Maintaining mango (Mangifera indica L.) fruit quality during the export chain

Dharini Sivakumar a,⁎, Yuming Jiang b, Elhadi M. Yahia c

a Department of Crop Sciences, Tshwane University of Technology, Pretoria (West Campus), Pretoria, South Africa
b Agriculture, Food and Photochemistry, South China Botanical Garden, Chinese Academy of Sciences, China
c Autonomous University of Queretaro, Avenida de las Ciencias S/N, Juriquilla, Queretaro, 76230, Qro., Mexico

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A B S T R A C T
Mangoes are tropical/sub tropical fruit with a highly significant economic importance. Preferable quality attributes include freedom from external damages such as bruises, latex or sap injury and decay, uniform weight, colour, aroma, firmness (with little give away, not soft), shape and size. The fruit is rich in antioxidants and recommended to be included in the daily diet due to its health benefits such as reduced risk of cardiac disease, anti cancer, and anti viral activities. Maintenance of mango fruit quality during the supply chain depends on many aspects including adequate orchard management practices, harvesting practices, packing operation, postharvest treatments, temperature management, transportation and storage conditions, and ripening at destination. Postharvest losses are high during the supply chain due to harvesting fruit at improper maturity, mechanical damage during the whole chain, sap burn, spongy tissue, lenticels discoloration, fruit softening, decay, chilling injury, and disease and pest damage. The aim of postharvest treatments and management practices in the supply chain is to create suitable conditions or environments to extend the storage life and retain the quality attributes, nutritional and functional compositions. This review summarises the available research findings to retain the overall mango fruit quality and to reduce postharvest losses during supply chain by adopting suitable postharvest novel technologies.

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1. Introduction

The mango, Mangifera indica L. is well known for its excellent exotic flavour and usually referred to as the king of fruit (Fig. 1). It is a dicotyledonous plant belonging to the order sapindales in the family Anacardiaceae. It is a popular and economically important fruit, widely cultivated in the tropics and subtropics. Mango was originated in the Indo-Burmese region (Subramanyam, Krishnamurthy, & Parpia, 1975; Tijptono, Lam, & Mendoza, 1984). The fruit is eaten fresh and in several other by-products, including juices, nectars, purees (Ploetz, Zentmyer, Nishijima, Rohrbach, & Ohr, 1994). Commercial mango production is reported in more than 87 countries. The prominent mango producing countries are India, China, Thailand, Indonesia, Philippines, Pakistan and Mexico (Tharanathan, Yashoda, & Prabha, 2006). Mango production is increasing outside the traditional geographical regions of mango cultivations such as in Central and South America, Australia, South-east Asia, Hawaii, Egypt, Israel and South Africa, especially for export markets (Tharanathan et al., 2006). The most important exporting countries are Mexico (41% of the world market) followed by the Philippines (7.6%) and Pakistan (7.8%) (Sauco, 2004). Some mango fruit cultivars, such as from the Indian and the Sri Lankan regions, show strong aroma, intense peel colouration, delicious taste, and high nutritional value (Thanaraj, Terry, & Bessant, 2009). ‘Alphonso’ mango is considered as one of the best rated mango cultivar in the world, and some other cultivars (such as Ataulfo from Mexico) are becoming important in the markets. According to Lebrun, Plotto, Goodner, Ducamp, and Baldwin (2008), there are 49 species and thousands of mango cultivars. The popularity of the fruit in the international market is due to its excellent flavour, attractive fragrance, beautiful colour, taste and nutritional properties (Arauz, 2000). In addition, mangoes are good source of ascorbic acid, carotenoids and phenolic compounds, and other dietary antioxidants (bioactive compounds) (Talcott, Moore, Lounds-Singleton, & Percival, 2005). The cv. Nam Dok Mai No.4 contains total phenols ~3.42 mg (GAEg-1 DW) and reveals DPPH antioxidant capacity ranging from 10.94 to 28.16 µMTE/g (Corinstei et al., 2010).

Consumption of mangoes can provide significant amounts of bioactive compounds with antioxidant activity. Unfortunately, the consumers are experiencing inconsistent fruit maturity and ripening variability, sometimes even in a single consignment. Mango fruits have a short production season and storage life, and therefore fruit prices after seasonal peak can be very high and therefore may not be affordable by many consumers. The storage life of mangoes is limited to 2–3 weeks in air at 10 °C–15 °C (Yahia, 1998a). Variability in mango fruit quality is detected in the supply chain with respect to taste, flavour, colour, aroma, weight, size and shape, influenced by the production management practices. According to Kader (2002), quality performance of mangoes depends...
largely on external and internal quality parameters. Consumer acceptance is higher for mangoes free from external damages including bruises, latex or sap injury, decay, uniform weight, colour and shape which are external quality attributes. Internal quality attributes include uniform and intense flesh colour, freedom from damage, and adequate acidity (or pH) and SSC (brix°), depending on cultivar and type of consumer preferences (consumers in different regions have different preferences). Mango flavour quality depends on the type of cultivar, stage of maturity at harvest; postharvest handling methods including the type of treatments, and incidence of mechanical damages or chilling injury, which can also affect fruit flavour (Kader, 2008a, 2008b).

Production and postharvest practices, novel technologies and packhouse management have a great impact on retaining mango fruit quality and on the supply chain. Preharvest and postharvest handling practices and treatments play a major role in ensuring that the fruit reach the consumers with the optimum organoleptic, nutritional and functional quality attributes. Therefore, the objective of this review is to summarise the available information and research findings to retain the overall mango fruit quality and to reduce postharvest losses during the supply chain by adopting suitable postharvest novel technologies.

2. Mango fruit composition and quality attributes

Mango fruit is born in panicle and belongs to the subtype indeliquescent drupe. The fruit is large, fleshy and differs in size, shape, colour, fibre content, aroma, flavour and taste depending on cultivars, and has a characteristic conical projection termed as ‘beak’. The fruit can be differentiated into three parts, i.e. exocarp, the part that protects the fruit that is initially green and later changes to yellow or reddish or orangish depending on the cultivar and stage of ripening, and waxy. With advanced stage of maturity and ripening, chlorophyll content declines and carotenoids and/or anthocyanins tend to increase (Tharanathan et al., 2006). The mesocarp is the fleshy edible portion or the pulp, which is always yellow due to the presence of carotenoids (Ornelas-Paz, Yahia, & Gardea, 2008; Ornelas-Paz, Yahia, & Gardea-Bejar, 2007). The endocarp is the thick, tough, and leathery covering of the seed. The fruit has a single seed in the middle of the fruit, which is large, flat, and ovoid-oblong shaped. The edible portion contains mainly glucose, fructose and sucrose and the total sugar content of mangoes can vary from 11.5 to 25% depending on the type of mango and stage of ripeness. Different organic acids such as oxalic, citric, malic, succinic, pyruvic, adipic, galacturonic, glucuronic and mucic acids were reported to be produced by mango fruit, and citric is the major acid (Jain, Krishnamurthy, & Lal, 1959).

Mango fruit contains different classes of phytochemicals such as polyphenols, ascorbic acid and carotenoids, revealing health promoting properties mainly due to their antioxidant properties (Talcott et al., 2005). Polyphenols, gallic acid, gallotannins, mangiferin, quercetin, kaempferol, p-OH-benzoic acid, m-coumaric acid, p-coumaric acid and ferulic acid were reported in mango flesh (Saleh & El-Anasari, 1975; Schieber, Berardini, & Carle, 2003; Schieber, Ullrich, & Carle, 2000). Gallic acid and gallotannins were reported to decline during storage as a result of ripening or in association with loss of astringency which is a descriptive sensory attribute of mango (Lakshminarayanan, Subhadra, & Subramaniam, 1970). Haden and Ataulfo mangoes were reported to contain higher β-carotene content than Kent and Tommy Atkins (Ornelas-Paz et al., 2007).

3. Causes for quality loss

Mango postharvest losses are still very significant, especially considering that almost all the fruit are produced in developing countries. They are primarily due to harvesting fruit at improper maturity, mechanical damage caused during harvesting or improper field handling, sap burn, spongy tissue, lenticels discoloration, fruit softening, decay, chilling injury, and disease and pest damage, among others (Yahia, 1998a). Quality losses often occur due to tight fruit packing, using improper transport and inadequate field handling. Fruit losses during export can vary dramatically depending on postharvest handling and export conditions, especially with regard to rates of decay, pests and physiological breakdown.

4. Maturity and harvesting indices

Traditionally mango is harvested based on judgements by the growers by observing the appearance of the fruit. The selection of suitable maturity indices for harvest is very important. The quality and the postharvest life of mango fruit depend on the maturity stage at harvest. Therefore, the fruit has to be harvested at the suitable stage of maturity in order to develop the optimum sensory quality attributes and extended postharvest life (Yahia, 1998a). Immature fruit are more sensitive to chilling injury during cold storage and may fail to ripen adequately. Fruit harvested at over mature stage is highly susceptible to mechanical damage such as bruising, decay and water loss, resulting in quality deterioration (Yahia, 1998a). Over matured fruit show defects like jelly seeds or jelly pulp after harvest (Yahia, 1998a). Therefore, suitable maturity indices for harvesting are very important in order to minimise the quantitative and qualitative losses.

Generally, physical, physiological and chemical parameters are used to define the maturity stage. Physical methods to determine maturity in mango include softness of the cheek, peel colour, development of shoulder, and specific gravity (Kosiyachinda, Lee, & Poernomo, 1984). These factors are very useful, but their application depends on the type of mango, region of cultivation, and type of market and consumers. Age of the fruit is also considered as a simple method to confirm maturity, calculated from induction, full bloom and fruit set. Generally, harvest maturity in mango is reached about 12 to 16 weeks after fruit set (Yahia, 1998a). However, days from full bloom is most recommended, because they can be implemented as a standardized factor (Yahia, 1998a). The age of fruit (days) at a certain harvest maturity based on full bloom or fruit set varies according to different geographical regions and cultivation conditions. According
to Kosiyachinda et al. (1984), 'Carabo' mangoes can be harvested after 84 days from full bloom. Mangoes for shipping to distant markets or for long-term storage are harvested at the mature-green stage while still firm, and the ripening will continue after harvest. Furthermore, maturity level at harvest is a crucial factor for the development of acceptable flavour quality during ripening (Kader & Mitcham, 2008). In addition, mango fruit accumulates dry matter during fruit development and becomes denser as it matures. Therefore, specific gravity was considered as a possible maturity index. Specific gravity generally ranges from 0.97 to 1.04, but sometimes it does not contribute to determining fruit maturity (Yahia, 1998a).

During fruit maturation, soluble solids content (SSC) tends to increase while titratable acidity (TA) decreases. According to Tharanathan et al. (2006) titratable acidity increased from the sixth to the tenth week after fruit set, and then with increase in fruit maturity a decline in titratable acidity was noted. SSC is not generally used as a commercial maturity index for mangoes, but it complements other indices such as colour formation and flesh colour, and for most markets mangoes have to be harvested at about 9–10% SSC. Some mango cultivars are characterised by a strong taste and the SSC and TA or the SSC/TA can contribute to determining the suitable maturity stage for harvest. Sugars acids, and phenolic compounds are the primary taste components in the fruit. SSC/TA ratio commonly indicates ripeness and taste for some markets; the higher the ratio the sweeter the fruit (Mizrach, Flitsanov, Schmilovitch, & Fuchs, 1999).

Flavour (taste and aroma) is an important quality trait that determines to a great extent, the consumer acceptance of the fruit. According to Baldwin (2010) flavour is taste plus odour and is mainly composed of sweetness, sourness, and aroma that correspond to sugars, acids and volatile compounds. Flavour is determined primarily by genetic factors and it can be affected due to preharvest conditions, postharvest handling, packing operations and storage. Changes in mango aroma can be attributed to transformational changes in fatty acid profile (from palmitic to palmitoleic acids) during ripening, and fruit can reach their best flavour if harvested after the start of ripening. Increase of glycosidically-bound aroma compounds (terpenes) was observed in the flesh of Kensington Pride mangoes as maturity progressed (Lalel, Sing, & Tan, 2003b).

Optimum skin colour is an important fruit quality parameter that affects consumer acceptance and preference. The obvious noticeable change during ripening is skin colour change from dark green to olive yellow or yellow or a base colour. Some cultivars show reddish bluish skin colour mainly due to the presence of anthocyanins (Tharanathan et al., 2006). These skin colour changes are due to the disappearance of chlorophyll and the appearance of other pigments (carotenoids and/or anthocyanins) as mentioned before. Carotenoids are the predominant pigments in yellow cultivars. Presence of the anthocyanin phenodonin-3-galacytosa has been reported in the skin of some types of cultivars (e.g. Tommy Atkins) (Proctor & Creasy, 1969). However, skin colour is not considered as an adequate maturity index because it is commonly observed after the fruit has started to soften, in addition to that skin colour is usually not very uniform in several mango cultivars. Uniform colour development is observed in yellow cultivars, but some cultivars do not change the green skin colour much. Skin colour development is greatly influenced by the fruit position on the tree and fertiliser application practices, among other factors. Flesh colour changes, however, are uniform when fruit advances in maturity stages, and therefore it can serve as adequate maturity index. Although it is a destructive index, it is used as a maturity index in several producing regions, because it is consistent (Kader, 2008a, 2008b). Carotenoids are responsible for the attractive flesh colour, and at advanced maturity the flesh is usually yellow to orange (Medlicott, Bhogol, & Reynolds, 1986). Although it is difficult to establish standard maturity indices for mangoes due to the diversity of cultivars and growing conditions, it is essential to establish them for a particular cultivar, growing region and for local or export markets. Maturity indices for 'Tommy Atkins', 'Keitt', 'Kent' and 'Haden' are based on the position and thickness of the shoulders and colour of the flesh closer to the skin. The fully mature fruit of the earlier mentioned cultivars will show a completely formed shoulder with a depression around the peduncle, firm and green in colour.

According to Slaughter (2009), there are a number of promising technologies for non-destructive assessment of mango maturity. Flesh colour was found to be consistent in 'Tommy Atkins', 'Keitt', 'Kent' and 'Haden' mangoes (Kader, 2008a, 2008b). The development of a non-destructive flesh colour sensor for mango would help the harvesting team to correlate physical indices such as shape and size with flesh colour in order to determine the appropriate maturity stage at harvest (Slaughter, 2009).

5. Harvest

Harvesting fruit before or after the ideal picking date and any harvesting methods that cause mechanical damages such as bruising or cuts on the fruit surface will negatively affect fruit quality. The cut or bruised fruits are easily infected with decay causing fungi such as Aspergillus sp and Botryodiplodia, Diplodia natalensis (Yahia, 1998b). Mechanical injury at harvest can cause 'spongy tissue', where the symptom is expressed as desiccated spongy like tissue in ripe fruit and the symptom can be observed only when the fruit is cut open. At this specific spongy region, the flesh remains unripe due to biochemical disturbances and deposition of non hydrolysed starch taking place during storage (Amin, 1967). The affected part of the flesh was reported to show low pH, sugar, ascorbic acid content and β-carotene content, and altered amylase and invertase activity (Amin, 1967).

Mango is harvested manually, usually with the help of some harvesting aids, and multiple harvesting is adopted since all the fruits are not matured at the same time. Fruits are harvested from tall trees by using poles fitted with bags adapted with a scissors or knife. Ladders are used in some regions and hydraulic lifts are not common. It is recommended to harvest fruit when the temperature is not high, which will reduce field heat in the fruit and thus would maintain it for longer periods by reducing metabolic activity. However, cultivars with high sap or latex content should not be harvested very early in the day due to high latex flow early mornings. Fruits are normally picked from the lower side of the tree in order to avoid sap oozing on the fruit below. The stem will snap easily with a slight pull for the mature green fruit that is ready for picking, although the use of scissors is recommended when possible. Fruits are picked with approximately 5 cm petiole in order to prevent the spurt of resinous sap. Sap injury or burn of the skin affects fruit quality by affecting the skin colour and promoting decay development, and also affects the skin of the pickers. Severity of sap injury on the skin was correlated to higher nitrogen content in the fruit (Yahia, 1998a). Terpinolene (58.9%) and car-3ene (59.1%) were identified as major volatile component in the sap of 'Kensington' and 'Irwin' mangoes respectively (Robinson, Lovesy, & Chacko, 1993). Sap injury associated browning in the fruit skin was mediated by polyphenol oxidase (PPO) and laccase enzymes in the fruit skin (Robinson et al., 1993). Furthermore, Robinson et al. (1993) reported that the sap from ripe mango fruit showed higher PPO activity than the unripe fruit, and among the Australian cultivars 'Kensington' mangoes had higher PPO activity than 'Irwin' mangoes. It is recommended to trim the peduncle up to 1 cm and to place the fruit stem-end facing downwards in field creates/racks to stop the flowing sap (de sapping) (Yahia, 1998b).

Mango sap and its negative effects can be reduced by adopting different methods such as by using detergent dips and sprays prior to de-stemming under water using lime, picking without stems onto a harvesting aid such as racks and dipping or spraying detergent on the fruit immediately, cleaning latex from fruit skin using 0.5–5% CaCO₃ solution, washing the fruit in 1% aluminium potassium sulphate
solution after harvest (Holmes & Ledger, 1992). Of all these recommended methods, harvesting rack was recommended as the most effective method which reduces sap burn down to about 16% (Holmes & Ledger, 1992).

6. Control of postharvest decay

Postharvest diseases reduce fruit quality and result in severe losses. Latent infections such as anthracnose (caused by Colletotrichum gloeosporioides), Alternaria black spot (Alternaria alternata) and stem-end rot (caused by Lasiodiplodia theobromae or Dothiorea dominicana or Botryosphaeria spp.) are the predominant postharvest diseases that cause severe postharvest losses and affect fruit quality during the supply chain. Anthracnose symptoms are expressed as dark, sunken lesions on ripe fruit with pink, slimy spore masses (Jeffries, Dodd, Jegar, & Plumbley, 1990). Stem-end rot develops as a dark rot from the stem-end as the fruit ripens. Incidence of postharvest decay during the postharvest management practices occurs as a result of spores (inoculums) coming in contact with the fruit. The spores are dispersed in the air or by contact and take place when the conditions are suitable for germination and growth (Arauz, 2000). Conditions that favour the activity of postharvest pathogens include the presence of high relative humidity (RH), warm temperature, and nutrients from the fruit surface, mainly sugars. Fruit becomes susceptible to infection as it softens. During harvesting, packing and transportation operations, small openings in the skin or wounded areas on fruit surface become the ideal sites for these pathogens to gain entry to the fruit tissue.

According to Johnson (1994), stem-end rot is reported to cause significant losses in mango during transit and storage, especially when anthracnose is controlled completely. Anthracnose and stem-end rot pathogens infect during fruit development, harvesting or de-laxing or de sapping procedures and continue to advance causing significant losses in storage (Johnson, 1994). Susceptibility of mango fruit to postharvest diseases increases during storage due to a series of physiological changes occurring in the fruit favouring the establishment and colonisation of the pathogen (Eckert, Ratnayake, Sievert, & Strange, 1996), and also to environmental conditions. The quiescent infections in climacteric fruit are terminated with reduction of antifungal compounds (combination of 5-(12-cis-hexadecenyl)) resorcinol and 5-pentadecylresorcinol (resorcinols), production of ethylene (the ripening hormone in plants), and due to the changes in nutritional and texture changes (Flaishman & Kolattukudy, 1994). Postharvest disease control begins in the field and involves cultural and chemical practices and cultivar selection. Cultivars such as ‘Tommy Atkins’ and ‘Keitt’ are known to be less susceptible than ‘Irwin’, ‘Kent’, and ‘Edward’, and ‘Haden’ is highly susceptible to anthracnose (Arauz, 2000; Cambell, 1992).

Generally, control of postharvest disease in mango is achieved by adopting proper preharvest and postharvest management practices such as strict orchard hygiene management, application of fungicides and temperature management during storage and shipping. Postharvest temperature management is important because postharvest diseases are favoured at temperatures above optimum.

6.1. Control of postharvest diseases with fungicides

Generally, storage temperatures of around 10 °C can delay decay development (Snowdon, 1990). However, a residual protection against postharvest diseases is important after removal from the cold storage environment. Control of postharvest decay due to quiescent infection is achieved commercially in South Africa by combination of thermal and fungicide prochloraz treatments. Postharvest treatment with prochloraz has been used as protectant spray. Resistance to prochloraz in Pseudocercospora herpotrichoides isolates has been reported by Cavelier, Pinaud, and Prunier (1994) and Cavelier et al. (1994). Considerable variability in sensitivity among the C. gloeosporioides isolates from mango was reported by Arauz (2000). Prochloraz is the only fungicide used for postharvest disease control in mangoes. Resistance to prochloraz in Pseudocercospora herpotrichoides isolates has been reported by Cavelier et al. (1994). In South Africa, prochloraz treatment is adopted in packhouses before wax (Citershine™) application. For fruit intended for the local market, a 2 min dip in a heated (50 °C) prochloraz emulsion is suggested while export fruits are dipped for 20 s at 25 °C in prochloraz solution and followed by a 5 min hot water treatment (HWT) at 50 °C. Furthermore, hot water washing (15–20 s) followed by fungicide prochloraz (Sportak 45% a.i.) (900 mg mL−1) and waxing (polyethylene emulsion) was commercially successful in Israel in controlling the incidence of Alternaria alternata during low temperature storage (3 weeks, 12 °C) and ripening (another week at 20 °C) for cvs. Tommy Atkins, Keitt, Lilly, Haden (Prusky et al., 1999).

6.2. Hot water treatment (HWT)

Heat treatments especially HWT are widely used in many countries for insect and decay control in mango (Aveno & Orden, 2004). Mango exporting countries are in a position to regulate the treatment due to the specific guidelines enforced by the importing countries, such as the specific duration for disinfection of the specific pest. HWT as a decay control treatment is applied commercially in few countries due to its efficacy (Anwar & Malik, 2007; Jacobi, Wong, & Giles, 1995). Bagging of mango fruit before harvest and postharvest treatment for 10 min HWT (52–55 °C) was reported to reduce the anthracnose infection by 83% and stem-end rot by 100% (Aveno & Orden, 2004). The temperature and the duration of the treatment depend on the size or weight of the fruit, stage of maturity (Jacobi, Macare, & Hertherington, 2001), cultivar type and growing conditions (Anwar & Malik, 2007) and type of disease. It is recommended to subject the fruit to HWT within 24 h after harvest (Aveno & Orden, 2004). In countries like the Philippines mango flotation in 10% salt solution was practiced and if the fruit floats, HWT treatment is delayed (Aveno & Orden, 2004).

HWT technology was shown to increase profit as a result of lower damage and higher market value (Aveno & Orden, 2004). On the other hand, it can be practiced by small and medium scale mango farmers with compatible practices, easily adopted in the supply chain, applicable for health conscious consumers and environmentally friendly method (Aveno & Orden, 2004).

6.3. Biocontrol agents

Biological control using microbial antagonist could be used on its own or in combination with a reduced concentration of synthetic fungicides (El Ghaouth et al., 2002). In South Africa biological control research programmes on mango commenced in 1987, with a biological control agent (B. licheniformis) (Burger & Korsten, 1988). The effectiveness of the biocontrol agent at 102 cfu mL−1 was shown to improve when it was applied with integrated treatment; hot water dip (5 min at 45 °C) followed by quarter strength of recommended rate of prochloraz treatment for 20 s and waxing with Citrashine™ (Citrishine Pvt Ltd., Johannesburg, South Africa) (Govender, Korsten, & Sivakumar, 2005).

6.4. Use of modified or controlled atmospheres (MA/CA)

Postharvest disease control via maintaining the host resistance can be improved by shipping or storing fruit under CA conditions with higher CO2 atmospheres. Short storage life of the mango fruit becomes the major constrain especially when exporting mangoes to distant overseas markets. The application of MA/CA technology allows extending the storage life while retaining the overall quality. MA/CA with higher CO2 and lower O2 (than normal air atmosphere) can delay
ripening by inhibiting the production of ethylene, delaying the biochemical activities associated with ripening such as; slowing down the changes in skin and flesh colour, flavour, aroma and texture (fruit softening), and promoting resistance to the attack of postharvest pathogens by increasing the concentration of antifungal compounds due to oxidative process (Prusky & Keen, 1993).

A reduced O₂ concentration of around 3–5% and an elevated CO₂ concentration of 5–10% are the suggested atmosphere compositions for a successful MA/CA system for mango fruit (Kader, 1994; Yahia, 1998b, 2009). However, the CO₂ concentration in MA/CA is critical. Mature green mango fruit (cv. Tommy Atkins and Kent) in modified atmosphere packages (MAP) with CO₂ composition of over 10% results in skin discolouration, uneven ripening and off-flavour development, most probably due to the formation of acetaldehyde and ethanol (Postharvest Innovation Programme Progress Report, 2009). Although higher concentration of CO₂ above 10% can prevent the incidence of postharvest diseases due to its fungistatic or toxic activity, CO₂ concentration must not result in any quality defects in terms of off-flavour development, CO₂ injury such as skin discolouration or greyish flesh colour or fruit softening (Laléil, Singh, & Tan, 2003a). CA (3% O₂ and 10% CO₂) resulted in lower anthracnose incidence in ‘Tommy Atkins’, and after removal from cold storage to room temperature conditions, the residual effect of CA was clearly demonstrated on the control of anthracnose (Kim, Brecht, & Talcott, 2007). Storage temperature, the environment such as CA/MA, to light and oxygen exposure, is one of the key factors influencing stability of phenolic antioxidants in fruits during postharvest storage (Piljac-Žegarac & Sämek, 2010). However, the CA storage (21% O₂ + 97% N₂; 3% O₂ + 97% N₂; and 3% O₂ + 10% CO₂ + 87% N₂) had minor effect on the retention of total soluble phenolics and antioxidant capacity in fully ripe cv. Tommy Atkins mangoes (Kim et al., 2007).

6.5. Development of tools for the early detection of decay

There is an urgent need to implement a suitable early detection method for the incidence of postharvest pathogen in the supply chain, because the economic costs of postharvest losses are higher than the losses at the orchards. The total cost of postharvest supply chain will include the expense of postharvest practices such as harvesting, sorting, packing, shipping and storage, in addition to the cost involved in production management (Jeger & Plumley, 1988). Therefore, according to Moalemiyian, Vikram, and Kushalappa (2007) an automated tool based on the detection of specific volatile compounds produced by postharvest pathogens would be beneficial to diagnose diseases during large scale operations at the pack houses in order to make appropriate management decision, e.g. how long the fruit can be stored and which lot can be stored longer, quality at harvest or prior to packing. Moalemiyian et al. (2007) identified a volatile metabolite (1-pentenol) specific to Lasiodiplodia and unique to Colletotrichum, using gas chromatography–mass spectrometry head space analysis. It is also shown that the characteristic compounds produced are cultivar-dependent. This finding has potential to be implemented commercially to make smart management decisions such as how long a particular lot of mangoes can be stored or can it be stored longer, and will it facilitate the reduction of postharvest losses due to decay by planning the commercial operation (Moalemiyian et al., 2007).

7. Control of invasive pests

7.1. HWT and fruit quality

Mediterranean fruit fly (Ceratitis capitata) and Mexican fruit fly (Anastrepha spp.) infest mango in the form of eggs, larva and adults (Jacob et al., 2001). High incidence of these insects in mangoes is a major problem encountered in many production regions. Generally, mangoes destined for export to several countries (not to Europe and Canada), and sometimes even mango shipped to different regions in the same country, are subjected to quarantine treatments, such as hot water (HWT), hot air, or irradiation treatments. However, HWT is the widely adopted commercial treatment in many mango exporting countries.

When harvested fruit in the pack house are exposed to the high temperature of HWT, a stress is induced and the degree of impact depends on the length and temperature of the treatment. Certain cultivars were reported to develop external and internal heat injuries, and HWT was reported to affect ripening by accelerating skin colour development. HWT at 55 °C for 5 min (for decay control) caused 80% heat damage in unspecifie cultivar (Spalding & Reeder, 1972). Therefore, selection of specific HWT regimes is important for different mango cultivars. United States Department of Agriculture (USDA) regulations require a HWT dip at 46.1 °C for 65 to 110 min (depending on fruit weight) for mango exported to the US for insect control (USDA-APHIS, 2002). HWT can damage the quality of mango fruit when treatment is not applied adequately and fruit not cooled immediately after (Yahia & Campos, 2000). Small fruits are more susceptible to heat damage compared to larger fruits.

In Tommy Atkins mangoes, lenticels became darker when the fruit was dipped in the water at 46 °C for 120 min (Mitcham & Yahia, 2009). Hydro cooling (21 °C) is adopted after HWT, either immediately if the HWT is applied for 10 min extra to the time assigned, or fruit can be hydrocooled after a holding time of 30 min at room temperature when fruit is treated at exactly the time assigned. Hydro cooling the fruit after HWT is efficient in reducing pulp temperature rapidly (Sheilie & Mangan, 2002) and slow down the metabolic activity of the fruit (De Leon et al., 1997). Hydro cooling water has to be sanitized to prevent contamination with foodborne pathogens such as Salmonella or E. coli species since an outbreak of Salmonella enteric Serotype Newport infection was reported (Sivapalasingam et al., 2003). Long waiting time after receiving the fruit in the pack houses and before the treatment especially if fruits expose to direct sun, latex on fruit surface, higher temperatures above the required set-point for the required HWT in the dipping tanks, improper management of hydrocooling after HWT, delaying the packing operation, inadequate handling, and improper storage temperatures, can all negatively affect fruit quality and postharvest life.

Temperature and immersion time play a major role in determining mango fruit quality after treatment and during storage. Improper HWT in terms of unfavourable higher temperature or increasing dipping times can result in skin scalding, lenticels spotting and retention of unripe starchy areas in mango flesh (stem end cavity) (Paul & Armstrong, 1994). The degree of damage caused by HWT varies by cultivar. Since mango is rich in nutritional compounds with health promoting properties, especially for their antioxidant properties, from consumer’s point of view it is essential to know whether HWT affects the antioxidant and nutritional property of the fruit after harvest. According to Kim, Lounds-Singleton, and Talcott (2009), HWT at 46.1 °C reduced the total soluble phenolics and antioxidant capacity 4 days after storage irrespective of the treatment duration. The findings of Kim et al. (2009) enable to conclude that fruit subjected to HWT has the possibility of losing some nutritional benefits due to heat triggering oxidation processes during prolonged storage and transport, especially when arriving by sea shipment. During ripening, starch is converted to sugar due to the hydrolysis of starch granules in the chloroplast (Selvaraj, Kumar, & Pal, 1989). Sugar production from starch was reduced by HWT (45 °C for 75 min or 48 °C for 60 min). Increase in dipping temperature during HWT directly affected the development of carotenoid content in the flesh. On the other hand, HWT at higher temperatures such as 52 °C for 20 min was observed to enhance skin colour development during ripening (Jacob & Wong, 1991). Sensory properties with respect to texture were affected by HWT temperature and dipping time. Hot water-treated (45 °C, 75 min; 48 °C, 60 min) and ripened fruit after
storage did not show any negative effects on consumer preference. The negative effects on organoleptic properties of HWT can be pronounced when mature green fruit is subjected to HWT (Anwar & Malik, 2007). Integrated application of HWT (46.1 °C for 75 min) and CA (3% O₂ and 10% CO₂) delayed ripening and inhibited the decline of total phenolic compounds in the flesh mainly due to the effect of CA treatment (Kim et al., 2007). In light of these observations, HWT and CA combination may have beneficial effects on the control of invasive pests and postharvest diseases.

7.2. Vapour heat treatments

Alternative treatments to HWT such as vapour heat (VHT) or forced hot air treatments (FHT) are adopted by some exporting countries. VHT is adopted for mangoes exported from Australia, Thailand, the Philippines and Taiwan to the Japanese market. FHT is effective in controlling internal pests (Laidlaw, Armstrong, Chan, & Jang, 1996). According to Shellie and Mangan (2000), skin temperature is kept cooler while the flesh bellow the skin reaches the temperature that kills the pests due to the evaporative cooling effect of FHT at lower RH. FHT is a commonly adopted quarantine treatment in the Cook Islands and Fiji.

7.3. Irradiation and fruit quality

Irradiation is recommended as quarantine or phytosanitary treatment. The purpose of irradiation is to kill or to sterilise microbes or insects by damaging their DNA. According to the Food and Drug Administration (FDA, 1986) the approved dosage for irradiation treatment on fresh produce is 1 kGy (100 krad). However, 1 kGy may not be effective to kill insects, and such high doses negatively affect the quality of almost all fresh fruits. On the other hand, sterilisation of most insects can be achieved with doses below 0.75 kGy without negatively affecting fruit quality. Consumption of irradiated food treated with up to 10 kGy has been reported to be safe by the World Health Organisation, Food & Agriculture Organisation and the Atomic Energy Agency. Generally, gamma rays (from Co60) are used for food irradiation, product handling, construction cost, and the maintenance of irradiation facilities is costly. India had signed an agreement with the USA to export irradiated mangoes (APHIS, 2007), and therefore mango export increased. Mexico, the largest mango exporter, has a commercial gamma irradiation facility and has already exported irradiated mango to the USA. The cost of food irradiation depends on many factors such as dose requirement, commodity tolerance to irradiation, product handling, construction cost, and the maintenance of the facility. Furthermore, it has to be used routinely for a cost effective operation. Since mango fruit industry is seasonal the facility has to be shared with other fruit crops according the growing season in order to use the facility optimally.

The effectiveness of irradiation on mango fruit quality depends on irradiation dose, cultivar, and fruit maturity stage (Mitcham & Yahia, 2009). Fruit damage or irradiation stress can be expressed as softening, uneven ripening or surface damage. Fruits that are partially ripe were not affected by irradiation. Haden mangoes subjected to 250 Gy at 1/4 or 1/2 maturity stage did not show any problem (Mitcham & Yahia, 2009). Keitt mangoes, subjected to 600 and 900 Gy showed retention of colour, taste and texture after 9 days in storage (Lacroix, Bernard, Joblin, Millot, & Gagnon, 1992). Lower irradiation doses between 100 and 150 Gy affected the flavour, and doses higher than 750 Gy caused loss of ascorbic acid content in ‘Irwin’ and ‘Sensation’ mangoes (Mitcham & Yahia, 2009).

Although incidence of anthracnose during storage was reduced with increasing irradiation doses up to 600 Gy (Johnson et al., 1990), 1 kGy failed to provide a complete control of anthracnose in mangoes. Integrated treatments using a dose of 750 Gy with HWT at 40 °C for 20 min (Brodick, 1979) or 50 °C for 5 min (Mitcham & Yahia, 2009) was effective in controlling anthracnose. However, using higher irradiation doses is cost effective to the growers than using lower doses. If higher irradiation doses are adopted, the incidence of irradiation stress injury in mango fruit can be higher and can increase postharvest losses.

8. Ripening temperature

Mature-green mangoes are commonly ripened at destination. During ripening temperature management is an important factor. Mature-green mangoes ripened at 20–23 °C showed good appearance and eating quality (Paull & Chen, 2004). According to Kader and Mitchell (2008), skin colour improved when fruit were held at 15.5 to 18 °C, but the flavour remained tart. Ripening is affected at temperatures over 30 °C, and between 27 and 30 °C the skin of the fruit was reported to become mottled with strong flavour. Mango fruit picked at mature-green stage exposed to 20–100 μL L⁻¹ ethylene for 24 h at 21 °C and 95% RH had uniform and rapid ripening (Barmore, 1974).

9. Reducing fruit softening, extending the storage life, retention of antioxidants and fruit aroma

Mangoes are climacteric and ripen rapidly after harvest, and it is highly susceptible to postharvest losses. The plant hormone ethylene mediates the ripening of the fruit, increases respiration, fruit softening, colour changes and production of aroma volatiles (Wills, McClaslon, Graham, & Joyce, 1998). The application of 1-methylcyclopene (1-MCP) inhibits fruit ripening by binding to the ethylene binding sites irreversibly. Fruit softening in mangoes occurs as a result of degradation of protepectins and increased soluble pectins. Application of 1-MCP was reported to inhibit fruit softening, delaying the climacteric peak, rate of respiration, weight loss and increased ascorbic acid content during mango fruit storage (Alves et al., 2004; Jiang & Joyce, 2000). Biosynthesis of fatty acids and aroma volatile compounds responsible for the fruit aroma is dependent on ethylene biosynthesis. The application of 1-MCP at higher concentrations (10 and 25 μL L⁻¹) was reported to affect the production of different classes of volatiles, such as monoterpenes, esters and aldehydes and specific compounds of these groups of aroma volatile (Lalel, Sing, & Tan, 2003). Lower 1-MCP concentration (1 μL L⁻¹) had less effect on the aroma profiles of ‘Kensington Pride’ mangoes (Lalel et al., 2003). According to Miyake and Asada (1996), the antioxidant system includes catalase (CAT, EC 1.1.1.16), superoxide dismutase (SOD, EC 1.15.1.1.1), guaiacol peroxidise (GPX, EC 1.11.1.7), ascorbate peroxidise (APX, EC 1.11.1.11) and glutathione reductase (GR, EC 1.6.4.2). Considerable loss of antioxidant fraction occurs during ripening and the application of 1-MCP on ‘Dashehari’ mango reduced the accumulation of H₂O₂ and O₂ and resulted in cellular damage by increasing SOD and CAT activities with a marginal APX activity (Singh & Dwivedi, 2008).

1-MCP concentrations between 1 and 100 μL L⁻¹ were reported to be effective in extending the storage life of mangoes (Jiang & Joyce, 2000), but may increase the incidence of stem-end rot (Hofman, Jobin-Decor, Meiburg, Macnish, & Joyce, 2001). Therefore, retention of good quality fruit with 1-MCP application can be achieved with an efficient postharvest disease control. Postharvest treatments that extend storage life are important in developing countries where cold chain infrastructure is not well established. In those circumstances, application of 1-MCP may provide a suitable alternative to extend the postharvest life of mangoes at ambient temperature (25 °C) for the domestic markets in the developing countries. Commercial use of 1-MCP on mangoes is determined by the cost of 1-MCP treatment relative to its beneficial effects. Factors such as performance of different mango cultivars to 1-MCP application in terms of quality.
improvement, how effectively 1-MCP application can be included in the packing line operations, the size of the industry whether it is for export or domestic market, how long the storage life has to be extended, and whether it is registered for commercial application in those specific importing countries, determine the cost/benefit of the treatment (Watkins & Miller, 2004). Performance of different mango cultivars to 1-MCP application needs to be investigated in detail for commercial application. According to Watkins and Miller (2005), cultivars that have lower ethylene production rates after harvest respond better than the cultivars that produce higher levels of ethylene, and the delays between harvest and 1-MCP application also affect the effectiveness of the treatment. Furthermore, application of 1-MCP in combination with CA has to be investigated for potential mango export cultivars, because according to Watkins and Nock (2003) the two technologies are effective when used in combination.

Waxing was reported to delay ripening and fruit softening in mangoes (Baldwin et al., 1999). Generally, waxes or edible coatings are used as postharvest applications to reduce gas exchange and weight loss during the supply chain. According to Baldwin et al. (1999), the use of hydroxypropyl methylcellulose on Tommy Atkins mangoes was effective in delaying fruit softening and colour development during ripening.

10. Preventing lenticels discolouration and loss of cosmetic appearance

Lenticels discolouration is an important quality concern and a principal factor for commercial acceptability (Bally, O'Hare, & Holmes, 1996). The observed red colouration (red spots) on the fruit surface is reported to be due to the production of anthocyanins (Kangatharalingam, Pierce, Bayles, & Essenberg, 2002) flavonoids (Dixon & Paiva, 1995), and phenylpropanoid derivatives (Du Plooy, Combrinck, Regnier, & Botha, 2009). Lenticels discolouration is a result of the stress that the fruit underwent before harvest (especially by wind or cold) (Jacobi & Giles, 1997; O'Hare, Bally, & Underhill, 1996). After harvest, inadequate handling, or postharvest treatments such as vapour heat or hot water treatment, could induce lenticels spotting especially when sap or latex is in contact with the skin. Storage temperatures below 10–12 °C were shown to accelerate the incidence of red spots which was associated with chilling injury (Pesis et al., 2000).

11. Chilling injury (CI) and its alleviation

Cold chain management extends postharvest life and maintains the overall quality of horticultural produce during the supply chain by reducing the metabolism and thereby reducing senescence and ripening. However, many tropical and several subtropical fruits are sensitive to low temperature. CI occurs when the mango fruit is exposed to temperatures lower than 10 °C, and it takes place as a result of malfunction or disruption of cellular wall membrane function that affects the transfer or flow of cellular fluids in and out of the cell, resulting in irregular metabolites (amino acids, sugars and mineral salts) (Wills, Lee, Graham, McGlosson, & Hall, 1981). CI in mangoes becomes a major constrain during long marine refrigerated shipping.

Typical CI symptom manifests as brown or gray scaled like discolouration of the skin, lenticels, pitting (Pesis et al., 2000), uneven ripening (Lederman, Zauberman, Weksler, Rot, & Fuchs, 1997), reduction in carotenoids, break down of the flesh (Lizada, 1991), decrease in development of aroma and colour during ripening, electrolyte leakage, reduction of SSC, fruit becomes prone to develop rots, and storage life is reduced. CI generally develops after the fruits are transferred from the chilling temperature to room temperature (no chilling). The severity of CI depends mainly on the maturity of the fruit, duration of storage or shipping at chilling temperatures and the type of packaging used (Medicott, Sigrist, & Sy, 1990). Preharvest factors such as low temperatures during fruit development can cause CI after harvest.

It is evident from the available literature that oxidative stress is an early response of horticultural produce to CI because it could initiate membrane degradation resulting in lipid peroxidation (Dat et al., 2000; Shewfelt & del Rosario, 2000). The finding of Wang et al. (2008) on the increase of malondialdehyde content in mango fruit stored at low temperature (4 °C) explains the disruption of lipid peroxidation and membrane integrity. Enhanced accumulation of active oxygen species (AOS) in plant cell is reported to be a direct result of stress-induced cellular changes resulting in the occurrence of CI. Hydrogen peroxide (H2O2) was regarded as a stable molecular AOS species and it is considered as a signal molecule associated with the environmental-related stress response (Foyer, Lopez-Delgado, Dat, & Scott, 1997).

Chilling tolerance in horticultural commodities has been attributed to the ability to breakdown of H2O2 and other oxidants by CAT, APX and glutathione reductase (GR). The ideal method of alleviating CI is to store or to ship every mango cultivar at its ideal temperature, and to avoid exposure at lower (than adequate) temperatures. An alternative method for reducing CI is low temperature conditioning, which involves storing mango fruit at temperatures just above the specific temperature at which CI occurs, in order to induce tolerance to CI. Cold shock treatment at 0 °C for 4 h and thereafter transfer to 20 °C for 20 h prior to storage at 2 °C, 85–95% RH for 12 days significantly enhanced CAT and APX activities in mango fruit (Zhao, Jiang, Cao, Zhao, & Gu, 2006). CAT is part of the primary defence system against AOS (Wang et al., 2008). APX and GR play an important role in protecting the mango fruit from CI (Zhao et al., 2006). According to Zhao et al. (2006), cold shock treatment increased glutathione (GSH) and phenolic contents and non-enzymatic antioxidants in the mango fruit, and it could be regarded as part of the mechanisms involved in inducing chilling tolerance, which is involved in ascorbate-GSH pathway that mediates decomposing and detoxification of excess H2O2 in the cells. However, it is recommended to store mangoes at 8–13 °C (depending on cultivar and duration of storage or shipment) to prevent CI during the supply chain. It is also recommended to select and breed mango cultivars that are less susceptible to CI and show improved storage life at low temperatures (Phakawatmongkol, Ketsa, & van Doorn, 2004). MAP (~5% CO2 and ~10% O2) using micro perforated polyethylene or Xtend® film was effective in reducing CI in Tommy Atkins and Keitt mangoes for three weeks at 12 °C and one week at 20 °C (Pesis et al., 2000).

12. Implementing quality management practices in the mango supply chain

Consumer acceptance is determined by fruit quality in terms of taste, overall appearance, colour, size and freshness and safety (residue levels and food borne pathogens) of the fruit. Europe and USA are the largest importers of fresh produce and the safety of these products are managed by policies and regulations. Generally fresh produce are recognised as emerging vehicles causing food borne illness (Jacxsens et al., 2010). Inadequate sanitation practiced in the packing houses, hygiene deficiencies, improper water quality in the dipping tanks, and animal manure used for fertiliser application were reported to be potential sources of food borne pathogens (Jacxsens et al., 2010). The current quality assurance system includes tools and methods to control microbiological risks on fresh produce. However, improvement in adopted techniques, implementation of best production and handling practice will enable to ensure food safety of fresh produce in the supply chain (Jacxsens et al., 2010).

In some cases, pesticides have to be used to control diseases while the importing countries may request zero residue levels. Numerous factors are involved in maintaining mango fruit quality during the supply chain, such as; the application of pesticides, harvesting procedures, the timing of entire operational procedures, packaging...
operations (sorting, grading, HWT, waxing, and packaging), storage, temperature control, transportation, management organisation and market delivery conditions. Mango pack houses that export mangoes to the international markets may require obtaining a certification for international practice and standards such as Hazard Analysis and Critical Control Points (HACCP), and EurepGap certifications. HACCP are enforced in order to minimise the occurrence of hazards in the supply chain and to ensure correct product handling. EurepGap is mainly focused to maintain consumer’s confidence on fruit quality and safety through record keeping and traceability designed for farm level certification (EurepGap, 2001). In order to maintain an efficient quality management system in a supply chain, efficient and strict coordination between each player (the grower, harvesting crew, pack house management and workers, transporting agents, importing agents, storage, retailers, etc.) in the supply chain is important. Mango producers and exporters must have access to new technical and market information and training on postharvest management practices in order to provide information on maintaining the mango fruit quality during the supply chain. Furthermore, according to Kader (2008a, 2008b), heavy metals and pesticide residues in mangoes must meet the permitted levels according to the Codex Alimentarius Commission, and mangoes must be handled according to the recommendations of International Code of Hygienic Practice for Fresh Fruits and Vegetables and other relevant Codex texts (Codes of Hygienic Practices and Codes of Practice).

13. Fresh cut mangoes

Mango fruit is one of the major tropical fruits that gained popularity in the market (such as in Europe) as ‘fresh cut or ready to eat fruit’. Fresh cut processors are facing challenges with the type of mango cultivars, quality at harvest, incorrect ripening stages, and inconsistent supply of fruit, incorrect fruit sizes, treatments, packaging and marketing. Preharvest factors such as cultural practices, time of harvest and maturity at harvest, handling operation, the time between harvest and cutting operation also can affect the quality of the end fresh cut product (Kader, 2008a, 2008b). Operational factors such as sharpness of the cutting tool, surface area of the cut tissue or cubes, efficiency of removal of excess surface water present from the cut tissues, proper sanitation methods, application of suitable MAP, and maintenance of cold chain management determine the shelf life and the consumer acceptance of the fresh cut product (Kader, 2008a, 2008b).

Wounding (cutting) causes physiological and metabolic changes due to the activity of oxidation enzymes such as polyphenol oxidase and peroxidase, resulting in tissue browning (Oms-Oliu et al., 2010). Cutting operation increases respiration, stress ethylene production and accumulation of secondary metabolites at the injured site (Watada, Ko, & Minott, 1996). Furthermore, tissue softening is mediated in fresh cut tissue during storage by polygalacturonase and pectin methylesterase (Luna-Guzman & Barrett, 2000). The loss in colour, firmness, and flavour, and browning of the flesh affect the consumer acceptance of fresh cut mangoes at the retail market. Application of postharvest treatments such as anti-ripening agents, anti oxidants (ascorbic acid and citric acid) (Robles-Sánchez et al., 2009), firmness stabilisers (CaCl2), anti ripening agents (1-MCP) (Vilas-Boas & Kader, 2007), wrapping in edible film (Sothornvit & Rodsamran, 2007), and combination of chitosan coating and heat treatment (Dijoua et al., 2010), were investigated in order to retain the overall quality and to extend the shelf life. Among the tested treatments direct application of 1-MCP (1 μL−1 for 6 h at 10 °C) delayed softening and browning but failed to reduce the rate of respiration in fresh cut ‘Kent’ and ‘Keitt’ mango slices (Eduardo et al., 2007). On the other hand the integrated dipping treatment of ascorbic acid, citric acid and CaCl2 and low temperature storage (5 °C) allowed the maintenance of quality index up to 16 days (Robles-Sánchez et al., 2009). However, consumer acceptance was affected due to the development of off-flavour after 10th day. Peroxyacetic acid (Narciso & Plottó, 2005), or acidified sodium hypochlorite (He, Luo, & Chen, 2008), can be used as potential sanitizing agents on whole or cut mangoes in order to prevent the microbial spoilage at the retail shelf.

14. Conclusions

Fruit quality plays a major role in determining consumer acceptance of the fruit at the international markets. Therefore, mango exporting countries must enforce adequate quality assurance systems and postharvest management practices to maintain fruit quality during the export chain. Temperature management during storage and shipping is a critical factor that affects fruit quality at destinations, and mangoes should be stored and shipped at 8–13 °C (depending on cultivar and duration) and at 85–90% RH. After arrival, proper temperature management has to be practiced at storage or at the retailers’ shelf (8–14 °C). Decay and quality deterioration are the major postharvest problems of mango fruit during the export chain. Although fungicides such as prochloraz have been used commercially to control mango fruit decay, the resistance of the pathogens to these fungicides is increasing. Low temperature and MA/CA can delay fruit ripening and softening, but they need expensive equipments. Application of 1-MCP has potential for the commercial control of ripening and softening of harvested mango fruits especially in developing countries for long-distance transport because of its simplicity and low cost. However, the use of appropriate 1-MCP concentration still requires to be investigated further. Thus, it is necessary to develop integrated post-harvest technologies to better maintain overall mango fruit quality during the export chain.

There are barriers to the exportation of mango fruit because of quarantine issues associated with some pests. Heat treatments have been used as quarantine systems. The future development of integrated post-harvest technology for the export chain of mango fruit is likely to focus on disease and quality control involving in fungicides dip, heat treatments and temperature management.

References


