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Physiological Properties and Storage Technologies of Loquat Fruit

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ABSTRACT

Loquat usually has a high market value with a relatively short postharvest life, because the fruit are perishable, easily damaged and lose commercial quality after harvest and in storage. The general characteristics, quality properties, physiological disorders and decay of loquat fruit after harvest have been chiefly evaluated, and the advances in beneficial treatments, decay control and storage technologies are also introduced in this review.

Keywords: disorders, decay, *Eriobotrya japonica*, postharvest treatment, quality

Abbreviations: 2,4-D, 2,4-dichlorophenoxyacetic acid; **CA**, controlled atmosphere; **CAD**, cinnamyl alcohol dehydrogenase; **CAT**, catalase; **CI**, chilling injury; **GA**, gibberellic acid; **LOX**, lipoxygenase; **LTC**, low temperature conditioning; **MAP**, modified atmosphere packaging; **NAA**, α-naphthalene acetic acid; **PAL**, phenylalanine ammonium-lyase; **PE**, polyethylene; **PE-pf**, perforated polyethylene; **PG**, polygalacturonase; **PME**, pectin methylesterase; **POD**, guaiacol peroxidase; **PPO**, polyphenol oxidase; **PUT**, putrescine; **ROS**, reactive oxygen species; **SOD**, superoxide dismutase; **SPD**, spermidine; **SPM**, spermine; **SSC**, soluble solids content; **TA**, titratable acidity

CONTENTS

INTRODUCTION

Loquat (*Eriobotrya japonica* Lindl.) is a subtropical evergreen fruit tree that belongs to the family Rosaceae, subfamily Maloideae, which originates in the cooler hill regions of south western China and is very well adapted to temperate areas (Lin *et al*. 1999). Loquat was introduced to Japan in ancient times, then spread to other countries (Zhang *et al*. 1990). The history of loquat cultivation is more than 2000 years old, since the Chinese Han dynasty (100 B.C.) (Chen *et al*. 2003). Now, loquat is commercially cultivated in more than 20 countries, including China, Japan, India, Brazil, Israel, Italy, Spain, Turkey, USA, Austria, and so on. Among them, China, with more than 100,000 ha cultivating area and 380,000 tons of annual amounts, is the leading producer of loquat.

In this paper, we mainly reviewed basic properties, physiological disorders, decay and quality change of loquat fruit after harvest, as well as the advance in postharvest treatments and storage technologies.

RESULTS AND DISCUSSION

Maturity

The quality of loquats, including color, flavor, aroma and

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chemical compounds etc., are highly dependent on the ripening degree at harvest (Hamauzu 1999). Volatiles of fresh loquat fruit (cv. 'Tanaka') contains 78 compounds. Among them, fifteen compounds significantly contribute to the aroma, and the most potent aroma compounds in fresh loquat is phenylacetaldehyde. Additionally, other aroma compounds, hexanal, (E)-2-hexenal, hexanoic acid, β-ionone are also important (Takahashi *et al.* 2000). The skin color of loquat fruit shows a marked change from green to yellow during development and maturation and from yellow to deep orange during ripening. So the skin color is generally used as a parameter for harvest. In general, high quality loquat fruit have soluble solids content (SSC) >12%, moderate titratable acid (TA) from 0.3 to 0.6% and low flesh firmness (Ding *et al.* 1995).

Loquats harvested at the stage of high degree of ripening show the optimum quality. However, in commercial situations, where storage, transportation and shelf-life are involved, the fruit should be harvested at the eating-ripe stage before becoming fully ripe, that is, after the skin color has completely turned to yellowish-orange (Cuevas *et al.* 2003). The harvest date of the most cultivars is determined by skin color changes, described for each cultivar (Ding *et al.* 1998b). The harvest season of loquat in China lasts from the end of April to the middle of June when the market is short of fresh fruit, so loquat usually has a high market value. Amorós *et al.* (2004) reported that naphthalene acetic acid (NAA) at concentration of 25 and 50 mg L^{-1} and phenothiol at 50 mg L^{-1} treatments could increased fruit size and advanced fruit maturity in loquat (cv. 'Algerie'), and they found that physico-chemical variables related to fruit quality, such as colour (variable *L* ranging between 61.56 and 63.11, a/b ranging between 0.17 and 0.21), firmness (ranging between 3.33 and 3.58 N), ripening index (ranging between 6.08 and 6.38), and sugar (ranging between 5.0 and 5.5 g 100 g^{-1} FW of sucrose)and organic acid content (ranging between 1.0 and 1.3 g 100 g^{-1} FW of malic acid) were similar in loquat fruit picked at commercial maturity from control and treated trees. At the same time, the production of fruit (size from 46 to 53 mm) increased from 18.3 kg per tree to 28.6 kg in NAA-25 treatment and 3% of the total production was harvested 10 days earlier in auxin treatments than fruit from control trees. They considered that these treatments accelerated fruit growth and maturation, without any undesirable effect on nutritive and organoleptic properties of the fruit, and had an increase in its economic value (Amorós *et al.* 2004).

Flavor and nutrient

Loquat fruit are round or oval in shape weighing about 20 to 80 g and grow in loose clusters. The fruit has a smooth or downy, yellow or orange, sometimes red-blushed skin. Ripe fruit flesh is soft and juicy with a mild, sub-acid and sweet flavour, varying in colour from white to deep orange or salmon (Shaw 1980). It contains nearly all the essential nutrients, including proteins, minerals and carotenoids (**Table 1**).

Table1 Nutrient value of loquat fruit (100 g of fruit).

Constituent	Approximate value
Water content	86.73 g
Calories	47 kcal
Protein	0.43 g
Fat	0.20 g
Ash	0.50 g
Cholesterol	0 mg
Carbohydrate	12.14 g
Total dietary	1.7 g
Calcium	16 mg
Iron	0.28 mg
Magnesium	13 mg
Phosphorus	27 mg
Potassium	266 mg
Sodium	1 mg
Vitamin C	1.0 mg
Vitamin A	1528 IU

Data source, USDA National Nutrient Database for Standard Reference, Release 19 (2006). Available online at: http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl

Fruit flavor is closely related to the ratio between sugar and acid. The major soluble sugars and sugar alcohols in loquat fruit (cv. 'Mogi') were identified as being fructose (3.9 mg 100 g^{-1} FW), sucrose (2.4 mg 100 g^{-1} FW), glucose (2.5 mg 100 g^{-1} FW) and sorbitol (0.9 mg 100 g^{-1} FW) by Ding *et al.* (1998b), who found that sucrose declined rapidly and the rate was greater with an increase in storage temperature, while fructose and glucose changed slightly during storage and showed a similar concentration at different temperatures. Zheng *et al.* (2000a) reported that during storage of loquat fruit (cvs. 'Dahongpao' and 'Jiefangzhong'), total sugar decreased gradually when the fruit was stored at 20ºC. At the beginning of storage, sucrose declined rapidly, which led to an increase of reduced sugar. He *et al.* (2005) analyzed loquat fruit (cvs. 'Jiefangzhong' and 'Zaozhong 6') by High Performance Liquid Chromatography (HPLC) and detected 7 types of organic acid. For 9 maturity of 'Jiefangzhong' loquat fruit, the concentrations of these organic acids are malic acid 7.435 mg g^{-1}, lactic acid 0.583 mg g^{-1}, oxalic acid 0.259 mg g^{-1}, tartaric acid 0.245 mg g^{-1}, pyruvic acid 0.031mg g^{-1}, citric acid 0.191 mg g^{-1}, fumaric acid 0.686 μg g^{-1}. Among them, malic acid (about 85%) and lactic acid (about 10%) were the main organic acids. In ripe loquat fruit (cv. 'Mogi'), malic acid was the principal non-volatile organic acid and represented about 90% of total acids. Along with the decrease of storage temperature, the declining rate of malic acid concentration (decreasing to 200 and 250 mg 100 g^{-1} FW at 20ºC and 1ºC after storage for 10 days, respectively) was reduced further, while that for fumaric acid increased more (decreasing to 2.9 and 2.7 mg 100 g^{-1} FW at 20ºC and 1ºC after storage for 10 days, respectively) (Ding *et al.* 1998b). Compared with the changes in sugar, organic acids in loquat fruit (cv. 'Wuxing') declined more rapidly, which made the ratio of sugar and acid increase, resulting in a loss of fruit flavor (Ding *et al.* 2006). In addition, cryptoxanthin and β-carotene were the main pigments in loquat pulp. Their concentration increased during the whole storage period at 20ºC and the first 30 days of storage at 1 or 5ºC. The concentrations of cryptoxanthin increased from 0.7 to 1.7 mg 100 g^{-1} FW at 20ºC and 0.7 to 0.8 and 0.9 mg 100 g^{-1} FW at 1 or 5ºC. For β-carotene, the concentrations increased from 0.7 to 1.17 at 20ºC and 0.7 to 1.1 and 1.2 mg 100g^{-1} FW at 1 or 5ºC (Ding *et al.* 1998b).

Firmness

Firmness of loquat fruit changes dramatically in postharvest storage. It obviously increases when the fruit are stored at a low temperature. Zheng *et al.* (2000b) found that lignin content of loquat fruit (cv. 'Dahongpao') also raised and showed a positive correlation with the increase of firmness at the same time. Cai *et al.* (2006b) reported that loquat fruit (cv. 'Luoyanqing') firmness and lignin content increased steadily after harvest at 20ºC and thus is not a specific low temperature response, and considered that activities of enzymes related to lignin synthesis, such as phenylalanine ammonia lyase (PAL), cinnamyl alcohol dehydrogenase (CAD) and peroxidase (POD) also increase. Among the enzymes associated with lignin synthesis, PAL activity increased rapidly during the first 3 days and reach a peak of 12 U mg^{-1} after harvest and then declined in the fruit flesh, while CAD and guaiacol-POD activities showed a persistent rise over the whole 8 days, and increased from 3.24 to 5.26 and 4.21 to 10.85 U mg^{-1}, respectively at 20ºC. When stored at 0ºC, activities of PAL, CAD and guaiacol-POD in loquat fruit increased to 11, 5.53 and 11.23 U mg^{-1}, respectively. In addition, Zheng *et al.* (2000a) observed stuck peel, leathery and juiceless pulp in loquat fruit (cvs. 'Dahongpao' and 'Jiefangzhong') after 3 weeks of storage at 1ºC following an increase in firmness and lignin content. But little change in firmness and lignin were detected when fruit were stored at

12ºC.

Respiration rate and ethylene production

Loquat, as a non-respiration climacteric fruit, produces relatively low amounts of ethylene, and is not particularly sensitive to ethylene exposure after harvest (Blumenfeld 1980). The ethylene production rate declined significantly over the first 2-7 days at various temperatures, and showed a lower rate at a lower storage temperature (20ºC, 0.95 µl kg^{-1} h^{-1}; 1ºC, 0.15 µl kg^{-1} h^{-1} after storage for 7 days) (Ding *et al*. 1998b). Loquat cultivars have a rapid rate of fruit softening. Respiration rate and ethylene production of loquat fruit gradually decreased during postharvest storage, and were strongly influenced by temperature (Zheng *et al*. 2000b). Ding *et al*. (1998b) obtained similar result that low temperature could significantly decline the respiration rate and inhibit the production of ethylene. In the study, the respiration rate of 'Mogi' loquat fruit was strongly influenced by storage temperature, with the highest rate at 20°C (40 ml CO_2 kg^{-1} h^{-1}) and the lowest one at 1°C (5.6 ml CO_2 kg^{-1} h^{-1}) after storage of 4 days. Although ripening of non-climacteric fruit may be ethylene-independent, results from Cai *et al*. (2006a) indicated that ethylene treatment (100 µl L^{-1}) could enhance, while the inhibitor of ethylene perception 1-methylcyclopropene (1-MCP) at concentration of 5 µl L^{-1} inhibited significantly, the ethylene release of loquat fruit (cv. 'Luoyanqing') stored at 20ºC. Similar results have also been reported for other non-climacteric fruits, such as cherries (Gong *et al*. 2002), citrus (Porat *et al*. 1999), and strawberries (Tian *et al*. 2000).

Membrane integrity

Membrane integrity is associated with the senescence and the onset of chilling injury. Relative electric conductivity is thought to be an index to evaluate the integrity of the cell membrane (Whitlow *et al*. 1992). An increase in electric conductivity of flesh tissue in loquat fruit (cv. 'Luoyanqing') was found at both room and low storage temperature (Cai *et al*. 2006c). Leakage of the cell membrane may be caused by the attack of reactive oxygen species (ROS, such as $O_2^{\cdot -}$, $^{\cdot}OH$ and H_2O_2). $O_2^{\cdot -}$ production rate in loquat fruit (cvs. 'Luoyanqing') markedly increases from 56 to 84 nmol kg^{-1} s^{-1} with peak value of 108 nmol kg^{-1} s^{-1} at 4 day along with an increase in electric conductivity during the 8 day storage at 20ºC (Cai *et al*. 2006a). We found an increase from 32000 to 48000 U kg^{-1} in activity of lipoxygenase (LOX), which is considered to be partly responsible for the formation of $O_2^{\cdot -}$, and a decrease from 32000 to 14000 U kg^{-1} in activity of superoxide dismutase (SOD), which can scavenge superoxides, in 'Wuxing' loquat fruit during storage at 25ºC (Ding *et al*. 2006). The result may explain the reason for the accumulation of $O_2^{\cdot -}$.

Physiological disorders

Loquat fruit are easily bruised and scratched, and the damaged areas usually turn brown or black in air later (**Fig. 1**). The main causes of loquat fruit quality loss after harvest were considered to be internal browning, dry pulp tissue and adherence of the peel and flesh (Ding *et al*. 2002a), and these disorders might be the result of tissue lignification (Cai *et al*. 2006b). In addition, low temperature injury is a major limitation for long-term storage of loquat fruit.

Browning

Usually loquat fruit are harvested at a relatively high degree of ripening and with soft fresh, and the extrusion between fruits usually happens during the transport and postharvest storage, so that browning is quite severe. The browning reaction in fruits and vegetables is a widespread phenomenon. It is an undesirable reaction and will decrease the commercial value of crop products because of the unattractive appearance and concomitant development of an off-flavour (Friedman 1996). Tissue browning, due to oxidative reactions of phenolic compounds by oxidases (e.g., polyphenol oxidase or PPO) and the reaction products, *o*-quinones, to various polymerized products, results from loss of compartmentalization within the cells when exposed to physical and/or physiological stresses (Ding *et al*. 2006). Loquat fruit have a relatively high concentration of polyphenols, of which the main phenolic compounds in ripe fruit are chlorogenic acid (45 mg 100 g^{-1} FW), neochlorogenic acid (22 mg 100 g^{-1} FW), hydroxybenzoic acid (3.8 mg 100 g^{-1} FW) and 5-feruoylquinic acid (6.8 mg 100 g^{-1} FW) (Ding *et al*. 1999). When the mechanical damage or chilling injury happens, the polyphenols can be oxidized by PPO and lead to browning of the skin, which make the fruit lose its commercial value.

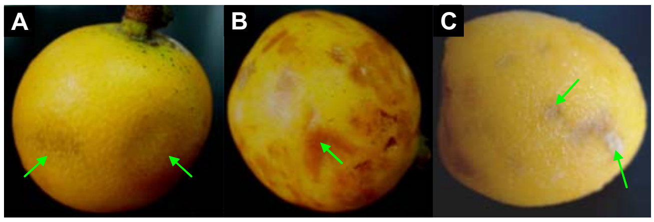

Fig. 1 Physical injures (**A**, **B**) and physiological disorder (**C**) of loquat (cv. 'Wuxing') fruit after harvest and in storage. (**A**) bruised damage; (**B**) scratched damage; (**C**) woodiness. Arrows indicate the injury sites.

Ding *et al*. (1998a) purified a kind of PPO from loquat (*E. japonica* Lindl. cv. 'Mogi') fruit, and found that the molecular weight of the enzyme was about 58,000 and 55,000 by SDS-PAGE and FPLC gel filtration chromatography, respectively, with the optimum pH of 4.5 and temperature of 30ºC. In substrate specificity, a maximum relatively activity was shown with epicatechin (186.2%) as taking chlorogenic acid to be 100%, followed by chlorogenic acid, neochlorogenic acid (97.6%), 4-methylcathechol (87.6%), and pyrocatechol (83.8%), and no activity was apparent toward monophenol and *p*-diphenol (Ding *et al*. 1998a). The enzyme activity was markedly inhibited by sodium ascorbate, diethyldithiocarbamate, metabisulfide, dithiothreitol, mercaptoethanol, NaF, NaN_3, L-cysteine, and reduced glutathione. Ding *et al*. (2002a) investigated six sulfhydryl compounds and identified that L-cysteine (0.6~2.0 mM) appeared to be an effective browning inhibitor.

Purple spot

Purple spot, a physiological disorder, is the most important problem reducing loquat fruit quality, which affects loquats worldwide, particularly in China, Brazil and Spain (Ojima *et al*. 1976; Gariglio *et al*. 2002). The disorder occurs on the exposed surface, and affected fruit show an extensive area of slightly depressed surfaced, of purple color and irregular in shape. Symptoms appear at fruit colour break and affect epidermal tissue without damaging the flesh. The affected area on fruit is easily infected by saprophytes. Gariglio *et al*. (2002) reported that about 15% of annual fruit production is injured in Spain, reducing external fruit quality and decreasing commercial value by 40-50%. They indicated that purple spot incidence varied from year to year and depends on location and harvest time, and could be affected by environmental factors, and considered that minimum temperature and fruit exposure to sun (no wrapping), both at the stage of fruit colour break, were the main environmental factors causing the onset of purple spot of loquat fruit (Gariglio *et al*. 2003). In contrast, purple spot began at the deepest rind cell layers in the fruit and purple spot incidence was highest at the beginning of harvest time, indicating that some endogenous factors in loquat fruit should be involved during the disorder happening (Gariglio *et al*. 2002). Localized fruit calcium deficiency and water imbalance between flesh and epidermal tissues may be responsible for purple spot (Caballero 1993). Calcium nitrate, calcium chloride, Ca-EDTA, ammonium nitrate and potassium nitrate at a concentration of 150 mM applied 2 weeks before fruit colour break significantly reduced the proportion of purple-spotted fruit (Gariglio *et al*. 2005). However, the specific mechanism of purple spot is still unknown.

Chilling injury

Loquat fruit are sensitive to low temperature and are easily injured when they are stored at temperatures lower than below 5ºC (Cai *et al*. 2006c). The symptom of chilling injury (CI) is expressed as flesh woodiness, adhesion of the peel to the flesh, leathery and juiceless pulp and internal browning in loquat fruit (Lin *et al*. 1999). CI is a major limitation for long-term storage of the fruit. Zheng *et al*. (2000a) observed that firmness of loquat fruit (cvs. 'Dahongpao' and 'Jiefangzhong') gradually increased in postharvest storage at 1ºC and the fruit showed typically symptoms of chilling injury after 3 weeks storage. They considered that the occurrence of chilling injury was related with the abnormal metabolism of cell wall substances since pectin methyllesterase (PME) and polygalacturonase (PG) activities and water-soluble pectin content declined while protopectin, lignin and fiber contents, and PAL activity increased. For loquat fruit (cv. 'Dahongpao'), water-soluble pectin content decreased from 0.07 to 0.44% FW, and protopectin, lignin and fiber content increased from 0.33 to 0.53%, 1.0 to 1.4% and 0.25 to 0.35%, respectively. PME and PG activities decreased from 74 to 41 and 14.4 to 0.2 U kg^{-1}FW, while PAL activity increased from 690,000 to 940,000 U kg^{-1}FW. Meanwhile, they found that the levels of free polyamine (spermine (SPM), spermidine (SPD), and putrescine (PUT) in flesh changed with the occurrence of CI. In the Dahongpao loquat fruit at 1ºC, SPM level decreased gradually in the first two weeks, then increased sharply and reached a peak value (25 nmol g^{-1} FW) after three weeks, thereafter it decreased rapidly. SPD level decreased steadily from 10 to 2.6 nmol g^{-1} FW during the first three weeks and increased significantly afterwards. PUT level evolved in a similar way as the SPM level did except that it increased slowly in the first two weeks. The fruit showed symptom of chilling injury after three weeks. These results suggested that an increase in SPM level might be a defense response against chilling injury, while the accumulation of PUT could be a cause of the injury and the increase in SPD level could be a consequence of chilling stress (Zheng *et al*. 2000b).

Physical damage

Careful handling and packing during and after harvest are important for the storability of loquat fruit. By experimenting with simulating mechanical stress on fruit, damaged fruit (cv. 'Jiefangzhong') showed physiological changes, such as increase in malonaldehyde (MDA) content from 8 to 15 mmol g^{-1} (8 to 10 mmol g^{-1} in control), and first increase and then decrease of respiration rate (peak value 63 mg kg^{-1} h^{-1}, while 53 mg kg^{-1} h^{-1} in control) and PPO activity (peak value 900 U, while 700 U in control); these physiological changes were responsible for fruit browning (Chen *et al*. 2003). At harvest, the fruit stem should be cut from the tree with a knife, and by holding the stem, the fruit should be carefully put in a basket whose inside surface is smooth and covered with soft paper, to avoid mechanical injury. After harvest, fruit should be selected for appearance without physical injuries and infections, classed on size and color, and parceled with soft paper in a paper or plastic box; about 10 kg of fruit are usually packaged in a box for transportation and sold. In an experiment simulating transport, vibration absorber sheets appeared to reduce the percentage of damaged fruit by about 20-40% (Barchi *et al*. 2002).

Fruit decay

Loquat fruit are perishable, particularly when the fruit are damaged or when chilling injury occurs in low temperature storage (**Fig. 2**).

Fig. 2 Symptom of fruit decay in storage. (**A**) the decayed tissues are soft, watery and browning; (**B**) Mycelial growth of *B. cinerea* in infected tissues; (**C**) soft water-soaked spot.

Anthracnose is a main disease of loquat fruit in China. The disease is caused by *Colletotrichum gleosporioides* Penz. At the beginning, a circular spot with hazel color emergences at the surface of fruit. Then the spot enlarges gradually and depress into the surface. When environmental humidity is high, the whole fruit may rot and the fugal fruiting bodies are formed on the rotten surface.

Canker is a bacterium disease caused by *Pseudomonas syringae* pv. *eriobotryae* (Takimoto) Young, Dye and Wilkie, and usually occurs on the branches of loquat trees. Loquat canker is widely distributed throughout every loquat cultivation area and causes great disturbances in fruit productivity (Lin *et al*. 1999). However, loquat fruit can also be infected by the pathogen after harvest through wounds. The symptoms of canker disease are coarse pericarp and slits on peduncle.

In addition, several other pathogens, including *Diplodia natalensis*, *Pestalotia* sp., *Aspergillus niger*, *Botrytis cinerea*, and *Phytophthora palmivola*, also infect loquat during growth and harvest periods.

POSTHARVEST TREATMENTS AND STORAGE TECHNOLOGIES

Low temperature storage

Loquats have a short postharvest life. The storability of the fruit is correlated with storage temperature. The storage time of loquat in air at room temperature is about 6-9 days (Shaw 1980). Low temperature storage is effective at reducing fruit decay, and rates of respiration and ethylene production and extending storage life of loquat fruit are comparable at room temperature. Moreover, the optimal storage temperature for loquat fruit is dependent on variety, for example, the optimal storage temperature for loquat varieties of Jiefangzhong and Zaozhong 6 were 6-8°C and 8-10°C, respectively, with acceptable storage time of 30 d (He *et al*. 2004). Ding *et al*. (1998b) recommended that the conditions for commercial storage of loquat fruit were 0 to 5°C with >90% RH. They found that fresh fruit quality of 'Mogi' loquat could be maintained for up to 30 days at 1 and 5°C and the effective storage life at higher temperatures was 15 days at 10°C and 10 days at 20°C, and considered that low temperature also significantly reduced the loss of loquat weight; weight loss was 15.9% after 20 d at 20°C, and 8.3, 8.9 and 14.4% after 60 d at 1, 5 and 10°C, respectively (Ding *et al*. 1998b).

Low temperature conditioning (LTC) is an alternative technique for increasing tolerance to low temperatures. It is beneficial when fruit and vegetables are conditioned by exposure to temperatures slightly above the critical chilling range showing more resistance to subsequent lower temperatures (Wang 1993). The crucial factors of this technique are temperature differences between conditioning and storage temperature and the duration of the conditioning treatment. Cai *et al*. (2006c) reported that LTC as conditioning at 5°C for 6 days before 0°C storage, effectively alleviated the CI of loquat (cv. 'Luoyangqing') fruit, and reduced the increase of firmness, lignin content and browning index, and retarded the decrease of juice during storage and it was beneficial to retard the decrease of sugar content and titratable acidity. They considered that LTC might provide an effecttive commercial low temperature treatment maintaining acceptable external and internal quality of loquat fruit, extending low temperature storage life and allowing harvesting and handling of near-ripe fruit with more favourable quality characteristics.

Modified atmosphere packaging

The compounds of storage atmosphere are important for the storability of loquat fruit. By sealing fruit in polyethylene (PE) bags with different gas permeability, modified atmosphere packaging (MAP) is effective to adjust the atmosphere compounds around the fruit by fruit respiration. Ding *et al*. (1998b) reported that use of PE bags could effectively retard weight loss, and total weight loss of fruit stored at 20°C was 15.9% after 20 days, while that of fruit stored at 1, 5 and 10°C was 8.3, 8.9 and 14.4%, respectively, after 60 days of storage. In addition, PE bags minimized decreases in organic acids, citric acid and succinic acid concentrations were 35 and 5.2 mg per 100 g pulp, respectively, and remained relatively constant during storage. They found that inside PE bags, higher CO_2 and lower O_2 concentration were accumulated at 20°C compared with that at 5°C, and ethylene concentration was higher at 20°C than that at 5°C in PE bags, and it was higher in thicker bags at 20 or 5°C (Ding *et al*. 2002b). Higher gas permeable MAP showed a lower incidence of decay at 20 and 5°C, and fruit in 20-30 μm-thick PE bags could be stored for 2 months with acceptable quality and minimal risk of decay at 5°C (Ding *et al*. 2002b). The decay of loquat fruit was caused predominantly by an internal flesh browning followed by complete rotting. Ding *et al*. (2002b) reported that use of PE bags could effectively retard weight loss, minimizes decreases in organic acids and reduce increase of carotenoid content, compared with that in perforated polyethylene (PE-pf) bags. After 60 d at 5°C, fruit in PE bags had less than 1.5% weight loss, while that in PE-pf bags had 8.9 % weight loss. In addition, after storage of 60 d at 5°C, organic acids in fruit packaged in PE-pf, PE-20, PE-30 and PE-50 μm thickness bags decreased by 60%, 35%, 30% and 27%, respectively, compared with the initial levels. Moreover, fruit in perforated or higher permeance PE bags had higher levels of carotenoid compared with that in low gas permeance bags. Also, internal browning and brown surface spotting occur during long-term or high CO_2 storage (Ding *et al*. 1999).

Packaging in perforated PE film bags (0.15% perforation) and stored at 1, 5, 10, 20°C, respectively, loquat (cv. 'Mogi') fruit showed different storability and physiological responses (Ding *et al*. 1998b). They also indicated that along with the decrease of storage temperature, the incidence of breakdown declined. It reached 40% after 30 d at 20°C, while 8, 10 and 29% after 60 d at 1, 5 and 10°C, respectively (Ding *et al*. 1998b). In a recent experiment, we found that MAP treatment showed more effectiveness in reducing fruit decay, off-flavours and weight loss at 1°C than at 6°C. And packaged in polyethylene (PE) bags, loquat (cv. 'Wuxing') fruit showed a notably lower decay index and more reduced value of SSC/TA at 1°C than that at 6°C (Ding *et al*. 2006).

Fig. 3 Loquat fruit stored in air at 25°C for 7 days (left) and in CA condition with 10% O_2 + 1% CO_2 at 1°C for 60 days (right).

Controlled atmosphere conditions

On regulating the atmosphere composition, controlled atmosphere (CA) is more accurate than MAP. The storability of loquat (cv. 'Wuxing') fruit stored in CA and MAP at 1°C was investigated by Ding *et al*. (2006), who found that CA with 10% O_2 plus 1% CO_2 was more effective in reducing fruit decay and prolonging storage time in comparison with other storage (**Fig. 3**). After 49 d of storage at 1°C, CA fruit had decay index of 7%, SSC/TA value of 4.0, pH 4.2, endo-PG activity of 1657 U kg fresh weight^{-1}s^{-1} and exdo-PG activity of 1624 U kg fresh weight^{-1}s^{-1}, while MAP fruit had decay index of 17%, SSC/TA value of 4.4, pH 4.5, as well as 1787 and 1889 U kg fresh weight^{-1}s^{-1} of endo-PG activity and exdo-PG activity, respectively. In addition, after 28 d storage at 1°C, ethyl acetate content in CA fruit were 0.4 μmol kg fresh weight^{-1}s^{-1}, while that in MAP fruit was 0.9 μmol kg fresh weight^{-1}s^{-1}. Loquat fruit could be stored in this CA condition at 1°C for more than 50 days with normal flavour and a low decay index of about 7%. In addition, a short term, high-O_2 treatment at the beginning of storage had little effect on fruit flavour, but stimulated ethanol accumulation in loquat fruit, and reduced activities of PPO, POD, PAL, endo-PG and exo-PG (Ding *et al*. 2006). After 49 d storage at 1°C, PPO activity of CA fruit was 1272 U kg fresh weight^{-1}, while that of MAP fruit was 1504 U kg fresh weight^{-1}. In addition, after 49 d at 1°C, Activities of LOX, SOD, CAT and POD in CA fruit were 31882, 85371, 248768 and 4020 U kg fresh weight^{-1}, respectively, while those in MAP fruit were 58314, 45839, 282568 and 3397 U kg fresh weight^{-1}, respectively. From the results, CA condition was more effective in reducing PPO activity and oxidative stress than MAP condition, which may be the reason why loquat fruit stored in CA condition had a lower decay index than that kept in MAP condition (**Table 2**).

Additional approaches

The storability of loquat fruit is obviously influenced by the application of growth regulators before harvest and ripening degree at harvest. The application of some plant growth regulators, such as NAA, gibberellic acid (GA) and 2,4-dichlorophenoxyacetic acid (2,4-D), retarded ethylene production and respiration rate, improved the vitamin C content, prolonged the storage time and improved the quality of loquat fruit (Chaudhary 1994).

Wu *et al*. (2004) reported that a pre-storage heat shock of 48-52°C for 10 min effectively alleviated the CI of loquat (cv. 'Jiefangzhong') fruit stored at 2-5°C. Pre-storage treatment by immersing fruit in an aqueous solution of 1 mmol L^{-1} acetyl salicylic acid at 20°C for 5 min, also effectively

Table 2 Decay index of loquat (cv. 'Wuxing') fruit under different storage conditions during storage.

Storage conditions	Decay index (%) during storage							
	0 d	7 d	14 d	21 d	28 d	35 d	42 d	49 d
control	0	7.7 ± 0.8 a	14.1 ± 1.2 a					
1 ± 1°C MAP	0	2.2 ± 0.2 c	2.0 ± 0.2 d	2.9 ± 0.3 b	6.1 ± 0.5 b	11.1 ± 0.4 b	15.6 ± 0.4 b	16.7 ± 0.9 b
6 ± 1°C MAP	0	5.7 ± 0.3 b	9.1 ± 0.7 b	12.2 ± 0.9 a	12.2 ± 1.1 a	20.0 ± 0.9 a	26.7 ± 0.5 a	27.8 ± 1.4 a
CA-I	0	2.1 ± 0.3 c	3.3 ± 0.5 c	3.7 ± 0.5 b	4.4 ± 0.6 b	5.1 ± 1 c	6.7 ± 1.1 c	6.7 ± 0.8 c
CA-II	0	0 d	2.4 ± 0.4c d	3.2 ± 0.3 b	5.6 ± 0.7 b	5.7 ± 1.1 c	5.9 ± 1.2 c	6.1 ± 0.7 c

Data are means ± S.E. Different letters within a column indicate significant difference (P<0.05). Control: in air at 25°C, 1±1°C MAP, 6±1°C. MAP: in polyethylene bag (0.01 mm thickness) at 1±1°C or 6±1°C. CA-I: in 10% O_2+1% CO_2 at 1±1°C. CA-II: in 70% O_2 for 24h, then in 10% O_2+1% CO_2 at 1±1°C.

alleviated CI symptoms of loquat fruit at 0°C and during subsequent shelf life at 20°C (Cai *et al*. 2006b). In addition, the effect of exogenous acetyl salicylic acid on loquat CI was probably attributed to its ability to inhibit the accumulation of superoxide free radicals and reduce activities of cinnamyl alcohol dehydrogenase (CAD), PAL and POD. Zheng *et al*. (2000b) reported that treatment of SO_2 retarded the decrease of TA and percentage juice and retained the acceptable quality in loquat (cv. 'Dahongbao') fruit after 35 d of storage at 1°C. Treatment with 1-MCP (5 μl L^{-1}, at 20°C, for 12 h) also reduced the incidence of internal browning and increase firmness in loquat (cv. 'Luoyangqing') fruit stored at 0°C and the corresponding shelf life (Cai *et al*. 2006a).

Decay control

Although diseases caused by pathologies are generally not serious in harvested loquat fruit, some methods are necessary to control the diseases in some production regions. In order to control spoilage, maintain quality and storage-life, loquat should be pre-cooled at lower than 5°C within 20 h of harvest and kept in low temperature storage (Shinbori and Nakai 1991). Some anti-fungal chemicals were effecttive to control the diseases by spraying before harvest or by dipping after harvest and before storage. MAP (13-18% O_2 and 2-4% CO_2) and CA (10% O_2 and 1% CO_2) at low temperature, have been successfully used to reduce decay, maintain quality and extend storage life in many fruits (Ding *et al*. 2006).

In addition, careful handling and packaging during and after harvest are important because loquat fruit are easily bruised and scratched, and the damaged areas usually turn brown or black, and are infected by pathogens. So careful handling and packaging during and after harvest are important to avoid mechanical damage and reduce decay, and low-temperature storage is essential for extending postharvest life.

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