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Quality Properties of Harvested Mango Fruits and Regulating Technologies

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ABSTRACT

Mango (*Mangifera indica* L.) is a typical climacteric fruit with an obvious change in physiology and quality after harvest, including rapid ripening, quality deterioration, flavor loss and fruit decay. In addition, chilling injury easily occurs in mango fruit when they are stored at unsuitable low temperatures. This paper mainly reviews basic properties, physiological disorder, and quality change of mango fruit after harvest, as well as the advance in postharvest handling and storage technology.

Keywords: decay, *Mangifera indica*, physiological disorder, postharvest treatments, quality changes

Abbreviations: **ACC**, 1-amino cyclopropane-1-carboxylic acid; **ACS**, 1-aminocyclopropane-1-carboxylic acid synthase; **ACO**, 1-aminocyclopropane-carboxylic acid oxidase; **APX**, ascorbate peroxidase; **ASC**, reduced ascorbate; **CA**, controlled atmosphere; **CAT**, catalase; **CI**, chilling injury; **GR**, glutathione reductase; **GSH**, reduced glutathione; **GSSG**, oxidized glutathione; **H_2O_2**, hydrogen peroxide; **LOX**, lipoxygenase; **MAP**, modified atmosphere packaging; **MDA**, malondialdehyde; **MeSA**, methyl salicylate; **MeJA**, methyl jasmonate; **NIR**, near infrared; **OA**, oxalic acid; **O_2^-**, superoxide anion; **PE**, polyethylene; **PHT**, postharvest heat treatments; **POD**, guaiacol peroxidase; **RH**, relative humidity; **ROS**, reactive oxygen species; **SA**, salicylic acid; **SOD**, superoxide dismutase; **SSC**, soluble solids content; **VHT**, vapour heat treatment

CONTENTS

INTRODUCTION

Mango (*Mangifera indica* L.), belonging to the *Anacharidiaceae* family, is a typical climacteric fruit with high commercial values on the international fruit market (Baldwin *et al.* 1999). Native to Southeast Asia and India, mango fruit growing throughout the tropics is widely consumed in the world because of its attractive aroma, delicious flavor and excellent nutritional properties. At present, mangoes are produced on a large scale in India and other subtropical countries (Mitra and Baldwin 1997). Cultivated for over 6,000 years, the mango comes in over 50 varieties.

As a tropical fruit, mango is also susceptible to a number of physiological disorders due to low temperature during storage and even suffers from chilling injury (Ding *et al.* 2007). At ambient temperature, harvested mango fruit at the mature stage ripen quickly, and have a short postharvest life, which is limited by physiological deterioration related to over-ripening and by pathogen development leading to decay (Johnson and Coates 1993). Rapid ripening in combination with infection by microorganisms is a serious cause of postharvest loss in mango fruit and limits transport of fresh fruit from the harvest site (Zheng *et al.* 2007a). In this review, we mainly evaluate the general cha-

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racteristics, quality attributes, physiological disorder and decay of harvested mango fruit, and then introduce advances in postharvest handling and storage technology.

FACTORS AFFECTING POSTHARVEST QUALITY OF MANGO

Maturity

In developing and maturing periods of mango fruit, the shape, firmness, and colour show a marked change, while most volatile compounds are glycosidically bound and liberated (Sakho *et al.* 1985). Carbohydrate content and flesh color are also objective indicators of fruit maturity (Subedi *et al.* 2007). According to the standard made by Subedi *et al.* (2007), the maturity of mango fruit (cv. 'KP') is determined on the basis of visual and sensory criteria as follows.

• Stage 1 (immature) – narrow cheeks, rough and hard skin.
• Stage 2 (pre-mature) – cheeks narrow, but slightly fuller compared to stage 1 and skin slightly smoother but hard.
• Stage 3 (early maturity stage) – full shoulder, down in top, smooth skin and slightly beaky.
• Stage 4 (optimum maturity stage) – fully formed, down in top, full nose and slight smooth skin.
• Stage 5 (ripening stage, too ripe for packing) – fully formed, breaking color and started softening.

In general, maturity stage at harvest can greatly affect fruit ripening and quality of mango fruit (Bender *et al.* 2000a). Mango fruit harvested at the stage of high degree of ripening show the optimum quality. In commercial situations, where storage, transportation and shelf-life are involved, fruit should be harvested at the mature green stage; when they are physiologically mature before the onset of the climacteric rise (Lakshminarayana *et al.* 1970). Additionally, with the development of modern equipment, more advanced technologies are employed to measure fruit maturity. Saranwong *et al.* (2004) successfully developed a technique to predict ripe-stage eating quality of mango fruit from harvest quality, such as nondestructive measurement by near infrared (NIR) spectroscopy. Lebrun *et al.* (2008) discriminated mango fruit maturity by volatiles using electronic nose and gas chromatography.

Nutrient and flavor

Mango fruit contain nearly all the essential nutrients, including proteins, minerals and vitamins (**Table 1**). Especially, they are an excellent source of vitamins compared to other fruits. One hundred grams of edible portion of mango fruit contains about 765 IU of Vitamin A, which is much higher than other fruits. Eating mango may provide vitamin A in human liver, thus is highly beneficial for the prevention of vitamin A deficient disorders like night blindness. Moreover, 27.7 mg Vitamin C is present in 100 g of mango fruit. Both vitamins A and C are antioxidants and help prevent free radical injury and thus reduce the risk of certain cancers.

Table 1 Nutrient value of mango fruit (100 g of fruit).

Constituent	Approximate value
Water content	81.71 g
Calories	65 kcal
Protein	0.51 g
Fat	0.27 g
Ash	0.50 g
Carbohydrate	17.00 g
Total dietary	1.80 g
Calcium	10 mg
Iron	0.13 mg
Magnesium	9 mg
Phosphorus	11 mg
Potassium	156 mg
Sodium	2 mg
Vitamin C	27.7 mg
Vitamin A	765 IU

USDA National Nutrient Database for Standard Reference, Release 21 (2008). Available online at: http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list-nut-edit.pl

Fruit flavor is closely related to sugars and acids. The major soluble sugars of mango fruit contain glucose, fructose and sucrose. The compositional changes of mango fruit during ripening were analyzed through nuclear magnetic resonance spectroscopy by Gil *et al.* (2000), who reported that sucrose in pulp was found to predominate over fructose and glucose at most ripening stage, and content of citric acid, the most abundant organic acid in unripe mango, decreased markedly while alanine increased significantly after the initial ripening stage. In general, soluble solids content (SSC) increased and titratable acids (TA) decreased gradually whenever the mango fruit (cv. 'Zill') was stored at room or low temperature (Ding *et al.* 2007). Additionally, Saranwong *et al.* (2004) pointed out that dry matter and starch also had a high relationship with eating quality. Mango fruit containing sufficient amount of dry matter and starch at harvest would have excellent eating quality after ripening.

In addition, fresh mango fruit contain the 267-435 volatile compounds. Among them, terpene hydrocarbons are the major class, with contents of 16–90%. δ-3-Carene is the major compound in most mango cultivars. Additionally, other aroma compounds, such as limonene, β-ocimene, myrcene and α-terpinolene, are also important (Lebrun *et al.* 2008).

Fruit firmness

Firmness of mango fruit declines gradually during ripening and affects the fruit storability (Han *et al.* 2006). Sometimes, fruit firmness is regarded as an indicator of storage life. Nowadays many advanced techniques are used to measure firmness. Jarimopas and Kitthawee (2007) developed a high-speed impact sensing technique using a low-mass impact tester, which determines mango firmness rapidly, accurately and non-destructively. It is known that cellular wall structures have a high correlation with firmness. Redgwell *et al.* (1997) considered that swelling of the cellular wall was associated with the movement of water into voids left in the cellulose–hemicellulose network consisting of solubilized pectin, while the solubilization of pectin in the cellular wall was essential for ripening-associated softening (Brummell and Harpster 2001). Additionally, low temperature storage is beneficial to maintain fruit firmness. Han *et al.* (2006) found that mango fruit stored at 14°C softened rapidly with a significant decrease in firmness after 14 days of storage due to ripening in postharvest periods. Low temperature storage was more favorable than 14°C to keep higher firmness of mango fruit. Ding *et al.* (2007) proved that mango fruit stored at 5°C exhibited much higher firmness than at 14°C in the same storage period.

Respiration and ethylene

Mango usually shows a high respiration rate and releases ethylene during fruit ripening, resulting in a short storage life. Zheng *et al.* (2007a) reported that the peak (13 nmol kg^{-1} h^{-1}) of ethylene production rate in mango fruit (cv. 'Zill') appeared at 17 days of storage at room temperature (25°C). However, they found that mango fruit dipped in 5 mM oxalic acid (OA) solution for 10 min at 25°C showed a significant decrease in ethylene production rate, indicating exogenous OA application inhibited markedly ethylene production during storage, which is an important contributor to delaying the ripening process of mango fruit.

Respiratory climacteric of mango fruit may correspond to optimum eating ripeness, or may precede or postdate ripening according to fruit type. Montalvo *et al.* (2007) indicated that the climacteric peak of non-refrigerated mango was noted on day 6 of storage with a respiration rate of 109.2 ml kg^{-1} h^{-1}, while for refrigerated mango the peak was delayed for 4 days and respiration rate was smaller than for non-refrigerated mango (97.6 ml kg^{-1} h^{-1}). This effect may

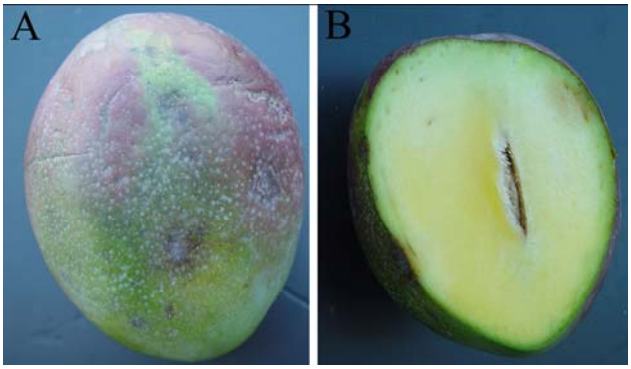

Fig. 1 Symptoms of chilling injury (CI) in mango fruit. The fruits suffering from CI show (**A**) sunken lesions and (**B**) pulp discoloration.

be attributed to the low storage temperature (13°C) because refrigerated temperatures can slow down fruit metabolism. As ripening of climacteric fruit should be ethylene-dependent, Medlicott *et al.* (1987) reported that ethylene in air at concentrations of 10 µl l^{-1} and above could initiate ripening of mango fruit (cv. 'Tommy Atkins'). The report by Montalvo *et al.* (2007) further demonstrated that application of 100 µl l^{-1} of ethylene for 12 h stimulated the synthesis of 1-amino cyclopropane-1-carboxylic acid (ACC) and increased ACC oxidase activity in 'Ataulfo' mango fruit, resulting in a concomitant production of ethylene and the subsequent acceleration of ripening with a net gain of 4 days in the ripening time.

Chilling injury

Mango fruit is sensitive to low temperature and easily injured when exposed to temperatures below 7 to 13°C, depending upon ripeness, variety and exposure time (Phakawatmongkol *et al.* 2004). The symptoms of chilling injury (CI) include peel pitting and sunken lesion on the peel, uneven ripening, poor flavor and increased susceptibility to decay (**Fig. 1**) (Mitra and Baldwin 1997). Thus, CI is a major limitation for long-term storage of mango fruit. Han *et al.* (2006), who observed that mango fruit (cv. 'Red 6') stored at 5°C showed typically symptoms of CI after 3 weeks of storage, considered that the occurrence of CI was related with structural changes in the cellular wall of the pericarp. These results suggested that wax with poor permeability might be one factor leading to chilling pitting, and abnormal separation in the cellular wall, disappearance of swelling and severe decomposition in the outer pericarp responding to CI. Additionally, Ding *et al.* (2007) considered that reactive oxygen species (ROS) probably participated in CI development.

Fruit decay

Mango fruit are perishable, particularly when the fruit are damaged or when CI occurs under low temperature stress. Anthracnose caused by *Colletotrichum gloeosporioides* is the major postharvest disease of mango fruit in all mango producing areas of the world (Dodd *et al.* 1997). *C. gloeosporioides* attacks mango fruit before and after harvest and the damage is more prominent at postharvest stage. Circular spots emergence with hazel color on the surface of fruit, then enlarge gradually and depress into the surface. When environmental humidity and temperature are properly high, the whole fruit may rot and fugal fruiting bodies are formed on the rotten surface (**Fig. 2**).

Black spot is a bacterial disease caused by *Xanthomonas campestris* pv. *mangiferaeindicae*, and usually occurs on the leaf of mango trees. Bacterial black spot is endemic in the major mango-producing regions of the world and causes great loss in market value and fruit yield (Gagnevin *et al.* 1997). Several other pathogens, including *Alternaria alternata*, *Phomopsis* spp., *Lasiodiplodia* spp. and *Pseudomonas syringae* pv. *syringae* also infect mango fruit during growth and at harvest period (Cazorla *et al.* 1998; Prusky *et al.* 2002). In addition, mango fruit can be infected by the pathogens after harvest through wounds (Manicom 2008).

Fig. 2 Symptom of Anthracnose in mango fruit. (**A**) Severe occurrence of anthracnose during storage; (**B**) Mycelial growth of infected tissues.

Careful handling

Mango fruit are easy injured during the postharvest chain, so that careful handling and packing after harvest are important for mango fruit to extend postharvest life. By experimenting with dropping mechanical stress on mango fruit (cv. 'Rosa'), Santos *et al.* (2004) indicated that dropping led to an accelerated rate of weight loss, darkened skin, pulp browning, fungi infection, and soaked areas on fruit at preclimacteric maturity stages. At harvest, pull out of stems from fruit when harvesting has to be avoided at all costs because broken skin at the point of attachment of the stem is particularly susceptible to a decay condition known as stem end rot. After harvest, fruit should be selected for appearance without physical injury and infection, classed on size and color, and parceled with soft paper in plastic box or fibreboard tray for transportation and sale.

Heat treatment

Postharvest heat treatments (PHT) have emerged over the past decade to maintain the postharvest quality of mango fruit around the world. The treatments have several positive effects in fruits including amelioration of chilling injury, insect and decay control, and ripening delaying (Yahia *et al.* 2000). Currently, there are three methods of PHT in use to retain the postharvest quality of mango fruit. They are vapour heat treatment (VHT), forced hot-air treatment (FHAT) and hot water immersion treatment (HWT) (Jacobi *et al.* 2001a). HWT at 38 or 46°C for 30 min increased mango fruit resistance to chilling temperatures (Zambrano and Materano 1998). A similar result was obtained by McCollum *et al.* (1993), who found that mango (cv. 'Keitt') fruit kept at 38°C for 24 or 48 h before storage at 5°C for 11 days significantly decreased chilling injury, while non-heated fruit developed typical symptoms, such as severe rind pitting and discoloration. Ketsa *et al.* (2000) also reported that mango (cv. 'Nam Dokmai') fruit heated at 38°C for 3 days had a lower disease incidence and developed less chilling injury than non-heated fruit in 4°C storage. In addition, heat treatment at 38°C for 3 days could inhibit ethylene production of mango (cv. 'Nam Dokmai') fruit due to inhibition of 1-aminocyclopropane-1-carboxylic acid synthase (ACS) and 1-aminocyclopropane-carboxylic acid oxidase (ACO) (Ketsa *et al.* 1999), maybe leading to delay of fruit ripening (Yahia *et al.* 2000). However, Jacobi *et al.* (2001a) reported that immersion of mango fruit in hot water at 42–49°C induced a range of external and internal heat injury in a number of cultivars, including 'Tommy Atkins', 'Keitt', 'Kensington', 'Irwin', 'Haden' and 'Carabao'. The severity and incidence depends largely upon the mango variety, method of heat application and the level of stress suffered by the tissue. They pointed out that exposure of mango fruit to 22°C for 24 h or longer could induce some protection against heat injury (Jacobi *et al.* 2001b).

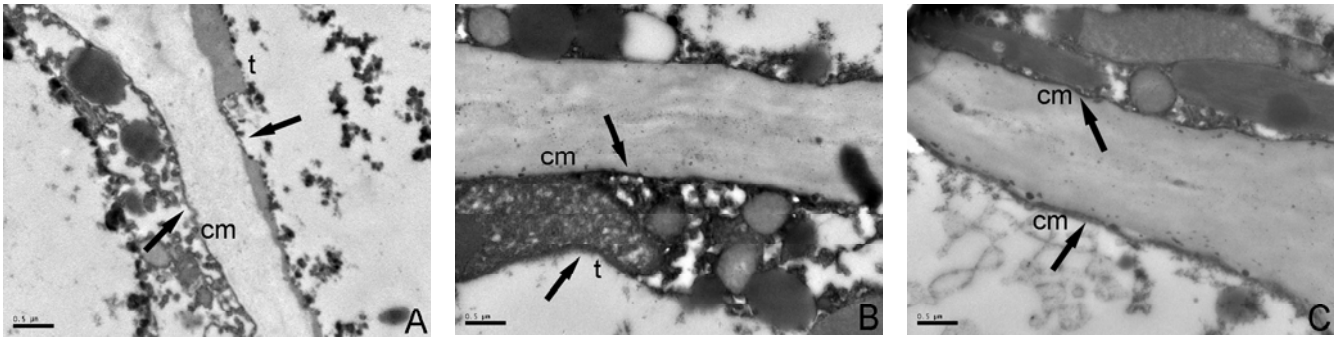

Fig. 3 Changes in pericarp of mango fruit after Ca or OA treatment. (**A**) Cell sections of control, the membrane structures of vacuole became obscure or damaged. (**B**) Cell sections after Ca treatment, much more Ca containing antimonite precipitates (CaAP) was distributed in the cell membrane (cm) and tonoplast (t), cell membrane and tonoplast were intact and clear. (**C**) Cell sections after OA treatment; more CaAP deposited in cell membrane, cell membrane was intact. Scale bar: 0.5 μm.

UV-C irradiation

It is well known that UV-C irradiation increases the shelf life of many fruit due to its direct antimicrobial activity on bacteria and fungi (Marquenie *et al.* 2003; Nicholson and Galeano 2003) and elicitation of defense responses in plant tissue (Stevens *et al.* 1996). Recently, several studies of UV treatment have been carried out on mango fruit. González-Aguilar *et al.* (2007b) showed that application of short UV-C irradiation treatment to mango (cv. 'Haden') fruit induced defense-related enzymes, improved quality and prolonged the shelf life. A similar observation was reported by González-Aguilar *et al.* (2001), who found that UV-C treatment for 10 min prior to storage was an effective and rapid method to reduce decay of mango (cv. 'Tommy Atkins') fruit without UV damage and adversely affecting quality attributes. In addition, UV-C irradiation appeared to be a good technique to improve the total antioxidant capacity of fresh-cut mango (cv. 'Tommy Atkins') (González-Aguilar *et al.* 2007a).

Coating treatment

Edible coatings have the potential to extend the shelf-life and ensure quality of foods by preventing changes in aroma, taste, texture and appearance (Arvanitoyannis 1999; Tharanathan 2003). The gas barrier characteristics of edible films and coatings are of great benefit, and, thus, development of edible films with selective permeability to gases (oxygen, carbon dioxide and ethylene) enables control of respiration and possibly microbial decay (Cuq *et al.* 1995). Baldwin *et al.* (1999) tested two types of coatings on mango fruit. One was polysaccharide-based and the other was carnauba. The results indicated that both coatings created modified atmospheres, reduced decay, and improved appearance but only the polysaccharide coating delayed ripening and increased concentrations of flavor volatiles. The carnauba coating significantly reduced water loss compared to uncoated and polysaccharide-coating treatments. Effects of different coatings (carnauba-based; soybean lecithin-based; carnauba and soybean lecithin-based; eugenol-based) on biochemical changes of 'cat Hoa loc' mango fruit were studied by Hoa and Ducamp (2008), who found that the soybean lecithin-based manual coating at 2% was the most effective in increasing fruit storage time by about 3 days under ambient temperatures.

Oxalic acid treatment

Oxalic acid **(**OA) is an organic acid with low molecular weight, and has been used for food preservation. Many researches have made clear that OA is not only an anti-browning agent for harvested fruits (Zheng and Tian 2006) but also available as a natural antioxidant in the natural and artificial preservation of oxidized materials (Kayashima and Katayama 2002). Our previous work has reported that a pre-storage OA treatment (5 mM dip for 10 min) in combination with controlled atmosphere (6% CO_2 +2% O_2, 14°C) extends the storage time and decreases the incidence of mango fruit (cv. 'Zill') decay (Zheng *et al.* 2005). The physiological effects of OA decreased lipoxygenase (LOX) activity and increased superoxide dismutase (SOD) and ascorbate peroxidase (APX) activity in peel, coincident with a decrease in reactive oxygen species (ROS) (Zheng *et al.* 2007b). In addition, at or above 5 mM, OA with natural pH or after neutralisation, also inhibited *C. gloeosporioides* development *in vitro* (Zheng *et al.* 2007b).

Zheng *et al.* (2007a) point out that application of exogenous OA at 5 mM is effective in decreasing ethylene production and decay of mango fruit (cv. 'Zill') during storage periods at 25°C (when disease index of mango fruit reached more than 80%, that of OA treated fruit was nearly 40%). The results demonstrate that OA treatment is a promising method to suppress postharvest deterioration and extend the shelf-life of refrigerated mango fruit due to a combination of physiological effects associated with delaying the ripening process, and direct effects including low pH inhibiting the development of postharvest fungal pathogens such as *C. gloeosporioides*. Moreover, we have observed that preharvest treatment of exogenous OA at 5 mM could increase Ca content in pericarp of mango fruit, resulting in higher plasma membrane integrity (**Fig. 3**).

Salicylic acid treatment

Salicylic acid (SA) or MeSA are also applied in the control of CI and decay of mango fruit during storage periods. In our experiment, mango (cv. 'Zill') fruits were immersed in aqueous solutions (2 mM) of SA for 10 min to determine the effects of exogenous SA on reactive oxygen species (ROS) metabolism, quality and CI of the fruit stored at 5 and 14°C. The results indicated that exogenous SA application effectively enhances mango fruit tolerance to low-temperature stress, and SA-treated fruits stored at 5°C showed a significantly lower CI index than non-SA-treated fruit (Ding *et al.* 2007). In addition, SA-treated fruits had lower superoxide anion (O_2^-) content, higher hydrogen peroxide (H_2O_2) content, LOX activity and higher activities of SOD, catalase (CAT), guaiacol peroxidase (POD), APX and glutathione reductase (GR) (Ding *et al.* 2007). It was suggested that the effect of SA on mango CI was probably attributed to inhibition of O_2^- accumulation and induction of higher reducing status of ascorbate and glutathione.

Han *et al.* (2006) investigated the response of physiologic metabolism and cell structures in mango fruit to exogenous MeSA under low-temperature stress. The results from fourier transform infrared (FTIR) spectrometry indicated that in MeSA-treated fruit, the cellular wall of the exocarp contained lower amounts of pectic substances, aliphatics, phenolics, carboxylate and carboxyl substances but had more esterified substances. They also found that cellular wall of the fruit stored at 5°C appeared obvious separation

between two-cell contacts by scanning electron microscopy (SEM), but the phenomena of wall separation between two cells were slight in the fruit stored at 14 and 5°C with MeSA treatment. These data provide new insight that MeSA enhanced fruit tolerance to low temperature stress by affecting the cellular structure and composition of mango fruit. In addition, González-Aguilar *et al.* (2000) reported that exposure of mango (cv. 'Tommy Atkins') fruit to methyl jasmonate (MeJA) vapors (10^{-4} mol L^{-1}) for 24 h at 25°C reduced CI during subsequent storage for 21 days at 7°C and after 5 days of shelf life at 20°C.

Decay control

In order to control spoilage, maintain quality and storage-life, González-Aguilar *et al.* (2007b) applied short UV-C irradiation to mango (cv. 'Haden'), resulting in an increase in defense-related enzymes and prolonging the shelf life of mango fruit. Some chemicals, such as OA (5 or 10 mM), 2,4-dichlorophenoxyacetic acid (2,4-D) ranging from 75 to 175 μg ml^{-1}, and prochloraz (225 μg ml^{-1}) effectively controlled the diseases caused by *Colletotrichum gloeosporioides* and *Alternaria alternate* in mango fruits by spraying before harvest or by spraying or dipping after harvest and before storage (Kobiler *et al.* 2001; Prusky *et al.* 2006; Zheng *et al.* 2007b). Modified atmosphere packaging (MAP) created in low-density polyethylene bags has been successfully used to reduce decay, maintain quality and extend storage life in mango fruit (Illeperuma and Jayasuriya 2002).

In addition to physical and chemical controls, nowadays biological control has attracted greater attention. Govendera *at al.* (2005) reported that *Bacillus licheniformis* could effectively control mango postharvest diseases on a semi-commercial scale. Other antagonists, such as *Brevundimonas diminuta*, *Stenotrophomonas maltophilia* and *Candida membranifaciens* were also effective in controlling naturally infected mango fruit (Kefialew and Ayalew 2008).

Moreover, careful handling and packaging during and after harvest are important because mango fruit are easily bruised and scratched, and the damaged areas usually are prone to being infected by pathogens. Standard practices during and after harvest are important to avoid mechanical damage and reduce decay for extending postharvest life.

Low temperature storage

Low temperature storage is effective in slowing physiological metabolism, maintaining quality, reducing decay and extending storage life of fruit. At ambient temperature, mango fruit harvested at the mature stage ripen quickly, and have a short postharvest life. However, mango fruit is susceptible to CI when exposure to lower temperatures, the optimal storage temperature for mango fruit is above 13°C (Mitra and Baldwin 1997; Phakawatmongkol *et al.* 2004). In addition, refrigeration combined with the postharvest application of chemicals such as polyamines including spermine, spermidine and putrescine ranging from 0.01 to 1.0 mM (Malik and Singh 2005), or a combination of 2% (w/v) $CaCl_2$ + 6% (w/v) waxol + 0.1% Bavistin™, a fungicide (Waskar and Gaikwad 2005), can extend the shelf-life and reduce deterioration by delaying the ripening and/or successfully controlling postharvest diseases in mango fruit.

Modified atmosphere packaging

The compounds of storage atmosphere are important for the storability of mango fruit. By sealing fruit in polyethylene (PE) bags with different gas permeability, MAP is effective to maintain fruit quality. The main factors include increased CO_2 and decreased O_2 levels, which reduce respiration rate, limit water loss and suppress diseases. Martínez-Ferrer *et al.* (2006) reported that MAP systems with gas mixture (4% O_2 + 10% CO_2 + 86% N_2) could effectively extend the shelf life of mango and pineapple. High quality of 'Karuthacolomban' mango fruit stored at 13°C and 94% relative humidity (RH) could be maintained by low-density polypropylene bags that create modified atmosphere conditions (Illeperuma and Jayasuriya 2002). CI could be alleviated (Pesis *et al.* 2000) and postharvest disease development could also be suppressed (Illeperuma and Jayasuriya 2002) when mango fruit (cv. 'Keitt') were stored in macroperforated PE or Xtend™ film at 12°C.

Moreover, Yuen *et al.* (1993) demonstrated that shrink-wrap or sealed PE packaging delayed ripening, and had reduced peel injury of mango (cv. 'Kensington Pride') after 30 days storage at 20°C compared to unpackaged fruit. Rodov *et al.* (1997) found that microperforated film was more beneficial for mango (cv. 'Tommy Atkins') packaging, as it avoided the accumulation of dangerous levels of CO_2 that can cause off-flavours and peel injury. MAP created in low-density polyethylene bags has been successfully used to reduce decay, maintain quality and extend storage life in mango fruit.

Controlled atmosphere conditions

Compared to MAP, controlled atmosphere (CA) is more accurate to regulate concentration and/or the ratio of O_2 and CO_2 in a storage environment. CA has proved to be effective at limiting fungal decay development, maintaining quality and extending postharvest life of climacteric fruits, such as apple, kiwifruit and mango. Bender *et al.* (2000b) found that preclimacteric mango (cv. 'Haden' and 'Tommy Atkins') fruit were able to tolerate 3 KPa O_2 for 2 or 3 weeks at 12 to 15°C in CA storage, and low O_2 and high CO_2 affected fruit ripening differentially. Lalel *et al.* (2005) reported CA storage in 6% CO_2 and 3% O_2 appears to be promising to extend the shelf-life of 'Delta R2E2' mango for up to 38 d, while still allowing the fruit to ripen normally with a yellow skin colour, good taste, high TSS and TSS/acid ratio, and high total sugars content. Zheng *et al*. (2005) reported that OA treatment, in combination with controlled atmosphere (6% CO_2 + 2% O_2) storage at 14°C, can extend the storage-life and decrease the incidence of decay in mango fruit (**Fig. 4**).

In addition, Lalel and Singh (2006) investigated the effect of CA storage on production of aroma volatile compounds of 'Delta R2E2' mango, and considered that CA-storage for up to 38 d in 6% CO_2 and 3% O_2 appeared promising for 'Delta R2E2' mango, without causing significant fermentation products, especially ethanol and acetaldehyde. Kim *et al.* (2007) have reported that the combination of both CA (3% O_2 + 97% N_2, or 3% O_2 + 10% CO_2 + 87% N_2) and pre-storage heat treatment (treated for 75 min at 46°C) can delay fruit ripening and improve fruit quality.

CONCLUSIONS AND FUTURE PERSPECTIVES

Mango is a favorable fruit due to its attractive aroma, delicious flavor and rich nutrition. However, harvested mango fruits rapidly ripen and easily lose flavor and decay, resulting in a short shelf-life and decline in marketing value. Although some chemical compounds, physical treatments and storage techniques have been proved to effectively control decay and extend storage time of mango fruit, the me-

Fig. 4 Mango fruit (cv. 'Shengxin') treated with 5 mM OA for 10 min and then stored in CA with 6% CO_2 + 2% O_2 at 14°C for 30 days.

chanisms regulating fruit ripening and inducing resistance of mango fruit should be paid attention to investigate on the basis of molecular and proteomic approaches, in order to integrate new technologies and improve the quality of mango postharvest fruit. In addition, genes related to mango fruit ripening, such as *pTHMF 1* (Bojorquez and Gómez-Lim 1995), *ETR-1* (Gutierrez *et al*. 2001) have been cloned. It is better to further study the function and expression of the genes, leading to deeply understanding of postharvest quality properties. Therefore, genetic transformation to extend shelf-life may revolutionize the mango industry in the future.

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