2. RIPENING IN MANGO FRUIT AND ITS MANIPULATION BY LOW TEMPERATURE

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[1]Abbreviations used: ACIAR, Australian Centre for International Agricultural Research; ASEAN, Association of South East Asian Nations; CA, Controlled atmosphere; CI(I), Chilling injury (index); FCI, Flesh colour index; M A Modified atmosphere; PEB, Polyethylene bag; PCI, Peel colour index; PG, Polygalacturonase; T A. Titratable acidity; TSS, Total soluble solids.

INTRODUCTION

The development of technologies to manipulate the postharvest behaviour of fresh fruit and vegetables has come from studying the effect of various postharvest storage treatments on specific commodities under controlled conditions. Storage technology refers to the postharvest treatments which extend the shelf-life of a product by delaying the onset and progress of its senescence and ultimate death (58). For climacteric fruit, storage involves some kind of manipulation of postharvest ripening. A classical example is the use of modified and ethylene-free atmospheres to keep banana fruit (55) and avocados (11) in a non-ripening or preclimacteric condition. A primary factor in most postharvest storage technologies presently available for fresh fruit is the use of refrigeration to slow the rates of respiration and other postharvest physiological and biochemical processes in the product.

Mangoes (Mangifera indica L.) are climacteric fruit (28) and like other fruits of tropical origin, they are susceptible to chilling injury (CI) if they are held below some critical minimum temperature (72). While there is no commonly agreed critical temperature for mangoes, the fruit is considered at risk at temperatures below about 10° (68) to 13°C (54). However, when mature green mango fruit are stored at temperatures above 10°C, slow ripening of the fruit generally occurs and the shelf-life is extended to two or three weeks (23).

During the last 20 years, there have been two international symposia (New Delhi, 1969; Bangalore, 1985), an ASEAN - region research project (40), and Australian research workshop Cairns, 1986 (see Reference 8), an ACIAR collaborative postharvest research project and workshop in Bangkok, 1986 (see Reference 76) and numerous research publications all of which have involved postharvest studies on mango. But in spite of all this effort, international trade in mangoes remains meagre (67). Presumably, there is still a lack of effective and/or economically viable storage technologies.

This chapter firstly examines the mango ripening process in terms of the visual and other sensory changes which occur as a result of postharvest physiological and biochemical events. These are then related to the practical aspects of manipulation of postharvest ripening and the development and adaption of storage technologies with special emphasis on the use of low temperature. Secondly, the achievements and gaps in knowledge are assessed and, lastly, suggestions are made for possible future research directions.

POSTHARVEST RIPENING IN MANGO FRUIT

The three criteria important for the determination of ripeness and ripe-fruit quality in mangoes, result from softening and changes in colour and taste.

Fruit softening

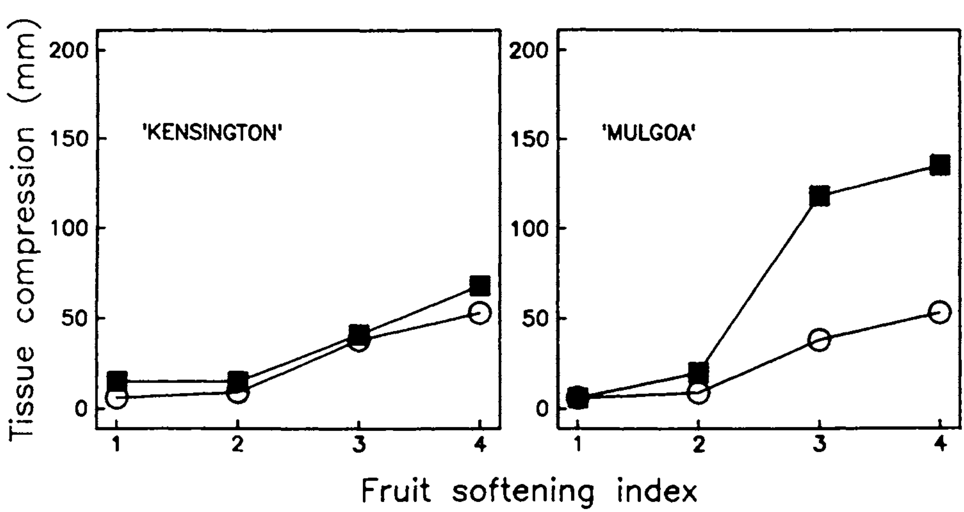
Softening is a fundamental process in fruit ripening and is, perhaps, the universal indicator of the process. However, ripeness is an imprecise state because the attainment of ripeness is usually judged by the feel of the fruit as assessed usually by finger pressure. Such a method is not quantitative, is highly subjective and based on an individual's preferences, and does not take account of possible wide differences in textural properties in the fruit of various cultivars, i.e. some may be intrinsically firmer than others at the fully soft ripe stage. Nevertheless, the feel of the fruit is probably the consumer's final arbiter whether a mango fruit is ripe and ready to eat.

Changes in the cell wall structure are responsible for softening in ripening fruit. Degradation of pectins (28) and a correlation between softening and polygalacturonase (PG) activity (50) have both been reported for mango. Also, Tandon and Kalra (66) reported that increasing quantities of calcium were released into fruit flesh causing a loss of firm texture and consequent softening.

In a recent study, Lanzan and co-workers (31) reported on changes in PG and cellulase activity in different parts of ripening 'Harumanis' and 'Mulgoa' mangoes. They concluded that cellulase was unlikely to be involved significantly in the softening of 'Harumanis' because its activity decreased during ripening. They did find, however, that there were differences in the activity of PG between the inner and outer parts of the mesocarp which correlated with the differences they found in softening patterns within single fruit. Chaplin and co-workers (unpublished) found that the inner mesocarp was significantly softer than the outer mesocarp in four mango cultivars at the full-ripe stage (Figure 1). This disparity may partly explain some of the uneven ripening disorders observed in mango cultivars such as 'Mulgoa' and 'Harumanis'. The biochemical aspects of softening are reviewed in more detail in the chapter by Medlicott and Jeger (Chapter V.I.) and that by John (Chapter V.3).

Figure 1

Compression in 5 mm core sections of mango mesocarp recorded at 30 seconds following application of a load of 50g. Core sections were taken from fruit at different stages of ripening and compression of inner (closed symbols) and outer (open symbols) mesocarp sections were measured separately. The ripening stages were related to the fruit softening index where 1 = fully firm; 2 = first softening; 3 = advanced softening; 4= fully (ripe) soft. Adapted from (74).



Changes in colour

In mango cultivars like 'Alphonso', 'Carabao' and 'Kensington', peel chlorophyll degrades during ripening (12, 29, 39). Thus, workers in the Philippines commonly use a six-point colour index to describe the various ripening stages in 'Carabao' mango (40). Loss of chlorophyll in the mango peel during normal ripening is, apparently, a sensitive process which sometimes does not go to completion. Postharvest factors such as high temperature (8) and modified atmospheres rich in carbon dioxide and low in oxygen (12) are known to suppress degreening during ripening in 'Kensington' mangoes.

Some commercially important mango cultivars such as the 'Harumanis' mango from Malaysia, do not degreen during natural ripening or after treatment with exogenous ethylene (G. Chaplin and A. Abdullah, unpublished). Also, in other mango cultivars, chlorophyll is not apparently the dominant pigment in the peel of non-ripe fruit. For example the peel of several Florida mango cultivars is typically deep magenta to purple in colour. Anthocyanins are important in such cultivars.

The synthesis of carotenoid pigments during ripening is also a sensitive reaction and is impeded in mangoes ripening at ordinary temperature after having been previously subjected to low temperature (74). It also has been shown that exposure of nonripe mangoes to modified atmospheres rich in CO_2 and low in O_2 inhibits carotenogenesis (12).

The documented studies on the biochemistry of changes in pigments during ripening are almost entirely concerned with carotenoid pigments. The total carotenoid content in ripened mangoes varies among cultivars and can be seen as differences in absorbance of standardised chloroform extracts (53). So while the intensity of colour may be correlated with the carotenoid content, it may be that the actual tone of the colour is due to differences in the composition of carotenoid pigments.

A comprehensive analysis of carotenoid pigments in the flesh of mango fruit found a mixture of α and β- carotenes with about 60% as the α- form (24, 42). The presence of some (yellow) colour in the inner mesocarp of firm unharvested fruit is often taken as a field-indicator of the attainment of horticultural maturity (I. Baker, personal communication). It has been speculated that the appearance of yellow colour in the mesocarp may also be indicative of an early stage of ripening in mango fruit (M.C.C. Lizada, personal communication).

The yellow flesh colour in mango fruit varies in its intensity and shade and is influenced during fruit ripening by both pre- and postharvest factors (64). Variations in the colour in the mesocarp are recognised in different mango cultivars, and qualitative assessments using objective parameters have recently been reported (53). These include absorbance measurements of chloroform extracts from mango mesocarp and tristimulus indices based on light meter measurements of redness, greeness and intensity.

Changes in taste

The development and nature of flavour and odour is probably one of the least researched aspects of ripening in mango fruit. The unique flavour attributes in the fruit of particular cultivars of mango are legendary. For example, 'Alphonso' is arguably the most prized mango in India, while in the Philippines, the 'Carabao' is readily proclaimed as having the best mango flavour. Over recent years, since the availability of better analytical equipment, several studies have used gas chromatography and mass spectrometry to identify numerous headspace and constituent volatile flavour components (eg. 5, 34, 35, 52). However, the specific volatile flavour components responsible for the particular flavours found in different mango fruit have yet to be clearly identified.

Two principal changes in the chemical composition in ripening mangoes which are important in taste and the perception of flavour quality are the increase in sugars and the decrease in acids. Sugar accumulation results from the hydrolysis of starch (69) and forms a high proportion of the soluble solids in ripe mango fruit (28). Glucose, fructose and sucrose were identified in unripe 'Dashehari' mangoes as the main sugars with glucose and fructose being more plentiful (65). However, ripening of the fruit leads to a change in the relative proportions and generally sucrose becomes the most prevalent form (57). A study of the fruit of 17 mango cultivars growing in Australia revealed an average ratio of 8:3:1 of sucrose:fructose:glucose (53). However, in MG50, 'Sabre' and 'Saharanapur' mangoes, fructose exceeded sucrose. The sugar content in ripened mangoes is conveniently assessed as a function of the TSS as measured in a droplet of juice in a refractometer. The TSS content is expressed as degrees Brix or as a percentage. Values vary widely among cultivars from as low as about 10% to an upper value of perhaps 22%. The TSS is, therefore, an easily measured quality attribute of ripe mangoes. Seasonal variations in the TSS values in ripend 'Kensington' mangoes have been noted (G. Chaplin, unpublished data). However, it is not known whether this derives from differences in the content of hydrolysable starch or from differences in the extent of hydrolysis during ripening.

Acidity is the second important quality attribute of ripe mango fruit. The acidity declines during ripening and can be readily assessed by measurement of the pH in the flesh or extracted juice. Additional measurement of total acidity can be made by laboratory titration. Citric acid is usually the predominant organic acid present (18). As with sugar content, the pH and acidity levels of ripe mango fruit vary widely among cultivars (13) and thus contribute to wide variations in the sugar/acid ratios. Studies in Australia have shown that this ratio is an important determinant of eating acceptability of mango fruit (53).

The assessment of sensory quality in mango fruit has generally been made using subjective descriptions. Examples of these include "... pleasing flavour" (45); "... characteristic pleasant and strong aroma" (20); "... extremely attractive flavour" (36); "...poor skin colour" (37). Quality evaluations of this kind are often meaningless to a reader who may not have seen or tasted the particular cultivar in queston and, therefore, they have no basis of interpreting the description used. Hence, there is a need to develop and use objective descriptions.

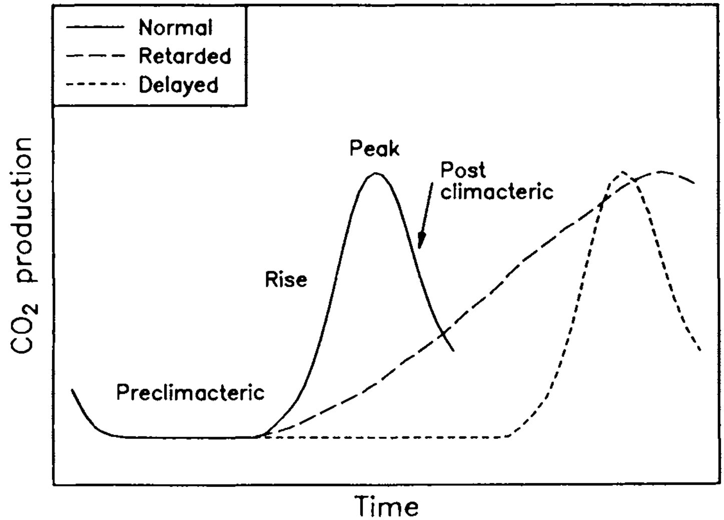
Physiology of ripening

Mango fruit are usually harvested at the so-called mature-green, or physiologically mature stage of growth and development and before the commencement of ripening. This is to allow time for the various postharvest procedures of sorting, packaging and transportation to the market place to be accomplished before the fruit become fully ripe. Various indices have been used to identify the attainment of the stage of "maturity" in mango fruit. These include fruit characters such as colour, shape and specific gravity (63). The subject of maturity indices of mango is considered in a separate chapter in this series (Harvey, Chapter IV). It is necessary here, however to emphasise that maturity and ripening are not synonymous terms. The separation, however, between the two phases is not easily identified. Fruit maturation comes at the culmination of the physical growth and development of the fruit and can, for example, be judged from the pattern of dry matter accumulation. Natural ripening of the fruit follows and is the process which renders the fruit attractive for human consumption (38).

Mango belongs to the 'climacteric' class of fruit in which two important physiological events are the transient increases in the rates of respiration and of ethylene synthese. A typical climacteric respiration pattern is shown in Figure 2.

Figure 2

Schematic representation of the respiratory pattern during ripening of climacteric fruit. The diagram shows two types of changes to the normal pattern that may be achieved by storage technologies.



The commencement of ripening in mango fruit was linked by Leley et al (32) to the climacteric rise in respiration. He reported that the peak respiraton rate occurred 2-5 days after harvest. However, such a short preclimacteric period observed in that study could be due to the fruit having commenced ripening before harvest. In other studies, the time from harvest to peak respiration has varied from 6 days in 'Kensington' mango (8) to 9 days in 'Golek' (43). Mature-green 'Kensington' mangoes can have a preclimacteric of up to at least 14 days at 20°C (G. Chaplin, unpublished).

The role of endogenous ethylene in the ripening of mangoes is not well understood. For many years, the production of endogenous ethylene has been considered the "trigger" to the ripening process in climacteric fruits (38). Burg and Burg (9) showed that the patterns of ethylene production by 'Kent' and

'Haden' mangoes followed closely the respiratory pattern. However, several workers have claimed that the ethylene production pattern lags after the respiratory rise (e.g. 8). However, irrespective of the timing of the peak rate of ethylene production in ripening fruits, it is notable that ethylene producting in mango fruit is extremely small at approximately 1 L $kg^{-1}h^{-1}$ in comparison to that in other fruit (1, 11, 70).

With some fruits, such as tomato, the timing of the increase in the rate of ethylene production is used as the indicator of the commencement of the ripening process. The very small increase in ethylene production in mango means that it is unlikely, even under laboratory conditions, that endogenous ethylene evolution would be a useful indicator of the commencement of ripening in mangoes. Conversely, there is also a lack of evidence to show that ripening of mango can be prevented or delayed in storage systems which remove ethylene.

Exogenous ethylene can, on the other hand, induce and accelerate ripening in mango fruit (6). Improved marketing prospects have been demonstrated in mangoes "pre-ripened" with ethylene before shipment (7). Acetylene produced from calcium carbide is commonly used in India to induce and enhance ripening in mangoes (52).

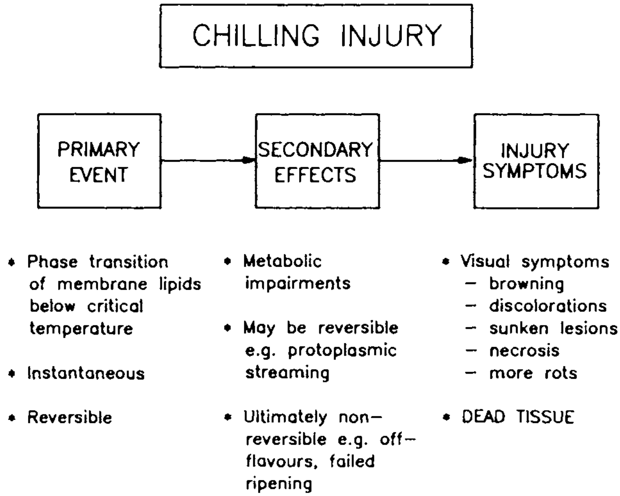
All of the physical, chemical and physiological changes associated with ripening and described above have a biochemical basis. In this chapter, only brief comments have been made on some of the principal kinds of biochemical reactions influencing the progress and completeness of the ripening phenomenon. A detailed review of the biochemistry of ripening in mango fruit is presented in the chapter by Medlicott and Jeger in this volume.

Ripening in mango is clearly a complex process. It is proposed that, for most practical purposes, softening is the main aspect of ripening. Storage treatments to manipulate ripening must, therefore, also influence the commencement and the subsequent rate of softening. All other aspects of ripening described here, i.e. changes in colour, flavour and chemical composition, can be considered as elements in the development of ripe-fruit quality. These need, in stored fruit, to resemble closely those of similar fruit allowed to ripen immediately after harvest under normal ambient conditions which presumably reflects optimal quality of the given batch of fruit.

MANIPULATION OF POSTHARVEST RIPENING IN MANGO FRUIT

Technologies to manipulate the ripening process in mango fruit are applied commonly for any one of three reasons. They are to accelerate the process, to make the process more uniform for a given batch of fruit, or to delay the commencement, or to retard the progress, of ripening (see Figure 3). While technologies for either of the first two objectives may be important in some situations, they will not be considered at any length in this chapter. However, technologies to delay the onset or to retard the progress of ripening are central to the theme of the present review and can simply be considered as fruit storage technologies.

Figure 3 Overview of pathway of chilling injury



Retardation by temperature management

Refrigeration is the most widely used technology to delay and retard the ripening and postharvest deterioration of horticultural commodities. The general effect of reducing the postharvest temperature is to bring about a corresponding decrease in the respiration rate which, in turn, delays the onset of the respiratory climacteric and the associated events of fruit ripening (73).

The simplest form of low-temperature storage technology therefore, is to expose the commodity to a particular temperature for a particular time. Thus, standarized time X temperature studies are required for the development of such storage technologies in any given situation. While the shelf life of mango fruit at ambient temperature generally ranges from about 3 to 10 days this can be increased to about three weeks by lowering the storage temperature of the fruit to about 13°C (23). Studies of mango fruit which have involved constant storage at lower temperatures than this commonly conclude that storage by such methods is not practical due to the development of CI (chilling injury) symptoms in the fruit (e.g. 54, 67).

The term CI (Figure 2) refers strictly to the physical symptoms resulting from exposure to a chilling temperature (21). Various physiological parameters such as reduced protoplasmic streaming (46) have been used to measure the chilling response. A primary event, resulting in the various effects, is the immediate physical phase transition in membrane lipids below the critical temperature (48). The use of the term, however, is often misleading but in this chapter the term CI is used to mean the visual symptoms of injury. These are characterized by dark scald-like discolourations in the peel of mango fruit which commonly become sunken necrotic lesions (23). Other common symptoms are an inhibition of ripening, internal discolouration and a grey scald-like discolouration of the skin.

Though there is certainty that CI will eventually occur in mango fruit exposed to chilling temperatures, there is a lack of agreement about the precise storage conditions and temperatures necessary to induce visual symptoms of CI in mango fruit. This is partly because the symptoms do not develop instantaneously but require some time of exposure before they appear (64). In some cultivars 12°C, and even as high as 15°C (72), has been reported to cause injury. Thus, these data indicate that there may be differences in the critical temperature between mango cultivars i.e. differences in chilling sensitivity as defined by Raison and Lyons (49) and, secondly, there may be individual fruit-to-fruit differences in the severity of CI symptoms which develop following a given exposure i.e. differences in the chilling response. (49).

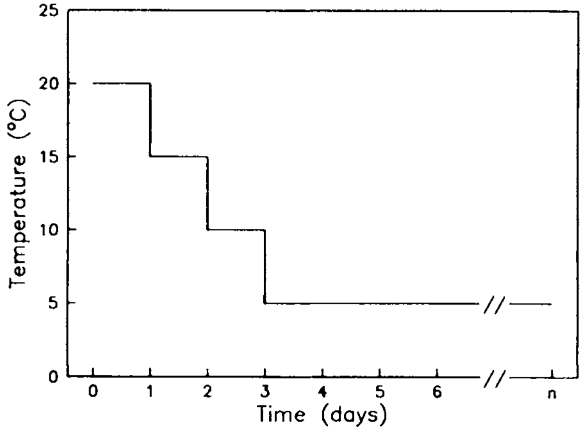
These differences could be due to many factors, of which many are speculative and little understood. It is presumed that genetic factors have a general control over the intrinsic sensitivity (22). However, certain preharvest cultural or environmental factors (64) and fruit maturity (44) are also thought to predispose certain storage behaviour. Postharvest treatments have also been shown to modulate the chilling response in some fruit (3, 4).

A major consideration in the development of low temperature storage technology is, therefore, the necessity to establish the storage conditions which cause CI. Romani (51) has emphasised the dilemma that storage treatments which are effective in delaying postharvest ripening processes may cause physiological injury to the commodity. Hence, the problem with a safe (i.e. high enough not to cause CI) storage temperature is that fruit ripening may not be delayed long enough to be commercially useful.

In 'Kensington' mango, visual CI symptoms do not occur at 10°C but the fruit are fully ripe after four weeks storage at this temperature (G. Chaplin, unpublished). Thus, such a storage treatment is unsatisfactory for markets where the shipping time is longer than this. Lower temperatures and/or alternative approaches are needed, therefore, to give extra postharvest life to the fruit. Thus, a second major consideration in the development of technology is the elucidation of methods to ameliorate or avoid the onset of CI symptoms. The optimum temperature ranges for mango storage/ripening are further covered by Medlicott & Jeger (Chapter V. 1).

A few reports have indicated that lower storage temperatures in the chilling range can be tolerated if the temperature of the fruit is lowered stepwise (Figure 4) rather than immediately to the final tempeature (30, 43, 67). This process is sometimes referred to as temperature adaptation or temperature conditioning. In this context, the terms may be synonomous with acclimation, acclimatization, and hardening and infers some adaptive changes to chilling temperatures by the commodity (22). Mukerjee and Srivastava (43) interpreted their results with stepwise temperature reduction during storage as indicating that the increase in TSS in the fruit during storage caused a decrease in the critical temperature of the fruit. However, they did not provide an independent/physical measurement of the critical temperature as defined (49).

Figure 4 Schematic representation of a stepwise reduction of storage temperature treatment.



Recent studies with 'Kensington' mangoes (74), showed that the fruit tolerated low temperatures of 1° or 5°C better after a stepwise reduction in temperature compared to fruit which were cooled immediately to the respective final storage temperatures (Table 1). These data also showed, however, that the fruit underwent a change in postharvest physiological state when subjected to the former treatment i.e. the fruit commenced to ripen whereas those cooled immediately to the final temperature remained apparently non-ripening for a longer time. Many other fruits also undergo an apparent change in chilling sensitivity/response with partial ripening (16). It is interesting to note, however, that the above response with mangoes is in contradiction to that observed in avocado fruit where chilling sensitivity apparently increased markedly during the respiratory rise and at the climacteric compared to both the pre- and postclimacteric stages (14, 27).

Table 1 Effect of storage treatment on the severity of chilling injury in 'Kensington' mangoes immediately after storage and subsequently after ripening at 20°C.

Storage Treatment	Chilling Injury Index[a]	
	After Storage	After Ripening
Control at 20°C	na	1.00a
Stepwise to 1°C	2.6b	3.75b
Immediate to 1°C	4.8d	5.00c
Stepwise to 5°C	4.0c	1.80a
Immediate to 5°C	4.0c	3.60b
Stepwise to 10°C	1.0a	1.00a
Immediate to 10°C	1.0a	1.00a

[a]The higher the index the more severe the injury. na indicates not applicable. Means in columns with the same letter are not significantly different ($P<0.05$). Data taken from (74).

Figure 5 Schematic representation of an intermittent warming cycle during low temperature storage.

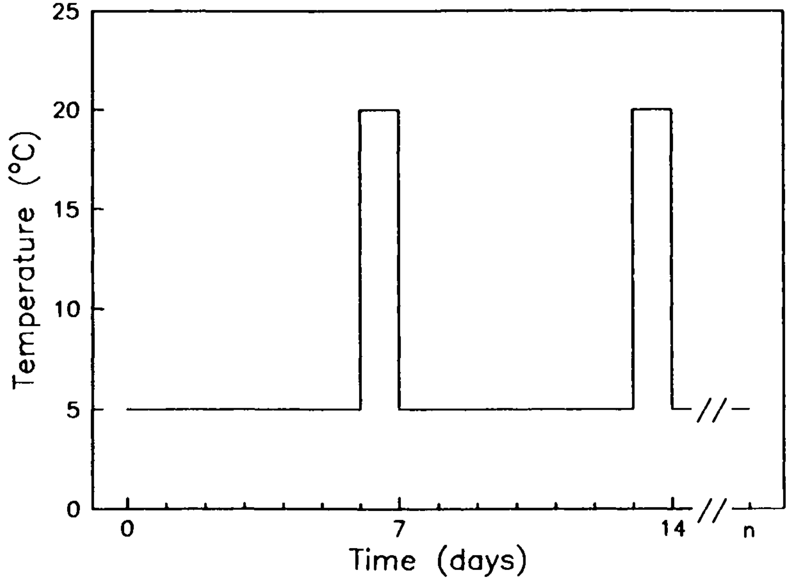
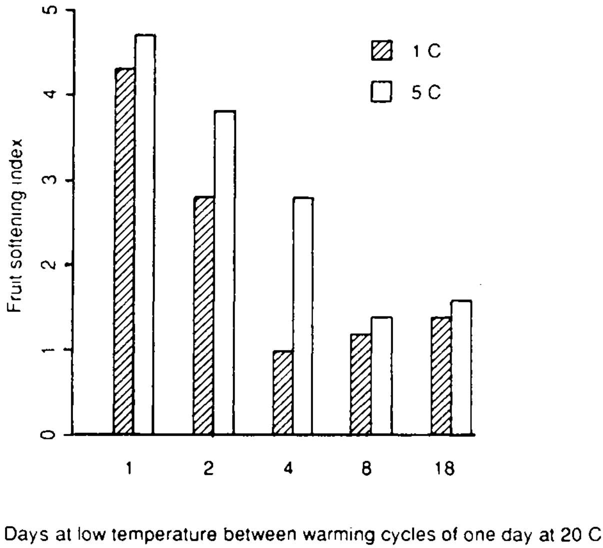


Figure 6 Effect of the frequency of a 24 hour warming cycle on the softening in 'Kensington' mangoes stored at 1°C or 5°C for 18 days. Adapted from (74).



The dual term "sensitivity/response" has been used above because evidence is lacking to indicate whether there has been a change in the critical temperature necessary to induce incipient CI symptoms or whether the fruit have become able to withstand a longer exposure time before the onset of symptoms. It has long been known that fully ripe mangoes can be stored for several days at 2°C without appreciable further deterioration (2).

The change in the chilling sensitivity/response observed in ripening mango is, as yet, unexplained. Kane et al. (25) have proposed that it may be linked with alterations to the fatty acid composition of mesocarp mitochondria as the fruit ripens. Chaplin and co-workers (74) have concluded that unspecified changes in the mango fruit peel during the initiation or progress of fruit ripening are responsible for the observed alterations in the severity of visual CI symptoms in mangoes stored at chilling temperatures. They have also observed that CI symptoms in the unripe or ripening fruit are apparently more prevalent in green areas of peel than in the yellow, coloured peel. Analysis of the peel from partly ripe 'Alfonso' mangoes following storage at 2°-5°C showed that chill-injured peel had less starch breakdown and less soluble sugar than uninjured peel taken from the same fruits (15). These observed differences are, presumably, responses to chilling and not causes of CI.

Another storage treatment utilizing a variable temperature approach is that of application of intermittent warming cycles (Figure 5) to commodities stored at low chilling temperatures. This treatment has decreased low temperature breakdown in apples (60) and low temperature injury in peaches and nectarines (3). The severity of CI in 'Kensington' mangoes stored at 5°C was also significantly reduced by intermittent warming of the fruit to 20°C (74). In this study, fruit softening increased as the frequency of warming cycles increased (Figure 6) and also, there was less CI when the fruit had short-duration cycles at low temperature with frequent warming cycles compared to fruit exposed to longer-duration low temperature storage with fewer warming cycles. The reduction in CI was correlated with the extent of fruit softening (ripening) after the storage phase (Figure 7). The improvement here in storage quality of mangoes was similar to that recorded for grapefruit (17) in which low temperature storage mainly affected the incidence of external injury and had little effect on internal fruit quality. It has been postulated that this treatment ameliorates CI by the removal of toxic compounds during the warming cycles (33).

Atmosphere composition and pressure treatments in combination with low temperature.

The application of controlled atmosphere (CA) or modified atmosphere (MA) storage techniques to manipulate ripening is dealt with in Section 1 of this chapter by Medlicott and Jeger. There are, however, some studies relevant to this chapter where MA treatments and low temperature have been combined and some of these are described.

Enclosure of fruit in sealed polyethylene bags (PEB) in order to create a modified gas storage atmosphere has resulted in an effective storage technology for banana fruit (55). This technology is able to maintain the fruit in an apparently non-ripening preclimacteric state. However, the application of similar treatments to 'Kensington' mangoes caused harmful responses and also did not prevent softening in the fruit so stored (12). When 'Amelie' and 'Julie' mangoes were subjected to pre-mixed atmospheres, comprising different ratios of oxygen and carbon dioxide, it was found that the best atmosphere was one containing 5% oxygen and 5% carbon dioxide (26). Sive and Resinzky (59) also reported that the storage life of 'Tommy Atkins', 'Maya', 'Haden' and 'Keitt' mangoes at 13°-14°C was extended to between 6 and 10 weeks under CA conditions, depending on cultivar. Meanwhile, the wrapping of 'Tommy Atkins' fruit in heat-shrinkable film prior to storage for 2 weeks at 12°C caused no significant differences in fruit firmness, colour of the peel, decay, or time to ripen when compared to fruit held in air (40). As could be expected, however, the film-wrapped fruit had significantly less weight loss, but off-flavours were detected subsequently in the ripened fruit.

Recently, it has been shown that visual symptoms of CI were significantly less in 'Carrie', 'Common', 'Kensington' and 'Zill' mangoes stored for 15 days at 1°C in PEB than in similar fruit stored in air (75). In the 'Common' mango, visual symptoms of CI were eliminated by the PEB treatment (Table 2). The mechanism of this beneficial effect on storage quality is now known.

Table 2 Effect of storage time in air or polyethylene bags [a] (PEB) at 1°C on severity of chilling injury in four cultivars of mango fruit after ripening in air at 20°C.

Chilling injury index [b]								
Storage time (days)	CARRIE		COMMON		KENSINGTON		ZILL	
	AIR	PEB	AIR	PEB	AIR	PEB	AIR	PEB
1	1.0^{a}	1.0^{a}	1.0^{a}	1.0^{a}	1.0^{a}	1.0^{a}	1.0^{a}	1.0^{a}
3	1.0^{a}	1.0^{a}	1.0^{a}	1.0^{a}	1.0^{a}	1.0^{a}	1.3^{a}	1.0^{a}
5	1.2^{a}	1.0^{c}	2.2^{c}	1.0^{a}	1.3^{a}	1.0^{a}	1.7^{b}	1.0^{a}
7	2.4^{b}	1.0^{a}	3.0^{bc}	1.0^{a}	3.4^{c}	1.2^{a}	2.6^{b}	1.6^{a}
9	2.6^{b}	1.4^{a}	3.8^{c}	1.0^{a}	2.6^{b}	2.2^{a}	2.6^{b}	2.1^{b}
15	3.2^{cd}	1.8^{b}	4.2^{de}	1.0^{a}	5.0^{e}	3.8^{cd}	3.8^{cd}	2.7^{bc}

[a] Low density polyethylene bag 0.04 mm thickness, measuring approximately 150 mm x 200 mm.

[b] The higher the value the more severe the injury. Means in rows followed by the same letter are not significantly different (P<0.05.). Data taken (75).

Most of the above studies report on the various qualitative aspects of storage of mango fruits in MA at low temperatures. It has not yet been demonstrated, however, that such technology can significantly and consistently extend the storage life of the fruit.

Two notable studies on storage at reduced pressure have been reported in Florida and Israel. After 3 weeks at 13°C at various low pressures, 'Irwin', 'Tommy Atkins' and 'Kent' mangoes had better quality than those stored at normal pressure (61). In the study with 'Pairi', 'Maya' and 'Haden' mangoes (4), control fruit in air at 13°C had softened markedly by 16 days whereas the fruit at low pressure remained firm for up to 35 days. Although all of the fruit stored at different pressures attained similar TSS and TA levels, irrespective of storage treatment, the normal fruit peel colour changes which accompany ripening were impaired. The prospects for adoption of low-pressure storage technology for mangoes do not seem good because of the specialized and expensive facilities necessary.

Application of chemicals and growth regulators

During the last several decades, a large number of studies involving the responses to calcium treatments, and mechanisms of calcium action in plants, have been reported. The association of calcium with various postharvest changes and with storage disorders in fruit has been of particular interest. The ability of exogenous calcium to depress the rate of postharvest respiration and to delay the onset of the respiratory climacteric in avocados (69) is an important result. Other demonstrated benefits of exogenous calcium include the reduction in the severity of visual CI symptoms in avocados (10) and the reduction of low-temperature storage disorders of apples (56). However studies of the effects of calcium on mangoes are few. In one such investigation, added calcium delayed ripening but also irreversibly suppressed colour changes in the peel during eventual ripening (71). Poovaiah (47) has proposed that the effects of calcium on ripening can be partly attributed to a reduction in the microviscosity of membranes associated with senescence.

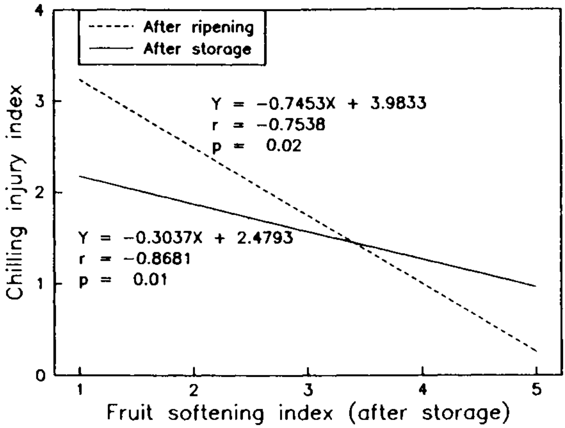
The present potential for other chemical sprays or dips to bring about a substantial increase in the postharvest life of mangoes appears to be small, though the range and number of documented studies is also very small. Development of yellow colour, weight loss and shrinkage were retarded in 'Dashehari' mangoes treated with several growth regulators, the most effective being 2, 4, 5-T and 2, 4-D (19). However, such treatments of fruit did not cause significant differences in firmness compared with untreated fruit. Similarly, only a minor delay to ripening of 'Boribo' mango was achieved by treatment with benzylaminopurine (45). These kinds of results do not, therefore, provide particular encouragement for similar studies to be continued. Furthermore, there seems to be an increasing trend away from the chemical treatment of foodstuffs because of perceptions of possible dangers to health.

CONCLUDING REMARKS AND RECOMMENDATIONS

Our knowledge of the mechanism, and our ability to control the onset and progress of postharvest ripening in mangoes is of great importance. The challenge being confronted is to develop storage technologies which will enable transport of mangoes to the most distant markets anywhere in the world using surface transport methods. Clearly, there is no simple storage technology presently available, such as a single temperature, by which the postharvest life of any of the commercially important mango cultivars can be extended beyond about three weeks. Also, there is no method yet available which has been shown to maintain mature-green mangoes in the pre-climacteric stage. Furthermore, there does not seem to be any reliable guide as to when ripening actually commences in mango fruit.

Mango storage research in the short-term should concentrate on developing postharvest temperature regimes that are specific to individual cultivars and

Figure 7 Relation between the softness of fruit after storage at 1°C or 5°C and the severity of visual symptoms of chilling injury. Adapted from (74)



that can maximise the delay or retardation of ripening while avoiding the damaging effects of CI and other possible storage disorders. Although I have not considered postharvest diseases in this review, our ability to develop treatments to control, especially, anthracnose and stem-end rots will be of fundamental importance to the effectiveness of storage technologies that are developed since these diseases become especially prevalent in stored mangoes.

The possibility of finding storage technologies to keep mangoes non-ripening while in transit will depend on research which will likely be of a more fundamental and longer-term nature. There is, of course, a theoretical possibility that by bio-engineering techniques, the ripening in mangoes could become a process under the control of some external trigger. Alternatively, by similar techniques it might be possible to develop a mango that is much less chilling sensitive and which could, therefore, tolerate much lower storage temperatures thereby increasing the storage life.

However, it seems that studies should at first concentrate on two aspects, viz., the nature of the physical and biochemical responses to low temperature in mango peel which lead to visual symptoms and second, the characterization and progress of softening and other ripening changes in the mesocarp. A third and inter-related area needing more research is the effect of storage treatments on the sensory quality of the fruit. It needs to be remembered that storage treatments, especially those involving low temperatures, will probably produce some degree of impairment of the final ripe fruit quality. Quality is not absolute but is comprised of a set of relative values. These may well vary with the cultivar and also, to a large extent, with the consumer, who is the final arbiter of the success of postharvest technologies that are applied.

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