Chapter 2

Literature Reviews

Introduction

Mango belongs to the family Anacardiaceae, with about 75 genera and 700 species, mostly tropical, with some subtropical and temperate species (Nakasone and Paull, 1998). The mango originated in the Indo-Burmese region (Subramanyam *et al*., 1976). The mango has been cultivated in India for over 4000 years. Indian traders and Buddhist priests probably introduced the mango into Malaysia and other East Asian countries during the 4th or 5th century BC and to the Philippines between AD 1400 and 1450. The Portuguese, the first Europeans to establish trade routes with India, transported the mango to East Africa and Brazil. Spanish traders took the mango from the Philippines to the west coast of Mexico before the English arrived at the Hawaiian Islands in 1778. The mango was introduced into Hawaii from the west coast of Mexico between 1800 and 1820, with credit being given to Don Francisco de Paula Martin, a Spanish horticulturist. Apparently, the Brazilian introduction was spread to Barbados and to other islands in the Caribbean area. Mango is now found in all tropical areas, as well as many subtropical regions of the world, attesting to its wide range of adaptability (Nakasone and Paull, 1998).

Mango cultivars may be classified into two groups: Indian or Indo-Chinese, based mainly on peel pigments and sensory characteristics of the pulp. Most of the Indian varieties, which possess stronger aroma and more intense peel coloration, are monoembryonic and require asexual propagation methods for consistent reproduction of the cultivar. On the other hand, most of the cultivars grown in the South-east Asia region are largely polyembryonic (Kusumo *et al*., 1984). Due to the contrasting flavors of these groups, population accustomed to the taste of Indo-Chinese varieties perceive the Indian types as ‘medicinal’ or possessing a ‘turpentine’ flavor (Lizada, 1993).

Fruit Growth and Development

The fruit of mango is a drupe of variable size and shape, ranging in weight from a few grams to more than 1 kg. It is fleshy, flattened, rounded or elongated in shape. A number of basic forms of the major morphological characteristics are used in describing the fruit (Nakasone and Paull, 1998).

Fruit growth shows a simple sigmoidal growth curve in terms of length, thickness, mass and volume against days from anthesis (Mendoza, 1981, Lam *et al*., 1982). Immature fruit skin is green or purplish and, upon ripening, becomes yellow, yellowish red, reddish or purplish red. The peel (exocarp) is thick and the flesh (mesocarp) of ripe fruit is yellow or orange-yellow and juicy. The pericarp can be separated into exocarp, mesocarp and endocarp at about 14 days after anthesis (Kader and Mitcham, 2003). There is a period of 9-14 weeks after fruit set when growth rate decreases, and this is associated with hardening of the endocarp and accumulation of starch and sugars. The endocarp is hard, with fibers that may extend into the flesh. The period from fruit set to maturity depends upon cultivars and climate which can range from 10 to 28 weeks. The 'Saigon' mango grown in hot climate is ready for harvest in 12-13 weeks. In cool areas where mean temperatures fall below 20°C, maturation is delayed by up to 4 weeks (Nakasone and Paull, 1998).

Harvest Maturity

Mango fruit growth follows a simple sigmoid pattern (Mendoza, 1981, Lam *et al*., 1982, Tandon and Kalra, 1984). The period of rapid growth is characterized by an increase in alcohol-insoluble solids, principally starch (Lizada, 1993). The accumulation of these is accompanied by increased amylase activity in 'Dashehari' (Tandon and Kalra, 1984) and 'Haden' varieties (Fuchs *et al*., 1980). The increase in dry matter has been recommended for use as an index of maturity in 'Kensington Pride' (Baker, 1984) and specific gravity has been used as a maturity index in 'Alphonso' (Subramanyam *et al*., 1976), 'Dahehari' (Kapur *et al*., 1985) and 'Carabao' varieties (Cua and Lizada, 1990).

Maturity at harvest is the most important factor that determines storage life and final quality. The final quality of the mango depends not only on the physiological processes occurring during ripening, but also on processes during fruit development and maturation (Mitra

and Baldwin, 1997). Immature fruits are more subjected to shriveling and mechanical damage, and are of inferior quality when ripe. Overripe fruit are likely to become soft and mealy with insipid flavor soon after ripening. Any fruit picked either too early or too late in its season is more susceptible to physiological disorders and has a shorter storage life than fruit picked at the proper maturity (Kader, 2003).

Mitra and Baldwin (1997) reported on the various maturity indices for harvesting mango fruits and have been suggested for several varieties. Harvest maturity is determined by using criteria, such as change in color, fullness of cheek and hardness of endocarp. The most reliable indicator of maturity is hardened endocarp, however, this test is a destructive test. Fruit set dates can be established as an index for harvesting. The fruit set date for each tree is determined when the panicles show a high percentage of initial fruit set. Tridjaja and Mahendra (2000) found that the optimal maturity of 'Arumanis' mango fruit for consumption was reached when fruit was harvested at 13-14 weeks after fruit set, characterised by the values of 16.8-17.0% TSS, 0.18-0.22% TA, pH 4.8, fresh color rating of 6-6.5, and a taste score of 5.

There is no particular parameter for judgment of fruit maturity, it depends on mango type, variety, production conditions and location. Physical, chemical and physiological parameters are used to define the maturity stage for harvesting of fruits. Useful chemical parameters are acidity, soluble solid content, phenolic constituents and carbohydrate content (Ketsa *et al*., 1991). Titratable acid correlated very well with days after flower induction in the 'Carabao" mango (Del Mundo *et al*., 1984), decreasing in the fully mature fruit to < 44.8 meq/100 g. In 'Alphonso', titratable acid increased from the sixth to the tenth week after fruit set and steadily declined thereafter as the fruit matured (Lakshminarayana, 1973). Physical parameters are size, shape, surface color, pit around the pedicel, lenticels and specific gravity (Ketsa *et al*., 1991). As the mango fruit matures, bloom develops as wax and is deposited on the peel (Kosiyachinda *et al*., 1984). The chemical nature of mango wax deposits as well as changes during maturation, await characterization (Lizada, 1993).

Harvesting

Harvesting is accomplished by experienced pickers who are hired by the collectors, contract buyers or by the farmers themselves. The quality of the harvested crop will be greatly

influenced both by the ability of the picker to choose mature fruit and by the method of harvesting employed in the process. Ideally, repeated harvesting of the same tree should be carried out to ensure that only mature fruit is harvested. However, there is much resistance to this and the normal practice is for pickers to harvest all the fruit on a tree regardless of the stage of maturity. Hence, there is a range of maturity in harvested produce particularly when harvesting is earlier than ideal (Kosiyachinda and Mendoza, 1984).

Mango fruit are harvested by hand if the pickers can reach them (Mitra and Baldwin, 1997). Except for young trees where hand picking is convenient, some tool to assist in picking is needed to obtain fruit that is beyond reach. The picking tool may be used from the ground or after climbing the tree. Many of these tools are made of rattan, nylon or canvas formed into a half-elliptical basket which is attached to a bamboo pole or other lightweight material. On the upper end of most tools is a heavy gauge looped wire to facilitate separation of the fruit from the stalk (Kosiyachinda and Mendoza, 1984).

About 1-2 cm of peduncle is usually left attached to the fruit in order to avoid rupture of the resin ducts, which results in later undesirable blemishes. In general, for the short-time shipment, mango fruit will be harvested after color break. Fruits destine for long transportation distance or storage should be harvested when they are still firm, green and physiologically mature (Mitra and Baldwin, 1997).

Ripening Processes

Ripening is the composite of the process that occur from the latter stages of growth and development through the early stages of senescence and that results in characteristic aesthetic and /or food quality, as evidenced by changes in composition, color, texture, or other sensory attributes (Kader, 2003). Ripening of fruit is accompanied by a change in peel and pulp color, conversion of starch to sugar, flesh softening and aroma development. It is generally accepted that continued production and action of ethylene are required for intregation of these biochemical changes (de Morais and de Assis, 2004). Furthermore, during ripening of fruit, a number of enzymes increased in activity, due to flesh firmness are wildly used for defining postharvest quality of almost fruit (Prasanna *et al*., 2006).

Pigment changes

Peel color is an important criterion of acceptability of the mango (Lizada, 1993). The peel color of fruit changes on ripening from dark green to olive-green, sometimes reddish, orange-yellow or yellowish hues appear from the base color, depending on the cultivar. Chloroplasts in the peel are transformed into chromoplasts containing red and yellow pigments (Kader and Mitcham, 2003). Some cultivars also develop a reddish blush, which has been attributed to anthocyanin, and some remain green, e.g., 'Harumanis' and 'Katchamita' (Lizada, 1993).

Substantial losses in peel chlorophyll content of 'Keitt' mangoes occur after the fruit begins to soften (Medlicott and Thompson, 1985). There is a rapid destruction of chlorophyll, with chlorophyll a preferentially degraded relative to chlorophyll b in 'Tommy Atkins' mangoes (Medlicott *et al*., 1986). A more rapid loss in chlorophyll a is typically observed in senescence or chemical degradation of extracted chlorophylls (Simpson *et al*., 1976, Peiser and Yang, 1977).

Parikh *et al*. (1990) observed well-arranged grana and osmiophilic globules in the chloroplasts of the cells in the peel of unripe mangoes. This granal membrane loses integrity during ripening and osmiophilic globules appear, indicating the transformation of the chlroloplast to a chromoplast containing red or yellow carotenoid pigments. Medlicott *et al*. (1986) reported differing patterns of change in carotenoids and anthocyanins, with former increasing during ripening. In contrast, the anthocyanin levels gradually declined, indicating that were unmasking accounts for the increased prominence of blush in some cultivars. The principal carotenoids reported in ripe 'Alphonso' mango peel were β–carotene, xanthophylls esters and xanthophylls. β-carotene and auroxanthin were found to constitute 55% and 12.5%, respectively, of the peel carotenoids in 'Tommy Atkins' (Medlicott, 1985). The only anthocyanin pigment identified in the peel is peonidin-3-galactocide, which was extracted from 'Haden' (Lizada, 1993).

Pulp carotenoids continue to increase in the detached fruit as ripening proceeds, with the carotenoid level in the ripe fruit varying among cultivars. In the fully ripe 'Badami' and 'Alphonso' mangoes, β–carotene constituted more than 50% of the total carotenoids, with phytofluene the next most abundant (Lizada., 1993). In 'Tommy Atkins', β–carotene also constituted about two-thirds of the pulp carotenoids (Medlicott, 1985). The predominant xanthophyll in this variety was found to be violoxanthin (Lizada, 1993). The pulp carotenoid

level in the ripe fruit varies among the cultivars (Table 2). The fractions of carotenoids suggested that more than 50% of total carotenoids consist of β-carotene (Mitra and Baldwin, 1997).

Vasquez-Caicedo *et al*. (2002) evaluated physical characteristics of nine Thai mango fruits (Chok Anan, Nam Dok Mai #4, Rad, Mon Duen Gao, Keaw Sawoei, Okrong Keaw, Okrong Thong, Kaew and Maha Chanok). The resulted showed that fruit maturity did not correlate with peel color in all cultivars. Color saturation (chroma) and yellowness (b*) showed the highest correlation coefficients between color of peel and flesh, repectively. Only the peel of 'Maha Chanok' 'Kaew' 'Rad' and 'Chok Anan'showed visible color changes that could indicate full ripeness as well. Peel of 'Maha Chanok' mango showed red spots over a green-yellowish background at its harvest time, and develop up to a bright yellow peel color with red chicks. Peel color of 'Kaew' mango completely turned to yellow-orange at full maturity. Also peel 'Chok Anan' and 'Rad' mangoes turned to a dark yellow color, but still showed some greenish parts that did not vanish during ripening. However, flesh color of 'Nam Dok Mai #4 had one of the most intensive and bright yellow-orange flesh color, together with 'Kaew' and 'Maha Chanok', contrasting with 'Okrong Keaw' 'Okrong Thong' which rather showed pale yellow-greenish mesocarp color.

The color of the 'Kaew' and 'Chok Anan' mango pulp reduced particularly the L* value while a* and b* values increased during the ripening process (Homdork *et al*., 2006). The L* value of 'Kaew' mango pulp reduced during long-term storage at ambient temperature and 15ºC (Pimpimol and Khamsee, 2001)

Fruit temperature is the most important factor in ripening mature-green mangoes. Ripening at 15.5-18ºC may result in the most attractive skin color while ripening at 27-30ºC may result in mottled skin and above 30ºC, ripening is retarded (Kader and Mitcham, 2003). Mango fruit stored at low temperatures and subsequently ripened at room temperature failed to synthesize as much carotenoids as do fruits held continuously at room temperature (Lizada, 1993). However, a hot water dip (52-55˚C) for 5-10 minutes increases the color intensity of both the pulp of 'Tommy Atkins' mangoes (Medlicott *et al*., 1985) and the peel of 'Carabao' mangoes (Lizada, 1993).

A controlled-atmosphere (CA) condition (3% CO_2 + 3% O_2) showed a great efficiency in retention of hue angle of both peel and pulp color of 'Nam Dok Mai' mangoes (Singkaew *et al*.,

2004). The most promising CA storage in 10% CO_2 condition reduced peel and pulp color changes of mature green 'ChoK Anan' mangoes more than 10% CO_2 or 5 and 10 % O_2 when storage at 13°C (Wimonwat *et al*., 2005). However, 'Chok Anan' and 'Maha Chanok' mangoes treated with calcium carbide showed increase of the peel L* value but decrease of the pulp L* value during their ripening periods at ambient temperature for 12 days (Rattanapanone *et al*., (2004).

Pectic substances, cell wall constituents and enzyme activity

During ripening, mango fruit is accompanied by softening and is brought about by alterations in the cell wall metabolism and is due frequently to the partial solubilisation of pectin or cellulose. Pronounced softening during ripening limits the marketable life of the mango. Softening is accompanied by cell wall disruption (Parikh *et al*., 1990), with the middle lamella appearing as an electron-translucent area on electron micrographs of the ripe fruit (Medlicott, 1985).

In most of the varieties examined, an increase in water-soluble polysaccharides has been observed during ripening (Lazan *et al*., 1986). In contrast, Roe and Bruemmer (1981) reported a decline in water-soluble polysaccharides in ripening 'Keitt' mangoes, which they attributed to the possibility of extensive polymer degradation such that the products become soluble in ethanol.

Changes in pectin consituents during ripening of 'Keaw' and 'Chok Anan' mango fruit showed that a progressive increase in water-soluble and ammonium oxalate-soluble pectin whereas the level of alkaline-soluble pectin decreased during that time (Homdork *et al*., 2006).

Brinson *et al*. (1988) examined cell wall constituents of 'Ngowe' mango and reported a decline in uronic acid content as a percentage weight of the whole wall, i.e., from 25% in the unripe to 19.1% in the ripe fruit. In contrast, the uronic acid content of the water-soluble polysaccharides increased from 7% in the unripe to 90% in the ripe fruit. Moreover, galactose and arabinose each constitutes about 30% of the water-soluble polysaccharides of the cell walls of the unripe fruit. A higher uronic acid content of the water-soluble polysaccharides was observed in the ripe compared to the unripe mesocarp. These observations were interpreted to indicate that during ripening the mango cell walls are degraded, releasing the combined monosaccharides of the pectin complex. The water-soluble pectic materials in the cell walls lose arabinose and galactose, accounting for the galacturonan-rich polysaccharides in the mesocarp (Lizada, 1993).

Ripening of the mango fruit is characterized by softening of the flesh. The peak of ripeness is associated with a fairly narrow range of firmness. Limited information is available on mango cell walls and the softening process during ripening (Ali *et al*., 1995, Tucker and Seymour, 1995), and there are considerable differences among cultivars (Selvaraj and Kumar, 1989). Softening of mango fruit is characterized by an increase in the solubility of cell wall pectins (Mitra and Baldwin, 1997). In mangoes, the ripening as characterized by changes in tissue softness and is believed to be initiated in inner mesocarp tissue close to the seed, and to progress outward. Pectin solubilization in inner and outer mesocarp tissues was comparable. Pectin depolymerization appeared to begin earlier in the inner mesocarp than in the outer mesocarp tissue (Lazan and Ali, 1993). Physiological maturity in tree-ripened mango fruit was reported to be associated with a drop in pectinmethylesterase (EC 3.1.1.11, PME) activity (van Lelyveld and Smith, 1979). The peel of mango was reported to have higher PME activity than the pulp (Mitra and Baldwin, 1997).

In 'Carabao' mango, considerable PME activity could be measured during ripening, increasing as the fruit approaches the half-life (50% yellow peel color) stage and declining thereafter. A similar pattern was observed in some of the varieties examined by Selvaraj and Kumar (1989).

Inner mesocarp of 'Carabao' mango exhibits softening ahead of the outer mesocarp (Cua and Lizada, 1989). The difference in the degree of softening between portions of the mesocarp is evident even in the ripe fruit, and this difference appears to be variety-dependent (Chaplin *et al*., 1990). The jelly seed disorder (van Lelyveld and Smith, 1979) and premature ripening around the seed (Winston, 1984) might be extreme examples of such difference (Lazan and Ali, 1993).

The presence of polygalacturonase (EC 3.2.1.15, PG), the enzyme responsible for degrading the (1—>4)-linked galacturonic acid residues, has been reported in ripening mangoes (Lazan *et al*., 1993). PME which catalyses the deesterification of methyl groups from acidic pectins, is also detectable in ripening mangoes (Ali *et al*., 1995). Other cell wall hydrolases detected in ripening mangoes are cellulase (Abu-Sarra and Abu-Goukh, 1992), β-galactosidase (Lazan and Ali, 1993, Ali *et al*., 1995), galactanase and xylanase (Ali *et al*., 1995). In general, water-soluble polysaccharides increased during ripening (Brinson *et al*., 1988), in 'Keitt'

mangoes, however, water-soluble and alkali-soluble pectin increased as the fruit lost its firmness and became soft (Lizada, 1993).

Mitcham and McDonald (1992) studied the cell wall modification during ripening of 'Keitt' and 'Tommy Atkins' mango fruit. They observed that cell wall neutral sugars, particularly arabinosyl, rhamnosyl and galactosyl residues, decreased with ripening in both cultivars. 'Keitt' had more loosely-associated, chelator-soluble pectin, accumulated more soluble polyuronides and retained more total pectin at the ripe stage than did 'Tommy Atkins'. Both cultivars had similar PG activity which increased with ripening. The molecular mass of cell wall hemicellulose decreased with ripening. They indicated that enzymatic and/or non-enzymatic processes, in addition to PG activity, are involved in the extensive softening of fruit. In 'Sensation' mangoes, galactose was the only cell wall neutral sugar to show a significant decrease during ripening (Seymour *et al*., 1990). Such loses of neutral sugars could possibly be attributed to hydrolysis of galactans and arabinogalactans by β–galactosidase having galactanase activity. The β–galactosidase activity showed a parallel increase to tissue softening during ripening, and the close correlation between changes in β–galactosidase activity, tissue softness, and increased pectin solubility and degradation. The β–galactosidase might play an important role in the cell wall pectin modification and softening of mango fruit during ripening (Ali *et al*., 1995). Moreover, Evangelista *et al*. (2003) found that during storage 'Tommy Atkins' mangoes, there was an increase in the activity of PG and β–galactosidase enzymes and no activity of PME.

Chaimanee (2003) found that the increase in both endo and exo PG activities correlated well with the increase ripeness of 'Nam Dok Mai' mangoes. Analysis of proteins extract from ripening fruit by elcetrophoresis indicated that at least three proteins at molecular weight 67,000, 34,000 and 32,000 were associated with PG activity. The increase in exo-PG was highly correlated with ripening whereas endo-PG activity was constant. Exo-PG was extracted from ripe mango mesocarp tissue. The enzyme has the relative molecular weight of 66 k and 58 k as detected by SDS-polyacrylamide gel electrophoresis (Chaimanee *et al*., 2003). 'Chok Anan' and 'Maha Chanok' mangoes treated with calcium carbide showed increase of the peroxidase (POD) and polyphenol oxidase (PPO) activities including total soluble protein during fruit ripening. There were 12 and 13 bands of soluble protein that separated by SDS-polyacrylamide gel

electrophoresis from Chok Anan' and 'Maha Chanok' mangoes, respectively, (Rattanapanone *et al*., 2004).

The studied to multiple forms of PG from 'Alphonso' mango fruit found that the PG from mango pulp revealed three isoforms (I, II, III) upon ion exchange and gel chromatography, each having an abundance of 68%, 6% and 26%, and molecular weights (M_r) 40, 51 and 45 kDa, respectively. The pH optimum for isoforms was between 3 and 4. PG-I was stable over a wide pH range (4-7.5) unlike PG II and III, which were stable at pH 4 and 5, respectively. The optimum temperature was around 40°C for all the three isoforms. Their apparent K_m for pectic acid was in the range 0.22-0.25 mg/ml. The V_{max} for PG I, II, and III was 5.7, 3.6 and 4.4 mol GaldA equivalent/h, respectively. Cd^{2+}, Cu^{2+} and Fe^{2+} and EDTA inhibited whereas GalA, Gal, Fuc, Rha and Ara stimulated PG-I activity, in particular.The major endogenous substrates for mango PG were identified to be two rhamnogalacturonans varying in their sugar ratio. These result are discussed in the light of protein dissolution in vivi in ripening mango (Prasanna *et al*., 2006)

There were various postharvest treatments such as modified-atmosphere packaging and modified-atmosphere coating, as well as storage at low temperature, retarded softening and resulted in corresponding retardation of both PG and galactosidase activities (Lazan and Ali, 1993).

Proper temperature management during storage is essential to retard ripening and extend shelf life (Kader, 2003). Low temperature treatment has been reported to result in a positive effect on the texture quality of several fruits and vegetables (Castro *et al*., 2005). Such that, at ambient temperatures, shelf life of this climacteric fruit is short, about 7-14 days to fully ripe. Fruit of 'Keitt', 'Tommy Atkins' and 'Muska' from successive harvests show an increasing rate of ripening changes during 21 days' storage period at 12°C, suggesting a decrease in storage potential as the season progressed (Nakasone and Paull, 1998).

'Nam Dok Mai' mangoes which storage at 8, 10, 13 or 20°C, ripening indicated by firmness loss due to softening occurred faster and at comparable rate at 13 and 20°C. However, fruits held at 13°C had more yellowish peel, lower weight loss, repiratio rate and electrolyte leakage, longer ripe life and consequently longer shelf life of about 25 days than fruits held at 20°C which lasted for 15 days. Fruits held at 13 and 20°C did not exhibit normal ripening changes

based on firmness, peel and pulp color and respiration. They showed peel and pulp discoloration and incurred higher weight loss than fruits held at 13 °C. These chill-induced changes in physiology and quality of the fruit resulted to shortening of shelf life to 20 days (Dongkhum and Kanlayanarat, 2003).

Controlled-atmosphere (CA) storage, in conjuction with temperature management, offers the potential to extend markedly the storage life of many important horticultural crops. Such as ripening of 'Nam Dok Mai' mangoes were delayed at 20°C when O_2 was reduced from 19 KPa to 7 KPa (Nakasone and Paull, 1998). 'Nam Dok Mai' mangoes which were stored at 13°C in 70 and 90% O_2 (superatmosphere) had lower fruit softening than 0 and 50% O_2 (Yingsanga and Kanlayanarat, 2004).

CA storage condition (10% CO_2) was the most promising in delaying firmness of mature green 'ChoK Anan' mangoes more than 5% CO_2 or 5 and 10 % O_2 when storage at 13°C (Wimonwat *et al*., 2005). A 3-5% O_2 condition more reduced softening and respiration rate of 'Nam Dok Mai' mangoes than in air (Jansasithorn *et al*., 2005a), similar to 3-5% CO_2 condition delayed softening of 'Nam Dok Mai' mangoes, but at 10-15 % CO_2, the fruit developed surface discoloration, pitting and off-odor (Jansasithorn *et al*., 2005b).

'Nang Khang Wan' mango fruit which were subjected to various heat treatments as follows: 5, 10 and 15 minutes at 46°C and 2, 5 and 8 minutes at 50°C and then storage at 5°C, mango treated at 46°C for 15 minutes decreased PME and PG activities but did not effect on firmness and WSP content (Katawatcharakul, 2000). Similarly, hot water treatment at 55°C for 5 minutes retarded softening and reduced the PG and PME activities of 'Nam Dok Mai' mango fruit (Benetez, 2004)

Carbohydrate metabolism

The starch that has accumulated in the maturing fruit is rapidly lost during ripening such found in 'Kaew' mangoes (Pimpimol and Khamsee, 2001) and this loss is evident in the chloroplast where the starch granules become progressively smaller as ripening proceeds (Selvaraj and Kumar, 1989). Starch granules completely disappear in the ripe fruit (Parikh *et al*., 1990). During ripening, the accumulated starch hydrolyses, with formation of sugars. The hydrolysis of starch granules in the chloroplast continues until ripening (Kumar *et al*., 1994). The hydrolysis of starch and formation of sugars have been associated with amylase activity (Fuchs *et*

al., 1980). The high activities of both sucrose synthetase (EC 2.4.1.13) and invertase (EC 3.2.1.26) in the mesocarp during ripening are indicative of active sucrose metabolism (Kumar *et al*., 1994). Hexoses and hexose phosphates can be formed from pyruvate by gluconeogenesis (Selvaraj and Kumar, 1994). The activity of glucose-6-phosphatase (EC 3.1.3.9) was reported to increase up to the three-quarter-ripe stage, whereas fructose-1,6-diphosphatase activity increased as the fruit ripened from the three-quarter-ripe to full-ripe stage (Kumar and Selvaraj, 1990). The glycolytic enzyme hexokinase activity was detected only at the ripe stage. The phosphofructokinase showed maximum activity at the ripe stage, while pyruvate kinase activity was found to increase until the three-quarter-ripe stage and declined at ripening (Selvaraj and Kumar, 1994). The pattern of change in hexokinase, phosphofructokinase and pyruvate kinase activities suggests the activation of glycolysis in ripening mango fruit (Lizada, 1993).

Peacock and Brown (1984) reported that the total sugar content of the ripe 'Carabao' mango is one of the highest reported, with values exceeding 20%. However, the lower sugar contents reported for other varieties such as "Golek' (Lam *et al*., 1982) might simply reflect differences in the degree of ripeness when optimum eating quality is attained (Lizada, 1993). Sugars constitute 91% of soluble solids from the mesocarp of the ripe 'Ngowe' mango (Brinson *et al*., 1988). Glucose, fructose and sucrose have been reported to be in similar concentrations in ripe mangoes (Selvaraj and Kumar, 1989), with sucrose being the predominate sugar (Kumar *et al*., 1994). Sucrose contributed 57% of total sugar in ripe 'Keitt' mangoes, with fructose and glucose making up 28 and 15%, respectively (Medlicott and Thompson, 1985). Several reports (Lakshminarayana, 1975, Krishnamurthy and Mendoza, 1984, Lizada, 1993) suggest simultaneous increase of glucose, fructose and sucrose during ripening but some report showed a gradual reduction in both glucose and fructose and a continuous increase of sucrose during ripening in Florida mango cultivars, as 'Haden', 'Irwin', 'Kent' and 'Keitt' (Vazquez-Salinas and Lakshminarayana, 1985)

Selvaraj and Kumar (1989) reported that non-reducing sugars, principally sucrose, increase in later stages of ripening. This is consistent with the high activity of the gluconeogenic enzyme fructose-1,6-diphosphatase (EC 3.1.3.11) in the ripe fruit of several mango cultivars (Kumar and Selvaraj, 1990). In most of the varieties examined, fructose was the predominant reducing sugar. Along with an observation that pentoses exhibited a five-fold increase during

ripening, this was considered as suggestive of an increase in the oxidative pentose phosphate pathway, which generates the necessary reducing equivalents (NADPH) for biosynthetic processes. Increases were also reported in glucose-6-phosphate dehydrogenase (EC 1.1.1.49) and 6-phosphogluconate dehydrogenase (EC 1.1.1.44) (Lizada, 1993).

Changes in chemical characteristic during ripening of 'Keaw' and 'Chok Anan' mango fruits showed that sucrose, glucose and fructose were the main soluble solid idendified and their concentration gradually increased during the time (Homdork *et al*., 2006). Similarly, the TSS content of 'Kaew' mango fruit increased during storage which was varying due to maturity, as shown in Table 1 (Pimpimol and Khamsee, 2001).

Table 1 Total soluble solids (TSS, %), (titratable acid TA, %) contents and TSS/TA ratio of 'Kaew' mango fruit at different maturity stored at 15ºC after storage for 4, 8, 12 and 16 days

Degree of Maturity	Storage life											
	4 days			8 days			12 days			16 days		
(brine solution floated)	TSS	TA	TSS /TA	TSS	TA	TSS /TA	TSS	TA	TSS /TA	TSS	TA	TSS /TA
Specific gravity 1.04	7.60	1.60	4.75	11.00	1.10	10.00	15.80	1.10	14.36	17.40	1.10	38.67
Specific gravity 1.06	9.00	1.40	6.43	12.30	1.00	12.30	16.70	0.80	20.88	18.60	0.80	37.20
Specific gravity 1.08	10.60	1.40	7.57	13.80	0.40	34.50	18.60	0.30	62.00	19.40	0.30	77.60

***** Source: Applied by Pimpimol and Khamsee (2001)

Organic acids

Organic acids decrease as the fruit ripens (Table 2). The predominant acid is citric acid, followed by varying amounts of glycolic, malic, tartaric and oxalic acids (Lizada, 1993). The predominant organic acids in 'Keitt' mangoes were citric acid and malic acid but tartaric, oxalic, ascorbic and œ–ketoglutaric acids were also identified (Medlicott and Thompson, 1985). In 'Badami' mangoes, citric acid was identified as the major organic acid, though malic acid and succinic acid were also present (Lizada, 1993). In 'Fazli' mangoes, five organic acids (oxalic, citric, malic, pyruvic and succinic acids) were detected, tartaric acid was also present in 'Zardalu', where all these acids were in higher concentration (Kumar *et al*., 1993). However, Lizada (1993) reported that in general, levels of citrate and succinate gradually decrease during

ripening, while malate shows different changes with different cultivars. In 'Alphonso' mangoes, the levels of malic dehydrogenase and succinic dehydrogenase increased with the onset of ripening, whereas the level of citrate synthase increased several fold on maturation but decreased markedly at ripening. The activity of malic enzymes increased during ripening, reaching its maximum a little ahead of the climacteric peak and then declining (Dubery *et al*., 1984).

Table 2 Citric acid and malic acid contents (μg/mg pulp) in mango fruit cultivars during maturation and ripening.

State of fruit development	'Fazli'		'Zardalu'	
	Citric acid	**Malic acid**	**Citric acid**	**Malic acid**
Preharvest				
Immature	2.04±0.25	3.65±0.90	7.68±1.06	-
One-third mature	2.55±0.35	3.40±0.45	5.40±0.80	-
Half-mature	3.39±0.34	2.80±0.30	8.78±0.77	8.70±1.42
Two-thirds mature	4.65±0.42	3.50±0.78	13.68±1.84	7.17±0.40
Three-quarters	2.99±0.49	2.47±0.63	-	-
mature	0.82±0.25	0.42±0.08	13.89±1.42	6.55±1.07
Fully mature				
Postharvest				
One-thirds ripe	-	2.97±0.40	3.90±0.33	3.72±0.12
Two-thirds ripe	3.75±0.54	3.57±1.00	2.05±0.56	3.41±0.75
Fully ripe	-	3.89±0.83	2.42±0.38	2.19±0.34
Overripe	3.73±0.31	-	0.85±0.37	0.91±0.11

* Source: Applied by Kumar *et al*. (1993)

The amount of organic acids in fruit and vegetable, sometime could express as total titratable acid. In general, titratable acid declines as the mango ripens, such as dropping from 48 meq/100 g in the preclimacteric to 5.6 meq/100 g in the postclimacteric 'Badami' mango (Lizada,

1993). Similar patterns have been reported for other varieties (Mitra and Baldwin, 1997), such as 'Kaew' mangoes (Pimpimol and Khamsee, 2001).

Changes in chemical characteristic during ripening of 'Keaw' and 'Chok Anan' mango fruit showed that the titratable acid of both varieties decreased. However, fluctuation in ascorbic acid level during the ripening was observed in 'Keaw', on contrary, the ascorbic acid content in 'Ckok Anan' increased to maximum then declined (Homdork *et al*., 2006).

Nutritional values

Ripe mango is considered to be an excellent source of vitamin C, B_1 and B_2 and pro-vitamin A (Table 3-4). It is one of the most luscious of all tropical fruits with flavors varying from exceptionally sweet to turpentine (Lizada, 1993). Known for its unique flavor and attractive appearance, this fruit is a valued source of export income for the producing countries (Medlicott *et al.*, 1986, Mitra and Baldwin, 1997).

People consume mango simply because of its pleasant taste and flavor without much thought about the content of minerals, vitamins, lipids and amino acid. However, the mango is a good to excellent source of provitamin A (Table 5) and is considered a fair source of vitamin C, although this varies greatly among cultivars, with a range between a low of 5 mg and as high as 142 mg/100 g of fresh material (Nakasone and Paull, 1998).

Table 3 Proximate analysis of mango fruit (in 100 g edible portion as ripen).

Nutrient		Variety	
		Haden	**Pirie**
Proximate:	- Water (g)	84.12	79.97
	- Energy (KJ)	234	301
	- Protein (g)	0.9	0.55
	- Lipid (fat) (g)	0.02	0.20
	- Carbohydrate (g)	15.05	18.91
	- Fiber (g)	0.54	0.70
	-Ash (g)	0.42	0.37
Minerals:	- Calcium (mg)	8	6
	- Iron (mg)	0.16	0.16
	- Magnesium (mg)	12	12
	- Phosphorus (mg)	10	15
	- Potassium (mg)	159	126
	- Sodium (mg)	0	3
Vitamins:	- Ascorbic acid (mg)	15.10	15.00
	- Thiamine (mg)	0.041	0.081
	- Riboflavin (mg)	0.057	0.061
	- Niacin (mg)	0.300	0.460
	- Pantothenic acid (mg)	-	-
	- Vitamin A (IU)	3813	4735

* Source: Nakasone and Paull (1998)

Table 4 Physical and chemical characteristics and nutritive value of nine Thai mango fruits (Chok Anan, Nam Dok Mai #4, Rad, Mon Duen Gao, Keaw Sawoei, Okrong Keaw, Okrong Thong, Kaew and Maha Chanok) evaluated at fully ripe stage

Attribute	Average	Minimum	Maximum
Mass (g)	262.3	184.2	347.8
Flesh (%)	64.2	52.8	70.5
Seed (%)	19.5	12.8	29.0
Peel (%)	16.3	15.0	17.5
Total phenol index** (mg/100g)	85.3	35.0	117.1
ß-carotene (mg/kg fresh weight)	6.72	0.66	15.72
Chroma	64.5	56.8	70.3
Hue angle	83.3	74.9	92.9
Firmness (N/cm^2)	2.42	2.00	3.12
Fiber (% dry weight)	1.83	1.22	2.34
Total pectin (mg gallic acid/kg)	4497	2379	6483
Water-soluble pectin (mg gallic acid/kg)	2899	1862	4314
Oxalate-soluble pectin (mg gallic acid/kg)	577	159	949
Alkaline-soluble pectin (mg gallic acid/kg)	1020	358	1656
Glucose (g/100g)	1.02	0.31	1.60
Fructose (g/100g)	4.41	2.74	5.39
Sucrose (g/100g)	10.05	6.64	13.65
Total soluble solids (TSS) (%)	16.6	15.0	18.7
Titratable acid (TA) (g citric acid/100g)	0.25	0.16	0.36
TSS/TA (w/w)	74.2	47.6	114.1
pH	4.46	3.98	5.08
Citric acid (g/100g)	0.29	0.11	0.44
Malic acid (g/100g)	0.05	0.01	0.17

* Source: Vasquez-Caicedo *et al*. (2002) ** Expressed as catechol equivalents

Table 5 Carotenoids in the pulp of some Indian mango cultivars.

Cultivar	Total carotenoid content (mg 100 g^{-1} fresh weight)
Amin Buland Bagh	0.74
Gaurjeet	1.54
Benazir Sandila	0.73
Gulab Khas	1.19
Benazir	1.22
Nisar Pasaand	2.08
Mallika	1.19
Amin Khurd	0.97
Langra Gorakhpur	0.69
Anupan	0.46
Mazuk Badan	0.38
Asodia Deoband	0.90
Bareillywala	0.88
Sohrab Sah	0.92
Bangalora	0.45
Saheb Pasand	1.20

* Source: Mitra and Baldwin (1997)

Respiration and ethylene production

Mango is a climacteric fruit and such undergoes increased (autocatalytic) ethylene production, along with a breakdown in carotenoids in the peel (yellowing), enhanced respiration and softening. Together with the ethylene elevation and respiratory climacteric in mangoes, the catalase and peroxidase activities were found to increase considerably, due to the disappearance of the heat-labile and non-dialysable inhibitor of these enzymes (Mitra and Baldwin, 1997).

The patterns of respiration and ripening behavior vary among the varieties, the climatic conditions and the locations where the fruit is grown. In 'Alphonso' mangoes, the respiratory peak was observed at five days after harvest and fruits ripen within seven or eight days while in 'Kent' and 'Haden' varieties, the peak was observed at ninth and eleventh day, respectively, and in 'Pairi' mangoes, on the ninth day after harvest (Mitra and Baldwin, 1997). The respiration decreases as the fruit matures, and the respiration rise then commences with ripening. Ethylene production also decreases as the fruit matures, is then undetectable for a time and reappears upon ripening (Akamine and Goo, 1973). Although Burg and Burg (1962) stated that ethylene rises when or before carbon dioxide production rises in ripening mangoes. Biale and Young (1981) included mangoes among the fruits in which ethylene rises after carbon dioxide production rises.

Ethylene production by mango fruit tissue, as in many other climacteric fruit, is maximal at the onset of the climacteric phase of fruit ripening. The small amount of ethylene present in the fruit at harvest is sufficient to initiate ripening (Mitra and Baldwin, 1997). The ethylene production starts before full ripeness is reached. In 'Carabao' mangoes, the peak of ethylene production was found at 110 days after flower initiation, which declined as the fruits approached full maturity (Cua and Lizada, 1990).

As with the ethylene production associated with maturation, postharvest ethylene production is accompanied by increase in both ACC synthase (EC 4.4.4.14) and the ethylene-forming enzyme (EFE) (Lizada, 1993).

The respiration rate of 'Nam Dok Mai' mango in 3-5% O_2 condition was lower than in air Jansasithorn *et al*. (2005b). The most promising CA storage in reducing respiration rate and ethylene production of mature green 'ChoK Anan' mango was 10% CO_2 or 5 and 10% O_2 when storage at 13°C (Wimonwat *et al*., 2005).

1- Methylcyclopropene (1-MCP)

Blankenship and Dole (2003) reported that 1-methylcyclopropene (1-MCP) has been added to the list of new tool for extending shelf life and quality of plant products. Not only does commercial use of 1-MCP promise to advance commercial agriculture. Watkins (2002) has summarized the effects of 1-MCP on fruit and how it relates to ethylene physiology. At standard temperature and pressure, 1-MCP is a gas with a molecular weight of 54 and a formula of C_4H_6.

1-MCP is thought to occupy ethylene receptors such that ethylene cannot bind and elicit action. 1-MCP is released from EthylBloc® powder in approximately 20-30 minutes. Completed release may take longer at low temperatures (Blankenship and Dole, 2003). The affinity of 1-MCP for the receptor is approximately 10 times greater than that of ethylene. Compared with ethylene, 1-MCP is active at much lower concentrations. 1-MCP also influences ethylene biosynthesis in some species through feedback inhibition (Sisler and Serek, 1997). The safety, toxicity and environmental profiles of 1-MCP in regard to humans, animals and the environment are extremely favorable. The compound is used at low rates, has a non-toxic mode of action and is chemically similar to naturally occurring substances (Blankenship and Dole, 2003).

There were many researchers who had studied the effect of 1-MCP on the fruit. The conditions for use of 1-MCP vary with respect to active concentration, temperature, exposure time and method of application (Blankenship and Dole, 2003). Harris *et al*. (2000) reported that 5 and 50 nl/l 1-MCP had no effect on unripe bananas and 500 nl/l delayed ripening. In apples, 1 μl/l was effective in delaying ripening (Rupasinghe *et al*., 2000). Watkins *et al*. (2000) found that the response of 'McIntosh' and 'Law Rome' apples to 1-MCP was more dependent on concentration than the response of 'Delicious' or 'Empire'. A 100 nl/l 1-MCP inhibited ethylene by 50% in 'Anna' apples, but did not inhibit volatile production, while 1 μl/l produced 70% inhibition and 95% ethylene inhibition (Lurie *et al*., 2002). A concentration of 0.09 μl/l for 24 hours was not enough to elicit a response in avocado softening while 0.45 μl/l for 24 hours affected softening and associated enzyme activity (Jeong *et al*., 2002). Feng *et al*. (2000) found that 30 nl/l or higher was sufficient to delay ripening in avocado. Pesis *et al*. (2002) used 300 nl/l 1-MCP could reduced avocado mesocarp discoloration. In apples, a given concentration of 1-MCP had less effect on firmness as storage temperature was lowered (Mir *et al*., 2001) and it was hypothesized that lower temperature might lower the affinity of the binding site for 1-MCP. A relationship was noted between treatment time and temperature, apples at 3°C required 9 hours treatment, whereas only 6 hours was needed at higher temperatures to delay ripening (DeEll *et al*., 2001). However, Blankenship and Dole (2003) reported that in most studies, treatment duration ranged from 12 to 24 hours, which was sufficient to achieve a full response. An exposure of 6 hours at 0.45 μl/l was not enough to induce respiratory or ethylene production changes in avocado (Jeong *et al*., 2002). A time/temperature relationship was noted with banana

(Jiang *et al*., 1999) such that higher concentrations of 1-MCP were required for shorter treatment times. Cultivar and plant development stage should also be considered. 'Empire' apple required less treatment time than 'Cortland' to achieve the same effect at the same 1-MCP concentration (DeEll *et al*., 2001). 1-MCP effects in apricots (Fan *et al*., 2000) and 'Redchielf' strain of 'Delicious' apples (Mir *et al*., 2001) decreased with advanced fruit development.

Andkard (2004) reported that the 1000 nl/l 1-MCP and 12 hours exposure had the best effect on ripening control of 'Maha Chanok' mango fruit. However, 'Nam Dok Mai' mango which was fumigated with 0-400 nl/l 1-MCP for 12 hours did not show any response in retardation of ripening process of stored mango that all treatments involved ripening after 10 days of storage (Boonchoo *et al*., 2004).