CHAPTER V RIPENING AND POST-HARVEST TREATMENT

1. THE DEVELOPMENT AND APPLICATION OF POST-HARVEST TREATMENTS TO MANIPULATE RIPENING IN MANGOES

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INTRODUCTION

Mango (Mangifera indica L.) is an important fruit crop valued for its characteristic flavour and aroma. It is a fruit of increasing commercial importance for developing countries where production for export has increased several fold in recent years. Imports of mangoes into Europe have doubled between 1981 and 1985. However, trade, and in particular international trade, is currently restricted because of the limited capacity for air transport and the long distances to the consumer markets. In addition there is a lack of established technology regarding harvesting, handling, transport, storage and ripening of mangoes, which often results in high levels of wastage, unsynchronised ripening and poor quality fruits. The expansion in trade of mangoes is expected to continue and will be greatly facilitated if technical problems associated with the post-harvest handling chain can be identified and overcome. The introduction of sea transport appears essential for increasing trade volumes and reducing costs. However, due to perishability, there are inherent problems involved with extending the storage life and marketing period of mangoes while aiming to provide the consumer with high quality fruit.

The development and application of post-harvest technologies demands as a prerequisite a knowledge of the physiology of the ripening processes in mangoes. The major sensory changes occurring during mango ripening are covered by Chaplin (Chapter V.2). This review will concentrate on the biochemical events occurring during fruit ripening. Methods for controlling ripening are identified and discussed in view of the suitability for application in mango post-harvest handling.

BIOCHEMISTRY OF RIPENING

Fruit growth and development is followed by ripening which transforms the fruit from a mature plant organ into an attractive edible fruit. This occurs due to alterations in the relative activities of metabolic pathways in fruit tissues, resulting in major biochemical changes. These include changes in the rates of respiration and ethylene production, peel pigmentation, texture, sugar and acid content and volatile production.

Respiration and ethylene production

Fruits have been divided into climacteric and non-climacteric classes on the basis of respiration patterns during ripening (16,17). Mangoes belong to the first class, a characteristic rise in respiration having been found in Alphonso (62) and Pairi mangoes (57). The climacteric pattern for mango is described by Chaplin (Chapter V.2).

The climacteric has been defined as "a period in the ontogeny of certain fruits, during which a series of biochemical changes are initiated by the auto-catalytic production of ethylene, marking the change from growth to senescence, involving an increase in respiration and leading to ripening".(94). Respiratory activity is indicative of the storage capacity and, as it is related to external factors, its study is of significance with respect to handling and storage.

In addition to showing a large increase in respiration, climacteric fruit also show increased ethylene production during ripening. Ethylene has been identified and

classified as a natural plant hormone exerting a major influence on many aspects of plant growth, development and senescence, including ripening initiation (1).

Mangoes have been shown to produce ethylene in a typical pattern with the rate of production reaching a peak at the same time or slightly following the respiratory maximum (19). Kent and Haden mangoes have been shown to have preclimacteric internal ethylene levels of 0.01 $\mu l\ l^{-1}$ rising to 0.08 $\mu l\ l^{-1}$ at the onset of the climacteric rise, and 3.0 $\mu l\ l^{-1}$ at the peak (19).

Peel Pigmentation

For the majority of fruits, the first sign of ripening is the loss of green colour. The appearance of different fruits, including mangoes, depends on the relative amounts of individual pigments present in the peel. Yellow and green colouration is imparted by the lipid soluble plastid pigments, chlorophylls and carotenoids; whereas red colouration is due to the water soluble anthocyanins present in the vacuoles. With few exceptions, for example, the avocado, Granny Smith apple and some mango varieties eg. Amelie, climacteric fruits show a rapid loss of green colour on ripening. Analysis of peel colouration in mangoes has generally been limited to colour score ratings based on the loss of the green ground colour, or the development of yellow colouration (83, 117). The chlorophyll content of the peel of Dashehari mango decreased to negligible amounts during ripening (50). The total carotenoid content of the peel has been examined in Mamey mangoes, although the nature of these carotenoids has not been established (98). Analysis of the anthocyanins of mango peel identified paenoidin-3-galactoside as the single anthocyanin present (91). Anthocyanin content has been found to remain constant or decrease slightly during ripening in association with decreasing chlorophyll and increasing carotenoid contents (74). Ultrastructural analysis of peel chloroplast to chromoplast transition showed almost complete breakdown of the chloroplast lamellar system and the development of large osmiophillic globules associated with colour changes (74).

Pulp Pigmentation

Mangoes are well known for their intense yellow to orange pulp colour imparted by a high carotenoid content. Values up to 9 mg 100 g^{-1} have been reported (48), and they are therefore an important source of Vitamin A. Several studies have been conducted on the metabolism of carotenoids during ripening (26, 48, 49). Phytofluene was found to be the major carotenoid in partially ripe mango (39.3%), with β-carotene the major one in unripe (37.5%) and fully ripe fruit (50.6%) (48). The major xanthophyll present in unripe mango was mutatoxanthin (9.44%), whereas auroxanthin constituted the major hydroxylated carotenoid of the partially ripe (5.07%) and fully ripe (10.4%) mangoes (48). Lutein was found to be absent (49) but was shown to be present in unripe fruits, decreasing as ripening proceeded (48).

Texture

Pulp firmness is one of the most important criteria, both for transportation and storage evaluation, as it is directly related to shelf-life, susceptibility to bruising and consumer acceptability. The mechanism, enzymology and control of fruit softening are covered in general by John (Chapter V.3). Textural changes in fruit

probably results from changes in the structure and composition of the cell walls. The degree of degradation at the stage of optimum ripeness varies between different fruits in accordance with the texture considered acceptable. For example, an apple should preferably be firm and crisp, a texture resulting from limited breakdown in the cell wall structure (54). In pears, degradation proceeds further and the texture is no longer crisp (71). The degree of textural change that is acceptable in mango is considerably greater than most other fruits and hence substantial breakdown in cell wall structure can be envisaged.

Softening has been interpreted as a change in the pectin materials cementing the cell walls and is characterized by the solubilisation of pectic substances from the middle lamella. During ripening in apples there is an increase in the water soluble pectin which can be correlated with cell separation and softening (54). Loss of firmness has been associated with a decrease in insoluble pectic substances and in increase in water soluble pectic materials in avocado (63) and tomato (67). Changes of a similar nature have been found in mangoes. Water soluble pectin in Himsager and Langra mangoes increased from 1.9 to 9.6% and from 1.8 to 11.86% respectively (12). Accordingly, the water insoluble pectin contents in these varieties were found to decrease from 28.8 to 18.6% and from 31.6 to 19.2% respectively. A gradual decrease in protopectin and an increase in water soluble pectin has been shown during ripening of Mamey (96), Alphonso (79), Carabao (81), Keitt (95) and Dashehari mangoes (50). Other constituents of the cell wall including cellulose and hemicellulose showed no appreciable change during ripening and appeared to have an insignificant role in textural changes in mango (50).

The appearance of water soluble pectin and the loss of firmness associated with ripening are believed to be related to the activity of the pectin enzymes. The enzyme frequently implied as being involved in the solubilisation of pectin is polygalacturonase (PG). This enzyme is a cell-wall-bound glycosidase that acts on de-esterified regions of pectin by the hydrolytic cleavage of the -1, 4 glycosidic bonds between adjacent polygalacturonic acid groups. PG has almost exclusively been implicated in fruit softening, mainly because of its absence in unripe tomato fruits followed by a dramatic increase in activity during ripening (41, 78, 87, 121). In firm mango fruit, PG activity was barely detectable, but as the fruit ripened a good correlation was found between the increase in PG activity and softening (95).

If the increase in water soluble pectins and softening during ripening is due to the action of PG, then pectin methylesterase (PE) may also play a role in textural changes. The galacturonic acids of the middle lamella are highly methylated, and since PGs are specific for de-esterified regions of pectory the action of PE may be a prerequisite for that of PG. The role of PE may thus be to modify the pectin structure prior to PG action.

PE activity in relation to the ripening of various fruits has been shown to increase in banana (47) and tomato (45), remain unchanged in banana (18), or decrease in avocado (8). In Keitt mangoes, PE activity declined during the first stage of ripening but then levelled off (95). Analysis of PE activity during ripening of four Pakistani mango varieties showed decreases occurred in Langra, decreases and then increases in Dusehri and Awar Ratual, and irregular changes in Chausa (7).

Sugars

Although appearance may influence the initial decision to purchase, the fruit needs to be organoleptically acceptable to ensure repeated purchase. Taste is mainly a balance between sugars, acids and aroma, with sweet fruits generally being more acceptable.

An increase in sugar content is one of the major changes accompanying ripening, and occurs as a result of starch hydrolysis. During development of the mango fruit, sugars are transported into the growing fruit where they are converted into starch (46). The level of starch increases as the fruit matures and has been found to be the main carbohydrate at the mature green stage (15,109). During subsequent ripening the hydrolysis of starch to sugar occurs; in Alphonso mango almost complete hydrolysis from 14% fresh weight of pulp in unripe fruit to 0.3% in fully ripe fruit has been shown (70).

The regulation of the biosynthesis and degradation of starch has been recently reviewed (90). The enzyme responsible for starch hydrolysis is probably starch phosphorylase; the activity of this enzyme has been shown to increase during ripening of a number of fruits (22). In mango, increased amylase activity has been shown to be associated with rapid starch hydrolysis (35,70). Thus in mangoes, both starch phosphorylase and amylases contribute to the sugar development in the fruit, although their relative importance is uncertain.

Numerous reports are available in the literature expressing the sugar content in terms of soluble solids, total sugars, reducing sugars and non-reducing sugars. Total sugars in ripe fruit have been found to vary considerably between 10 and 20% of fresh weight depending on the variety, maturity and storage conditions (3, 37, 51, 76). During ripening soluble solids and total sugars content increase; however, there are conflicting data regarding the relative contribution of reducing (glucose and fructose) and non-reducing sugars (sucrose) to the total sugar content. Reducing sugars have been found to increase (100) or remain constant (55) during ripening. At the commencement of ripening of mango, the majority of the sugars were reducing in nature, but the ripe fruit contained more non-reducing sugars (in the form of sucrose, 17%) than reducing sugars (3%) (59). Non-reducing sugars predominated during ripening of Edward mangoes (24) and sucrose predominated in three of four Indian varieties studied (55). In Badami mangoes pre-climacteric sucrose levels were found to be lower than those of glucose and fructose, while in post-climacteric fruit, levels of all three were similar (102). High performance liquid chromatography analysis of individual sugars showed that sucrose predominated throughout ripening of Keitt mangoes, with fructose being the major reducing sugar (76). All three sugars increased during ripening: sucrose by 3.5-fold, and fructose and glucose by 2.5 and 2.7-fold respectively.

Organic Acids

Organic acids make an important contribution to the quality of fruits as taste is related to the balance between the sugar and acid contents. The organic acids present in all fruits occur in solution, partly free and partly as their salts (22). Most fruits contain organic acids at levels in excess of that required for the operation of the Krebs cycle and other metabolic pathways. The excess is generally stored in the vacuole away from other cellular components. The large reserves can be mobilized for use in the mitochondria as oxidizable substrates in

the tricarboxylic acid cycle. High respiratory quotient values support the proposals that organic acids act as preferred substrates in many fruits (118).

During ripening mangoes show a substantial loss of acidity as indicated by pH or titratable acidity (3, 29, 37, 56, 76). The predominant organic acids have been shown to be citric acid with lesser amounts of succinic and malic acid (102), and tartaric with lesser amounts of citric acid (80). The initial decrease in acidity in Alphonso mango was due to the loss of malic and other acids while citric acid increased from unripe to partly ripe fruits and decreased thereafter (80). In Badami mangoes the reduction in citric acid was the major cause of acid loss, while malic acid increased slightly, being present in lower concentrations than succinic acid in pre-climacteric and climacteric fruits (102). In Keitt mangoes the initial decrease in acidity was due to a high rate of loss of citric acid with only a small loss of malic acid (76). Other organic acids identified include tartaric, oxalic, glycolic, succinic, pyruvic, oxaloacetic and α-keloglutaric acids (34,56,76). Analysis of the concentration of the keto acids during the climacteric rise showed that the levels of α-ketoglutaric and pyruvic acids followed the respiration rate (56).

Volatiles

Several reports have been published on the volatile components responsible for the characteristic aroma of mangoes, and identified major differences in aroma components between the varieties (31, 52, 65). Analysis of the volatile components of three varieties from Sri Lanka identified terpenes as the main volatiles, with monoterpene hydrocarbons contributing 50-63% w/w of the total volatiles and sesquiterpene hydrocarbons 14-19% (66). The lipid content of the pulp has also been correlated with aroma (40).

HARVEST MATURITY IN MANGOES

A major problem found with mangoes in both the fresh fruit and processing industries is that commercial consignments usually comprise fruits of a wide range of physiological ages. Under the current conditions of ripening, this produces a lack of uniformity of ripening among fruits. This, therefore, results in fruits offered for sale at different stages of ripeness and quality at any particular time.

Maturity indices are important for deciding when to harvest so as to provide some flexibility and to ensure the attainment of acceptable eating quality. These two aims are not always compatible. The frequent need to transport fruit long distances has necessitated harvesting them at less than ideal maturity which has resulted in less than optimum quality. Maturity indices are discussed further in Chapter IV by Ena Harvey. In the light of this chapter though it is important to realise that the potential quality of ripe fruit is determined by many factors, of which the stage at which the fruit was harvested is most important.

MANIPULATION OF THE ENVIRONMENT TO CONTROL RIPENING

Mangoes are usually harvested and transported in the firm, green pre-climacteric state, and then ripened under ambient conditions. The quality of the ripe fruit is dependent on the environment during transport and the ripening procedures

employed. Successful storage of mangoes is based on delaying the onset of the climacteric for as long as required without causing loss of quality or damage to the fruit. The techniques involved are generally based on the storage atmospheres and a lowering of the storage temperature. Successful ripening is dependent on satisfactory storage followed by techniques which will induce synchronous ripening of the fruits without reducing fruit quality. Methods to control or initiate ripening that are in use or suggested for climacteric fruits include control of temperature and humidity, application of ethylene or acetylene gas, controlled and modified atmospheres, waxes, chemical treatments and irradiation.

Temperature

The enzymatic reactions controlling ripening may have slightly different temperature coefficients. Thus under its natural ambient conditions the fruit will accept slight fluctuations in temperature with the differential slowing-down or speeding up of reactions and will ripen normally without showing obvious signs of physiological stress. If subjected to extremes of either high or low temperatures an imbalance in reaction rates may occur which could result in reduced production of essential substances, eg. sugars, and an over-production of potentially toxic substances, eg. acetyaldehyde. A range of temperatures exists over which normal ripening will occur and exposure to temperatures outside this for a sufficient length of time will cause injury.

Mangoes and many other fruits of tropical and subtropical origin may develop chilling injury at temperatures below a certain critical value, approximately 12°C. (See Chaplin Chapter V.2). High temperatures are also detrimental to the ripening process. For example, bananas fail to ripen normally above 30°C, they remain green and the pulp becomes soft. In avocadoes at 30°C, as at 5°C, the fruit fails to ripen and the internal tissue darkens (16).

Detailed studies have not been carried out with mangoes and no reliable recommendations are available on the temperatures required for optimum ripening. At 19° - 21°C mangoes of an unspecified variety developed better quality characteristics when compared to those ripened at high room temperatures (28° - 30°C) (105). Increases in soluble solids and acidity loss were greater at 19° - 21°C and fruits tasted better due to a balanced sugar:acid blend.

For Florida mangoes, 21°-24°C has been recommended as the optimum ripening temperature range, with 15.5°-18.5°C also being satisfactory (44). At 15.5µ-18.5°C fruit developed an attractive appearance but were generally tart and required an additional 1-3 days at 21° - 24°C to attain a good flavour. Fruit ripened at 26.2° - 32.2°C frequently possessed strong flavours and a mottled skin, although this did not occur in Kent and Keitt mangoes at 26.7°C. In addition softening was delayed at 32.2°C compared to 26.7° or 29.4°C, and occurred usually more slowly at 32.2° than at 21.1° and 23.9°C.

Temperatures below 25°C adversely affected the development of typical aroma, flavour and carotenoid formation in Alphonso mangoes (114). On ripening, carotenoid formation was considerably reduced in fruits stored continuously at low temperature; the respective reductions in values for 7°, 15° and 20°C stored fruits were 30, 34 and 51% of room-temperature-stored fruits (29°C).

Carotenoid content of low-temperature-stored fruit could be improved by removing fruits to temperatures above 25°C while they were still in the pre-climacteric state. Once ripening had been initiated at low temperature, fruits did not develop comparable carotenoid levels when removed to higher temperatures (29°C). Reduced carotenoid development at low temperature has also been shown for Julie (116), Mamey (96) and Kent (120) mangoes. Alphonso mangoes held continuously at 7° and 15°C were sweet to taste when ripe, buth were found to be bland and atypical in terms of aroma and taste (114). Fruit ripended at 7°, 15° and 20°C showed higher pulp acidity and lower soluble solids content than those ripened at room temperature (29°C). Higher acidity and lower sugar levels were shown in low-temperature-ripened Totapuri (51) and Kent (120) mangoes. Storage of Pairi mangoes at 10°C had no effect on soluble solids development as compared to fruit stored at 28°C, although the low-temperature-ripened fruit were found to be sour as a result of high acid content (59).

Analysis of compositional changes during ripening in Haden, Irwin, Kent and Keitt mangoes over the range 16°-28°C identified 20°-22°C as optimal for storage and ripening to obtain sufficiently acceptable quality (119). Acidity loss was slower at 16°C, while total and -carotenoids were higher at 22°-28°C than at 16°-20°C. No differences were obtained with respect to carbohydrate and soluble solids metabolism. A similar study with Tommy Atkins mangoes, over the wider temperatures range of 12°-37°C, showed that fruits held at 12°C did not develop full eating quality (75). At 12°C, sugar levels were comparable with those at other temperatures, but acid levels were higher, the fruits retained some green colouration, had a lower pulp carotenoid content and showed incomplete softening. At 17°C, fruits underwent softening, degreening and sugar development, but showed reduced acidity loss and pulp carotenoid development. Fruits stored at 22°, 27° and 32°C all developed good quality characteristics of high chlorophyll breakdown, high pulp carotenoids, a good texture and a balanced sugar: acid ratio. Similar characteristics were noted at 37°C, although the peel generally appeared mottled and the pulp had slightly lower sugar: acid ratios.

The majority of reports on the temperature effects on mango ripening have been concerned with low temperature storage to prolong storage life and to identify critical chilling injury temperatures. There appears to be considerable variation in the minimum temperatures which can be used for mango storage. Storage at 5°C or slightly higher was the most suitable temperature for Taimour and Pairi mangoes (2). Both varieties were affected by storage at 0°C, and the severity of chilling was proportional to the duration of cold storage. Neelum and Romani mangoes stored at 4°C, showed no marked deterioration in quality when stored for 62 days (107). Optimal conditions for Totapuri mangoes were 5°-7°C where fruits could be stored for seven weeks and subsequently ripen upon transfer to 19°-21°C (104). Storage of Neelum mangoes at 6° or 9°C resulted in chilling injury within 15 days (98), with a similar response being shown by Alphonso mangoes at 7°C (84). Development of flesh colour was reduced at 10°C and below, although no evidence of chilling injury was found when Julie was stored at 5°C or above (116).

Storage of Francisque mangoes for three weeks at 4°C induced chilling injury and accelerated softening after fruit were transferred to 20°C (53). Fruit stored for three weeks at 12°C showed incomplete ripening which was, however, completed after one week at 20°C. Removal of Alphonso mango after 21 days at 11.1°-12.2°C to room temperature (27°-32°C) did not induce normal ripening (61). Chilling injury symptoms have been observed in fruits stored at 11°-12°C,

with the severity increasing with successive drops in temperature (112). Chilling injury symptoms were displayed in Kent mango stored at 8°, 10° and 13°C (120). Storage of Alphonso mangoes at 10°C for 30 days resulted in chilling injury (115), while the optimal storage temperature for storage of Totapuri mangoes was greater than 13°C (83). Storage suitability of Tommy Atkins mangoes was related to harvest maturity and time of harvest in the season (73). Mature (stage B) and half-mature (stage A) fruit harvested in early season remained unripe during 21 days storage at 12°C but subsequently ripened to good quality at 25°C. However in mid and late season harvests, mature fruit showed ripening changes during storage at 12°C, including softening and soluble solids development, while half-mature fruits remained unripe. No evidence of chilling injury was apparent under these conditions.

Alternative methods of temperature manipulation have involved stepwise reductions in temperature or intermittent warming to overcome chilling injury during storage. This subject is dealt with extensively by Chaplin (Chapter V. 2).

Ethylene

Ethylene is a major determinant of the onset and rate of ripening of climacteric fruits. Removal of ethylene from the environment surrounding fruits retards ripening whereas an exogenous supply of ethylene frequently accelerates ripening. In climacteric fruits treatment with ethylene brings about a shift in the time of the onset of the climacteric peak. It has been suggested that ethylene does not alter the shape of the respiratory curve nor cause any change in the major chemical constituents (16). Ethylene is effective only if applied during the pre-climacteric stage prior to the increase in ethylene production by the fruit. Application of ethylene at the post-climacteric stages does not change the respiratory rate. In non-climacteric fruits stimulation of the rate of respiration has been observed throughout the post-harvest life (16). In non-climacteric fruits the process is reversible, whereas in climacteric fruits, once initiated, no return to a pre-climacteric stage will occur upon removal of the gas.

To induce the climacteric and subsequent ripening, it is necessary to treat the fruit with an optimum or higher concentration of ethylene for a given minimum period of time. Ten-day old cantaloupe melons required 24 to 48 hours of 100 $\mu l.l^{-1}$ ethylene to induce a complete climacteric, but in 30 day fruit, the period was 12-24 hours (72). This apparent decrease in sensitivity to applied ethylene as the fruit approaches the onset of the natural climacteric has also shown for green bananas (20), and honeydew melons (88). If sufficient exogenous ethylene is made available to immature tissue, the system responsible for the natural tolerance to this gas should be overcome, and fruits of all physiological ages should commence to ripen at about the same rate. This phenomenon has been observed in several climacteric fruits (89).

There are several ways of applying gaseous ethylene commercially. One is the so-called "shot" method in which ethylene is introduced from a gas cylinder into an air-tight room. The room is then ventilated with fresh air before the carbon dioxide concentration exceeds 1% and ethylene is reintroduced. These operations may be repeated 4-10 times at intervals of 6-8 hours over a period of 24 hours or longer. Fruits are thus in intermittent contact with ethylene. Another more recent method is the "trickle" method by which ethylene is added continuously to the circulating air. Constant air change prevents accumulation

of carbon dioxide in the room and the ethylene concentration is monitored with a simple colorimetric analyzer. In some producer countries where ethylene gas is not available, the ethylene releasing compound 2-chloroethylphosphonic acid ($ClCH_2CH_2PO_3H_2$), commercially known as ethrel, can be used as a substitute. The process of ethylene evolution from ethrel has been described (122).

A study on the effect of ethylene gas on the ripening of several Florida varieties of mango showed a reduction in the ripening time which appeared dependent on variety (10). Fruit were treated with 5 or 10 µl l^{-1} ethylene at 30°C and 95% relative humidity for 24 or 48 hours, and then transferred to 21°C until soft. Temperature modified the effectiveness of ethylene on ripening; generally, the lower the temperature during treatment the less immediate was the response. Tommy Atkins treated with 10 µl l^{-1} continuously at 21°C required 7 days to soften, compared to 4 days with a treatment of 10 µl l^{-1} for 48 hours at 30°C, then held at 21°C. Ethylene was found to enhance degreening, but did not affect the red colouration. Treatment, temperature and time were shown to be important factors determining the effectiveness of ethylene on colour development, with 5 or 10 µl l^{-1} at 30°C for 24 or 48 hours showing a final colour equivalent to control fruit when soft. If treatment exceeded 48 hours at 30°C, chlorophyll degradation of several varieties was reduced and final colour development was incomplete. At lower temperatures, treatment time could be extended without causing any undesirable effects on colour development. Recommended treatment conditions for advanced ripening and improved ripening uniformity for Florida mangoes were given as 10 - 20 µl l^{-1} ethylene at 21°C for 12-24 h under high humidity (11). Treatment of Haden, Maya and Mabruka mangoes with 0.1 ml l^{-1} ethylene at 25°C and 90% relative humidity for 48 hours shortened the ripening time, with the effect being most noticeable at the beginning of the picking season, as compared with more mature fruits picked later (36). No differences were noted in sugar development or acid loss between treated and control fruits. Treatment with a range of ethylene concentrations from 0.00013 to 1.0 ml l^{-1} for 24 h at 25°C on Tommy Atkins indicated that 0.1 ml l^{-1} or above was required to initiate ripening (73). Initiated fruit showed rapid softening and peel colour development, while advancement of acidity loss, soluble solids and pulp colour development were less pronounced.

Ethylene released from ethrel has been used to induce and synchronise ripening in several fruits: immature climacteric fruit such as banana and melon have been treated with ethrel to achieve uniform ripening (89). For mangoes, most reports in the literature are concerned with ethylene application as liberated from ethrel. Treatment of several Florida varieties with ethrel hastened ripening and there was a tendency for treated fruits to develop a better skin colour, with no difference in the flavour rating (23). Similarly a reduced ripening time was obtained with ethylene treatment of eight Indian varieties (13). It was also found that in some varieties soluble solids, total sugars, reducing sugars and acidity were increased due to the treatment, whereas in others it was reduced. Treatment of Alphonso mangoes with 0.5 and 1.0 ml l^{-1} ethrel in hot and cold water and allowing ripening to occur at 24° - 28°C and 68% relative humidity, showed ethrel and hot water accelerated ripening with reduced spoilage (60). Treated fruits possessed excellent surface and ground colour, while those treated with ethrel in cold water showed no marked changes in external colour, but exhibited similar changes in ripening and respiration. High concentrations of ethrel in hot water induced discolouration in slightly bruised fruits. A study on the effect of 1, 2 and 4 ml l^{-1} ethrel on the ripening of the Chirutapudigoa variety in India showed increased amounts of ripe fruit after 3 days (93). External colour development was found to be more rapid in treated fruits, with

slightly higher total soluble solids and acidity than the controls. Treatment of Baneshan, Ko.8 and Mulgao mangoes in India with ethrel in a chamber hastened ripening of the three varieties within 48-60 hours as compared to 108-120 hours in controls (101). The most characteristic change due to ethrel was the advancement of peel colour development. Treated fruits were completely yellow, while controls were green/yellow or yellow/green, indicative of less advanced stage of ripeness. Treatment caused increases in the levels of reducing sugars except in Mulgao. Acidity varied with variety: treated Baneshan fruit showed a reduction, whereas Ko.8 and Mulgao showed higher acidity than the respective controls.

Acetylene

Acetylene is an ethylene analogue, and is used in some countries as a ripening agent where ethylene is not available or is too expensive, eg. for bananas in Egpyt (99) and the Philippines (64). Acetylene can generally be obtained in the pure form, as used in welding operations, or can be liberated from calcium carbide by the addition of water. The effect of acetylene liberated from calcium carbide has been investigated for Dashehari mangoes (68). Forty fruits were ripened with 4 g and 8 g of calcium carbide at room temperatures. Colour development was found to be best with 8 g, but these were inferior in taste. Fruit ripened with 4 g of calcium carbide were found to be good in colour and flavour rating, showing higher soluble solids, total sugars and pigments, with lower amounts of acids than control fruits. Mangoes exposed to acetylene gas and stored at cold as well as ambient temperatures showed rapid colour changes but the taste was insipid (112). No details were given on the variety and treatments. Acetylene added as calcium carbide at 2 g kg^{-1}, was found to halve the ripening time of Alphonso mangoes (85). However, the total carotenoid content was reduced in treated fruits and the aroma development was impaired. Treatment of Tommy Atkins mangoes with a range of acetylene concentrations, 0.01, 0.1, 1.0 and 2.0 ml l^{-1}, for 24 h at 25°C showed 1.0 ml l^{-1} or above was required to initiate ripening (73). Exposure to 0.1 ml l^{-1} acetylene hastened softening but had no effect on soluble solids, peel and pulp odour development, and acidity loss. Analysis of 0.1, 0.2, 0.4, 0.8 and 1.6 ml l^{-1} acetylene on Amelie mangoes under similar conditions indicated that ripening could be initiated with all concentrations but with different effects on the individual ripening process; the maximum reduction in ripening time was observed with 0.8 and 1.6 ml l^{-1} acetylene (Medlicott, unpublished data).

Controlled Atmosphere Storage

Controlled atmosphere (CA) storage involves the addition or removal of gases in a storage chamber resulting in an atmospheric composition different from that of air. By using regulated amounts of oxygen (O_2) and carbon dioxide (CO_2), ethylene production and ripening can be retarded. The storage life of fruits decreases rapidly as fruits gain the capacity to produce ethylene, and the ability of CA storage to retard ripening diminishes as the ripening processes are initiated. Carbon dioxide is a natural inhibitor of ethylene action, but it becomes ineffective when internal ethylene levels accumulate. Oxygen is required for the fruits to produce ethylene and low temperatures retard the rate of metabolism. These factors form the basis for the operation of CA storage. Potential benefits of CA storage include:

1. reduction in the rate of senescence and associated physiological and biochemical changes;

2. reduction in ethylene sensitivity;

3. reduction in the incidence or severity of decay through direct or indirect effects on post-harvest pathogens and spoilage micro-organisms.

The critical concentration of O_2 for mangoes, below which anaerobiosis may occur, has been reported as 9.2% (103). Mango has a fairly low tolerance to CO_2; at 15% the fruit did not develop normal colour although there were no effects on flavour (9). Storage at 12°C with 5% O_2 and 5% CO_2 was possible for 20 days; off-flavours and skin discolouration were detected in fruits stored in atmospheres containing 1% O_2 (43). Haden mangoes could be stored for 6 weeks under 2% O_2 and either 1 or 5% CO_2 at 10-11°C, although high losses occurred due to storage rotting (106). Storage in CO_2 at concentrations above 10% was found to result in fermentation within 3 weeks, while storage under 6% O_2 and 10% CO_2 at 8°C was possible for 4 weeks in Haden and 6 weeks for Carlotta, Jasmin, and Sao Quirino mangoes (17). Optimum concentrations for Julie and Amelie mangoes have been reported as 5% O_2 and 5% CO_2 at 11°C for 4 weeks (53). Thus the extension in storage life obtained by CA treatments is unlikely to be commercially attractive on the basis of the results available to date.

Modified Atmosphere Storage

Modified atmosphere storage (MA) differs only from CA storage in the degree and methods of control. MA storage requires reduced O_2 levels and increased CO_2 although at no specific concentrations. This is usually achieved in transport systems by allowing the accumulation of CO_2 or facilitated by the introduction of nitrogen. It may also be achieved by sealing the fruits in polythene bags or plastic film wraps.

Storage of mangoes in polythene bags containing potassium permanganate (to absorb ethylene) at ambient temperature (20°-30°C) was found to delay ripening by five days (108). Additionally, no differences in quality were noted between fruits stored in bags and those stored in air. Philippine mangoes stored for 3 weeks at 10°C in polythene bags, with and without ethylene absorbants, ripened to normal colour, texture and flavour when subsequently treated with ethylene (33). Similar responses have been shown for Dashehari mangoes (39). Polythene wrapping of Julie mangoes delayed softening, sugar and colour development when stored at 14° or 21°C (116). Evidence of CO_2 toxicity was shown in fruits stored for over 21 days in polythene bags. On removal of Kensington mangoes from sealed polythene after various durations at 20°C, the fruit subsequently ripened with off-flavours and lacked normal peel colour (25). The gas atmospheres inside the bags varied between treatments but the CO_2 concentration often exceeded 20% and O_2 was often less than 5%. In addition the total post-harvest life of stored fruit was not consistently longer than control fruit. Storage of Langra and Dusehri mangoes in perforated polyethylene bags for 12 days at ambient temperatures (26°-34°C) resulted in excellent quality fruit after ripening (14). Storage of Tommy Atkins mango in three different heat-shrinkable plastic films at 12.8°C for 14 days resulted in firmer and green fruit compared to non-wrapped (77). However, when ripened, off-flavours developed in the wrapped fruit. Similarly, when film-wrapped at four different stages of ripening and stored at 21°C, fruit tended to have a higher

incidence of off-flavour at soft-ripeness than fruit not wrapped and ripened to soft-ripe (38). Thus in general, storage in plastic bags or film wrapping appears to be of doubtful practical use.

Hypobaric Storage

Reducing the atmospheric pressure lowers the O_2 partial pressure which reduces ethylene production and activity (21), and the metabolism associated with aerobic respiration. Additionally, internal levels of ethylene would be lowered due to the increased outward diffusion of volatiles from tissue under reduced pressure (21, 32).

Hypobaric storage methods have been shown to extend the storage life of bananas (5) and some deciduous fruits (100). Storage life of Israeli mangoes was found to be increased when the pressure was reduced below 100 mm Hg, with the prolongation being inversely related to pressure (6). When stored at 13°C at pressures of 760, 100, 75 and 50 mm Hg, fruit remained unripe for 16, 25, and 35 days respectively. No effect on ripening was noted at pressures above 250 mm Hg, while below 50 mm Hg the fruit desiccated. After transfer to 25°C, all fruits ripened although with only limited peel colour development resulting in green ripe fruit. Increased storage life of several Florida varieties was found at pressures below 152 mm Hg, although no differences were shown between storage pressures of 76 and 152 mm Hg (106). At present the extension in the storage life is not sufficient enough to warrant the high costs of hypobaric storage facilities.

Waxing

Wax coating, as a water wax emulsion and a refined mineral oil, has been shown to increase storage life of mangoes by 50% (69). Similar results have been obtained with paraffin wax on Totapuri mangoes (83).

Coating of Lucknow mangoes with a 6% wax emulsion and storage at 29°C resulted in an increased storage life ranging from five to eight days (38). Increased storage life has also been shown by several other investigator. (92, 97).

Irradiation

The major interest in the application of irradiation treatment is through disinfestation of fruit to solve quarantine problems. These include fruit fly and mango seed weevil control. In addition, ionizing radiation has been found to retard ripening in several mango varieties. A radiation dose of 8 Krad resulted in an extension of the storage life of Alphonso mangoes by 6 - 8 days at ambient temperatures (30). Storage life extension has been demonstrated in Irwin and Sensation mangoes but with differential effects (42). Irwin mangoes treated with 10 Krads was delayed by two weeks without any effects on quality development. Sensation mangoes, however, were delayed by only three days, and with detrimental effects on ripening, when treated with 250 Krads. Delayed ripening and good quality development during subsequent storage was found with radiation doses of 30 Krads (4) and 700 Krads (27). Commercial use of irradiation treatment for extension of storage life is unlikely due to the high cost and possible legal restrictions.

Chemical Control

Various chemicals and synthetic growth regulators applied in post-harvest dips have been found to retard ripening in mangoes. These include malic hydrazide (57, 82, 110), 2, 4, 5 -trichlorophenoxy propionic acid (28, 58), 2,4-dichlorophenoxy acetic acid (111), benzylaminopurine (86), Zineb and sodium diethyldithiocarbamate (110), succinic acid 2, 2-dimethylhydrazide, and chloromequat (59, 113). Chemical control of ripening is not presently used under commercial conditions and further studies are required to determine their suitability.

Post-harvest chemical treatments for disease control are often applied as hot water dips. Hot water treatments have been shown to increase the rate of ripening and may scald the fruit. This subject is discussed elsewhere (Thompson, these Proceedings) and not in this review.

CONCLUSIONS AND RESEARCH REQUIREMENTS

Suitable temperatures for the storage and ripening of mangoes are 8°-13°C and 20°-32°C respectively, with the optimum range depending on a number of factors including variety, origin and harvest maturity. The full mature stage (stage B) is the optimum harvest maturity for full quality development in the ripe condition. However, the half-mature stage of development (stage A) is the optimum maturity for prolonged storage at low temperatures, where fruits show reduced ripening compared to fully mature fruit, but still show subsequent ripening on transfer to higher temperatures. Ethylene or acetylene can be used to initiate and synchronise ripening. Suitable conditions for commercial application are suggested as 1.0 ml l^{-1} at 25°C and 90-95% relative humidity for 24 hours; this reduces the ripening time by 3-7 days. Other methods for controlling ripening, including CA, MA, irradiation and waxing, do not at the present time confer a great advantage over low temperature storage. A substantial increase in storage life would be required to offset the higher costs.

Increased trade in mangoes will be facilitated by the successful introduction of sea transport. Commercial varieties need to be screened for their suitability for prolonged low temperature storage and acceptable quality development during ripening at higher temperatures. Optimum harvest maturities need to be established for particular market requirements, and storage temperatures defined throughout the season. The shipping conditions and packaging requirements for optimum ventilation need to be defined. The stacking of cartons on the pallets, and of the pallets within the container, are of prime importance in ventilation for the maintenance of constant temperature conditions. Further work is required on alternative methods of prolonging storage. Financial and technical constraints in many mango producing countries suggest that waxing and chemical control probably offer the most potential for further investigation.

Extending the storage life also increases the risk of infection by saprophytic microorganisms and research needs to be continued on both pre- and post-harvest control. Additionally, the post-harvest response of the fruit may be influenced by pre-harvest conditions, including mineral nutrition, irrigation and control of vegetative growth. Thus for substantial progress to be made in expanding international trade, collaboration needs to be established and strengthened between researchers involved in all aspects of mango production, including pre- and post-harvest physiologists and pathologists.

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