1986 for the importation of mango from the Philippines. This treatment requires that mango be treated with vapor heat until surface temperature is 46°C and seed temperature reaches 46.5°C and it is held that way for 10 minutes. A vapor heat treatment has also been approved for the control of the Queensland fruit fly in ‘Kensington’ mango exported from Australia to Japan. The treatment consists in raising the pulp temperature to 46.5°C and holding it for 10 minutes. USA also approved a quarantine vapor heat treatment for the control of Mexican fruit fly (Anastrepha ludens) and other Anastrepha species in ‘Manila’ mango and for mango from Taiwan infested with the oriental fruit fly.

The hot air is usually forced over the surface of the fruit, which will slowly heats the pulp. When air at 50 °C was forced over mango surfaces, all stages of mango fruit fly, West Indian fruit fly and Anastrepha serpentina were killed when the seed surface temperature reached 48°C. Mango fruit weighing over 700 g can not be treated with this system.

8.10.2. Hot water treatment

The use of hot water treatment as a quarantine system was intensified after the elimination of EDB. The use of this quarantine system in Mexico started in 1988 for the control of fruit fly (Anastrepha ludens and A. obliqua) for fruits exported to USA and Japan. It consists of exposure to temperature of 46.1°C for 65, 75 or 90 minutes depending on fruit weight. This system is now widely used in different mango growing regions in Mexico, Central and South America and the West Indies. By 1995 almost 90 plants were installed in these regions with a cost estimated at 150,000 to 300,000 dollars/plant. This system did not reduce the mango export as it was thought, but rather increased it. For example in 1986 (using EDB as a quarantine system) Mexico exported to the USA 36,685 MT worth 25 million dollars, while in 1993 (using hot water treatment) export was up to 94,439 MT worth almost 72 million dollars. The treatment was also found to be effective in the disinfestation of insects other than the genus Anastrepha.

After quarantine treatment is applied fruit must be introduced to an isolated, insect-proof area to prevent re-infestation. From here on (packaging, transport, etc) and until the fruit is received at the importing end, secure measures are implemented to prevent re-infestation.

After heat treatment, fruit is usually cooled with water at ambient temperature and/or with forced air cooling. In Mexico, fruit is first cooled in ambient water immediately after hot water treatment for about 20 min., packed, and then cooled with forced-air cooling.
8.11. Waxing

Waxing, which involves the coating of fruit skin with a thin layer of wax, can be beneficial as a barrier to mass transfer (water vapor and gases), can improve visual appearance of the fruit, and can provide an internal modified atmosphere. This is especially beneficial when the fruit is treated with something (such as hot water) that can deteriorate the bloom of the fruit after harvest. However, inadequate application of waxes can result in fermentation of the fruit. Waxing of mango is not commonly used mainly because of the risk of off-flavor development. It is used by some exporters in Mexico to reduce water loss of fruits treated with hot water for control of insects. The use of light waxes is preferred to heavy waxes which can hamper color development. Aqueous wax emulsion, consisting of vegetable (sisal, sugarcane and carnauba) waxes and mineral petroleum (paraffin) with and without shellac and emulsifiers, increased the storage life of mangoes. When waxes are intended to be applied, it is important to investigate the regulation of the imported country regarding types of waxes allowed, but it is always preferable that these be of natural origin. If to be used, the wax should be applied in a thin uniform film, using preferably roller brushes, or a wax applicator, or by very light hand application. Dipping fruit in a wax emulsion is not recommended. The wax can be applied together with the fungicide. The fruit should be completely dry before applying the wax, otherwise foaming of water-emulsion waxes may occur.

8.12. Packing

Packaging is done manually. Exported fruit are commonly packed in a single layer in corrugated boxes. Size and weight of packages depend on the requirements of the importer, but mango is commonly packed in boxes with a capacity of 4 to 5 kg (Figure 6). Packages should meet several requirements:
1. They should protect the fruit from mechanical damage and from contaminants, and do not cause injury.
2. They should have a sufficient strength. These packages will commonly be in contact with a humid atmosphere, and that should not debilitate the structure of the package.
3. They should be designed with sufficient opening for ventilation. This is very important for cooling of the fruit, and also to liberate respiration gases.
4. Vents and opening in the packages should be in accordance to the direction of air circulation in the transport container.
5. They should be attractive, and should provide sufficient information including promotional data. Some of the information needed to be printed on the package are required (such as product name, source, class). Packaging should be a marketing tool and should portray an excellent marketing image.
6. The package should be easily opened and closed.
7. Preferably, packages should be recyclable.
8. Packages should be designed according to the requirements of the export market with regard to the material used and size and capacity of the package. Regulations of countries should be checked before using the package. Special attention should be given to the tendency of recycling in Europe, and the special material and sizes in Germany. It is also important to use packages that are compatible with the pallet to be used (for example 1.0 m x 1.2 m for Europe or 40" x 48" for USA).
9. The packages should be compatible with the handling system at the importing end.

Figure 6. Packing of mango fruit.
In Europe there is a strong tendency for recycling and standardization. Packages made of mixed products are to be avoided. Also to be avoid are stapled products. Waxed packages, acceptable in USA and other markets, are not acceptable in the EU market because they are not recyclable. It is important to communicate with the importer regarding the requirement of each country.

8.13. Palletizing

Palletizing allows much easier, faster and uniform handling, lower costs and better utilization of space in the storage rooms or transport containers. Pallet dimensions can be different in different export markets, and thus it should be investigated before shipping.

8.14. Cooling

Fruit, especially those that are heat-treated, should be precooled. Precooling is very important to absorb field heat. Precooling also decreases the refrigeration demand during cold storage or refrigerated transport. Precooling is needed to reduce possible high temperature damage and also to delay fruit ripening and to maintain fruit quality for prolonged periods. The delay in cooling mango fruit results in accelerated ripening and in short postharvest life and deteriorated quality. Mango fruit is commonly precooled after packing. The ideal pre-cooling method for mango is forced-air cooling. With this method the temperature of the fruit can be reduced from about 35°C to about 14°C (temperature when pre-cooling should be terminated) in 2 to 5 hours.

9. Storage and Transport

9.1. Storage

Packinghouse should include cold storage room or rooms, depending on the capacity and the quantity of fruits packed. Mango is not commonly stored for prolonged periods. However, after precooling the fruit should be moved immediately to the cold room or to the transport container. It is common (in case that fruit quantity is not sufficient to fill a transport container, or that the container is not ready) that fruit be held in the cold storage. Mangoes also need to be maintained in a cold storage room at the importing end before arrangements for marketing are finalized. It is important that the cold chain should not be interrupted (fast cooling, prompt placing in cold room or cold transport container, no exposure to high temperature). Fruit should be picked, packed, pre-cooled and placed in the cold storage or cold transport container within no more than 24 hours.

Cold storage room should be set at 10-14°C (depending on cultivar and holding period) and 85-90% relative humidity, should be equipped with adequate systems of air circulation, air exchange, and should be clean. Fruit should be stacked in a way that can permit an adequate circulation of cold air. Air circulation should be enough to establish a uniformity of temperature and gases in the room. Harvesting at optimum maturity, prompt cooling, the use of optimum temperature and optimum storage conditions can maintain most mango cultivars for 2 to 4 weeks. Several factors affect the storability of mango such as cultivar, stage of maturity, method of harvesting, handling, packaging and mode of transport.

The ideal holding temperature for mango depends on several factors such as cultivar, maturity stage and holding period. Temperatures between 12 and 13°C are generally considered to be optimum for mango storage and transport, with storage/transport at 12°C being recommended to reduce the risk of CI in Florida cultivars. Ripened fruit can be kept at temperatures lower than 8°C for up to 21 days, but fruit will deteriorate rapidly after removal from storage.

Shelf life decreases markedly with the delay in time of fruit placement in cool storage. Delay in time from picking until placement of the fruit under refrigeration increases the rate of ripening, especially for fruits picked at later stages of ripening. If the delay is prolonged, refrigerated storage/shipping may become totally ineffective in prolonging the life of the fruit. During ripening, lenticel damage increased and fruit was softer due to the delay in cooling.

CI symptoms in mango were reported at temperatures ranging between 3 to 12°C. CI sensitivity is influenced by various factors. Fruit harvested when nearly ripe are less prone of CI and fruit picked at earlier stage of maturation are more prone to CI and other storage-related disorders.
9.2. Ripening

Mangoes are commonly harvested at the mature green stage and ripened after harvest. The quality of ripened mangoes will depend on maturity at harvest and on ripening conditions, especially temperature. Only mature fruit should be harvested to ensure optimum flavor quality when fruit is ripe. Temperature management is very important during ripening of mature-green mango fruit. The ideal temperature for mango ripening is 20 to 22°C. Ripening at 15 to 18°C may result in the most attractive skin color, but flavor becomes tart. Flavor development is best at 27°C. These fruits will require about 2-3 days at 21-24 °C to attain sweet flavor. Ripening at 27-30°C results in mottled skin and a strong flavor. Optimum relative humidity during ripening is 90 to 95%. Ethylene is not commonly used, but it is preferred to ensure faster and uniform ripening. The use of 100 ppm ethylene at the mentioned temperature and RH conditions for 12 to 24 h can result in accelerated and uniform ripening within 5-9 days, depending on cultivar and maturity stage. Carbon dioxide concentration should be kept below 1% in the ripening room. Once ripened, mangoes can be kept at 10-13°C and 90-95% RH for up to one week.

9.3. Transport

Major losses occur during transport of mango fruit in developing countries. This is due to improper and rough handling, improper containers, poor roads and vehicles conditions, high transit temperatures, etc. Fruit can be transported by road, air, or sea. The method to be selected depends on the type of market, distance, cost of transportation and the stage of maturity of the fruit. It is recommended that a sample of shipped fruit be maintained to evaluate its quality during the shipping and marketing period. This sample should be maintained at the same conditions (temperature and relative humidity) of the transported fruit. Containers for land and sea transport should be: 1) clean, not damaged, and with adequate and well-functional air ducts; 2) pre-cooled before loading the cooled fruit; 3) refrigeration capacity should be adequate for the quantity of fruit to be transported; 4) containers should be equipped with a temperature registry system, these should be preferably more than one, and should be allocated in ideal places in the container, preferably inside the fruit pallet; 5) transport containers are designed for maintenance of temperature of the load and not to pre-cool it (not to remove field heat).

Many loads are transported by air shipments without refrigeration. There are different refrigeration systems used for transport: 1) mechanical refrigeration, containers are connected to electric energy aboard diesel trucks or ships; 2) cryogenic systems, in this system liquid nitrogen or carbon dioxide are introduced to the load; 3) dry ice, solid carbon dioxide blocks are packed with the product, this was used during air transport; 4) refrigerant gel, which can be used during air transport.

Land, non-refrigerated transport to local markets may be feasible if distances are short, and weather is not very warm. At warm weather, transport can be done at night when temperature is much lower. Refrigerated land transport containers should be revised adequately before loading to insure that conditions are proper. Fruit should be loaded after cooling and container should also be pre-cooled before loading. Transport container should be clean, and fruit should be stacked correctly to permit proper circulation of cold air and to prevent warming-up of the fruit.

In the last few years sea transport of perishable crops has increased significantly. Most of the exported mango in the world is shipped by sea. Companies that specializes in perishable transport are increasing. Sea container industry is better and port infrastructure is improving. Several treatments can be applied on board sea containers including modified and controlled atmosphere, quarantine treatments, and ripening treatments. Sea transport is less expensive than air transport, but slower and thus fruit need to be handled adequately to have a long postharvest life.

Some of the sea containers are characterized by vertical air circulation, where cold air is circulated from below, in contrast to the horizontal air circulation normally used in containers for land transport and in some containers for sea transport (similar to the system used for cold storage rooms). The vertical system is more efficient than the classical horizontal system in cooling the load. Cold air is forced through the packages to the upper part of the load. However, the package and the stack should be designed to be compatible with this system. Therefore, it is important to insure whether the cold air circulation in the container is vertical or horizontal, to be able to select the adequate packages and the stacking system.

Air transport is fast, but expensive. It should only be used when the fruit is very perishable, or its price in the export market is very high. Air containers (Table 8) are normally closed containers and usually made of aluminum or fiberglass. They are not ventilated and thus there can be an increase in temperature, especially if these are left at high temperature. Some of these containers are cooled with dry ice or with refrigerated gels.
9.4. Mixed loads

Mangoes can be transported or stored with other crops as a mixed load. Mixed loads have certain requirements, including:
1. Temperature and relative humidity. Mango should be stored or transported with crops with a compatible requirement for temperature (12-14°C) and relative humidity (85-90%).
2. Production/sensitivity to ethylene. Mango should not be transported/stored with crops that produce very high amount of ethylene nor with products that are very sensitive to ethylene.
3. Modified/controlled atmosphere. When CA or MA is used for mango transport, it is not recommended to mix it with other products.

10. Postharvest Technology

10.1. Temperature Management

Temperature is the most important factor affecting postharvest life and quality of fresh horticultural crops. Low temperature is needed to reduce metabolic activity, delay ripening and senescence, reduce water loss, prevents or reduce disease and insect activity, and thus the maintenance of postharvest life and quality. However, mango fruit, as almost all tropical fruits is very sensitive to low temperature. Chilling injury (CI) in mango is manifested initially as a brown discoloration on the skin, often accompanied by pitting. In more severe cases the skin coloration becomes more pronounced and then the flesh is also affected. CI also can cause uneven ripening, poor color and flavor and the fruit becomes prone to decay. Generally, storage below 10°C causes CI in all mango cultivars, although the time required to show visible symptoms varies between different cultivars, and depends on maturation stage and duration of storage or transport. CI can be reversed if the time of holding at low temperature is not as long. Variation exists in the degree of sensitivity of the different cultivars to CI. Ripe fruit can usually tolerate lower temperatures than less mature fruit. The best control of CI is to avoid exposure to temperatures lower than optimum. Other measures include maintenance in modified/controlled atmospheres, and conditioning at high temperatures (35-38°C) for few hours before storage at low temperature. Optimum minimum temperature for mango
Elhadi M. Yahia

cultivar and ripening stage.

High temperature is used to ripen the fruit and to control insects and diseases. However, the exposure of mango to longer periods of high temperature can cause fruit damage. Mango fruit usually remain green at temperatures of 28°C or higher and do not ripen when maintained at temperatures of 33°C or higher for prolonged periods.

10.2. Humidity Control

Mango fruit should be maintained at high humidity. Optimum RH is 85-90%. Lower RH will promote water loss, shriveling, uneven ripening and quality deterioration.

10.3. Packaging types and construction

10.3.1. Bamboo and other types of wooden baskets

These are commonly used in different regions for local markets, and have different shapes and sizes. They are usually used as collection, transport and marketing packages. The use of these baskets, especially for transport, presents several problems. They do not provide sufficient protection for the fruit, especially due to their shape and flexibility for being distorted. Tests were done on some of these baskets and were found to be characterized by compressive force that can cause an excessive damage on the fruit. Due to the shape of these baskets it is difficult to stack them more than one layer high without the risk of causing excessive damage. Their shape is also a major disadvantage during transport because it does not allow for a better utilization of space. In addition, some of these designs make them unstable and easily rolled off, and thus cause major fruit damage. Conventional cylindrical or conical baskets were modified into rectangular shape with or without a middle tray to improve stackability.

10.3.2. Rigid plastic containers

The tendency of using rigid plastic containers is increasing in different parts of the world. These have different sizes, but the most commonly used ones have a capacity of about 10-20 kg. They are mostly used to collect fruit in the field (as field packages) and for transport to the packinghouse. They have several advantages including: 1) their rigid structure provide protection to the fruit, 2) easy stacking, 3) better use of space, 4) easy to clean, 5) multiple use.

10.3. 3. Wooden crates

These containers are used in some mango growing regions. In Mexico, almost all the mango intended for local market is collected, transported and marketed in these containers. It is also used for export shipments from Indonesia, Malaysia and Thailand to Singapore. In the Philippines it is used to ship mangoes from production areas that are far from the wholesale market. These containers offer much better protection for mango than bamboo and wooden baskets. They are characterized with a rigid structure and thus can easily be stacked without deformation, and thus without causing fruit injury. In addition, these types of packages have the advantage of utilizing space adequately during transport, storage, and during exposition in the market. These containers also come in different designs and sizes. The most commonly used in Mexico has a capacity of about 14 kg of fruits, in Indonesia they have a capacity of 20 kg, in the Philippines a capacity of 15 kg and in Malaysia they use wooden boxes with a capacity of 30-40 kg. Some producers in the Philippines also use a wooden box with a capacity of 60 kg.

10.3.4. Corrugated cartons

Exported mango from different parts of the world, especially those transported by air, are usually packed in corrugated fiberboard cartons (Fig. 7). These have several advantages over other packages including:

1. Light in weight, which results in better handling by workers, and less expenses especially during air transport.
2. Smooth walls that cause less damage to fruit.
3. Can be easily printed and thus can be attractive, and can show needed information for promotion.
4. Their fabrication can be easily automated and their designs can be improved easily.

However, these packages do not have enough stacking force as compared to wooden boxes, and this force can easily be deteriorated especially by humidity (in case that they are not treated). Net weight usually ranges between 4 to 5 kg depending on the specification of the market. Cartons boxes, especially those used for export, should be clean, new and unbroken. Corrugated cartons absorb water, which can deteriorate their strength. Carton strength depends on the starch used for manufacturing, the outer liner (recommended strength 200 g m⁻²), fluting (125-160 g m⁻²), inner lining (230 g m⁻²), and the direction of fluting.

10.3.5. Package liners

These are materials that can be placed on the sides, top or bottom of the package or between fruits to provide additional protection. Several materials are used in packages for local markets such as newspapers in Mexico, and rice straw in Indonesia. These can result in accumulation of heat and ripening of fruit. A relatively expensive but more effective means of protecting individual fruit is to wrap them (individually) in polystyrene mesh bags.

10.4. Ethylene treatment

Mango is a climacteric fruit characterized by a series of biochemical changes initiated by the autocatalytic production of ethylene and an increase in respiration. The induction of ripening in mango has been used with several methods including leaves of particular trees. Mango fruit ripening can be initiated by ethylene and acetylene. Mango sensitivity to ethylene is very high compared to avocado (moderately low) and bananas (moderate). Mango ripening was triggered with 0.01 µl L⁻¹ ethylene, while bananas were triggered with 0.05-0.25 µl L⁻¹, and avocados with an ethylene concentration of up to 1.0 µl L⁻¹. Mango fruit response to treatment with ethrel is not consistent and is affected by the maturity stage at harvest. The recommended ripening conditions for mature, firm fruit of these cultivars is 10-20 µl L⁻¹ ethylene at 21°C for 12-24 h and 92-95% RH. Ethylene treated fruit had better eating quality than air-treated fruit as indicated by aroma and flavor ratings. Acetylene gas, liberated from calcium carbide by the addition of water or by contact with moisture in air, has been used in several countries as a commercial ripening treatment. Acetylene treatments (0.1-0.2 ml L⁻¹) for 24 h at 25°C initiates softening but do not affect the other ripening processes (peel and pulp color development, soluble solids content, pH) in mango fruit. However, all the ripening changes are initiated with exposure to 0.4-0.8 ml L⁻¹ for 24 h at 25°C.

10.5. Use of modified and controlled atmospheres

Modified (MA) or controlled atmospheres (CA) (lower levels of oxygen and/or higher levels of carbon dioxide compared to those found in normal air) are beneficial in delaying ripening, control diseases and insects. Major quantities of mango are transported in modified or controlled atmospheres. Optimum O₂ and CO₂ concentrations depend on the cultivar, storage period and the purpose of using MA and CA. The inadequate use of MA and CA can result in physiological disorders and quality deterioration.

A very early study by Singh et al. suggested that mangoes (cultivar not specified) could be kept in an atmosphere with
9.2% O₂ to prolong the ripening period. Moderate concentrations of O₂ (≥5%) and CO₂ (≤5%) atmospheres are not effective for disease control.

Storage of ‘Keitt’ mangoes in an insecticidal MA (0.03-0.26% O₂, 72-79% CO₂, and balance is N₂), and CA (0.2% O₂, balance N₂ or 2% O₂ + 50% CO₂, balance N₂) for up to 5 days at 20°C delayed fruit ripening as indicated by respiration, flesh firmness and color development.

Mango was shipped experimentally in low air pressure (LP) (80 mm Hg at 10°C) from Mexico to Japan and arrived in satisfactory condition after 28 days from picking. LP (152 mm Hg) was reported to be suitable for shipping or maintaining of mango, together with bananas and limes.

There is no current use of CA storage for mango, however, long-term marine shipping in MA and CA has been commercially used in different countries, including Mexico. The recent use of CA during shipping will most probably improve the quality of shipped fruit.

Optimum atmosphere composition for mango range between 3-5% O₂ and 5-10% CO₂. The most ideal atmosphere at any particular purpose should be decided on the basis of the cultivar, temperature, shipping period, treatment given to mango previous to MA/CA application (such as heat treatment), etc. CA and MA can be beneficial in delaying fruit ripening during long-distance marine transport for 2 weeks or more.

Atmospheres with very low levels of O₂ and/or very high levels of CO₂, especially at high temperatures, can control insects and are been developed as quarantine systems for mango. Mango fruits have shown to be very tolerant to insecticidal O₂ and CO₂ atmospheres. ‘Manila’ mango quality was not impaired when exposed to insecticidal CA (0% O₂ + 50% CO₂) at 40-43°C for 160 min, and then stored in air at 10°C and 85% RH for up to 20 days. These fruit were injured when exposed at these atmospheres at 44°C or higher and stored at 10°C for 10 day or more.

Information on the response of mango to CA and the benefits that can be gained are not very established yet. This is mostly due to diversity of cultivars, the variability between growing regions, but also to the limited amount of research and the little control in the type of research done on this fruit. There is no indication (at least for the next few years) that CA can be used for storage of mango. However, MA/CA can be used for transport of mango. In general MA/CA can be used when sea transport is more than one week, or when fruit is in an advanced stage of maturity. In general, a concentration of 3-5% O₂, and 5-10% CO₂ can be used, however different cultivars should be tested to determine their optimum requirements. In addition, the exact O₂ and CO₂ should be selected on the basis of fruit maturation, temperature used, and duration of treatment. CA is much more effective than MA, but more expensive.

To assure positive effects of MA and CA for mangoes, fruit should be harvested and handled adequately with special attention to maturity stage, avoidance of physical injury, sanitation, proper temperature management, and packaging.

11. General Recommendations

Some general recommendations for an optimum postharvest handling of mango include:
1. Apply an integrated pre-harvest program for fertilization, irrigation and for the control of diseases and insects.
2. Develop adequate maturity indices for different cultivars at different regions.
3. Only mature fruit should be harvested. Picking should be done several times. If this is impractical, then harvesting should be delayed until most of the fruits are nearly mature.
4. To reduce the problem of latex flow and staining, harvest in mid morning and avoid picking immature fruits, and picking right after rain.
5. Harvesting should be discontinued after mid day, when temperature is high, to reduce field heat.
6. Pickers should be trained to pick the adequate fruits and to handle fruit adequately, and should be supplied with needed picking tools.
7. It is important that fruit not be mechanically injured at any stage.
8. Picking baskets and tools should be designed to leave at least 2 cm of peduncle and should not harm the fruit.
9. Collection boxes or baskets should not cause injury to the fruit and should not be overfilled. Use adequate collection and field packages that do not injure the fruit and use the space efficiently during transport and storage. Do not overfill collection and field packages.
10. Never let fruit drop on the ground. Do not pack fruits (especially for export) that are collected from the ground.
11. Fruits should be accumulated in a shed in the field, should not be exposed to direct sun and to high wind, and should not be let in the field after harvest for longer hours.
12. Fruit should be transported as soon as possible to the packinghouse, cold store or market.
13. Transport should be done in adequate vehicles, preferably cooled. In case that vehicles are not cooled, they should be covered to protect from direct sun, high temperature, and wind. Transport vehicles should be equipped with adequate shock absorber systems to reduce mechanical damage. Transport should preferably be done during cold hours of the day, and should follow smooth roads.

14. If transport vehicles are refrigerated they should be used adequately. Vehicles should be clean, not damaged, with sufficient refrigeration capacity, with adequate air circulation. Product should be stacked in a way that can permit an ideal cold air circulation. Vehicle should be pre-cooled before stacking the product. It is recommended that product be stacked in pallets with adequate sizes.

15. In the packinghouse, fruit should be received in water with chlorine and an authorized fungicide.

16. Pack only fruits of high quality. Do not pack injured or decayed fruit, especially for export.

17. After a preselection step, where inadequate fruits are removed, fruit can be treated with hot water for disease control (50-55°C for 3-15 minutes). In this case fruit should be cooled immediately after treatment.

18. Fruit can be size or weight graded. Weight graders are more recommended because they result in better fruit uniformity. Waxing is not common in mango, but in case that it is used, one should use waxes of natural origin, and be applied in a thin film to avoid fruit fermentation. Refer to regulations of the importing country regarding if waxing is permitted and types of waxes allowed.

20. Packaging should be done manually with trained persons. Each package should be printed with the required information that indicate: origin of fruit, day of harvest, day of packing and packer’s name. This is very helpful to relate any problem that can appear during the market.

21. Packing line should be designed in a way that can be simple and do not cause injury to the fruit. In addition it should be designed to provide comfort for workers, especially with respect to light, temperature, height of packing tables, etc.

22. Packages should be designed and/or chosen to be efficient, with sufficient staking force, with sufficient vents, do not cause injury to fruit and be printed with sufficient information, especially promotional information.

23. Package design should be chosen on the bases of air circulation in the transport container (either vertical or horizontal).

24. Refer to the regulations of the importing country in relation to type of package material allowed, type of information printed, size of package, size of pallet, etc.

25. Packinghouse should be kept clean and organized.

26. Cool fruit rapidly using forced air cooling. The delay of cooling result in short shelf life. Exposure of fruit to high temperature for 3-4 days after harvest causes substantial postharvest losses, result in premature, uneven ripening in several cultivars. Fruit should be precooled at about 2°C above optimum temperature.

27. Maintain fruit at low temperature during storage and transport. Optimum storage temperature depends on the cultivar, but ranges between 10 and 13°C. It is important to define optimum temperature for each cultivar. Do not expose fruit to temperature below optimum (usually below 10°C).


30. Export is done better and more adequately through a better organized export association.

31. Quality is the key to a successful industry, especially for an export industry. Export market is very competitive, and the way to succeed in this market is to implement a “total quality control program”.

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