mangoes...

...a review

Commonwealth Science Council

MANGOES - A REVIEW

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CHAPTER I

1. INTRODUCTION

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Mango is one of the six major fruit crops in the world, having a world production of over 15 million tonnes per annum. The world demand for mango is increasing annually, particularly from temperate countries where it is rapidly gaining in popularity. However, compared to the information available concerning production, post-harvest treatment and processing of other major fruit crops eg. bananas and apples, there is a dearth of research-backed recommendations for the mango industry. This is because mango has, in the past, received little attention in research or trade.

Mango has been identified by various market studies of the Caribbean Island States (Hrapsky et al 1985; Commonwealth Secretariat Export Market Development Division 1985; Caribbean Farming 1986) as a high potential crop. On many of the islands, therefore, new mango orchards are being planted. It is hoped that it will become one of the major new crops of the region in an attempt to diversify from traditional export commodities (eg. sugar and bananas) for which there is declining market demand. The local and regional demand for mango in this region is also high and mango has nutritional value too, being rich in vitamins A, B & C and fructose, fibre and proteins. Mangoes, however, are highly perishable fruits and therefore suffer much wastage and post-harvest disorders, thereby restricting their marketing potential. Similarly current Caribbean varieties have low yields and irregular bearing and suffer greatly from disease, particularly anthracnose. Technology aimed at increasing production and reducing post harvest losses of mangoes in the Caribbean is undeveloped. Scientific work is required as a basis for the development and adaptation of appropriate technologies which will reduce post-harvest losses of mango, and which will allow for reliable production of fresh fruit of high quality for export. Technologies can also be adopted to local varieties for mango processing where there is a glut of suitable mangoes, or mangoes unsuitable for the fresh fruit market. These technologies must be developed and implemented in order to make this industry a profitable one.

The Commonwealth Science Council recently carried out a study of the mango industry in the Commonwealth Caribbean countries (Prinsley, 1986). In this study, the major problems facing the mango industry in this region were identified. These included:

1. **Post-Harvest Problems**

   i) Anthracnose post-harvest damage, causing huge losses and wastage of mangoes.

   ii) Short shelf life of mango.

iii) No standard indices for harvest maturity or for quality control.

iv) Restricted experience in processing of local varieties.

v) The banning of ethylene dibromide by the USA Environmental Protection Agency as a fumigant for fruit fly on fruit entering USA.

2. **Pre-Harvest Problems**

i) Fruit set and fruit drop.

ii) Irregular flowering and fruiting.

iii) Lack of knowledge concerning nutritional requirements of local varieties.

iv) Lack of standardised, well known cultural practices.

The development of a coordinated collaborative Caribbean research project concerning the solution of these major problems of the mango industry was therefore recommended. This project was planned and developed further at a CSC project planning meeting in Dominica in March 1987.

At this meeting selected experts in the field presented thorough reviews of research done world-wide concerning the major problems identified in this region. These reviews provided necessary background information to further research in the Caribbean and allowed identification of areas where more research was required.

This volume represents the collection of review papers. It is intended as a handbook for the Caribbean scientists involved in the CSC research programme but should also be of interest to other mango researchers and people involved in the mango industry.

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2. MARKETS FOR MANGOES FROM THE CARIBBEAN

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Most of the potential increases in regional mango production will be by export to extra-regional markets (Hrapsky et al, 1985). Little potential for market expansion exists in the small domestic markets of the principal mango producing countries in the Windward Islands. There is, however, limited potential for increased sales of fresh mangoes to Barbados and Trinidad and to hotels in the region for consumption by tourists. Extra-regional markets for mangoes have expanded considerably over the past 8 years, particularly in the UK and France (see Figure 1), the European Community in general (Figure 2), and in the USA (Figure 3).

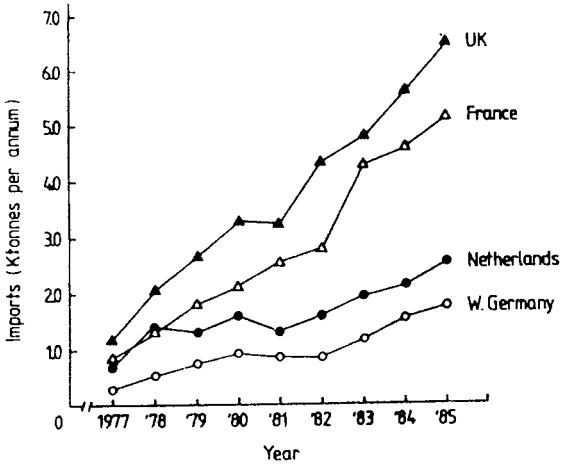

Figure 1: Imports of mangoes, mangosteens and guavas to Europe (where mangoes comprise 95% of the total)

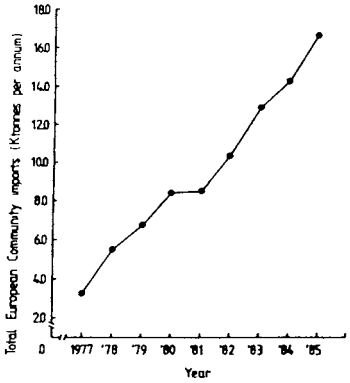

Figure 2: Imports of mangoes, mangosteens and guavas into the European Community (mangoes comprise 95% of the total)

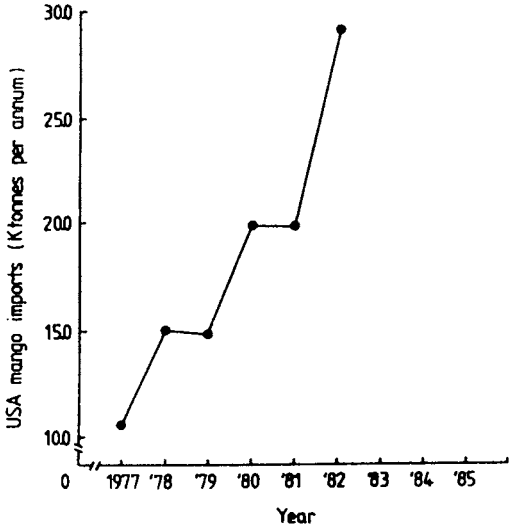

Figure 3: Imports of mangoes to the United States of America

The Western European market

Mango imports into the European Community have increased from 3,181 tonnes in 1977 to 16,830 tonnes in 1985 (see Figure 2). These are likely to continue to increase with larger non-European ethnic populations, more widely travelled European populations (acquiring a taste for tropical fruits) and continued and improved marketing strategies practised by European importers to reach others of the native European population (Fintrac International Ltd 1985; Hrapsky et al, 1985). The largest exporters to the EC are Mexico and Mali, each of which accounted for 14% of EC imports in 1983. In comparison, Jamaica, St Vincent and St Lucia accounted for between 1-2% each of EC imports in 1983 (Nimexe, Statistical Office of the European Communities).

However, with increasing demand for mangoes, it is likely that there will be room too for the increased production possible from many of the Caribbean islands. Three factors must be kept in mind regarding the potential for extra-regional market expansion to the EC.

(1) The expansion to date has mainly been in the 'Florida' varieties particularly those which ripen with a red blush. Of the islands studied, these are only grown in a large (and proven) scale in Jamaica and Belize. It is likely that much of the future demand will also be for those varieties which ripen to a red colour.

(2) Other islands produce largely the Julie mango, the skin of which usually remains green when ripe (although it sometimes unaccountably has a reddish colour). The taste of Julie is recognised by many - mainly West Indian immigrants - to be superior to other varieties. However, marketing promotions are

required so that conservative Europeans who normally 'buy with their eyes' are familiarised with the lack of relationship between skin colour and taste. Some importers in the EC are aware of the potential for Julie mango as a 'super-taste product' for the wider European population and realise the importance of this kind of promotion to the future of an expanded market for Julie mangoes, especially considering the likelihood that the West Indian immigrant market in the EC is already adequately supplied by Julie mango, and demand from this sector is unlikely to increase much more.

(3) Consistent high quality and reliable continuity of supply are essential for successful competition with major world producers for a place in the European market. The availability of a sea freight service by Geest provides a price advantage to Eastern Caribbean exporters shipping Julie mangoes, over the other world producers shipping by air. However, post-harvest research aimed at increasing product shelf-life and maintaining fruit quality on Geest ships over the 10-14 day journey is required to optimise use of this advantage.

The United States market

US mango imports rose from 10,521 tonnes in 1977 to 29,395 tonnes in 1982 (see Figure 3). Therefore, there is also an expanding market for mangoes in the US. However, at present, two major quarantine restrictions essentially close the market to many Caribbean islands:

(1) The restrictions on the use of ethylene dibromide (EDB-see Chapter 4) for the fumigation of mangoes against fruit fly, and the lack of an accepted suitable alternative treatment mean that most of the islands will not be able to export to the USA when the use of EDB is banned.

(2) The mango seed weevil has been found in St Lucia and in Dominica. This, like fruit fly, is a quarantine pest for the US, thereby restricting export of mangoes from these islands to the US.

Until these two problems are solved, it is unlikely that the US will be target market for many Caribbean islands.

The Canadian market

Demand for mangoes is also increasing in the Canadian market altnough import volumes are smaller than in Europe and the US (Hrapsky et al, 1985). As there are no quarantine requirements in Canada, there is potential for export to this expanding market. Additionally, the new CARIB-CAN trade agreement has led to the promotion of tropical fruits from the Caribbean in Canada.

Markets and Seasons

Mango in general is seen as a fruit for summer consumption in Europe, USA and Canada, and therefore is in greatest demand from June to August. This coincides with the West Indian production season from May to September. It, unfortunately, also coincides with the production seasons of other major world producers of mangoes such as Mexico, Mali, Venezuela and India. Thus, although demand is lower from November to April, this demand is not met by the low supplies in this period. Prices are therefore highest at this time. Unless the islands can extend their production season, they will continue to be in competition with major producers.

Markets for processed mangoes

Little information is available concerning the markets for processed mangoes other than juices, nectars and pulps. Mango juice on its own is generally too sweet for European taste but there is a large market for it in the Middle East. However in the European market is is commonly used in fruit-juice blends (of which there is currently a glut). Demand for mango pulp is growing for use in dairy goods and ice creams. There is also interest in other mango products such as dried mango.

Comparison with the Market for other fruit and vegetables

Market studies prepared for Dominica and St Lucia concerning the market for exotic and ethnic fruit and vegetables from Dominica in the United Kingdom, West Germany and the Netherlands both concluded that mango is of most interest to importers in all three countries compared to other commodities investigated. The St Lucia study also identified avocado as an alternative promising export, but the Dominica study found that it has only a limited potential market. Other commodities, such as pumpkin, plantain, christophone, dasheen, tannia and yams are of limited interest, only to ethnic importers (Export Market Development Divison, Commonwealth Secretariat, 1985).

Mango production profitability

Rigorous farm level yield and cost of production data for mango are not available, making financial and economic analysis difficult. However, analysis of the St Lucia Crop Diversification Project farm budget shows financial and economic internal rates of return greater than 50 per cent. These high rates of return suggest that mango production is profitable (Hrapsky et al, 1985).

Price of mangoes

Currently, mangoes are usually air-freighted to avoid the high risk of perishing on long sea voyages. The high cost of air transport adds considerably to the price at which they can be offered. If the technical problems of sea transport could be solved, and shelf-life could be

increased and quality maintained, a cut in unit price would be possible. This lower price level would allow mangoes to become an item of mass consumption, thus leading to a considerable expansion in the market (FAO, 1984).

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CHAPTER II

PRODUCTION

1. A Description of Pre-Harvest Factors Affecting Yield In Mango (Mangifera indica L)

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INTRODUCTION

The countries of the Commonwealth Caribbean have recently initiated programmes to develop mango and other fruit crops for domestic and export markets. Cultivation practices in mango are usually based on general principles of tropical fruit tree culture as there are few documented reports of research conducted on this crop in the region.

In this paper the pre-harvest factors affecting yield in mango are reviewed with particular reference to cultural practices, irregular flowering and nutritional requirements.

DESCRIPTION

Origin and Uses

The mango originated on the Indian sub-continent, and has been cultivated in that region for over 400 years. It has since spread throughout the tropics and has become naturalized in many areas. The mango was introduced to Africa about 1000 years ago, and arrived in the West Indies in the 1700's (Purseglove 1974 ; Cobley and Steele, 1976).

The mango is a popular fruit throughout the Caribbean, although commercial production is limited. Estimated total annual production in the region is approximately 200,000 tonnes, of which 40,000 tonnes (20 percent) is cultivated in established orchards, the major producers being Belize, with Jamica, Trinidad and the Windward Islands producing smaller quantities (Weir et al).

The majority of mangoes are produced from countless seedling trees growing wild or semi-wild, as volunteers, in cultivated areas, or planted in backyard gardens (Weir et al).

Mangoes are consumed primarily as fresh, ripe fruit; but the fruit may also be canned as slices or chunks in syrup, or used in the production of nectars or purees. Over-ripe fruit may be used in chutneys or pickles (Weir et al).

Botany

The mango tree is a large spreading evergreen, with a dense canopy which casts a characteristic deep shade on sunny days. The canopy often consists of a distinct crown of branches, but is often of indeterminate shape with long pendulous branches and no definite crown. The trees range in height, from 10 - 14 m, and may live up to 100 years (Cobley and Steele, 1976).

The leaves are alternate and simple, 12-40 cm long, up to 10 cm wide. The petioles are up to 10 cm long with a pulvinus at their base. The leaves are produced in irregular flushes during which a number of thin, flaccid, reddish-coloured leaves unfold, then become stiff and dark green as they mature (Cobley and Steele, 1976).

The inflorescence is a widely branched, terminal panicle 10-60 cm long, with 1000-6000 reddish-pink or almost white flowers. Both male and hermaphrodite

flowers occur on the same inflorescence, with only about 1-36 percent being hermaphrodite, this ratio varies between cultivars (Cobley and Steele, 1976).

Seedling mango trees begin to bear fruit after 4 - 6 years and production increases until they are about 20 years old, then declines. Production tends to be biennial and fruit take 2 - 5 months to mature. The mango fruit is a fleshy drupe 2.5 to 30cm long, and weighing from a few grams to 2kgs. Shape and size of the fruit may vary greatly between cultivars (Cobley and Steele, 1976).

Ecology

The mango thrives in a wide variety of soils, provided they are not water-logged, alkaline, or rocky; a pH of 5.5 to 7.5 is preferred. Mangoes may be grown at elevations from sea-level to 1330m in the tropics but do best below 665m (Purseglove, 1974).

Mangoes require a rainfall of 750 to 2500 mm per annum, preferably distributed into a distinct wet and dry season. The optimum temperature for growth is 21 to 27°C, and young trees especially cannot tolerate frost (Purseglove, 1974).

FACTORS AFFECTING YIELD

The yield of mangoes is highly variable and depends on the number and size of fruit produced, which in turn is determined by genetic and environmental factors. Genetic factors can only be altered through breeding, however the expression of the genotype can be influenced by environmental factors.

Any discussion of factors affecting yield can be divided into two sections: the first describing genetic factors, and the second describing the effect of environmental factors such as climate and cultural practices, on these genetic factors.

Genetic Factors Affecting Yield

Cultivar

Two main types of mango are generally recognized: the "Indian" and the "Indo-Chinese". The "Indian" types are usually monoembryonic (producing one seedling per seed), and are often highly coloured and fibreless with a distinct aromatic flavour. There are more than 1000 "Indian" type cultivars, included are the more important commercial cultivars, eg. Keitt, Kent, Palmer and Haden (Weir et al). However, the "Indian" type is usually very susceptible to anthracnose.

The "Indo-Chinese" type is polyembryonic (producing more than one seedling per seed), with fibrous, sweet-tasting flesh. The fruit lack attactive coloration and are usually poor bearers, however they are relatively resistant to anthracnose. (but see Thompson Chapter III).

A third type of mango is sometimes described: the "West-Indian" or "South American" type. It is polyembryonic, with fibrous, poor quality fruit, with a distinct turpentine flavour (Hobson, 1969).

The characteristics of several important West Indian cultivars are described in Table 1.

The initial choice of a cultivar will ultimately determine the bearing characteristics of the trees planted, and the response of these trees to subsequent cultural practices.

Flowering and Fruit Set

A mature mango tree in full bearing produces about 1000 infloresences, each with 500 - 6000 flowers. Therefore the potential yield is enormous. However, only 1-36 percent are hermaphroditic, and of these only 15-35 percent are pollinated, and only 0.1 - 0.25 percent reach the harvesting stage (Purseglove 1974; Cobley and Steele, 1976). Fruit drop occurs at all stages of development, and one of the main effects of environmental factors on yield is their influence on flowering, fruit set and fruit drop.

Fruit bud differentiation is thought to be determined by seasonal variations in the carbohydrate/nitrogen ratio and increase or decrease of carbohydrates particularly starch (Singh, 1968). Studies have shown a sharp rise in carbohydrates in shoots prior to fruit-bud differentiation. After flowering the reserve of carbohydrates drops and continues in a depleted stage until harvest. In an "off" year the maximum C/N ratio is reached a month earlier, but the highest value attained is lower than in an "on" year (Singh, 1968).

There appears to be a wide range in the C/N ratio favourable for fruit-bud differentiation in different varieties, and a high C/N ratio is apparently not always the criterion for flower-bud formation. Studies show that while a high C/N ratio and sufficient starch reserve in mango shoots may favour flowering, these by themselves cannot be taken as the decisive factors inducing flowering in different varieties (Singh, 1968).

Pollination is essential for fruit set, and is usually entomophilous. The flowers open during the night and early morning and are visited by short-tongued insects, primarily flies (Purseglove, 1974), but honey bees are also important.

Periodicity

Mangoes are generally irregular bearers, with a heavy crop in "on" years followed by a poor crop in "off" years, a phenomenon known as periodicity in cropping. Periodicity seems to be affected by the age of the tree, with younger trees being able to bear every year. Irregularity usually commences around 10 years of age and is more pronounced in neglected or wild trees (Singh, 1968).

It is generally thought that periodicity of flowering in mango is due to the depletion of food reserves during an "on" year. In addition the tree cannot grow as long as there is fruit on it. Thus the new flush of growth, which in turn produces infloresences, is delayed causing an "off" year (Singh, 1969).

This alternation of "on" and "off" years results in a rhythmic biennial bearing pattern, however various environmental factors such as frost or severe drought, may result in excessive flower or fruit drop turning an "on" year into an "off" year and setting up an irregular bearing pattern. Unfavourable conditions during an "off" year can delay the return of an "on" year, again resulting in an irregular bearing patter (Singh, 1969).

Climate

Rainfall

Mangoes require an annual rainfall of 75 - 250 cm per annum, of which the distribution is probably more important than the actual amount. Mango grows best when at least four months of dry weather occur from flowering to harvest (Mendoza and Suriyapananont, 1984). The onset of the dry period induces a growth check which promotes flowering (Anon, 1974; Anon, 1983).

There is some doubt as to the actual amount of water required during flowering and fruiting. While moisture is advantageous, during the period from flowering to harvest, rainfall promotes flower and fruit diseases. Rain during flowering is especially detrimental since it prevents pollination by insects resulting in heavy flower drop (Jackson et al 1984). In addition, rain, or even heavy dew encourages the flower disease anthracnose (Colletrotrichum gloeosporioides) (Wolstenholme and Mullins, 1982).

In general the fruit develop better in conditions of low atmospheric humidity, which lead to better colour, and decrease the likelihood of disease caused by fungi and bacteria (Mendoza and Suriyapananont, 1984). High humidity favours infection of panicles by powdery mildew (Oidium mangiferae) which results in a drastic reduction in yield (Wolstenholme and Mullins, 1982).

Light

Mango like all green plants requires light for photosynthesis. It is not certain if photoperiod influences time of flowering and season of availability, although flowering is generally initiated during the cool season when days are shorter (Mendoza and Suriyapananont, 1984).

The most noticeable influence of light is the development of the anthocyanin pigment responsible for the red to blue hue on the skin of mature fruit of various cultivars (Mendoza and Suriyapananont, 1984).

Temperature

Exceptionally high temperatures, combined with low humidity may induce parthenocarpy (small seedless fruit). More usually, low temperatures cause pollination failure or can lead to small seedless fruit in some cultivars (Wolstenholme and Mullins, 1982).

Cultural practices

Soil and Fertilizer

As mentioned before, the mango is able to thrive on a wide variety of soils. The presence of a large tap root enables the plant to utilize nutrient and food reserves far beneath the surface, and anchors the plant firmly.

Mangoes do best at a pH of 5.5 to 7.5. On acid soils, dolomitic lime should be applied to bring the pH as close as possible to the optimum of pH 6.8 (Hobson, 1969).

It is felt that periodicity in mangoes is conditioned by nutritional deficiency, mainly of nitrogen and proportionate increase and decrease of nitrogen in the tissues may be the main stimulus for growth or flower formation respectively (Singh, 1968). Excess nitrogen delays flowering, and contributes to the physiological disorders of "Soft Nose" and "Jelly Seed" (Mendoza, Suriyapananont, 1984).

Young trees require at least four applications per annum of a balanced fertilizer, such as 10-10-10, during the first two years, beginning with 0.1 kg per application in the first year (Hobson, 1969; Weir, et al). A rough guide to the quantity of fertilizer required is 0.5 kg per tree per year for every year of age of the tree, up to a maximum of 7 kg for older trees (Hobson 1969).

Once trees begin to bear, the nitrogen content of the fertilizer should be reduced to limit growth and stimulate bearing; types of fertilizer recommended include 16-9-18, 4-1-6 or 3-1-5 (Hobson 1969, Weir. Hobson (1969) recommends that bearing trees should always suffer from a slight nitrogen deficiency.

The frequency of fertilizer application should be reduced to twice per year for mature trees. The first half should be applied as soon as the first panicles are visible, and the other half as soon as the crop has been harvested (Hobson, 1969). Application of fertilizer should be followed by heavy irrigation where possible.

In addition to NPK fertilizer, 1.5 kg of magnesium sulphate per tree can be applied to mature trees. On calcareous soils, annual additional sprays of trace elements, especially zinc should be applied (Hobson 1969).

Increasing potassium and calcium levels decreases the likelihood of physiological disorders (Hobson 1969). The application of potash to trees with a high nitrogen level improves the colour and flavour of fruit. Potash deficiency is associated with small fruit and poor quality while excess potash causes increased physiological breakdown of fruit, due to calcium deficiency caused by high levels of potash in the soil (Mendoza and Suriyapananont, 1984).

Phosphorous deficiency is uncommon in mango, since the requirement for this element is low.

Spacing

The mango is intolerant of crowding and once the orchard becomes too dense, bearing is limited to the upper canopy (Anon, 1974). Crowding decreases the amount of light reaching the inner foliage, and creates a humid micro-climate conducive to disease. Trees may be planted at an initial spacing of 10m x 5m to fully utilize orchard space, however, well before crowding occurs trees should be thinned to a spacing of 10 m x 10 m.

Irrigation

Irrigation, where necessary, should commence only after the onset of flowering, and should cease after harvesting, a minimum of seven weeks (Mendoza and Suriyapananont, 1984; and Hobson, 1969). Infrequent heavy irrigations, penetrating to about 1.2 cm are preferable to frequent light irrigations (Hobson, 1969). It has been found that fruit from irrigated trees are up to 13-23 percent

heavier and bigger than those from non-irrigated trees (Mendoza and Suriyapananont, 1984).

Deblossoming

Deblossoming is the complete or partial removal of flowers or young fruits in an "on" year, in order to increase flowering the next year, thus resulting in a fair crop every year. Food reserves or any flow-inducing substances are conserved by removal of the infloresences in the early stages. Deblossomed shoots, instead of developing panicles and producing fruits, put out new vegetative growth with flowers and fruits the next year (Singh, 1968).

This technique has proved successful in biennial bearing varieties of apples, but its success in mango is not so well documented. The response of mango to deblossoming seems to be a varietal feature. In addition, the response is less marked in over-vigorous or vigorous trees. Severe deblossoming of up to half the tree seems to be necessary in order to get a satisfactory response, but more extensive studies are needed in this area (Singh, 1968).

Ringing

Flowering of mango trees in "off" years and increased flowering in "on" years can be successfully induced by ringing the branches. Ringing is best done by the means of half inch wide cuts immediately after harvesting, and the effect on flowering is seen during the next blooming. There is no residual effect. However, ringing as a regular practice is not recommended except in special cases, such as forcing of blossoming in over-vigorous trees; and the practice can be detrimental to older trees (Singh 1968).

Pruning

Pruning of mature mango trees is not usually required, nor is it recommended, however, training of young plants is essential in order to give them proper shape. This is especially true when the graft has branched too low. At least 75cm of the main stem should be kept free from branching, and the main branches should be spaced in such a way that they grow in different directions, and are at least 20 -25 cm apart. Branches which exhibit a tendency to crossing or rubbing each other should be removed in the pencil thickness stage.

Pruning of mature trees should be confined to the removal of diseased, pest-infested or dried shoots or branches (Anon, 1983).

Smudging

It has been found that mango trees can be made to flower at any time of the year by smudging, providing the tree is in a proper condition and the practice is common in the Philippines (Singh, 1968). During smudging the trees are smoked day and night for about a week from a specially prepared fireplace. Thereafter light fires are made morning and evening for a month or until the trees bloom.

There are conflicting reports in the literature as to whether it is the smoke/CO_2

or the heat which causes flowering (Singh 1968). However, more recently it has been suggested that it is the presence of ethylene in the smoke that induces flowering (Bondad, 1976).

Smudging is most effective when the last growth is well matured and the terminal buds are well formed. Although the method is successful in forcing flowering, it is laborious and expensive.

Bagging

Bagging is a technique that provides a physical barrier between individual fruit and the immediate environment, thus preventing contact between the host and the insect or fruit. Fruit are usually bagged 55 - 60 days from full bloom, and newsprint is the traditional bagging material in the Philippines where the practice is common. Polyethylene bags were found to be unsuitable. Bagging has been found to markedly reduce damage caused by leaf hoppers, anthracnose and stem-end rot (Mendoza and Suriyapananont, 1984).

Diseases and Pests

Mangoes are subject to attack by pests and diseases at all stages of development. Without an effective pest and disease control program, the harvest is considerably reduced. Major pests in the Caribbean region include fruit flies (Anastrepha spp.), scale insects, thrips and slugs. Major diseases include anthracnose (Colletotrichum gloeosperoides), powdery mildew and seedling leaf blight (Weir et al).

The appropriate insecticides and fungicides can be used to minimize the damage caused by pests and diseases, respectively. To be effective, control measures should be applied directly to the portion of the tree to be protected and during the weakest stage of development of the pest and disease (Jackson, et al 1984).

Chemical induction of flowering

In recent years, researchers have tested a wide range of growth regulators and other chemicals in an attempt to increase flowering in mango, and break the cycle of "on" and "off" years. The chemicals with the greatest promise are ethephon and potassium nitrate.

Ethylene in the form of ethephon can be used to induce flowering (Bondad, 1976) however, results are variable, and severe leaf abscission can occur when too high concentrations are used. Chacko et al (1974), based on experiments conducted in India, reported 200 ppm ethephon could be used to induce flowering and fruiting during the "off" year in the notedly biennial cv. 'Langra'. Higher concentrations of ethephon viz. 500, 1000 and 2000 ppm, induced moderate to heavy leaf abscission. Consecutive applications of 200 ppm ethephon for a period of three years did not cause any decline in the yield or vigour of treated trees.

Potassium nitrate can modify the flowering behaviour of mango, making it possible to produce fruit every year. In addition, the use of KNO_3 can advance the flowering and fruiting periods of mango by several months, and can induce

flowering of trees which remain vegetative, but are beyond normal bearing age (Bondad and Linsangan, 1979). The same authors report that spraying with concentrations of KNO_3 at rates as low as 10g/litre, induced 100 percent flowering in several Phillipine cultivars, within 7 to 14 days after spraying.

SUMMARY AND CONCLUSIONS

Mangoes are notorious for their irregular bearing pattern, and fluctuations in yield. The yield of mangoes is determined by a wide range of pre-harvest factors which may be classified according to (i) genetic or inherent factors such as cultivar, flowering characteristics and periodicity of cropping; (ii) climatic factors, such as rainfall, light and temperature and (iii) cultural practices such as fertilizer, spacing, irrigation, flower induction by various means and pest and disease control.

Genetic factors may be manipulated through breeding and through selection of appropriate cultivars for local conditions and potential markets and ongoing selection/screening of new cultivars is required.

Climatic factors are difficult to influence, but may be used to advantage by careful site selection.

Cultural practices are most amenable to change, and exhaustive research is required to determine the practices appropriate to the region, which will result in increased yield. The most immediate need is probably in the area of fertilizer use, in terms of amounts required, timing and composition.

Another promising area which could yield positive results in the near future is the use of growth regulators to induce flowering and even out bearing.

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2. A WHOLE PLANT APPROACH TO PRODUCTIVITY RESEARCH FOR MANGO

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CONTENTS

INTRODUCTION

Tree crop productivity research which is directed to cultivar selection and the establishment of field management practices has been traditionally discipline orientated. Findings are often related to specific situations and can be incompatible with other research results when developing crop management packages. This is because research commonly examines treatment effect on yield without fully investigating and understanding the interplay of the plant's response and the interacting environment. This paper provides a whole plant approach for productivity management research which assures compatible packages that can be developed far quicker than traditional methods. The research is based on understanding the plant's interaction with the environment when challenged or manipulated with treatments making the results far easier to apply widely and to be understood and used by the farmer.

The term productivity encompasses both fruit yield in numbers and weight and the fruit's market quality in a storage and transport performance and eating acceptability sense. The productivity research approach for mango is based on the morphological and physiological nature of a perennial evergreen tree. The tree is a complex structure highly influenced by the distinctive environment in which it grows. The environment varies through a calendar year in a common pattern for a given locality known as the weather or annual climatic cycle. Similarly the annual growth and development pattern of the evergreen mango tree responds to the environment and follows a distinctive cycle which can be identified. This is known as the annual plant phenological cycle.

As the weather pattern in each locality varies from year to year so the tree similarly responds, giving variation in the plant cycle. Progressive stages of the plant cycle interact and have influence over succeeding stages of the cycle throughout the year. An example is the impact of vegetative growth on the level of the subsequent flower development. This interaction can have an influence extending twelve months with variation in any stage being felt in crop production.

The paper establishes the relationship of the mango with other tropical fruits with respect to the mechanisms of productivity control. In addition an understanding of the phenological cycle of the mango and its response to the environment is described. On the basis of this model, an outline of how this understanding can be used to more effectively design and conduct research related to cultivar selection, nutrition and irrigation management, pruning and use of growth and flowering regulators is provided.

Genotype Control of Crop Productivity

Research in other crop species is used as a guide or stimulus for work in mango. To make use of these results we need to be aware of the productivity controlling factors, for those crops and mango, which are either similar or different. Because of differences only some research is applicable with some crops being more relevant than others.

The commercial fruit crops of the tropics are drawn from a broad range of plant families. The actual species in use have different plant structures and growth habits. Productivity is related to how the flowering and fruiting organs are produced on the plant in position and timing with respect to the vegetative,

mainly leaf development. This relationship is due to the fact that the commercial product of the tree is the fruit which is primarily developed from carbohydrates generated by and dependent on the photosynthetic capacity of the leaves. This is somewhat complicated in that in some species, total fruit development is dependent on current photosynthesis while others are variably dependent on both current and stored carbohydrate. This storage occurs in both the limbs and root system but is initially derived from the leaves. An example of the grouping of species is given by the limited list set out in Table 1. Another is provided by Verheij (1986). Plants within the subgroups have similar control mechanisms for productivity - hence avocado, lychee and mango are aligned.

Table 1 **The grouping of species with respect to productivity control mechanisms.**

EVERGREEN SPECIES

UNBRANCHED PLANTS	BRANCHED PLANTS
TERMINAL FLOWERING ◄	► TERMINAL FLOWERING
. Banana	. Avocado
. Pineapple	. Mango
AXILLARY FLOWERING ◄	. Lychee
. Papaya	► AXILLARY FLOWERING
. Coconut	- Present Seasons Wood
	. Orange
	. Guava
	. Passionfruit
	- First & Second Year Wood
	. Coffee
	. Macadamia
	► CAULIFLOROUS FLOWERING
	. Cacao
	. Jackfruit
	. Durian

DECIDUOUS SPECIES

BRANCHED PLANTS

AXILLARY FLOWERING ◄

. Custard Apple
. "Subtropical" Peach
. "Tropical" Apple

Some of the key differences between subgroups are as follows. The unbranched evergreens have greatest yields where near maximum vegetative growth is maintained throughout the year related to continuous favourable temperature, water and nutrient conditions. These plants have a consistent root to shoot

ratio, dry matter yield is in direct relationship to total plant weight and productivity is mostly dependent on current photosynthesis. Yield is consistent and predictable provided the above environmental factors are maintained.

The branched evergreens differ significantly within the group depending on the position of flowers. As a group with the exception of the cauliflorous plants they perform best where there are distinct seasonal periods of vegetative growth, dormancy and flowering. This is associated with annual climatic patterns related to hot and cool or wet and dry periods. Commonly highest performing plants have one harvest period in the year. The root to shoot ratio fluctuates in relation to the other parts of the plant. Yield is variably, (including negatively) correlated with total plant weight and hence vegetative growth. Yields are also irregular to biennial in nature, being very difficult to forecast. Productivity is dependent on both stored carbohydrate and current photosynthesis.

A good example of differences between subgroups of branched plants is that avocado productivity requires active summer vegetative growth while late winter spring growth, in association with flowering, is competitive and can reduce yields. With orange the summer vegetative flush only adds to the size of the tree and not productivity while the amount of spring leaf growth associated with flowering is positively correlated with yield. The cauliflorous crop Cacao performs best with small bursts of vegetative growth through the year although it can also perform well under a more defined seasonal pattern.

The management of the branched group differs greatly from those of the unbranched. The management of nutrition, irrigation and growth regulators between the branched subgroups is markedly different making the relevance of research results across subgroups very difficult to interpret.

The differences between groups and subgroups can best be understood by an appreciation of the differences between their annual phenological cycles.

The Annual Phenological Cycle of Mango

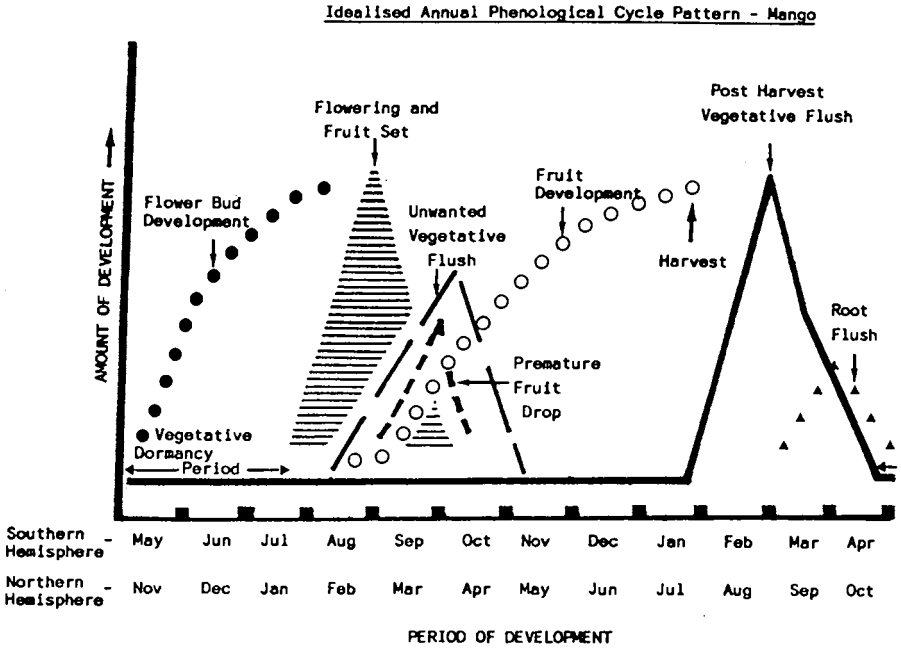
The phenology of mango relates to the periodic stages of the plant's visual development. On an annual basis this refers to the seasonal cyclic changes of vegetative growth, root growth, flower and fruit development.

In a given locality a species follows a "normal" phenological cycle. In this sense "normal" refers to that phenological pattern which is characteristic of a tree which has consistently high yields. It is known that in a year when a tree varies markedly from this normal pattern, yields are reduced or are non existent. This pattern is a function of the genotype as influenced by the local environment. The "normal" pattern reflects the ideal annual seasonal climatic pattern for the genotype.

The phenological pattern is strongly under environmental control, hence it does change somewhat from year to year. The pattern is also advanced or retarded in calendar time from locality to locality with respect to the commencement of the seasonal changes, particularly the rise and fall in temperatures or onset of wet or dry season. As cultivars within species have different vigour levels and variable responses to temperature the cycles vary between cultivars. Hence phenological cycles must be defined on a cultivar by locality basis when researching a crop for a country and indeed districts of that country where there are variable environments.

For this paper an idealised phenological cycle for mango, Figure 1, is used as a basis for discussion and for the associated research considerations. An example for avocado is given by Cull (1986). The graphical lines define the amount of development occurring at a given time (vertical axis) and the month in which it occurs (horizontal axis).

Figure 1



The idealised cycle presented is for a sub-tropical environment where the season and plant cycles are well defined. With such a cycle annual flowering and yields will be consistent. As you advance into the tropical zone where plant development is not so much under seasonal temperature control, but the onset of wet and dry seasons, the patterns are more variable due to locality and the inconsistent nature of rainfall as compared to temperature. Here the application of the phenological model is more difficult but the principle still applies which will be explained as follows.

Casual observers are often unaware of the defined cyclic patterns of branched evergreen trees, the large amount of growth and development that occurs with each vegetative flush or flowering, but more importantly they do not register the massive movement of plant reserves at these given times. It is this build up and effective redistribution and use of these reserves by the respective cycles of the tree which controls productivity. If the reserves do not have a period to accumulate or they are used in the development of non-productive tissue then productivity suffers.

To gain any understanding of productivity control of trees in each country and to establish a research base for mango an accurate record of the annual phenological cycle is required. As research progresses this is required for each of the principal cultivars under test and for each significantly different environment where mangos are to be grown in the country. It is important to identify the pattern which best and most consistently correlates with yield. From this a "normal" pattern for each locality is established. If yields are not high or those expected for a cultivar then this indicates that the environment is preventing that cultivar from settling into its required pattern to give good yields. This optimum pattern for that cultivar may be identified in another locality or another country.

The high yields associated with the normal cyclic pattern described in figure 1 are achieved because of the following. The mango produces its flowers on the terminals of the previous vegetative flushes, ideally those occurring soon after the harvest of the previous year's crop. They can be borne on older flushes than this (up to two years old), but such instances are on lower yielding, erratic bearing trees. The flowers dominate the terminals and if fruit or fruits are set then vegetative growth from that terminal will not occur until after the crop is harvested. The vegetative buds arise axillary at the base of the flowering panicle which abscises or is removed with the fruit allowing the vegetative growth to develop. At fruiting time those terminals which do not flower can and will develop vegetative growth. Also if flowers fail to set or fruit drops prematurely, this means no fruit are being carried on the terminals and they can develop vegetatively.

With this pattern the vegetative growth occurring after fruit removal provides the effective leaf area by leaf replacement and renewal of the photosynthetic capacity of the tree. This vegetative cycle ceases in April/October (figure 1) with maturation of the leaves. The plant remains visually dormant for three months during which time the plant lays down carbohydrate reserves and it is believed, reorganises its growth regulatory control to stimulate flower initiation and flower development. This process is little understood but it is thought that there is a need for the development of a certain carbohydrate concentration threshold in the terminal tissue plus some specific level of growth regulator or growth regulator trigger to stimulate flowering. The key point to register is that both these factors depend on a vegetative dormant period, flowering is commonly correlated with terminals which are healthy and have been dormant for 2 - 3 months and where temperatures are satisfactory for panicle growth.

These requirements are easily met in the very seasonal subtropical environment. Closer to the tropics, temperature control is less significant and the ability to achieve terminal dormancy for 2 - 3 months depends on the occurrence of sufficiently long dry periods. Under these conditions the actual cycles can become erratic. This is one reason why relatively dry localities with defined seasonal rainfall patterns are considered better for mango production. Here the ideal situation is where a 3-5 month dry period is followed by storm rain to stimulate flowering, and good ground water or irrigation is used to develop the crop. The wet season should start with harvest or shortly after to push the vegetative phase and thus complete the annual cycle.

In the tropics where temperatures are ideal for growth (vegetative or flowering) at any time of the year, trees often develop different phenological patterns between separate trees and within one tree, due to spasmodic dry and wet periods. On a given tree, flowers, maturing fruit and vegetative growth can be

seen at one time. This pattern is seen in citrus in the tropics but it is claimed that oranges following such an erratic pattern have an annual total yield significantly less than that achieved in a subtropical area with one crop. The spread of fruit maturity is an advantage for local markets but conflicts with the organisation of a commercial large-scale crop and the development of an export market.

Cultivar vigour plays a large part in the response to applied water. Very vigorous cultivars such as Tommy Atkins are reported to always stay vegetative in wet tropical locations, only seldom bearing fruit. On the other hand Julie with its lower vigour, almost dwarfing character, obviously can more regularly hold dormancy long enough, at least on part of the tree, to initiate flowering. This low vigour character could be one reason for the historical widespread adoption of Julie in the Caribbean region.

Other performance characteristics of a mango cultivar can be understood by a knowledge of its phenological response to the local environment. Where some terminals fail to flower or carry fruit and do grow vegetatively in conjunction with other flowering/fruiting terminals there is competition for plant reserves. If mango reacts like avocado and lychee, the other members of its subgroup, such competition will lead to increased fruit drop and lower yields because vegetativeness has a stronger draw on reserves than fruit. In subtropical areas late maturing fruit cultivars which carry good crops have only a short period to grow vegetatively before low winter temperatures induce dormancy. Such trees have low annual growth rates, giving stunted trees with low leaf area canopies. Such cultivars have to be planted at close spacings to achieve satisfactory returns per hectare and their actual productivity can be retarded and in some instances biennial bearing develops. Early flowering cultivars in cool areas can have pollination problems with small parthenocarpic fruit developing which have no commercial value.

Research Approach

The application of the phenological cycling approach to research requires two stages of work. The first is to define the base model for future work. This is done by identifying, recording and defining the "normal" cyclic pattern for each significant event in the environment under study.

The second stage is directed to studying methods of manipulating the plant so it can be made to conform as closely as possible, under a range of conditions, with the optimum normal pattern of assessing if and how other tree management procedures, such as pruning influence the cycle and hence productivity.

Preferably, work in the first stage uses research sites in plantations of known high performance. Alternatives are less formal plantings or if no plantings are available then traditional varietal research plots have to be established. At least three sites representing different environmental conditions and two cultivars are used. Monthly recordings of the phenological cycle of 10 trees of each cultivar (where two are used) per site are made. The period over which each feature extends for its development and the pattern and degree of development within each stage is measured. If practical leaf and soil nutrient analysis are also monitored through the year to provide additional basic data. By step-wise multiple regression analysis the features (ie amount of vegetative flush or length of vegetative dormancy) of the phenological cycle and their relevant degree of

development can be correlated with their influence on yield and quality. By this analysis the key features of the cycle and their required level of development are identified and the "normal" cycle established. The status, or degree of development, of these key features can be used as a predictive measure of potential yield. The optimum status being equivalent to maximum potential yield.

With this basic phenological cycle by productivity relationship, cultivars can be more reliably selected for trial in new sites of known environment. In trial sites more rapid and meaningful evaluation of cultivars can be made with respect to the environment using their adherence to the normal cyclic pattern for that locality as a selection criteria. Crop yield losses to pest, disease or climatic disaster do not negate totally a year's results. In addition it is feasible that meteorological records may be used to develop 10 or 20 year crop reliability predictions.

Second stage research, using replicated designs, sets out to test treatments which have potential to manipulate the cycle. Treatments are timed to influence specific stages of the cycle and treatment effects are measured as changes in the status of these stages and their variation from the "normal" pattern coupled with final harvested yield and quality measurements. Correlations between the status of stages and yield and quality further enhances the understanding of the "normal" cyclic pattern of the cultivars under test.

In the wet tropics where cycles are erratic the major manipulation aim is to bring the plant under control and force it into some form of cycling with emphasis on establishing significant dormant periods. In this instance locality or site selection for growing mango could be the key to success. Areas which do have observable "dry" periods or where soils have low water holding capacity are those where useful control may be achieved. Treatments which reduce vegetative vigour such as cincturing, growth regulators, or low nitrogen rates should be considered. The plant is however dominated by the environment and if control is to be reliably achieved with treatment, the cycles, no matter how weak, will have to be monitored so treatments can be timed to achieve a synergistic rather than antagonistic effect.

Nutrition is the major manipulator of productivity commonly used. Experience suggests that nitrogen is the major manipulator in branched evergreen trees and initial work should concentrate on this element. The required status of the other elements both major and minor can be determined by monitoring leaf nutrient levels in high yielding orchards as suggested above, in association with the first stage work. Using these results and optimum levels reported in the literature a fair estimate of the optimum leaf range for each element can be defined. Experience has shown that the range over which productivity is not influenced is wide and is readily maintained in practice. The principle of management is then based on yearly leaf analysis and through normal soil reserves or application of a designed supplementary fertiliser mixture the elements are kept within the optimum range. If optimum levels cannot be achieved research will be needed to assess rates, by soil types, by environment to understand how leaf levels can be adjusted to the optimum range. Yield type research may not be necessary.

Research with the manipulators such as nitrogen, water, growth and flowering regulators is aimed at specific stages in the cycle. Value for money is more likely to be achieved by applying nitrogen to stimulate the vegetative flush after fruit removal or produce more vigorous flowers at flowering. Nitrogen could

however decrease productivity by shortening or interfering with the dormancy period prior to flowering or increasing the vigour of vegetative flushes which occur concurrently with flowering and result in excessive fruit shedding. Research treatments in nitrogen and water should be designed to produce low, medium and high vegetative vigour levels and timed to influence important phenological stages of the crop. Results are recorded as impact on the development of these stages and yield and quality.

Flower regulator work is timed in conjunction with dormancy periods. Limited experience suggests that the regulators only enhance the dormancy effect and have their major benefit where length of dormancy is limited or borderline. Such regulators applied at the commencement or middle of a major vegetative flush are unlikely to have an effect. The concept to follow is to time treatments with respect to stages of the cycle and not calendar time and record responses in the cycle even at the expense of neglecting detailed yield results (ie yield estimated). A better understanding of treatment timing and response level will be forthcoming. Similar principles apply to the use of growth regulators and cincturing with respect to developing or extending the dormancy period.

Research in such cultural practices as pruning can also be related to its likely impact on the plant entering an unwanted extended vegetative phase. This phase can last for years at the extreme or interfere on a shorter scale with length of dormancy periods or fruit set stages. Cultivar reaction to pruning will vary and their reaction will determine how applicable pruning is for each cultivar. One could expect less vigorous cultivars to be more receptive to pruning.

Field research and marketing

It should be acknowledged that fruit at harvest is at its peak with respect to its ability to store, transport and be acceptable to the consumer. Post harvest treatments can only hold this peak or lessen the rate of decline. Field management and hence research establish the level to which the peak market quality rises at harvest and hence the ultimate success of the marketing chain.

Although reference in this paper has been mainly limited to yield for brevity the phenological cycle approach to research does also relate to fruit quality. Quality aspects such as fruit size, colour, texture, total soluble solids and sugar levels, all can be related to the competition and redistribution of carbohydrate reserves to the various stages of the cycle. Excess vegetativeness at the wrong period is most competitive in this regard. Mineral nutrient content and its relation to storage life can be monitored and managed using the nutrition research approach described in the paper.

The integration of pre- and post-harvest research is the ideal approach to assuring quality success in the market place.

Extension of Research Results

As all results can be related to a diagrammatic representation of the plant (Figure 1) and its responses, farmers can more readily see and understand in the field the application of the research findings and their implications to the long term cycle and performance of mango in commercial management. Because of this ability to see the technology in visual plant terms, adoption of research

results is high, and there is better use of a fuller integrated crop management package.

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CHAPTER III ANTHRACNOSE

THE DEVELOPMENT AND ADAPTATION OF METHODS FOR CONTROL OF ANTHRACNOSE

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CONTENTS

INTRODUCTION

Anthracnose is the most important disease of mangoes throughout the world and is caused as a result of infections by the fungus Colletotrichum gloeosporioides (Penz.) Sacc. There are two recognized forms of the conidial (asexual) stage of the fungus, C. gloeosporioides variety gloeosporioides and C. gloeosporioides variety minor. The latter is regarded as the pathogen of mangoes (29). The sexual state of the organism, Glomerula cingulata has not been shown to contribute to the infection cycle for anthracnose. The fungus attacks flowers, twigs, leaves and fruit, which results in typical dark brown necrotic irregular shaped spots on leaves which may also develop a curled margin. Infected twigs may die back and become cankerous while flowers turn black and are shed leaving a bare panicle stalk. Fruit which are affected in early stages of development will usually turn black and fall to the ground. Infections of more mature fruit can show as black, slightly sunken spots from pinhead size to blotches covering most of the fruit surface. Fruit which are apparently free from the disease at harvest may have latent infections in the form of subcuticular hyphae and appressoria which may cause subsequent development of lesions as the fruit ripens. Latent infections may also occur in lenticals. These lesions can coalesce and may cause the fruit to become completely rotten.

CONTROL OF ANTHRACNOSE IN THE FIELD

Orchard hygiene may help to reduce levels of infection and dead and discarded material should be removed and burnt. The development of the disease in the field is encouraged by damp conditions. It is, therefore, a more serious problem where trees are planted in humid valleys or away from prevailing winds or where there is a high rainfall or high ambient humidity. The spores can be spread by rain, particularly from infected upper branches of tall trees which are difficult to spray effectively.

It is, therefore, essential in areas where anthracnose is a problem to have an effective spray programme in order to maximize fruit yield and minimize subsequent post-harvest fruit losses. In comparison between copper fungicides in Florida (18) it was found that either cupric hydroxide at 2.4 g per litre or tribasic copper sulphate at 3.6 g per litre were the most effective treatments when applied with the organic sticker Nu-Film-17 at 0.125%. The sprays were applied at monthly intervals at about 57 litres per tree starting when the flower panicle was 4 to 5 cm long, which involved 12 sprays in total. Subsequently, McMillan (19) found that benomyl at 0.3 g per litre with Triton B1956 at 0.15 ml per litre gave very good anthracnose control. This was also applied at 57 litres per tree beginning when the flower panicles were 4 to 5 cm long at monthly intervals until 30 days before harvest.

Barmore et al (3) found that benomyl at 0.3 g per litre plus Vapour-Gard was the more effective treatment for anthracnose control, than either benomyl plus Nu-Film-17 or benomyl plus Triton. In Australia Grattidge (12) recommended mancozeb (800 g per kg) at 2 g per litre sprayed weekly during flowering then monthly until harvest to control anthracnose on mangoes in the field. He also found that in a wet season this spray programme increased fruit set many times. In experiments in Mexico (11) it was found that cupric hydroxide or captafol gave good control of mango anthracnose giving 62% and 43% healthy fruit respectively at harvest compared to only 7% on untreated. The spray programme was every 12 days throughout the season starting one month before

flowering. In Brazil, Donadio (9) recommended 15 sprays starting one month before flowering and continuing until harvest. Fungicides recommended were copper, mancozeb, ferbam, captafol, benomyl, maneb and thiabendazole. Medcalf (20) in Sao Paulo recommended mancozeb at 0.15 to 0.25% and dinocap at 0.03% applied 45 to 60 days before flowering and continuing to November with 10 applications in total. Fruit from this treatment had 66% of exportable quality compared to only 2% for untreated. In Florida Mitchell (21) recommended 25 applications of benomyl starting just before flowering and continuing right up to harvest. Mancozeb, chlorothalonil and ferbam were shown to be equally effective as field sprays against mango anthracnose in Florida (38). Zineb, maneb or captan applied at weekly intervals during flowering, then at monthly intervals, gave adequate anthracnose control (29). In studies in the Philippines field sprays with mancozeb or copper were superior to either captan or zineb (31).

Disease control programmes used on mango farms in Sao Paulo in Brazil were generally to start spraying about a month before flowering with one or two sprays, then continuing spraying through the flowering period; commonly every 15 days. After flowering, spraying was continued to just before harvesting. Different growers had different spraying frequencies, but mostly they were every 20 days. However, the intervals depended on weather conditions and growers inspected the crop at frequent intervals and decided subjectively when to spray depending on the condition of the crop and the weather. The fungicides used were benomyl, thiophenate methyl, zineb, maneb and various copper formulations (41). Copper has both insecticidal and phytotoxic properties and, therefore, if applied during flowering can reduce fruit set. The pre-harvest application of benomyl besides controlling anthracnose disease can enhance the colour of some cultivars which are not normally highly coloured (6).

VARIETAL RESISTANCE OF MANGOES TO ANTHRACNOSE

In a review (29) the varieties Carrie, Carabao, Florigon, Tommy Atkins and Saigon were listed as resistant to anthracnose, Kensington Pride as moderately resistant and Willard, Neelum Manoranijan as very susceptible. Some of the varieties listed above as resistant are listed elsewhere as susceptible (29, 38).

Akamine (1) stated that although there is some varietal difference in susceptibility to anthracnose disease in mangoes, all varieties are attacked. Hatton and Reeder (14) compared the percentage of fruit which developed anthracnose in 9 mango varieties in Florida. The study was only during one season, but there is some indication that levels on Zill and Tommy Aktins were less than the other varieties and that Sensation was particularly susceptible (Table 1).

Campbell (7) observed that Tommy Atkins appeared resistant to anthracnose. These observations were not confirmed by Evans and Thompson (10) who found that hot water fungicide treated Tommy Atkins had no anthracnose compared with 17% for untreated fruit after transport between Jamaica and Britain for 15 days at 13°C.

Table 1: **Percentage of ripe fruit with anthracnose.** Comparison between untreated or dipping for 5 minutes at 55°C after Hatton and Reeder (14).

Variety	Treated	Untreated
Irwin	4	34
Keitt	1	28
Kent	3	39
Lippens	1	47
Palmer	1	37
Sensation	28	62
Smith	15	46
Tommy Atkins	13	15
Zill	0	13

Murthy and Rao (27) described an interaction between mango varieties and fungicide treatment. Post-harvest fungicide treatments which significantly reduced anthracnose levels in Alphonso had no effects on levels on Totopari.

POST-HARVEST CONTROL OF ANTHRACNOSE

Post-harvest control of anthracnose disease usually refers to treatments which can kill the latent fungal infection without damaging the fruit. These infections are in the form of spores which germinate in moisture on the fruit surface during their development in the field. Appressoria are formed at the end of the germ tube within several hours of germination. These appressoria adhere strongly to the fruit surface and are much more resistant than spores. Some of them remain in this form, while others produce slender hyphae which grow through the cuticle and outer wall of the epidermal cells to form a mass of hyphae. Further development of the pathogen may be prevented by the resistance of the immature fruit. At this stage there may be no external symptoms of the infection. These latent infections usually remain viable for several months and give rise to anthracnose disease symptoms when the fruit begins to ripen (13).

Methods which have been successful in controlling these latent infections are chemical treatments, hot water treatment and gamma irradiation. Some of these treatments have been found to be most effective when applied in combination with others. Their use may be governed by legislation with maximum tolerance levels for chemical residues. Some treatments are banned entirely in certain countries.

The following fungicides have been shown to be effective post harvest against anthracnose either alone or in combination with other treatments:

benomyl methyl 1 - (butylcarbamoyl) benzimidazol - 2 - ylcarbamate

thiabendazole 2 - (thiazol - 4 yl) benzimidazole

thiophanate-methyl dimethyl 4, 4[1]-(O-phenylylene) bis (3-thiophanate)

imazalil 1 -(allyloxy - 2, 4 - dichlorophenylethyl) imidazole

etaconazole 1 - [2-(2,4-dichorophenyl)-4-ethyl-1, 3-dioxolan-2-ylmethyl] - 1H - 1,2,4 - triazole. (CA).

iprodione 3 - (3,5 dichlorophenyl) - N - isopropyl - 2,4 - dioxoimidazoldidine - 1 - carboxamide

captan N - 4 - (trichloromethylthio) cyclohexene - 1,2 - dicarboximide

kasugamycin [5 - amino - 2 - methyl - 6 - (2,3,4,5,6 - pentahydroxycyclohexyloxy) pyran - 3 - yl] amino α-iminoacetic acid

Fungicides Alone

In the studies of mango anthracnose it was found that the disease could be reduced if fruit were dipped in benomyl at 600 or 1000 ppm plus a surfactant (31). The treatment was more effective if applied within 24 hours of infection. Bleinroth et al (4) also demonstrated good control of mango anthracnose by dipping fruit for 2 minutes in 2000 ppm benomyl plus a surfactant. Sohi et al (36) reported good control of anthracnose on mangoes dipped in either 500 ppm benomyl or 900 ppm thiabendazole. They found no difference in effect between a rapid dip or a ten minute soak. Dipping Alphonso mangoes in 500 ppm benomyl significantly reduced infections and hot water did not enhance this effect (27). Contrary to these results Spalding and Reeder (37) found no reduction in anthracnose levels when mangoes were dipped in 1000 ppm benomyl or 1000 ppm thiabendazole. Muirhead (22) also found no effect of cold water dips with benomyl on mango anthracnose. He suggested that it may be due to the inability of the fungicide to penetrate the thick cuticle of the fruit.

In recent studies of fungicides which would give good control of anthracnose in cold water, it was found that dipping in 0.55 ml per litre prochloraz for up to 2 minutes significantly reduced the level of anthracnose compared with untreated fruits, but had significantly higher levels than fruits dipped in 1000 ppm benomyl at 52°C for 5 minutes (25).

In a recent study of the effects of fungicides on in vitro control of C. gloeosporioides, tolerance to benomyl and cross tolerance to thiabendazole and thiophenate-methyl was found. No tolerance to either imazalil or etaconazole was found and the latter was the most effective in controlling C. gloeosporioides, both in vitro and in vivo, on Tommy Atkins and Keitt mangoes (34).

Hot Water and Fungicides

There is evidence that hot water treatment alone will give good control of anthracnose (14, 17, 28, 31, 33, 35, 37). In some cases the inclusion of a fungicide

with the hot water enable lower water temperatures to be equally effective or the fungicide reduced the need for very precise temperature control (22, 33, 34). In commercial export trials from Jamaica to Britain taking 24 days at 13°C by reefer container almost all mangoes treated with hot water only (55°C for 5 minutes) had slight superficial anthracnose symptoms compared to untreated fruits which had much more severe symptoms giving a large proportion of wastage. The addition of benomyl (500 ppm) to the hot water resulted in fruits which developed no symptoms of anthracnose disease (40). In storage trials in Brazil using various hot water fungicide combinations it was found that hot water treatment at either 50°C for 30 minutes or 55°C for 10 minutes was required to give results comparable to 55°C for 5 minutes plus fungicide (33). Other workers have shown that gamma irradiation subsequent to a hot water fungicide treatment can enhance the control of anthracnose (15).

From the literature the general consensus would be that 55°C for 5 minutes with 500 ppm benomyl is effective in controlling anthracnose (Table 2). This, however, needs careful monitoring especially in view of the report of tolerance to benzimidazole fungicides (38). There are different strains of the fungus (22) and more detailed investigations into the epidemiology, life cycle and physiology of the fungus are required.

There are reports that hot water treatment can adversely affect the fruit. Pennock and Montaldo (28) reported that at 52°C and above there was a risk of scald. Other workers have shown some evidence of heat injury at 54.4°C for 5 minutes (37) and an acceleration in ripening at 53 - 55°C for 5 minutes (17).

Conversely, it was reported by Hatton and Reeder (14) that there was no evidence of heat injury at 55°C for 5 minutes. In an unpublished study of the effects of 55°C for 5 minutes it was found that chemical and physical changes which occurred during subsequent storage and ripening were similar in treated and untreated fruit. There was some indication that the climacteria peak of respiration could be slightly earlier in treated fruit compared to those not treated, but the difference would not be of commerical importance (42).

Commercial Application of Hot Water Treatment

Maintaining precise temperature for a precise time has been shown to be essential for effective control of anthracnose without damaging the fruit. Equipment used commercially for this purpose must provide these conditions with an adequate throughput often in the order of 2 tonnes per hour and more. In many countries growers have developed their own equipment (10, 12, 41), but usually these are for only a small throughput and often give inadequate temperature control.

A study was carried out on the design and development of equipment on a batch system for hot water treatment giving a throughput of 1 tonne of mangoes per hour (12, 40). This was successfully field-tested at a commercial packhouse in Jamaica over several years. Subsequent equipment was developed, based on the same design, by an exporter in Brazil with a 2 tonne per hour throughput. Some work has been done in Hawaii on a continuous system for application of hot water, and future equipment developments for mangoes may go in this direction.

Table 2: Recommended conditions for hot water treatments to control anthracnose post harvest on mangoes.

Ref.	Water temperature °C	Dipping time minutes	Fungicide ppm	Country
28	51 - 51.5	15	0	U.S.A.
35	54.4 - 55.8	5	0	U.S.A.
14	55	5	0	U.S.A.
37	54.4	5	0	U.S.A.
37	54.4	5	1000 benomyl	U.S.A.
37	54.4	5	1000 thiabendazole	U.S.A.
17	53 - 55	5	0	Mexico
15	55	5	1000 benomyl	South Africa
31	53	10	0	Philippines
23	55	5	0	Australia
23	51.5	5	500 benomyl	Australia
23	48.5	5	1000 benomyl	Australia
39	58 - 62	2	2000 benomyl	Zambia
12	52	4	500 benomyl	Australia
33	50	30	0	Brazil
33	55	5	1000 benomyl	Brazil
33	55	5	1000 thiabendazole	Brazil
33	55	5	1350 captan	Brazil
33	55	10	0	Brazil
5	55	5	1000 iprodione	South Africa
5	55	5	1000 benomyl plus 0.75 KGy irradiation	South Africa
34	55	5	2000 to 4000 Kasugamycin	Brazil
24	53.5	4	500 benomyl	Australia
25	52	5	500 benomyl	Australia

Discussion

Much of the information published on mango anthracnose disease is conflicting. Several reasons for this are possible including the fact that work has been done in several countries and differences in the environment and cultural practices may interact with control measures. There are known to be different strains of C. gloeosporioides which may respond differently to treatments. Evaluation methods vary with different research workers, as do the way observations are interpreted. Application of chemicals to tree crops can be difficult and, especially with large trees, it may not always be possible to ensure complete coverage. However, in spite of some anomalous reports all mango varieties currently grown commercially should be considered susceptible to anthracnose to some degree.

New sites for production should be selected which are least conducive to C. gloeosporioides. In sites where it is a problem a comprehensive field spray programme is essential based on experiments reported in the literature and the experience of the grower. Where fruits are to be marketed locally post-harvest control of anthracnose may not be necessary since the fruit may ripen quickly and disease symptoms remain superficial. However, effective post-harvest hot

water/fungicide treatment will almost always be essential if fruits are to be held in storage for extended periods during marketing, e.g. when they are exported in refrigerated containers.

Cultural practices, growth regulation and varietal and root stock selections to enable the production of dwarf open trees may be an important way of reducing anthracnose. If carried out effectively it can not only create a microclimate which is less conducive to fungal development, but facilitate effective spray applications.

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CHAPTER IV MATURITY INDICES

MATURITY INDICES FOR QUALITY CONTROL AND HARVEST MATURITY

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CONTENTS

INTRODUCTION

The stage of development at which a commodity is harvested has a direct bearing on its response to subsequent handling, storage, transportation and marketing practices, and on its ultimate quality and shelf life. The concept of 'maturity' is thus an extremely important one in postharvest technology.

A fruit is considered 'mature' when it has reached a sufficient stage of development such that, after harvesting and postharvest handling (including ripening where required), its quality will be at least the minimum acceptable to the ultimate consumer (Reid, (36)). 'Commercial' or 'horticultural' maturity has been used to describe the stage of development at which a commodity possesses the characteristics for utilization by consumers for a particular purpose (Reid, (36)). In other words, a given commodity may be horticulturally mature at any stage of development (Figure 1). This point is well illustrated in the case of the mango where immature green fruits are required by processors of pickles and chutneys, mature green fruit by shippers, and ripe, full-flavoured fruit by processors of canned products and consumers of fresh fruit.

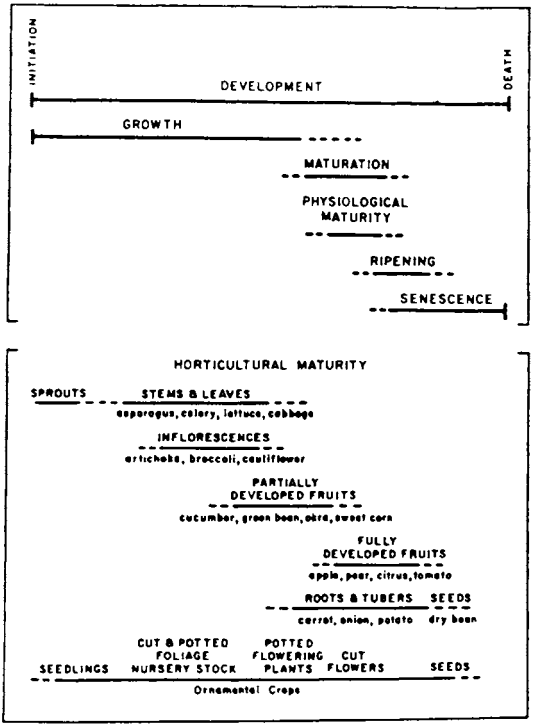

Figure 1: Horticultural maturity in relation to developmental stages of the plant (Watada et al. (45)).

The 'quality' of a fruit may be defined as that composite of characteristics which describes unique, peculiar and essential characteristics of the fruit, and which serves as a basis for determining the degree of acceptability, value and price of that fruit in the marketplace. Quality of fruits is often described in a wide range of terms such as market quality, edible quality, dessert quality, shipping quality, nutritional quality, and processing quality.

The relationship between maturity and quality implies a need for accurate and objective maturity determination. This need is further substantiated by the existence of regulations, published by marketing orders or legally appointed authorities, which frequently include a statement as to the minimum (and sometimes maximum) maturity acceptable for a given commodity. In addition, maturity indices and standards are of paramount importance for: the efficient management of labour and resources during harvesting; the planning of effective marketing strategies in order to take advantage of premium prices for early or late crops; the channelling of fruits to different uses according to their predicted internal quality development, and the determination of the type of postharvest treatments that should be applied according to the designated use of the fruits.

The success of the Caribbean mango as a commercial crop depends on the degree of quality control that can be exercised at all levels of the production-marketing process. At present, commercial consignments of mangoes for both the fresh produce and processing industries comprise fruits of varying physiological ages and quality and this results in inefficient and uneconomic marketing.

The lack of reliable maturity indices, the subjective nature of methods currently used for the evaluation of maturity, and the specificity of indices to location, variety and growing conditions, constitute major problems in the implementation of quality control measures. Little attempt has been made to evolve maturity indices which have practical significance. Existing practices therefore depend essentially on morphological characteristics which vary from cultivar to cultivar.

This Paper reviews the methods used for evaluation of maturity in mangoes and highlights the scope and limitations of the various methods. Critical quality control points which need to be monitored in the postharvest handling process are discussed, and the main requirements for establishing a quality control system for mangoes are defined.

DETERMINATION OF MATURITY

Requirements of Maturity Indices

The term 'maturity index' refers to any physical or chemical parameters of the fruit which change with time in quantity and quality, and which are highly correlated with the date of maturation and fruit quality. A maturity index should therefore:

- be objective, and simple to measure
- change rapidly and regularly with time so that differences are easily detectable

- relate consistently to the quality and postharvest life of the commodity for all orchards, districts and cropping seasons.

It should be noted that a maturity index can be applied in the assessment of maturity at harvest or at a subsequent inspection point and also in the more complex task of predicting the data of maturation of the fruit. In the latter case, measurements are made towards the end of the growing season. Once the relationship between changes in the index quantity and the quality and storage life of the commodity has been determined, an index value is assigned for the minimum acceptable maturity. When the pattern of change has been established for the chosen index quantity, measurements made early in the season can be used to predict the date at which the commodity will reach minimum acceptable maturity. This strategy has been applied successfully in the prediction of maturation dates of apples, avocadoes and kiwi fruit (Reid, (36)).

Mango Maturity Indices

The various quality components of fruits are listed in Table 2, with examples given for the mango. The degree of maturity in mango has been correlated with many of these components, including:

- flesh and surface colour
- specific gravity, weight and texture
- starch, titratable acidity, total solids and sugar content.

Table 2. Quality components of fresh fruits

Main Factors	Components
Appearance (visual)	Size: dimensions, weight, volume
	Shape and form: diameter/length ratio, smoothness, compactness, uniformity
	Colour: uniformity, intensity
	Gloss/Bloom: nature of surface wax
	Defects: external, internal Morphological Physical and Mechanical Physiological (soft nose, internal breakdown) Pathological (anthracnose) Entomological (seed weevil)
Texture (feel)	Firmness, hardness, softness
	Succulence, juiciness
	Toughness, fibrousness
Flavour (taste & smell)	Sweetness
	Sourness (acidity)
	Astringency (terpene levels)
	Aroma (volatile compounds)
	Off-flavours and off-odours
Nutritive value	Carbohydrates (including dietary fibre) Proteins Lipids Vitamins Minerals
Safety	Contaminants (chemical residues)

Source: Kader (15)

Investigations have also been carried out on the establishment of relationships between fruit quality and pre-harvest factors (production conditions, cultural practices), as well as on the biochemical changes associated with maturation. The indices derived, however, vary considerably from variety to variety and a combination of parameters, coupled with considerable experience are required for accurate determination of maturity.

Colour

The degree of maturity has been correlated with physical appearance and surface colour for some Indian and Florida varieties. Cheema and Dani (8) defined four stages of maturity, termed A, B, C and D, based on shoulder growth, size and surface colour for fruit of the Alphonso variety. At stage A, the fruit shoulders are in line with the stem and the skin is olive green. Stage B, suggested as the best stage for export, occurs when the shoulders have grown over the stem end. At stage C, yellow colouration develops, while at stage D, the fruits are fully ripe with a typical external flush.

Wardlaw and Leonard (44) described a similar system for the Julie variety, correlating changes in flesh colour with physiological and chemical attributes. They noted however, that, unlike the Indian varieties, the Julie showed little evidence of marked skin colouration on ripening. Surface colour, weight, and appearance (shoulder growth and pit formation at the stalk end), where used by Krishnamurthy and Subramanyam (19) for classifying Pairi fruit into three groups and for fixing the optimum stage of maturity.

Skin colour was recommended as a practical maturity indicator for the Dashehari variety following a study which also examined fruit weight, weight change per day, length, specific gravity, moisture content, skin and pulp colour, eating quality, shape and lenticel characteristics (Shuka and Bajpai, (40)).

Malevski et al (26) correlated ripening in the Haden variety with the intensity of red and yellow colourations at harvest, and concluded that both the maximum red and maximum yellow colour intensities at harvest could serve as good indices of maturity for this variety (Figure 2). They noted, however, that the use of external colour is time consuming and was subject to error in colour evaluation due to inaccurate maximum colour determination and/or anthracnose infection. The advantages of using external colour outweighed the limitations in that the index is objective and non-destructive, and correlates well with the velocity of ripening and the internal quality of the fruits.

In their assessment of fruit quality in various Australian mango cultivars, Satyan and Chaplin (38) determined that skin colour, combined with fruit size and flesh colour, correlated best with overall appearance (R^2 = 0.75). Fruits with a predominantly orange-coloured skin were preferred and greenness in the skin was not acceptable. Fruits with substantial amounts of strong red, magenta, violet or pale yellow colours in the skin were only marginally acceptable.

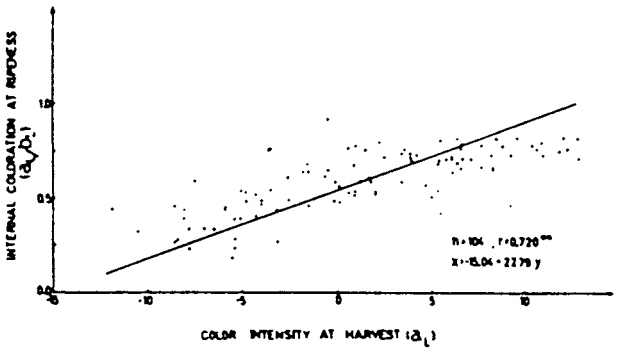

Figure 2. Relationship between the maximum initial red colour intensity at harvest (Hunter a_L and the maximum internal yellow colour intensity at ripeness Hunter a_L/b_L)

Pulp colour may be a more appropriate index than skin colour in some varieties. It is recommended as a harvesting index for Pairi and Haden varieties. In Haden, the pulp changes colour from white to yellow, commencing in the vicinity of the seed (Krishnamurthy and Subramanyam (19); Jacobs (14)).

Specific Gravity and Weight

Studies carried out by Harkness and Cobin (11) on the Haden variety showed that fruits having a specific gravity (s.g.) between 1.01 and 1.02, and a sucrose content of more than 1.0% were suitable for picking. Bhatnagar and Subramanyam (5) used specific gravity as the basis for grading harvested mangoes in India. Fruits with a s.g. of 1.02 ripened faster than fruits with an s.g. of 1.01 to 1.02, had a reduced shelf life and were suitable for consumption in the fresh state. Fruits having a s.g. lower than 1.0 generally took a long time to ripen, had a longer storage life, an increased susceptibility to infection, and were invariably of poor quality either in the fresh or processed form. Mukherjee (30) examined several physical, morphological and chemical indices in Indian varieties and suggested that specific gravity grading (water sinkers : >1.0 s.g.) was the most reliable method for maturity estimation. Flotation grading has also been suggested for the Carabao variety with fruit that sink in water being regarded as mature (Coronel (9)). Other workers have defined fruit as being mature at harvest when a specified percentage fail to float in water eg. 15% Sensation and Zill; 53% Peach (Anon (2)).

Specific gravity was used by Kapur et al. (16) as an index for determining the effect of maturity on processed mango products of the Dashehari variety. These researchers determined that fruits with a s.g. of 1.08 were superior for the production of canned slices, pulp and juice. Fruits with a s.g. of 1.1 gave products with inferior texture, flavour and taste, while fruits with a s.g. of 0.986 to 1.041 were totally unsuitable. Processing of the latter group resulted in products with a hard texture, cooked flavour and comparatively greater metallic absorption and discolouration. For the processing of Indian-style pickles, Narayana (32) recommends a fruit weight of at least 250g.

A number of workers have used fruit weight, together with other physical and chemical characteristics, for the determination of harvest maturity. Wardlaw

and Leonard (44) determined that maturation in the Julie variety is complete when the fruit reaches a weight of 350 g with conspicuous, raised shoulders and pale orange flesh. The fruit becomes tree-ripe when the weight is approximately 400 g with the stalk on mound and the flesh orange in colour. In the case of Pairi mangoes, it was concluded by Krishnamurthy and Subramanyam (19) that optimum maturity could be indicated by a weight of 260 ± 20 g, an olive-green surface colour, and outgrown shoulders. In Australian fruit, there was a highly significant linear relation between mean fruit mass and fruit size rating; fruits having a mass less 220 g were not acceptable (Satyan and Chaplin (38)).

Chemical Characteristics

Starch, total solids and sugar content have all been used singly, in ratios or correlated with other fruit characteristics for the determination of harvest maturity in various mango varieties (See Table (2)). There is some evidence that the relationship between ripe fruit qaulity and total solids may be affected by growing area (Peacock (33)) and it is likely that variety will also affect this relationship.

Table 2. Maturity standards for harvest: Alphonso and Pairi Mangoes*

Physical and chemical factors	Group A	Group B	Group C	Group D
Weight (g)	>320	300 ± 20	250 ± 20	<225
Specific gravity	>1.02	1.01-1.02	1.0-1.01	<1.0
Total soluble solids (%)	>10	8 ±1	7 ± 1	<6
Acidity (% malic acid)	<3.2	3.5 ± 0.2	3.9 ± 0.2	>4.1
Total carotenoids (µg%)	>800	600-800	400-800	<400
Alcohol-insoluble residue	>12.5	11.5-12.5	10.5-11.5	<10.5
Maturity	Over mature	Physiol. mature	Physiol. mature	Physiol. mature

* From Bhatnagar and Subramanyam (5).

Popenoe et al. (34) suggested that the starch content at the time of harvest could be a reliable index of maturity for some varieties grown in Florida. Teaotia et al. (42) suggested that a starch : acid ratio of 4 or more could be used as an index for determining maturity in the Langra variety. Hulme (13), on comparing Indian and Florida-grown mangoes, suggested that Florida-grown mangoes contain more sugar at the unripe stage than Indian mangoes at a comparable stage of maturity, and that sugar content was not a useful index for other varieties. Lam et al. (24) in their assessment of fruit drop, growth, respiration and chemical changes in Golek mangoes, found an increase in total solids, acids and sugars with maturity after fruit set and a decrease in citric acid and starch. They determined that fruits containing 8-9% starch were edible.

Recent investigations on minimum acceptable total soluble solids, as determined by consumer taste panels and the ratio of total soluble solids to total solids, confirmed the usefulness of total solids as a measure of maturity in Australian mango varieties. Baker (3) derived the following statistically significant relationships between °Brix and dry matter (DM) content for Kensington and Irwin mango varieties:

$$\text{Dry matter} = 2.72 + 0.98 \text{ Brix (Kensington)}$$

$$\text{Dry matter} = 3.14 + 0.90 \text{ Brix (Irwin)}$$

On the basis of these equations, a dry matter of 13° Brix was used as a minimum maturity standard, 15°Brix as the New South Wales standard and Brix level at 13% dry matter, the Queensland standard. The corresponding level for each of these for Irwin and Kensington are:

Kensington	Irwin
13°Brix = 15.5% DM	13°Brix = 14.8% DM
15°Brix = 17.42% DM	15°Brix = 16.6% DM
13% DM = 10.5°Brix	13% DM = 11.0°Brix

Research carried out on other Australian varieties, on the other hand, showed that titratable acidity, pH and total sugar content correlated well with the overall acceptability of the fruit, and that total soluble solids was a poor index of fruit quality (Satyan and Chaplin (38)).

Time to Maturity

Time to maturity has been expressed as days from full bloom, fruit set and fruit forcing, and has been recommended as a harvest maturity index. Generally, fruit is usually harvested 15-16 weeks after fruit set (Lakshminarayana et al. (22)). However, variations resulting from varietal differences, growing region, climatic conditions and methods used to determine growth rate, restrict the usefulness and wide application of these indices. In districts where conditions are considered virtually constant from year to year, they may be of practical value. Alternatively, the concept of heat units may be used to compensate for variable climatic conditions. In the case of the Baneshan variety, a value of 1426 celsius degree days has been derived as a harvest index using data collected over a period of 11 years (Rao and Srinath (35)).

For Philippine varieties, 82-88 days from full bloom, and 110-120 days after fruit forcing are recommended (Coronel (9)). In the case of Langra, Krishnabhog, Alphonso, Dashehari, Mamey and Amini varieties, 90 days after full bloom, as well as 110-116 days after fruit set has been used. Lam et al. (24) specified that fruits of the Golek variety should not be harvested until 12 weeks after fruit set if they are to be used for fresh consumption. Other authors have suggested that fruit will not withstand handling or prolonged storage if harvested later than 105 days from fruit set (Cancel and Perez (6)). In addition, the week in which median cropping occurs (ie. 50% of fruit ripening on the tree) has been used as a means of comparing the relative maturity of various varieties, and has been shown to be highly correlated with time of flowering (Beal (4)).

Lakshminarayana (20) demonstrated that fruits picked at any stage of maturity undergo respiration, ripening and biochemical changes characteristic of fully-matured fruits. However, he noted that fruits harvested prior to 'commercial' maturity have a longer storage life (23 days for fruit harvested 11-12 weeks after fruit set and 13 days for fully mature fruits), may not ripen uniformly and are subject to heavy spoilage. Compensation for the latter effects has been achieved to some extent in the case of Alphonso fruits by harvesting from 11 weeks after fruit set and using a hot water treatment to reduce spoilage and subsequent postharvest losses (Lakshminarayana et al. (21)). It was noted, however, that fruit harvested 11 - 12 weeks after fruit set resulted in ripened fruits which were more acidic, had a lower sugar content and a tendency to shrivel earlier. It was concluded that 14 weeks was the optimal time for early harvest of Alphonso mangoes.

Further work carried out by Lakshminarayana et al. (23) showed that Alphonso mangoes harvested at various stages of maturity from 13-16 weeks, and subjected to postharvest treatments of Ethrel at 500 and 1000 ppm in hot and cold water, resulted in accelerated and uniform ripening with reduced spoilage. The absence of mechanical injury in treated fruits was an important pre-requisite for obtaining good results.

In the case of 'horticulturally' mature mangoes for pickle processing, Sastry and Krishnamurthy (37) and Habibunnisa (11) found that pickles made from 6 to 8-week-old Amlet mangoes were of good quality, but that those made from 8 to 9-week-old fruits were superior in colour and flavour. They also found that high-acid mangoes (5-6% acidity) produced the best quality pickles. Pickles made from fruit less than 6 weeks old were hard and had a flat taste, whereas those made from fruit older than 10 weeks were soft and fruity in flavour and lacked firm texture.

Various growth regulators have been applied prior to harvest in an attempt to manipulate the length of maturation and spread the peak harvest season over an extended period of time. 200 ppm of ethephon applied to Carabao fruits at 54 days from full bloom, resulted in acceleration of fruit maturation by two weeks. When applied at 68 days from full bloom the soluble solids and titratable acidity were improved at the minimum acceptable maturity (Andam (1)).

Beta-naphthoxyacetic acid (B-NOA) applied at 25 ppm as a foliar spray at monthly intervals from fruit-set, hastened maturity by 2 weeks in Alphonso mangoes while maleic hydrazide at 750 ppm delayed harvest maturity by 2 weeks.

Fruits treated with B-NOA ripened earlier after harvest, developed attractive skin colour, and recorded higher carotene content in the flesh of the ripe fruit. Maleic hydrazide, on the other hand, increased fruit size, delayed the ripening process, interfered with carotene formation, and increased the susceptibility of fruits to fungal infection (Subramanyam et al. (41)).

Biochemical Indices

Data on enzymatic and physico-chemical changes associated with the respiration climacteric are essential in the development of reliable indices in all commercially important cultivars. These aspects are covered by Medlicott and Jeger (Chapter V.1) and Chaplin (Chapter V.2). However, to date limited studies

have been carried out on the prediction of harvest maturities using correlations based on biochemical changes in the fruit during maturation.

Attempts have been made to establish relationships between respiration rate and the major chemical constituents of the fruit. The results of these efforts have shown, however, that the magnitude in respiration differs considerably among cultivars, and with the physiological age of the fruit. In general, ripening and the respiratory climacteric are associated with increased sugar content due to starch hydrolysis; reduced titratable acidity to levels as low as 0.1 - 0.2%, resulting from increased utilization and decreased synthesis of organic acids; changes in pectiase activity leading to cell wall degradation and softening; increased yellow/orange pulp pigmentation resulting from biosynthesis of carotenoids, and production of aromatic volatiles. Overripe and tree ripe fruit, in contrast to fruit picked physiologically mature and then ripened, showed reduced levels of chemical constituents such as sugars, alcohol-insoluble solids and carotenoids. Nagy and Shaw (31) proposed that the so-called 'physiological ripening disorder' reported for Indian and Caribbean varieties might be an instance of fruit harvested beyond the stage of physiological maturity. On storage, such mangoes produced reduced quantities of total soluble solids, sugars, total carotenoids and beta-carotenes, and a 'spongy tissue' (disintegrating soft pulp, pale in colour, acidic with off-flavours).

Enzymatic changes associated with starch hydrolysis, pectic changes, and carotenogenesis in the ripening tissue have been investigated by a number of workers (Matoo et al. (28); Shashirekha and Patwardhan (39); Modi and Reddy (29). Similar investigations need to be carried out on Caribbean cultivars.

MANGO HANDLING SYSTEMS - QUALITY CONTROL

Quality control may be defined as the maintenance of quality at levels and tolerances acceptable to the buyer with minimum costs for the vendor (Kramer and Twigg (16)). The main requirements for the establishment of a successful quality control system for mangoes include:

1. Precise determination of the customer's preferences and specifications. This would include data such as estimated storage life and ripening schedules for distributors of green mature fruit; external and internal colour, size, flavour, and level of chemical residues for fresh mango markets; pulp colour, flavour, edible yield, porosity and texture of flesh for processed mango product markets.

2. Careful assessment of the production, harvesting and postharvest handling systems in order to determine critical points at which the specified market parameters need to be monitored and controlled.

3. The establishment of instruments and procedures by which these specifications can be measured at the designated control points and which are precise, accurate, rapid, simple, inexpensive and objective.

4. The establishment of sampling and inspection schedules which provide maximum information at minimum cost.

5. A system of data logging and analysis which would provide information necessary for updating and improvement of the system.

Critical Control Points

Figure 3 outlines a typical handling system for mangoes.

Harvesting

Fruits for fresh consumption and for processing are usually harvested in a physiologically mature but unripe stage and subsequently allowed to ripen at ambient conditions (30°C, 85% hr). Fruits should not be allowed to ripen on the tree since (1) the majority of fruits drop from the tree before they are ripe

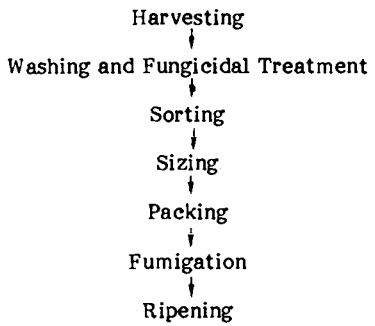

Figure 3. Typical Mango Handling System

enough for consumption, and (2) tree-ripe fruits are inferior in taste and aroma to fruits that ripen after harvest and their keeping quality is reduced.

Fruits may be harvested either directly by hand (tipping the fruit sharply sideways or upwards and snapping the stem) or by holding the fruit and severing the stem with clippers or a knife. Picking poles with bags and knife attachments are also used, especially for fruit that are out of reach.

Quality control during harvesting is centered on minimizing bruising and puncture injuries, and on the avoidance of skin blemishes caused by drying of sap exuded from the cut stem end. It is often recommended that the stem be trimmed to a length of 1 cm from the insertion in order not to rupture resin ducts that can cause blemishes and encourage the spread of disease.

Washing/Fungicidal Treatment/Heat Treatment

Washing of fruits combined with the use of heat and fungicides results in the removal of any remaining latex, and protection of the surface against infections by microbial agents, the most important one being Colletotrichum gloeosporoides which causes anthracnose. Critical control points include careful use of chemicals and compliance with maximum residue levels, and control of the time and temperature during the hot water treatment.

Sorting/Sizing

Sorting and sizing are necessary for removal of fruits which do not meet market specifications. Fruits which are judged to be immature, overmature, undersized or defective in any way are diverted.

Packaging/Storage/Ripening

Packaging of mangoes serves to protect the product during transport and marketing and to facilitate handling. Mangoes may be packaged in a variety of containers ranging from baskets and wooden boxes to fibreboard cartons. Internal cushioning materials include tissue paper, plastic film, newsprint, shredded paper, Kraft paper, paddy straw, leaves, vinylite, Pliofilm and woodwool.

Packaging should facilitate any postharvest treatments such as cooling, storage and ripening. The maturity of the mango must therefore be taken into consideration in terms of its postharvest physiology and handling requirements.

Storage conditions should be optimized in order to avoid the development of chilling and low temperature injury. In a study correlating minimum temperature tolerance and stage of physiological maturity, Thompson (43) determined that immature fruits suffered low temperature injury at 10°C and showed obvious symptoms at temperatures below 5°C. In the case of Julie and Ceylon varieties, best storage and ripening quality was observed for Stage B fruits at 7°C for 3-4 weeks.

The use of acetylene or ethylene to degreen fruit should be carefully considered since eating quality may be adversely affected.

RECOMMENDATIONS

The foregoing review has shown that, although extensive research has been carried out on the determination of maturity indices and standards for mangoes, the specific nature of the varietal characteristics, growing conditions, and production areas limits the usefulness and application of the indices derived. As a result, no universally acceptable set of criteria has yet emerged for the determination of mango maturity.

Greater research emphasis needs to be placed on the development of indices which have more practical significance and wider application. With respect to the Caribbean mango industry, however, specific harvesting and maturity indices need to be developed for varieties with significant commercial potential.

Existing subjective methods of evaluation should be correlated with objective measurements, and the use of objective, non-destructive test methods should be emphasized. In this context, sensory analysis, combined with objective measurements would be extremely valuable.

Attributes such as colour, flavour and aroma provide important bases for consumer acceptance, especially in fresh produce markets. Objective measurements using magnetic resonance and light transmittance techniques, colorimeters or colour matching standards and reflectometers, would provide objective data which could be correlated with consumer acceptance tests for

these attributes. At present, sensory analysis is the only reliable means of assessing odour in mangoes and basic research is needed on the nature of volatile and non-volatile constituents and their interactions.

Textural properties can be determined by chemical analysis of starch, perctin, fibre and other cell wall constituents. Instruments available for objective determination of properties such as hardness, deformation, cohesiveness, and juiciness include the teturometer, tenderometer, penetrometer, instron unit and succulometer.

Flotation grading based on specific gravity measurements appears promising for determining the suitability of harvested fruit for designated markets.

In view of the present production methods and orchard practices used in the Caribbean, mechanical harvesting would not be feasible. In this context, the regulation of the maturity of the fruit by application of synthetic plant growth regulators is promising since it would facilitate harvesting and subsequent postharvest handling practices.

Postharvest treatments using hot water together with chemical regulators, would be helpful in promoting uniform ripening and colour development, and in reducing postharvest losses by allowing for earlier harvesting.

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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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CONTENTS

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

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CONTENTS

[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,

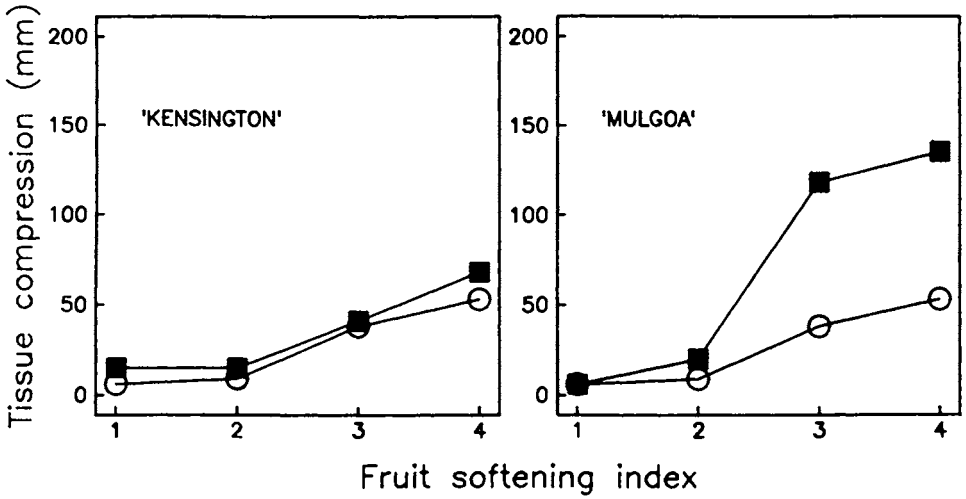
i.e. some may be intrinsically firmer than others at the fully soft ripe stage. Nevertheless, the feel of the fruit is probably the consumer's final arbiter whether a mango fruit is ripe and ready to eat.

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

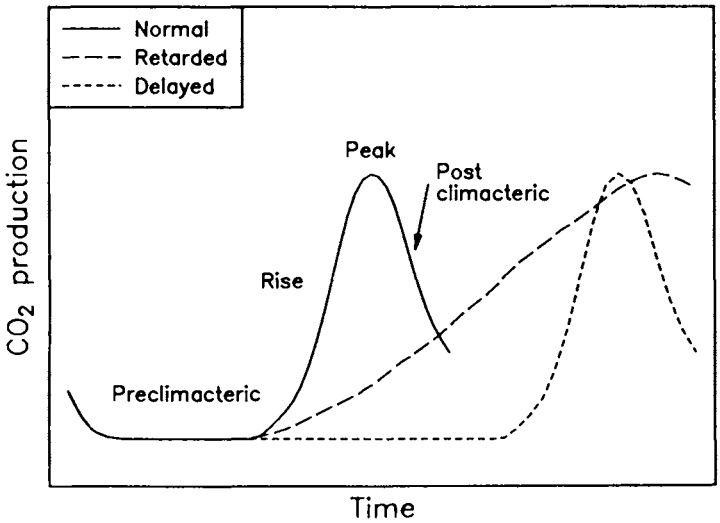
Mango fruit are usually harvested at the so-called mature-green, or physiologically mature stage of growth and development and before the commencement of ripening. This is to allow time for the various postharvest procedures of sorting, packaging and transportation to the market place to be accomplished 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).

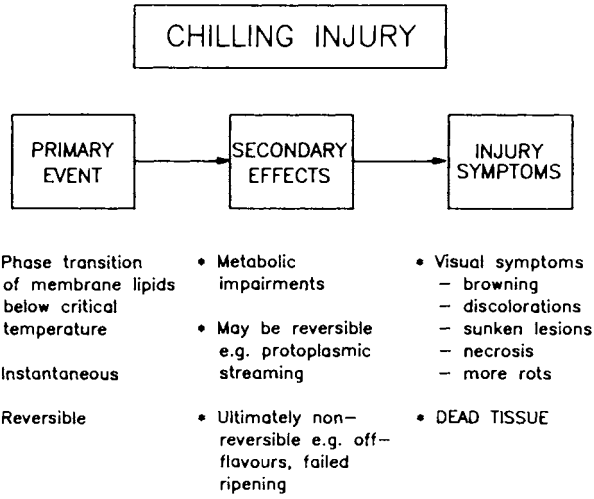
All of the physical, chemical and physiological changes associated with ripening and described above have a biochemical basis. In this chapter, only brief comments have been made on some of the principal kinds of biochemical reactions influencing the progress and completeness of the ripening phenomenon. 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).

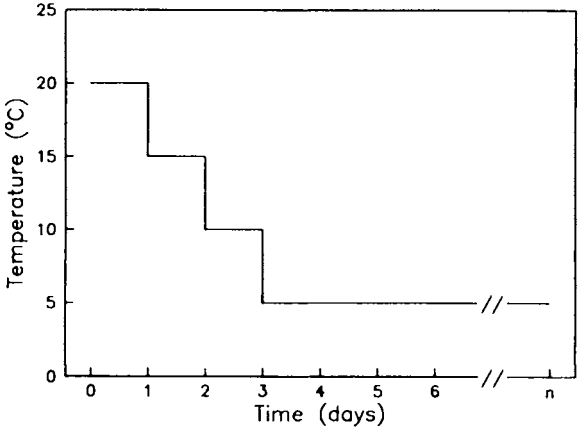
These differences could be due to many factors, of which many are speculative and little understood. It is presumed that genetic factors have a general control over the intrinsic sensitivity (22). However, certain preharvest cultural or environmental factors (64) and fruit maturity (44) are also thought 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.

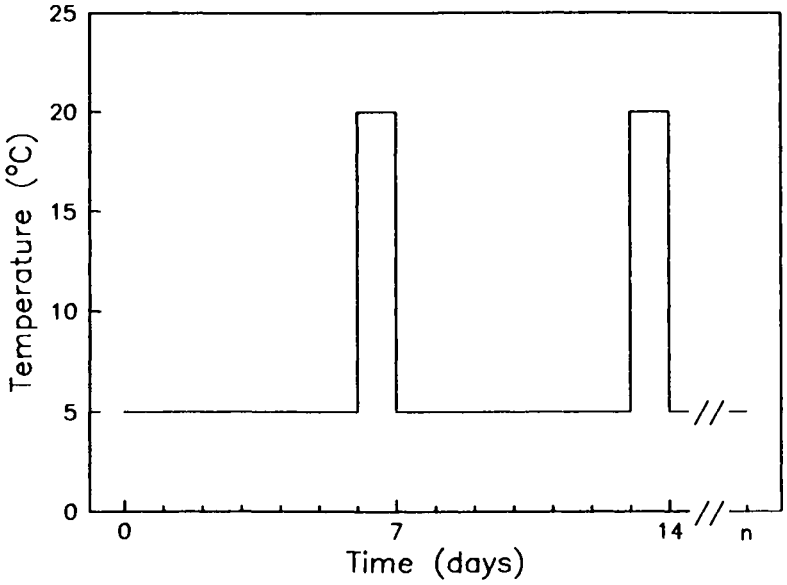
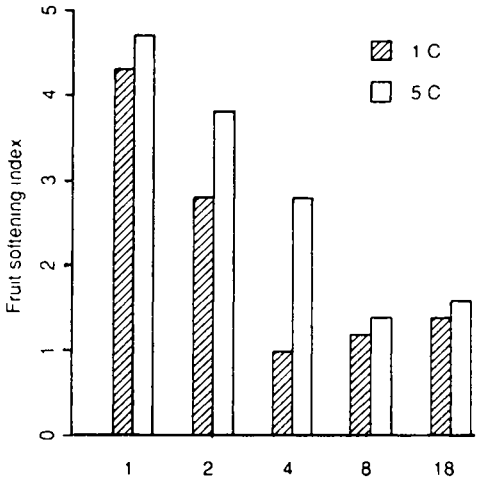


Figure 6 Effect of the frequency of a 24 hour warming cycle on the softening in 'Kensington' mangoes stored at 1°C or 5°C for 18 days. Adapted from (74).



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.

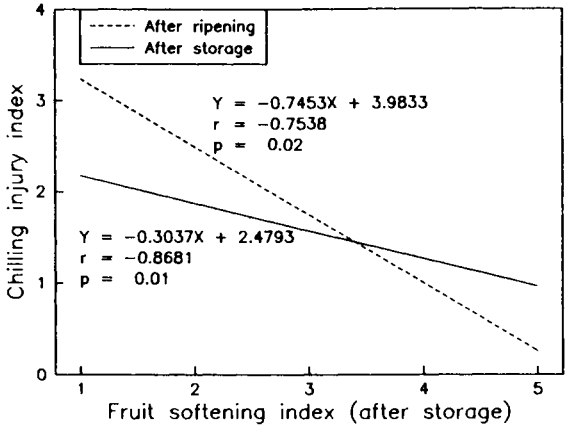
The present potential for other chemical sprays or dips to bring about a substantial increase in the postharvest life of mangoes appears to be small, though the range and number of documented studies is also very small. Development of yellow colour, weight loss and shrinkage were retarded in 'Dashehari' 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.

ACKNOWLEDGEMENT

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3. FRUIT SOFTENING

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CONTENTS

INTRODUCTION

Many fruits as they ripen, become softer and increasingly susceptible to fungal attack. Optimum quality is often associated with a certain degree of hardness and crispness, beyond which customer appeal diminishes. Development of technology to control this change is therefore of importance to fruit industries. For further information on such technologies and on other ripening changes (see Medlicott and Jeger V.i and Chaplin Chapter V.2).

CAUSE OF SOFTENING

Softening is usually accompanied by breakdown of the plant cell wall. The walls of parenchyma cells in the pulp region of fruits are made up almost entirely of carbohydrate material. Mature unripe fruit cells generally have rigid, well-defined walls whereas those from ripe fruits have soft, diffused walls. Ultrastructural studies have suggested that softening is accompanied by dissolution of the middle lamella region (between cells) which is rich in pectin, resulting in cell separation in tomato (9), strawberry (31), apple (4) and pear (4). This change appears to be brought about by hydrolytic enzymatic activity on the pectic component of the cell wall. Molecules from this fraction characteristically have a long backbone of galacturonic acid in α-1, 4-linkage with side chains containing galactose and/or arabinose attached to rhamnosyl residues (see Fig. 1). Other features of this polymer are regions of high branching, regions of low branching, and areas where the carboxylic acid group of galacturonosyl residues are methoxylated or acetylated.

Once fragmented by enzymes, pectin becomes detached from the rest of the cell wall. Such solubilization has been observed in mango (11,25), tomato (16), strawberry (31), date (47), apple (29), avocado and peach (39). This process together with mobilization of stored reserves of starch accounts for increases in soluble carbohydrates with ripening. Consistent with these observations, are reported decreases in cell-wall content of galacturonic acid, galactose and often arabinose (1,16,17,30,31). There is very little evidence to support significant loss of other cell wall components (hemicellulose, cellulose, hydroxyproline-rich glycoproteins) during softening.

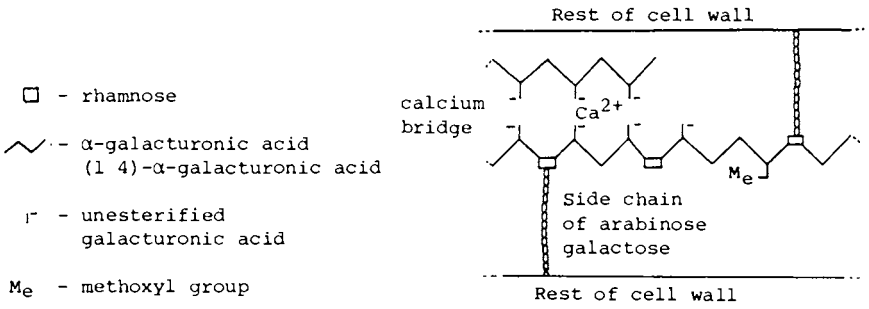

Figure 1. Structure of pectin and its attachment to the rest of the cell wall.

ENZYMOLOGY OF SOFTENING

Our present understanding of the mechanism of cell-wall softening is poor. (See Huber (23) for a comprehensive review of cell wall changes and enzyme changes during fruit ripening). One of the main problems is a lack of understanding of the full structure of pectin and how it is associated with the rest of the cell wall. For more detailed coverage of this topic, the reader is referred to recent reviews by John and Dey (28) and by Fry (14). It seems very likely that pectin molecules are covalently attached to the cell wall via their side chains. Thus, solubilization may be effected by internal cleavage of the latter and/or endo-hydrolysis of the rhamnogalacturonan backbone. The former activity requires hydrolysis of endogalactanases or endoarabanases whilst the latter can be effected by endopolygalacturonase.

Endopolygalacturonase (PG)

Endopolygalacturonase has been identified in many fruits (9,19,20,41,42) and possesses the capacity to randomly hydrolyse the rhamnogalacturonan backbone of pectin. However, it is not present in all fruits. After an extensive search, Brinson (8) concluded it was absent from Ngowe mangoes. This was subsequently supported by John (27). However, the enzyme is present in Keitt mangoes (46). Further, in a recent study, Lazan and co-workers (32) reported PG activity in 'Huramanis' and 'Mulgoa' mangoes.

Evidence for the involvement of PG in fruit softening is very convincing. Its activity becomes noticeable two or three days after the onset of ethylene production in tomato (54) and increases with ripening. It can singularly solubilize material from cell walls of unripe tomato (55), pear (2), and peach (40) under in vitro conditions. Using electron microscopy, Crookes and Grierson (9) showed that such activity in tomato can cause dissolution of the middle lamella. Although PG can degrade tomato cell walls in vitro, its action alone does not bring about reductions in cell-wall galactose as occurs during the natural process (55). Thus, it seems likely that cell-wall breakdown is caused by coordinated activity of at least two enzymes in this fruit. In pears, however, the enzyme is able to solubilize arabinose (2). It is becoming apparent that there may be different mechanisms for the solubilization of pectin in different fruits. Certainly, the absence of endo-PG in some fruits such as the apple suggests there are at least two classes of fruits with different mechanisms for cell-wall softening. One involving hydrolysis of the rhamnogalacturonan backbone and the other presumably hydrolysis of the side chains containing neutral sugars. A further complicating factor is variation in the sugar composition of the cell walls of fruits particularly between those belonging to different botanical groups. This has been demonstrated by Gross and Sams (17) who studied the cell-wall sugar composition of seventeen different fruits. They suggested that care should be taken to avoid generalizations about fruit softening. If initial structures are different to start off with, then their mechanism of degradation are likely to vary. This issue revolves around the presently debated question on the universal applicability of cell-wall models. Albersheim (3) suggested that one model may apply to the primary cell-wall of dicotyledonous plants. Presently this contention has not been widely accepted, although it has not been dismissed. Further progress is dependent upon a greater understanding of cell-wall structure and the study of a wider variety of plants. Much of the structure on cell-wall softening has been restricted to work on popular varieties of fruits such as tomato, apple, pear, avocado, mango and peach. These represent a tiny fraction

of the entire fruit spectrum and may not necessarily be representative of ripening in general. There is need for widening the number of species studied, and for work of a more biochemical nature.

It has been suggested that prior action by pectinmethylesterase (PME) which catalyses the hydrolysis of methoxylated galacturonosyl residues facilitates the activity of PG which has a preference for de-esterified pectin (33,35,38). PME has been found in mangoes (34), bananas (25), avocadoes (5), peaches (49), pears (37) and tomatoes (10). However, there is no clear correlation between its activity and cell-wall softening. Hamson (18) reported PME activity to be higher in unripe tomatoes whilst Hobson (22) observed 40% greater activity at the ripe stage.

Galactanase and arabanase

If the side chains of pectin which are thought to be galactans and/or arabinans and/or arabinogalactans are covalently attached to the cell wall as models indicate (28), then their endo-hydrolysis is necessary for solubilization of pectin in fruits devoid of PG. Such galactanase or arabanase activity has not been clearly demonstrated in fruits. Although unable to positively identify these enzymes in Ngowe mangoes, John (27) suggested their presence in a crude 3M LiCl extract from the walls of ripe fruits. This preparation which apparently did not contain PG was able to solubilize large polysaccharide molecules and a range of monosaccharides from cell walls of the unripe fruit. No oligosaccharides were detected. The changes brought about in degraded cell walls were similar to that which occurs during normal ripening.

Exoglycosidases

The involvement of exoglycosidases in cell wall breakdown has not been established. This class of enzymes (particularly β-galactosidase and α-arabinosidase) is of interest because they are present in a number of fruits and increase many-fold with ripening (2,8). They may be responsible for the removal of galactose and arabinose from cell walls, but this has not been demonstrated in vivo. Tomato (43) and apple (6) β-galactosidase are able to hydrolyse cell wall galactans. Otherwise, studies have mostly used artificial substrates such a β-nitrophenyl-β-galactopyranoside which may not accurately reflect true in vivo activity. Multiple forms of β-galactosidase have been identified in tomato (43) and mango (27). As exoglycosidases can only remove sugar residues from the end of large molecules, their action alone could not solubilize polysaccharides from the cell wall. Thus, they are unlikely to be of importance in cell-wall softening, unless in a regulatory role. Following initial cleavage by endoenzymes such as galactanase or arabanase, exo-hydrolysis of the exposed end groups becomes possible. Subsequent removal of these side chains may enhance the activity of PG or PME by reducing stearic hindrance.

CONTROL OF SOFTENING

Hobson (21) suggested that ripening should be considered as a number of key processes taking place simultaneously, each one having its own control mechanism which is loosely coordinated with those of other processes. Control of softening is dependent upon understanding the mechanism by which it is

brought about and its interrelation with other pathways. Traditionally, in biochemistry, analogues of substrates and the final product of reactions have been used to inhibit enzymatic catalysis. Theoretically, it is possible to reduce softening by inhibiting key enzyme(s) involved in this process, particularly at the initiation stage. However, little attention has been paid to this possibility. It is likely that cell-wall degradation may have a regulatory role in other processes occurring inside the cell. Control may be effected by solubilization of attached enzymes which may then partake in the furtherance of ripening by acting on substrates present in the cytosol. In support of this, results obtained from studies on the action of PG using cell-wall substrates suggest that protein as well as carbohydrate material is released (25,50,51). Further, some reduction in firmness of fruits has been observed prior to incipient ripeness (5,7).

Modification of substrate is another strategy that could be employed to control softening. Calcium is mainly located in the cell wall of plants (18) and plays a crosslinking role in the structure of pectin (28). Addition of this ion could have rigidifying effect on cell walls and stearically obstruct enzymes such as PG from reaching their sites of action. Alternatively, direct inhibition of enzymes could be possible. For example, in vitro studies of tomato pectic enzymes show that maximal activity of PME had a requirement for Ca^{2+}, whereas PG activity was inhibited by concentrations as low as 10^{-7} M (57). Application of Ca^{2+} has been shown to inhibit normal ripening of several fruits (12,52,56), however at higher concentrations skin injury and secondary microbial growth results (53).

Once the enzymology of softening is better understood, control could be executed at the genetic level by inhibiting synthesis of key enzymes. This opens up the possibility of delaying the onset of ripening rather than slowing down the ripening process once it has already started as present-day methods such as refrigeration do. Certainly, protein synthesis appears to occur at the climacteric stage during fruit development (13,15,29). This is supported by evidence of increases in the ratio of protein nitrogen to total nitrogen (24,48). It has not been established whether de novo synthesis of protein catalyzes the climacteric rise. However, reports of ripening-related changes in the levels of different transfer RNAs (36) and messenger RNAs (44,45) in tomato fruit support this contention. As previously mentioned, PG is synthesized de novo in tomato shortly after the onset of ethylene production.

Traditional methods for controlling ripening and thus softening such as low temperatures and modified atmospheres have been tried and tested over the years. Although these can be refined to give increases in storage life of fruits, they are unlikely to provide any dramatic advances in postharvest technology. This requires the development of a base of scientific knowledge which offers more than is currently known today. There is therefore a need to invest in long term projects aimed at understanding ripening at the molecular level to provide information for future exploitation. At the same time, research directed at fine tuning present-day technology to fulfil more immediate requirements also needs to be carried out.

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CHAPTER VI PROCESSING

DEVELOPMENTS IN TECHNOLOGY FOR PROCESSING OF MANGOES

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CONTENTS

INTRODUCTION

Mango (Mangifera indica L.) is the king among tropical fruits. It occupies relatively the same position in the tropics as is enjoyed by the apple in temperate regions. It is very much relished for its succulence, exotic flavour, delicious taste and nutritive value. It is recognised as one of the best fruits in the world market. Mango is now being cultivated in many countries of the world. However, India is the largest producer, accounting for 63% of world production (124). A fruit with many versatile properties has naturally found application for processing into various products. Starting from salt, pickled green mango slices and chutneys and going on to many products derived from ripe fruits, mango provides a wide range of products unparalled by any other fruit. Mango processing has earlier been briefly reviewed by several authors (17, 20, 40, 53, 105, 121, 129).

This review covers exclusively the technological developments in processing of mango including waste utilisation. Processing of mangoes present many problems to the industry. They are also summarised and presented.

BACKGROUND

World Production

World production of mango in 1983 is estimated to be 13.95 million metric tonnes. Of this India's share is 8.7 million metric tonnes. Other countries with notable production are Tanzania, Madagascar and Zaire in Africa; Mexico, Haiti and Dominican RP in North Central America; Brazil and Venuzuela in South America; Pakistan, Philippines, China and Indonesia in Asia. It is also now being grown in Florida and several Latin American countries. It is significant to note that almost all the production comes from developing countries. The mangoes grown in these countries are mainly consumed locally with only a small percentage being exported. The fruit therefore serves an important role in the diet of these people as a source of calories, vitamins and minerals.

Production in India

In India mango accounts for 40% of area and 39% of production of fruit crops. While the area increased by about 20%, production increased by about 13%.

Varieties

The names of varieties of mangoes grown in various countries are given in Table 1. A little over a thousand varieties are recorded in the literature of which 30-35 grafted varieties are cultivated in India on a commercial scale. Ten of the cultivars are popular for fresh trade as well as processing and Alphonso among them is the choicest variety. Baneshan, Totapuri, Neelum, Mulgoa, Dashehari, Fazli, Langra and Chousa are the other principle varieties. Non-fibrous pulpy varieties are largely used for processing. Seedling varieties and premature and preharvest drops are used for pickles (17). The season in many tropical countries starts around March/April and lasts till August/September with the exception of Kenya where cropping occurs throughout the year.

Table 1. Important Mango Varieties of Selected Countries

Country	Varieties
Australia	Kensington
Brazil	Bourbon, Carlota, Extrema, Haden, Non-Plus-Ultra
Cuba	Bizcochuelo, Haden, Macho
Egypt	Mabroka
India	Alphonso, Bombay Green, Bangalora (Totapuri), Bangana pally, Chausa Dashehari, Dushri, Fazli, Gulabi Khas, Himsagar, Kesar, Langra, Malda, Malkurad, Mulgoa, Neelam, Pairi, Raspuri, Rumani, Safeda Lucknow, Schooli Shah Pasand, Suvarnarekha, Zardaloo
Indonesia	Aroomanis, Gadoong, Golek, Wangi
Israel	Haden, Maya, Mabroka, Nimrod, Sarafend
Haiti	Madame Francis
Mexico	Ataulfo, Diplomatico, Esmeralda, Haden, Irwin, Keitt, Kent, Manila, Manzana, Naranja, Oro, Pina Canario, Sensation, Tommy Atkin
Philippines	Carabao, Pico
Pakistan	Sindhri and several Indian varieties
Puerto Rico	Colombo, Kidney, Haden, Mangotino, Mayaguezano
United States	Gouveia, Haden, Irwin, Keitt, Kent, Momi K, Palmer Pope, Sensation, Smith, Tommy Atkin

Source: Malo (1970), Malo (1972), Singh (1972), Wiltbank (1977), Lakshminarayana (1980) and Valmayor (1972).

International Trade

Total international trade in fresh mangoes is placed at around 23,000 tonnes per year valued at US $ 30 million, the major areas of import being Western Europe, West Asia and North America. Major suppliers of fresh mangoes include the Philippines and India, the two together supplying about 63% of world requirement of this fruit. Other notable suppliers are Mexico, Mali, Kenya, and South Africa. Nearly 65% of world imports of fresh mangoes is accounted for by Western Europe and West Asia. In India mango exports account for less than 0.1% of total production, the reason being that Alphonso variety, which accounts for only

2% of total production, is the single largest variety that is exported and hence there is scope for increasing the export by introducing other varieties (124).

Chemical Composition

The range in chemical composition of commercial varieties of mangoes grown in various countries is given in Table 2. Mango is a fairly good source of carbohydrates, vitamin C and a very rich source of provitamin A (28,38,40,108). Sixteen carotenoid pigments were identified in the Alphonso mango, 60% of which was β-carotene. Luteoxanthin and Violaxanthin which are seldom found in fruits, are reported to be present in significant quantity in this fruit (43).

World Production and Trade of Mango Based Products

India also dominates the world production and trade of processed mango products. It is reported that India accounted for 80% of the world total production of 20,000 tonnes in 1975 (124). The world total for processed mango products is not known exactly. However, it may be assumed that it does not exceed say 60,000 tonnes since the total production of India, the world's leading producer, reached only about 43,600 tonnes in 1980. India is estimated to have produced 43,583 tonnes of mango products valued at Rs.257 million in 1980. The major products in descending order are mango pulp, mango juice, mango pickle, mango RTS (Ready to Serve) beverage, mango slices in brine, mango chutney, canned mango slices, mango jam and mango squash. Production of dehydrated products and frozen products have just begun. Export from India increased from around 9,000 tonnes in 1971-72 to 27,000 tonnes in 1981-82. The value of export and unit value realised have increased over the years. The breakdown of export of products is given in Table 3.

India is dependent upon Gulf Countries and European export markets and now to some extent on the USSR. Hence, there is need for diversification of markets.

Table 2 Proximate Chemical Composition of Ripe Mangoes

Variety	Moisture %	TSS °Bri	Titratable acidity %	pH	Vitamin C mg/100 g	Sugars			Carotenoids ug/100 g	
						Red. %	Non-Red. %	Total %	Total	Beta
Alphonso	81.95	17.6	0.15	4.7	60.7	3.23	12.33	16.22	8344	4764
Bangenapalli	82.10	17.0	0.40	4.3	-	6.80		16.6		
Cherukurasam	79.80	19.0	0.29	4.2	-	4.10		15.3		
Haden	82.80	18.9	0.22	4.9	32.1	3.50		16.22		
Irwin	83.10	16.7	0.12	4.5	45.7	6.00		13.71	9212	4617
Keit	79.46	18.4	0.11	4.8	13.9	4.46		13.60	5902	2292
Kent	-	21.0	0.12	-	23.5	5.50		20.90	927	277
Pairi	84.2	15.0	0.14	5.8		5.40	7.7	13.50	5729	2613
Peddarasam	81.9	18.0	0.57	4.2		5.60		16.0	927	277
Sensation	-	15.7	0.15	4.4	55.0	4.30	9.0	13.30		
Suvarnarekha	80.7	18.7	0.45	4.5		5.3		17.9		
Totapuri		16.8	0.80	3.8	19.5	5.3	6.0			
Zill		15.9	0.16	4.6	14.0	3.2	10.9	14.1		

Source: Lakshminarayana (1980).

Table 3 Export of Processed Mangoes (Quantity: Tonnes, Value Rs. X 000)

Fruit/Product	1976-77		1977-78		1978-79		1979-80		1980-81		1981-82	
	Qty.	Value	Qty.	Value	Qty.	Value	Qty.	Value	Qty.	Value	Qty.	Value
Mango slices (dried)	37	220	343	1918	307	2169	738	4471	542	4660	21	247
Mango slices Brine	885	3754	832	4652	2213	12790	2049	12210	2769	17662	1096	7547
Mango Flour	116	887	42	395	16	197	-	-	12	138	24	331
Mango chutney pickle	352	1988	3895	21722	4819	29978	-	-	5081	42090	4961	46289
Mango juice	9632	46094	6295	31790	5743	34028	5728	37299	9647	58929	18478	74800
Mango puree paste etc.	3015	17472	3438	23038	2569	15715	1981	13724	3767	29910	7037	59727
Mango squash	-	-	-	-	-	-	37	310	65	628	18	374

Source: Monthly statistics of the foreign trade of India, Vol. 1 (Exports and re-exports) Mar. 1977, 1978, 1979, 1981 and 1982. Directorate General of Commercial Intelligence and Statistics, Calcutta, Govt. of India. Figures in each year represent for the period April to March.

PROCESSING OF MANGOES

In most mango growing countries the fruit is generally consumed in its fresh state. It is estimated that about 0.22% of mangoes produced in the world are processed (17). Mangoes are processed, at both raw and ripe stages of maturity, for conversion into a wide range of products as shown in Table 4.

Table 4. Utilisation of Mangoes for Processing (Products Range)

Green mangoes	Ripe mangoes	Mango waste	
		Peel	Stone
Mango pickle	Mango slices in syrup	Pectin	Starch
Mango chutney	Mango juice	Mango syrup	Fat
Mango slices in brine	Mango nectar		
Dehydated slices or powder	Mango squash		
Raw mango beverage	Mango RTS beverage		
	Mango syrup		
	Mango jam		
	Mango fruit bar		
	Mango powder		
	Strained baby foods		
	Mango cereal flakes		
	Mango concentrate		
	Mango aroma concentrate		

I. TECHNOLOGY FOR PROCESSING GREEN MANGOES

Mango Slices in Brine

Raw and unripe mango slices are preserved with salt for later conversion into pickles, chutneys, or as salt stock for export. The method consists of adding 15-20% salt to prepared slices, draining the liquid formed therein and replacing it with fresh salt. An improved method consists of steeping the slices in 10% brine containing 200 ppm of SO_2 for primary salting for 20 hours and 5% powdered salt

with 200 ppm SO_2 for storage (6). Addition of black mustard powder (0.5% level) or 0.1% sodium benzoate in 20% salt solution has also been suggested (41). The fibrous varieties are ideally suited for brine curing. Table and grafted varieties tend to become soft and mushy during storage. To overcome this defect, firming, using calcium chloride, alum after salt curing is recommended (67,125). Alternatively, the cured slices could be dried in the sun or in a cross flow air drier. Drying reduces bulk and results in economy.

Mango Pickles

This is an important product prepared from unripe green mangoes in some countries. Pickles are classified as salt pickles or oil pickles. The oil used is either mustard or gingelly oil. Cured slices are drained of the brine. Salt powder, spice mix (containing fenugreek, mustard powder, turmeric powder, red chilli powder, aniseed, etc.) and oil are shaken in a vessel. To this the slices are added, mixed well, packed into containers (glass jars or glazed jars) and properly sealed. Extra oil is added to form a 1-2 cms layer over the pickle to prevent the entry of air (17). Microbial spoilage due to moulds is common and could be checked by proper addition of salt and spices or 200 ppm of benzoic acid. Addition of a preservative emulsion is also suggested (7). Several recipes used in India and Pakistan have been reported (3,120).

The best stage of harvest for pickling is just after the endocarp starts hardening (37). Pickles made from 6-10 week old Amlet mangoes were of good quality but those from 8-9 week old fruit were superior in colour and flavour. High acid mangoes (5-6%) were found to produce the best quality pickles (100,101,102). For preparing pickle the following recipe is recommended (100): Mango slices - 250 gm, salt - 60 gm, mustard powder - 24-40 gm, chilli powder - 20 gm, turmeric powder - 2-4 gm, fenugreek seed - 2-4 gm, Bengal gram seeds - 2-4 gm, Gingelly oil - 20-30 gm.

Pickles are generally packed in glass jars. Salt pickle may be packed in polythene containers. Curing of pickles before canning, polythene lining inside the can, and the use of lacquered cans are measures suggested for packing pickles in cans (17,99).

Recently a process has been developed to dehydrate the salt cured mango fruit pieces, dry them, mix with spice mixture and pack to produce an instant pickle mix. This mix on addition of water and storing overnight is found to give good quality pickle the next day (85).

Mango Chutney

There are broadly two types of chutneys: (i) sweet chutney, and (ii) hot chutney. Sweet chutney is prepared either from fresh slices or brined slices. The fruit pieces are mixed with sugar, salt and cooked along with the spice bag to the consistency of jam. Then vinegar or glacial acetic acid is added and mixed well. The spice bag is then removed and the product is packed hot into sterilised bottles and sealed airtight. Cardamom, cinnamon, cumin, red chilli powder, garlic and onion are the spices used. Raisins, currants, almonds, dates are also used depending on the recipe.

Hot chutney preparation is similar to that of sweet chutney except that more spices and less sugar are used. Varieties like Tothapuri and Fazli are reported to be ideally suited for this purpose. The chemical composition of sweet chutney is give in Table 5. The subject of chutney has been reviewed exhaustively (8,111). A typical recipe for sweet mango chutney is as follows: mango slices - 100 kg, sugar - 100 kg, salt - 6.25 kg, mixed spices - 3.12 kg, garlic - 0.63 kg, red chilli powder - 1.56 kg, vinegar - 12.5 kg and ginger - 12.5 kg.

Table 5. Chemical Composition of Mango Sweet Chutney

Particulars	Mango sweet chutney
Total soluble solids (%)	64.4-71.1
Total sugars (%)	60.2-67.7
Acidity as citric acid (%)	1.02-1.63
Volatile acidity as acetic acid (%)	0.43-3.31
Total ash (%)	1.63-2.27
Salt content (NaCl) (%)	1.05-2.66
Crude fibre (%)	0.57-0.97
pH	2.60-2.80

Siddappa & Nanjundaswamy (1959).

Dehydrated Green Mango Powder

Raw mango slices of seedling varieties, dried in the sun and powdered, is referred to as 'Amchoor' in the trade and is used in culinary preparations in India. A better quality product is obtained by blanching the prepared slices of unripe fruit followed by sulphitation and drying (108). In Australia machinery has been developed for peeling unripe mangoes (54). Considerable quantity of green fruit drop is recorded due to adverse weather conditions. Utilisation of this type of fruit will go a long way in ensuring better returns to the growers (24).

Systematic studies have recently been conducted to improve the process of making 'Amchoor' by both sun and cabinet drying using totapuri, Pairi and two seedling varieties of mangoes. Optimum stage of maturity was between 9-10 weeks after fruit set. Sulphitation was helpful in better retention of colour and vitamin C. A drying period of 10 hours in a cabinet drier and 15 hours in the sun was necessary to reduce the moisture content to 2-3% when the tray load was 0.6 kg/sq. ft. and drying temperature was 55+5°C. During packing in polythene bags and storage a progressive decrease in ascorbic acid and starch and increase in reducing and total sugars were noticed (24).

Green mango pulp has also been successfully dried on an atmospheric double drum drier (30). Addition of corn starch and tricalcium phosphate was found to improve the flow characteristics of the dried powder. The powder was best stored in OTS cans or aluminium foil laminate pouches. The powder is suggested to be used as a base material for preparation of green mango drinks and thick mango chutney. The process has found commercial application in Calcutta. The chemical composition of green mango pulp and dried flakes is shown in Table 6. The powder is a rich source of carbohydrates, acidic, minerals and ascorbic acid. Loss of ascorbic acid during drying was 30%. The chemical composition of six sun-dried market samples of Amchoor (130) obtained from New Delhi market is shown in Table 7 for comparison. The acidity ranged from 14-18% with no ascorbic acid.

Unripe seedling mango gratings with addition of salt at 2% frozen and stored at -17.8°C is found to keep well and could be used for preparation of chutney (45).

Raw Mango Beverage

This is a popular product prepared and consumed at the household level in North India. A commercial process has now been developed to prepare raw mango beverage base and preserve it by bottling. Gel formation is overcome by enzymatic treatment. The product has been found to keep well for more than one year at ambient conditions (85).

II. TECHNOLOGY FOR PROCESSING RIPE MANGOES

Frozen Products

A great deal of interest is shown by several researchers in freezing preservation of mango. Whole mangoes packed in polythene bags and frozen at -30°C were found good for sucking after thawing (73,119).

Four important table varieties (Alphonso, Pairi, Padri and Mulgoa) were screened for freezing in the form of slices. They are peeled, cut into slices and packed into cans with sugar syrup (40-50°) containing citric and ascorbic acid and frozen at -30°C. During storage at -17.8°C, frozen slices retained their natural colour, flavour and texture even after 12 months (45). Airblast freezing and contact plate freezing at -40°C to -45°C have been suggested for getting a better quality product (54).

Alphonso mango slices in syrup were frozen under thirteen different conditions, stored 3 months at -28°C and the chemical, microbial and organoleptic qualities assessed. The quality was insensitive to the rate of freezing and addition of 0.1% vitamin C to the covering syrup. Pre-soaking of slices in calcium chloride solution (2%) was helpful in forming the slices. Fruit frozen in 40° Brix sugar syrup had better flavour than 20° Brix syrup. During freezing ascorbic acid decreased by 30-50%, reducing sugar by 30-50% and carotenoids by 15-30% (12,23).

Three Egyptian varieties, viz. Pyrie, Taymour, Alb-El-Tore were tested for freezing and none of them were ideal (98). Several varieties of mangoes grown in Hawaii were frozen as slices in various packs and the quality of thawed samples compared after frozen storage for several months. The samples frozen in syrup were superior to those packed in dry sugar or no added sugar or syrup. Ascorbic acid addition produced no improvement in quality (80).

Table 6. Chemical Composition of Green Mango Pulp and Flake Dried by Drum Drying

Particulars	Green mango pulp	Green mango flakes
Moisture (%)	81.5	5.1
Total ash (%)	0.6	3.1
Total sugars (%)	2.3	10.8
Total carbohydrates (%) (other than sugar)	14.1	68.3
Total protein (%)	0.4	2.1
Crude fibre (%)	0.4	2.1
Fat (%)	0.5	2.5
Acidity (%)	1.3	6.2
Ascorbic acid (mg%)	70.0	252.0 (30% loss during drying).

Gangopadhyaya et al. (1976).

Table 7 Chemical Composition of market samples of Amchoor

Particulars	Range
Moisture (%)	5.1-8.0
Acidity (%)	14.4-17.8
Reducing sugars (%)	8.3-10.7
Total sugars (%)	11.1-13.3
Tannins as tannic acid (%)	3.1-4.8
Water insoluble solids (%)	44.4-56.4
Alcohol insoluble solids (%)	28.5-33.5
Ascorbic acid	Traces

Usha & Anand (1981).

Significant differences were found in the texture of thawed frozen slices of different varieties with Haden and Irwin having fair firmness and Buchannare, Kensington and Waterhouse having poor texture. Steam blanching was also found to be not beneficial. The recommended procedure is to place the slices into containers and cover with 25-30°C Brix syrup, seal, freeze in a blast freezer at -23°C and store at -18°C or lower (19). Of the three types of syrup used for freezing of Haden mango slices, sucrose syrup (25-45° Brix) was found to give better flavoured slices than glucose syrup or glucose/sucrose mixed syrup. Calcium pretreatment resulted in better colour retention.

Bombay green, Dashehari, Langra and Chousa of North India and Baneshan of South India were evaluated for freezing of slices. The overall assessment showed that Dashehari was best followed by Baneshan, Langra, Bombay green and Chausa (1).

Frozen Mango Pulp

Mango pulp (Puree) from Alphonso and Pairi varieties with added sugar at 20% level remained in good condition after 12 months of storage at -17.8°C. Addition of citric acid and ascorbic acid helped in the retention of colour and flavour (17).

Bombay green, Dashehari, Langra and Chausa and Baneshan (Indian varieties) were evaluated for comparative methods of preservation of pulps by canning, freezing and chemical preservation. The variety Dashehari scored highest rating followed by Langra, Baneshan, Bombay green and Chousa, irrespective of the method of preservation. Canning was found to give a better quality product (2).

The storage quality of Totapuri mango pulp as such or with addition of ascorbic acid (500 mg%) which was frozen as a slab (7kg) in polythene bags (25 cm x 40 cm x 3 cm) and stored at -18°C for a period of 14 months, was studied along with canned pulp for comparison. It took 4.5 hours at -40°C for the slab to freeze in a plate freezer. During storage ascorbic acid, total carotenoids and the viscosity of the pulp decreased in all the samples. Nectar prepared from the frozen pulp at the end of 6, 10 and 14 months storage, indicated the development of off-flavour. This could be removed either by pasteurising the pulp before freezing or heating the pulp before use. Added ascorbic acid was found to be helpful in retaining colour and flavour (88). Changes in ascorbic acid, total carotenoids and viscosity of the samples at the end of 14 months storage at -18°C are given in Table 8.

Mango pulp (cv. Mallika) sterilised at 95°C filled into a HDPE* container and stored at -5°C for a year was analysed for microbial load and found to be negligible. The sensory quality of the stored pulp has not been reported (44).

Similarly Hawaii mango puree heated to 90°C, cooled to 35°C before filling into 30 lb tins with polythene liner and frozen at -23.5°C was found to keep well and the nectar prepared from it had better flavour than that made from unheated pulp (18).

* High Density Polyethylene

Table 8. Changes in Frozen Packed and Canned Mango Pulp (Totapuri) after 14 months Storage.

Particulars	Frozen control		Frozen with ascorbic acid		Canned	
	Initial	14 months at -18°C	Initial	14 months at -18°C	Initial	14 months at 4°C
Total soluble solids (%)	16.5	16.0	16.5	16.0	16.0	16.0
Acidity as C.A. (%)	0.45	0.48	0.45	0.47	0.50	0.52
Ascorbic acid (mg%)	17.0	0.9 (5.3)	65.0	12.8 (19.7)	14.0	8.9 (64.6)
Total carotenoids as -carotene (mg%)	4.2	2.15 (51.25)	4.2	3.24 (77.1)	4.10	3.75 (91.5)
Chroma. (%)	49.0	27.0	49.0	36.4	49.5	45.4
Viscosity (cp)	3950	2260 (57.2)	3950	2950 (74.7)	3795	3410 (89.9)

Figures in parenthesis indicate per cent retention.

Rama et al. (1984).

Sweetened mango puree containing 42-43% soluble solids was preserved by both canning and freezing the product diluted with three times its weight of water to form nectar. Sucrose and high fructose corn syrup (HFCS) were used as sweeteners. Canned mango puree sweetened with HFCS was preferred to frozen mango puree (9).

Canned Product

Mango Slices in Syrup

Mangoes are generally canned as slices, cheeks, shoulders or as dices. Of the several commercial varieties grown in India, Alphonso is most suited for canning (110). Other varieties such as Dashehari, Baneshan, Totapuri and Fazli gave canned products of mild flavour and pale colour. Mushiness of slices is a problem. Calcium firming treatment proved effective only in the case of Totapuri slices. In the case of Alphonso and Pairi varieties it proved ineffective and adversely affected the flavour (91).

Peeling and slicing are done by hand using different kinds of knives. Mechanised equipment for peeling of ripe mangoes has yet to be developed and it is a serious bottleneck in the industry. Lye peeling has been tried but not adopted commercially (17).

The prepared slices are filled into plain cans (401 x 411 size) and covered with hot syrup of varying strength (30-50° Brix) depending upon the variety, sealed and processed for 15 min at 100°C. Since the fruit has a pH of 4.0 to 4.5, citric acid is added at 0.25-0.40% to the covering syrup (110). Spin pasteurisation is preferred in place of stationary pasteurisation. The canned product has a shelf life of over 12 months at ambient temperature. Alphonso and Pairi varieties showed no loss of β-carotene after storage for 8 months at 25-30°C (110).

In some countries, slices are scooped with a curved knife from unpeeled cheeks cut from the fruit to give smooth surface. The stones and peels are passed through a pulper. In this process the yield of slices is reduced but the pulp yield is increased. The advantage in this method is the ease of handling unpeeled fruit (17).

The quality of the canned product depends upon the variety. Several researchers have studied the suitability of different varieties (1,50, 68, 82, 104, 126, 127). These include Indian varieties like Alphonso, Baneshan, K08, K016, Mulgova, Badami, Totapuri, Dashehari, Langra, Bombay green, Chousa, Safeda, Pairi and the recently developed hybrid varieties like Mallika, Amrapali and Hyderabad 165. Of the hybrid varieties, Mallika was found best from the point of cheek yield (53% as against 40% in other varieties), texture and flavour (50).

Langra and Sama Bahisht Chausa, two Pakistan varieties have been canned and canning effect on important constitutents studied. β-carotene showed little change during canning and storage for 200 days. Brix acid ratio increased by 40% while vitamin C content decreased by 20% on canning and a further 30% during storage (31). Similar changes have been reported in some Indian varieties (68).

Addition of ascorbic acid to the covering syrup at various levels imparted better flavour. The increase in flavour appraisal scores for Dashehari variety was

accompanied by an increase in the estimated values for volatile reducing substances. The retention of flavour was lost in the product with 100 mg% ascorbic acid addition. This is attributed to the reducing and oxygen scavenging action of added ascorbic acid during and after processing (97).

Factors influencing the pectin fraction and their influence on the texture of slices during canning and storage of mango slices have been investigated. Loss of texture during storage of mango slices canned only in sugar syrup is attributed to the conversion of protopectin to water soluble pectin. Addition of calcium salt to the covering syrup inhibited degradation of protopectin to a considerable extent (3).

In order to accommodate more fruit and to improve the texture and flavour of slices of cultivars normally considered unsuitable for canning, partial dehydration (40% weight reduction) before canning was investigated. Texture and flavour of dehydro-canned mango slices were reported to be better (63).

Canning of mango slices (Dashehari) with addition of mango pulp to the covering syrup to improve the quality has shown good possibilities. Addition of 15% mango pulp in the covering syrup was found to be the best. This method not only improved the flavour quality but also increased the drained weight percentage. Further drained syrup (with 15% pulp, 20° Brix and 0.3% acidity) could be utilised as a ready-to-serve beverage (51).

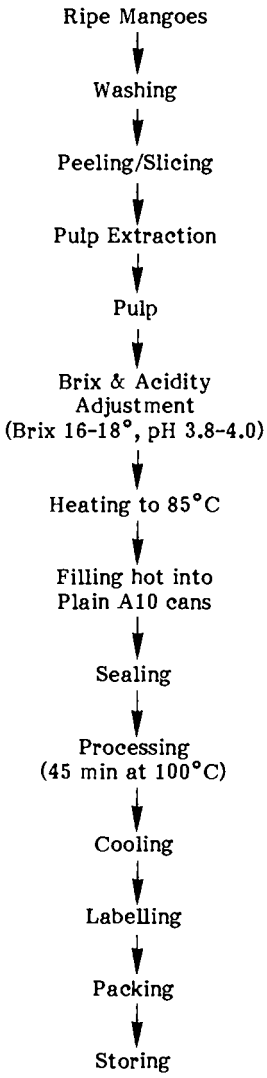
Canned Mango Pulp

The development of a mango beverage industry has increased the demand for canned mango pulp. The flow sheet for production of canned mango pulp is shown in Fig. 1. Fully ripe mangoes are selected and washed. They are peeled or cut into slices and passed through a pulper fitted with a 30 mesh sieve to obtain the pulp. The pulp as such with addition of citric acid if necessary to lower the pH to about 4.0 or sweetened and then heated to 85°C, is filled hot into plain cans (A10 size), sealed and processed at 100°C for 45 min and cooled (17). Addition of ascorbic acid at 100 mg% to the pulp is reported to be helpful in better retention of colour flavour and carotene (122).

Mango pulp used in the preparation of jams and squashes may be preserved in wooden or HDPE barrels by using SO_2 as preservative. For this purpose the required quantity of citric acid is added to the pulp to lower the pH to 3.8-4.0, heated to 85°C and cooled to 35°C. The required quantity of potassium metabisulphite (KMS) is added to pulp so that the pulp may contain 1000-1500 ppm of SO_2. The pulp thus prepared is filled into cleaned and sterilised barrels and sealed air tight and stored for subsequent use (17).

The mango jam prepared from the above sulphited pulp contained a higher than permitted level of SO_2 (40 ppm SO_2) in the prepared jam. A process has now been developed to preserve mango pulp in an HDPE container using mixed preservatives (300 ppm of benzoic acid + 200 ppm of SO_2). Jam made from such pulp contained SO_2 within the limit (71).

Figure 1 Flow sheet for production of canned mango pulp



A thermal process for bulk packing of mango pulp has been shown to decrease the cost of production without sacrificing chemical and nutritional quality (107). The process involves acidifying the pulp to pH 3.5, heating to 90°C, filling hot into polythene (HDPE) container, heat sealing, cooling and storing. This process is claimed to save 30-40% of the cost on packaging material. The product kept well for about six months.

Since hand peeling is time consuming and expensive, steam peeling and lye peeling have been tried (19). Puree was also extracted by passing unpeeled slices through a cutting mill and paddle pulper fitted with a 0.84 mm screen. Puree extracted thus was found to result in better flavoured nectar (18).

Steam peeling is reported to give higher yield of pulp (84 to 87%) as compared to mechanical peeling (75 to 79%). But both the purees produced were of similar quality (16). Higher yield may be varietal characteristics of Puerto Rican varieties of mangoes.

Mango Beverages

Mango beverages are becoming increasingly popular because of their appealing taste and attractive yellow colour. The flow sheet for production of canned mango juice nectar, ready-to-serve (RTS) beverage, mango squash and syrups are shown in Fig. 2.

Canned Mango Juice

Mango juice is prepared by mixing mango pulp, sugar, citric acid and water. The pulp content, brix and acidity may vary depending upon the buyer's specifications (pulp: 35-45%, Brix: 15-16°, acidity: 0.25-0.30%). The juice prepared according to the specification is heated to 85°C in an heat exchanger, filled hot into plain cans (401 x 411 size), sealed and processed for 20 min at 100°C, cooled and stored (17,57).

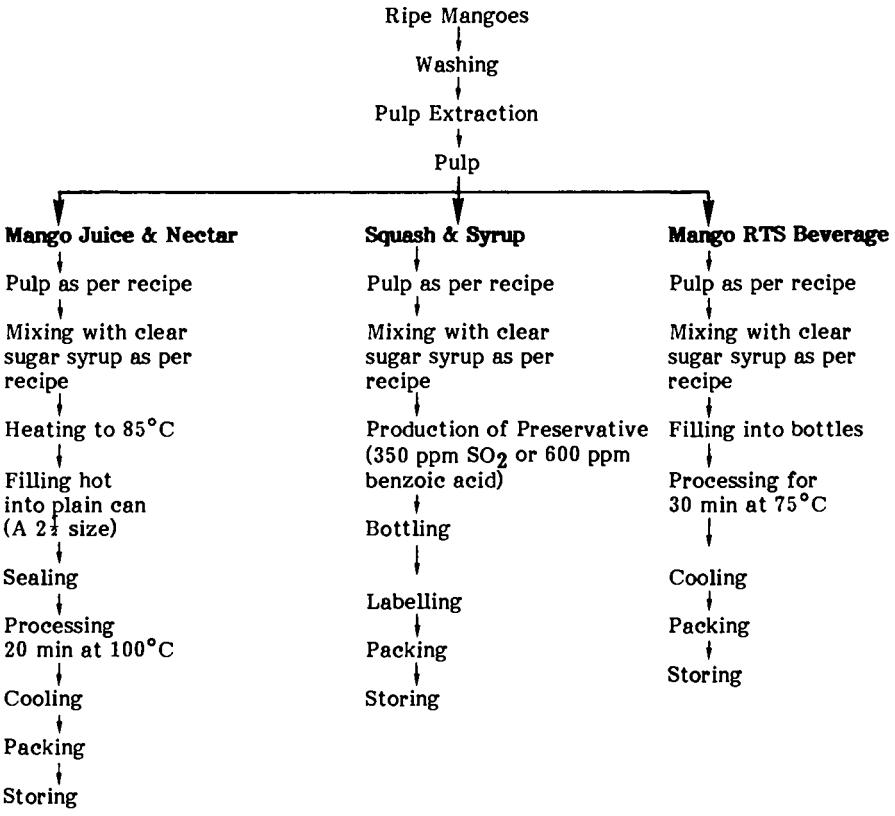
Canned Mango Nectar

Mango nectar is prepared and processed in the same way as mango juice. Mango nectar contains only 20% pulp according to Indian specifications. The other specifications are similar to mango juice.

Mango RTS Beverage

The mango ready-to-serve (RTS) beverage is prepared either from fresh pulp or stored pulp according to the following recipe: Pulp: 10%, Brix: 15°, and acidity: 0.3%. The beverage is filled into sterilised glass bottles and pasteurised for about 30 min at 75°C and cooled. Production of this beverage in returnable bottle is increasing year by year and is very popular in all the regions of India.

Figure 2. Flow sheet for production of mango beverages



Mango Squash

Mango squash contains 25% pulp, 45° Brix, 1.2-1.5% acidity and is preserved with either 350 ppm of SO_2 or 600 ppm of benzoic acid in bottles (17). It is to be diluted three times with chilled water by volume, mixed well and then served.

Mango Syrup

This is made similar to squash but contains total soluble solids up to 70-75%. It is bottled with or without the addition of permitted preservative (20).

The choice of the most suitable varieties for preparing the above mango beverages is the subject of investigation of many workers in India, Philippines, Sudan and other countries (10, 25, 49, 64, 95, 96, 126).

Thermal Process Schedule for Canned Mango Product

Thermal process schedules for canned Badami (Alphonso) mango products were evolved using thermal inactivation time (TIT) of the peroxidase enzyme system and an improved graphical method. The TIT was calculated to be

$$F_{175}^{18} = 1.$$

The calculated process time for a 401 x 411 size can at 100°C was 7 min for slices, 8 min for nectar, 7.5 min for juice and 5 min for pulp when the filling temperature was 80°C (69). The validity of these process times was tested at a commercial processing plant. No spoilage of the samples packed was noticed.

Similarly using pectin-esterase (PE) a thermal process schedule for mango (Totapuri) slices in syrup was evolved. The TIT of PE was found to be

$$F_{208.8}^{18.56} = 1.0 \text{ at pH } 3.6.$$

At 207°F for 401 x 411 size cans the process time required was calculated to be 14.4 min. Innoculated pack study using Cl. pasteurianum and B. coagulans confirmed the validity of the calculated process time (75).

Thermal resistance of the peroxidase enzyme and the mould Byssochlamys fulva and process calculations were determined to establish minimum process times for canned mango slices and juice. The enzyme was inactivated at a temperature insufficient to kill the heat-resistant mould. The minimum thermal process for canned mango slices and juice packed in 307 x 409 cans and processed at 100°C were 15 min and 19 min respectively (11).

Internal Corrosion in Canned Mango Products

The limit for tin content in canned products is being reduced in many countries of the world. Russia has specified that the tin content in mango juice to be not more than 100 ppm. Systematic investigations have been carried out to find the effect of various factors and processing practices on internal corrosion and tin pick up in canned mango juice (Table 20).

Mango nectar prepared from the Banganapally (Baneshan) variety caused less corrosion than nectar from Badami or Raspuri varieties. The degree of corrosion was inversely proportional to the viscosity of nectar. Among different fractions of mango pulp, only organic acid fractions were responsible for corrosion. β-carotene did not contribute to corrosion. Corrosion was greater in pulp and nectar prepared from unpeeled mangoes. The peel contains gallic acid and ellagic acid of which the former acts as an accelerator of corrosion. Leucopetunidin and leucopelargonidin have been identified in mango peel and they did not affect the process of corrosion (56).

Among the different processing variables tried, de-aeration of mango juice before filling into cans helped in reducing the extent of corrosion. Time lags between sealing and processing and high cooling water temperature accelerated corrosion. The presence of nitrate above 5 ppm level accelerated corrosion. Corrosion was found to be less when the concentration of pulp in the juice was treated (Table 9). Increase in concentration of acid accelerated corrosion (57). Other variables did not have much effect.

Table 9. Process variables and other factors on tin pick-up in canned mango juice (Totapuri) in ppm.

Variable	Initial	R.T. (25-30°C)		37°C	
		6 months	12 months	6 months	12 months
Control	30	52	120	123	520
Low filling temperature	32	53	125	128	507
De-aeration of juice	20	40	80	95	405
Time lag (3 hr)	51	77	152	142	545
Reduced processing time	28	47	115	116	525
High cooling water temp (55°C)	55	100	170	151	565
Nitrate (added) 5 ppm	40	97	158	152	520
10% pulp	53	95	180	207	550
20% pulp	36	86	153	150	525
35% pulp	30	75	120	123	520
45% pulp	26	68	87	106	402

Mahadeviah et al. (1975).

Electrolytic tin plate (E-100) with a tin coating of 22.4 g/M^2 and grain size of tin coating equivalent or larger than ASTM No. 9 were found suitable for canning mango nectar. Corrosion was found to be more in big size cans (401 x 411) as compared to small size (202 x 308) cans with mango nectar (58).

Ascorbic acid and its degradation products like furfural have been shown to act as accelerators of corrosion when added to mango nectar (55).

Polyester lacquered cans were found suitable for canning mango juice with satisfactory quality of the product with respect to taste and flavour as compared to cans coated with epoxy-phenolic lacquer which imparted lacquer taste and flavours (59).

Flexible Packaging Material for Mango Products

Preliminary studies have been conducted to evaluate the suitability of flexible packaging materials for packing mango products as the cost of cans is increasing every year. Polypropylene bags (300 gauge) were used for thermal packing of mango pulp and mango syrup and found to be promising (33). On the contrary, pouches made of polyester/polypropylene have been found to be unsuitable for

thermal packing of mango juice. But pouches of low density polypropylene, polycell, paper-foil-poly laminate and aluminium collapsible tubes were found satisfactory for packing mango jam (35).

Aseptic Bulk Packing System for Mango Pulp

Aseptic packing of mango pulp for export purpose has been adopted by three major mango processing units in India using the imported aseptic filling system from Italy and USA. Laminated bags made of poly/aluminium foil/poly/poly liner and poly/metalised polyester/poly/poly liner of 20 kg and 200 kg capacities have been used. Slight discolouration and slight off flavour development are the problems encountered during storage (85).

Mango Jam

Mango pulp extracted from fully ripe mangoes or bulk preserved mango pulp is cooked with a calculated quantity of sugar, pectin and citric acid to 68-70°C Brix. Citric acid is added to improve the sugar acid blend and also to avoid crystallisation of sugar in the jam. The jam is filled into sterilised cans or jam jars, sealed air tight, cooled and stored (20).

Mango Toffee

Mango Toffee can be prepared from mango pulp with other additives according to the following recipe: mango pulp: 53 kg, sugar: 30 kg, glucose: 4 kg, skim milk powder: 8 kg, and hydrogenated fat: 5 kg.

The fruit pulp is first concentrated in a steam jacketed kettle to about one third of its original volume. The other ingredients are then mixed and cooking continued to a final weight equal to about 1.2 times that of fresh pulp taken. The cooked mass is transferred to a level and smooth surfaced tray which has earlier been smeared with little fat and the product spread into thin sheet of 1.0 cm thick. It is then allowed to cool and set. The solid sheet is cut into toffees and wrapped in cellophane paper and packed in air tight tins (20).

A series of investigations have been conducted as regards the nutritive value, storage behaviour of the product, the role of additives like antioxidants and antimould agents, etc. on the quality of the product during long storage (116). The proximate composition of mango toffee is given in Table 10.

Dehydrated Products

Dehydrated Mango Slices

Mango slices dried by sun drying, cross flow air drying and through flow air drying have been compared. Through flow air drying was found to be most efficient. Between Badami and Raspuri varieties the former gave a better product. The dried product with 15% moisture, containing 1500 ppm of SO_2 was found to keep well for about 10 months at ambient storage conditions. Boiling the dried pieces for 10 min in 10% sugar syrup was found necessary for proper reconstitution (4).

Table 10 Proximate composition of various mango products prepared from Badami mangoes

Particulars	Mango toffee	Osmo-air dried mango	Mango cereal flakes	Mango custard powder	Sweetened mango powder
Moisture (%)	8.6	13.6	2.2	1.7	1.2
Ash - Total (%)	1.7	1.9	1.6	3.9	0.4
Ether extractives (%)	8.2	0.1	-	0.1	0.3
Protein (N x 6.25) (%)	6.0	2.2	3.9	11.0	0.3
Acidity as citric acid (%)	0.2	2.9	0.2	1.8	0.5
Reducing sugars (%)	6.8	53.3	32.8	25.9	5.2
Total sugars (%)	67.3	74.0	71.0	58.6	95.7
Crude fibre (%)	0.5	1.2	1.6	2.3	0.2
Starch (%)	-	-	17.9	8.4	-
Minerals:					
Calcium (mg%)	268	25.0	115	233	38.1
Phosphorus (mg%)	154	15.0	50	221	11.9
Iron (mg%)	1.1	1.6	7	13.6	2.6
Vitamins:					
True ascorbic acid (mg%)	4.8	53.4	150	55.5	18.6
- carotene (mg%)	6.5	18.4	7.2	21.1	2.3
Total carotenoids (mg%)	9.6	-	-	30.9	3.9
Thiamine (µg%)	-	-	-	71.5	-

Nanjundaswamy (1984): Siddappa et al. (1962).

Osmotic Dehydration

Mango slices have successfully been dehydrated by the osmotic dehydration using sugar syrup (70° Brix) as osmotic agent. The fruit pieces are cut into suitable sizes and dipped in 67-70° Brix syrup for varying periods, drained, dipped in sulphite solution, drained and the pieces dried in a cross flow air drier or under vacuum in a vacuum drier (12, 36, 42, 65, 72, 87, 128).

Alphonso mango slices were dehydrated by freeze drying and osmo-vac drying. Comparative evaluation of quality attributes such as retention of aroma, taste, colour and structural integrity indicated that osmo-vac dehydrated product was almost identical with those of freeze dried product (87). The economics of the process depend upon the availability of cheap sugar, or the possibility of using spent syrup (36, 72). Effect of osmo-air dehydration on ascorbic acid and - carotene content of mango is shown in Table 22. Retention of ascorbic acid was 55% after osmosis and 52% after osmosis and drying. Retention of - carotene was 82% after osmosis and drying. The proximate composition of osmo-air dried mango is given in Table 11.

Table 11. Effect of osmo-air dehydration on Ascorbic acid and -carotene content of mango (Badami).

Stage	Moisture content (%)	Ascorbic acid		- carotene	
		MFB mg%	Retention %	MFB mg%	Retention %
Initial	81.6	139.1		26.1	
After osmosis	63.2	76.6	55.1	21.5	82.4
After drying	13.6	71.6	51.5	21.3	81.6

MFB = Moisture free basis;

Nanjundaswamy (1984).

Intermediate Moisture Mango (IM Mango)

The IM mango is made by the immersion equilibration procedure wherein the fruit slices are blanched and equilibrated, in a solution composed of the following: glycerol: 42.33, sucrose: 42.33, water: 14.84, potassium sorbate: 0.45, and KMS: 0.1 per cent. The method consists of adding the fruit slices to the soak solution (Fruit : Solution = 1:2.4) previously heated to 95°C, keeping the fruit immersed in the solution at 90°C for 3 min and then quickly cooling the mixture to room temperature and allowing it to equilibrate overnight, draining it and packing the fruit pieces.

Three varieties of mangoes - Badami, Mulgoa and Neelum have been tried for preparing IM mango and the chemical composition of the three final samples are included in Table 12. The water activity achieved in the products (0.76-0.78) was sufficient to prevent bacterial growth while the sorbate present prevented the

growth of yeasts and moulds. The IM mango (Badami) packed in cans or paper/foil/poly pouches kept in acceptable condition for more than 9 months at room temperature and 4 months at 37°C.

Table 12 Chemical Composition of IM Mango of different varieties

Particulars	Intermediate Moisture Mango		
	Badami	Mulgoa	Neelum
Moisture (%)	34.8	34.5	32.9
Protein (N x 6.25) (%)	1.0	1.0	1.0
Ether extractives (%)	1.0	1.0	1.0
Reducing sugars (%) (dextrose)	2.4	2.0	2.8
Total sugars, sucrose (%)	28.1	32.9	26.4
Crude fibre (%)	1.8	1.6	1.0
Total ash (%)	0.4	0.7	0.7
Glycerol and other carbohydrates (by difference) (%)	33.9	29.3	38.0
SO_2 (ppm)	246	255	261
Ascorbic acid (mg%)	16.6	13.3	23.3
β- Carotene (mg%)	11.0	2.6	1.13
ERH (%)	78.0	76.0	76.0

Jayaram et al. (1976)

Mango Fruit Bar

This is a fruit confectionery product. The method of preparation is simple and involves mainly mixing the pulp with calculated amounts of sugar and heating the mixed mass to 80°C, cooling and incorporating KMS. The pulp thus prepared is spread in a tray and dried in a cross flow air drier at 70-80°C for about 22 hours. At the end of drying the dried sheet is cut into suitable size and wrapped in cellophane or glossine paper (20,70).

Variety of mango and consistency of the pulp have definite effects on the quality of the fruit bar. The thicker the consistency of the pulp the better is the texture of the final product. However, thinner mango pulp could as well be made use of for preparing mango and banana mixed fruit bar, by mixing mango and banana pulp at 3:1 ratio. The flow sheet for production of mango fruit bar is shown in Fig. 3. Proximate composition of mango fruit bar prepared from different varieties of mangoes is presented in Table 13.

Table 13. Proximate Composition of Fruit Bar from some Important Commercial Varieties.

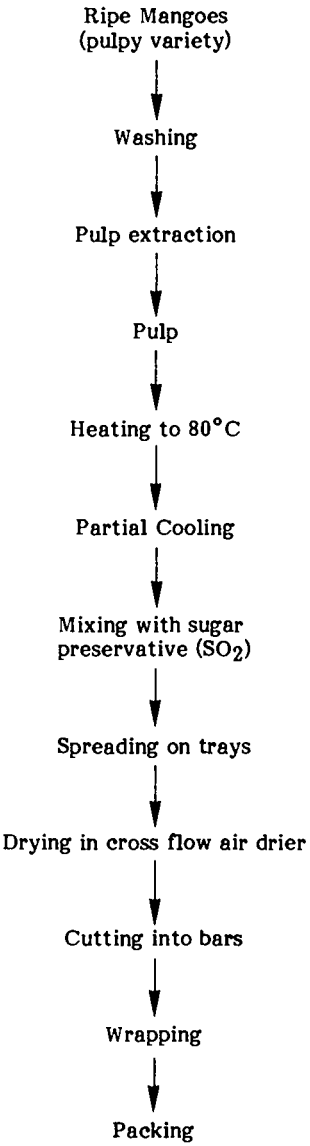
Particulars	Badami	Banganapally	Totapuri
Moisture (%)	16.0	15.7	16.1
Ash - Total (%)	2.0	1.7	1.1
Acidity (%)	1.2	1.1	0.9
Reducing sugars (%)	28.0	23.5	18.8
Total sugars (%)	65.0	68.2	69.5
Ether extractives (%)	0.1	0.1	0.1
Protein (N x 6.25) (%)	2.0	2.2	1.6
Crude fibre (%)	1.1	1.0	1.1
Carbohydrates other than sugars (%)	12.6	10.0	9.6
Minerals:			
Calcium (mg%)	3.0	3.0	2.4
Phosphorus (mg%)	15.0	14.4	9.4
Iron (mg%)	3.0	3.0	2.4
Ascorbic acid (mg%)	20.0	16.0	8.0
-carotene (mg%)	15.4	11.2	9.2

Nanjundaswamy et al. (1976)

Mango fruit bar is a hygroemissive product and keeps well in the range of 50-60% RH. When wrapped in cellophane or glossine paper and stored in an air tight tin the bars have been found to keep well for about a year at 25-28°C and six months at 37°C (70).

Addition of pectin at about 1.5% level and liquid glucose at 6% level to the prepared pulp is reported to be helpful in getting a product with a smooth texture (62, 103). Mango fruit bar is finding a special place in the design of combat rations, Antarctica food items and space food (85).

Figure 3. Flow sheet for production of mango fruit bar



Mango Cereal Flakes

Utilisation of mango pulp for preparation of fruited cereal products is a novel idea. The technique developed consists essentially in blending the fruit pulp with a small amount of wheat flour and sugars, adjusting the acidity and finally drying the blended and homogenised material on an atmospheric double drum drier (39). The following recipe was found quite suitable: Mango pulp: 100 kg. wheat flour (maida): 10.25 kg, sugar: 5.7 kg, glucose: 5.7 kg, calcium carbonate: 100 gm, sodium carbonate: 200 gm, pectin: 60 gm. The wheat flour is mixed with water and heated to gelatinise the starch. This is mixed with the mango pulp, the pH of which was adjusted to 5.0, and the mix heated to 85°C. The other ingredients like sugars, pectin in the form of solution were added, blended and homogenised. The homogenised product is dried in the form of flakes on the drum drier working at a steam pressure of 50-60 psig when the speed of rotation kept at 2-3 rpm and clearance between the drum at 0.35 mm. The product which dries in the form of a crisp, crinkled sheet is broken into smaller flakes and filled into 4 gallon friction top tins. It is designed to be used as breakfast food or as snack food (39). The critical relative humidity of the product is found to be 45%. Hygroscopicity of the flakes has been found to increase with increasing fructose content in the pulp. For preparing the flakes, Badami and Dushehari varieties have been found most suitable (47, 52). Flakes packed in pouches of aluminium foil laminate were found to have one year shelf life (81).

The flow sheet for production of mango cereal flakes is shown in Fig. 4, and the proximate composition is given in Table 10. With high carbohydrate, -carotene, ascorbic acid, and mineral content, mango cereal flakes are a highly nutritious product.

Strained Baby Foods

The manufacture of canned fruit and vegetable pulps free from excessive fibre has attained considerable importance in developed countries for feeding to infants. Systematic investigations have been done in India to produce strained mango pulp, strained mango custard and dehydrated mango custard (113). Incorporation of small quantities of skim milk powder and starch proved useful to facilitate drying (114).

Mango custard is prepared based on the following recipe: Mango pulp: 100 kg, sugar: 5 kg, skim milk powder: 5 kg, corn starch : 2.5 kg, and sodium bicarbonate to raise the pH of pulp to 5.6-5.8. The starch is first cooked into a paste with water and then mixed with sugar, milk powder and mango pulp. The mixture is then passed through a 60 mesh sieve and cooked for 5-6 min in a kettle. The pH is raised to 5.6, homogenised and dried on an atmospheric double drum drier into a thin continuous band. The dried product is powdered and packed in hermatically sealed cans.

Effect of canning and drum drying on proteins, ascorbic acid and -carotene have been studied. Drum drying preserved more ascorbic acid than canning. -carotene was quite stable in both cases (113). The dried product packed in cans under N_2 kept well for about a year at 5°C and about six months at 37°C (114).

Feeding trials with children have given good results and shown their usefulness in milk diets (46). The proximate composition of drum dried Badami mango custard powder is given in Table 10. The flow sheet for manufacture of mango custard powder is shown in Fig. 5.

Figure 4 Flow sheet of production of mango cereal flakes

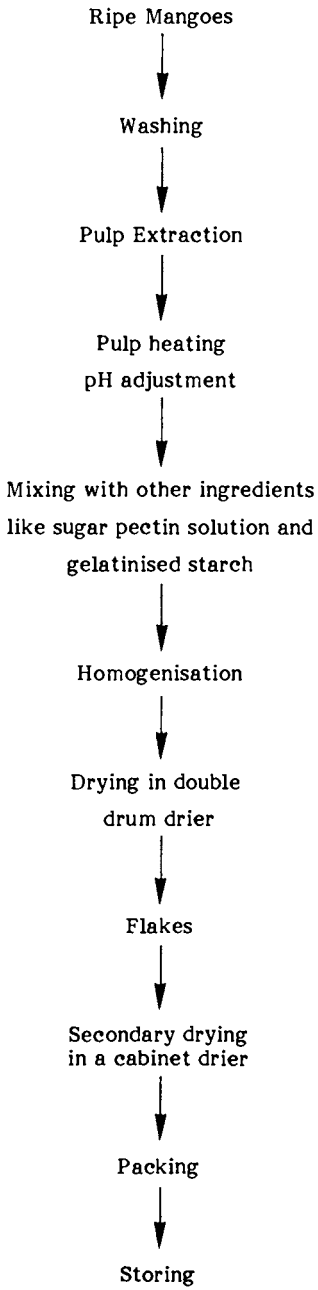
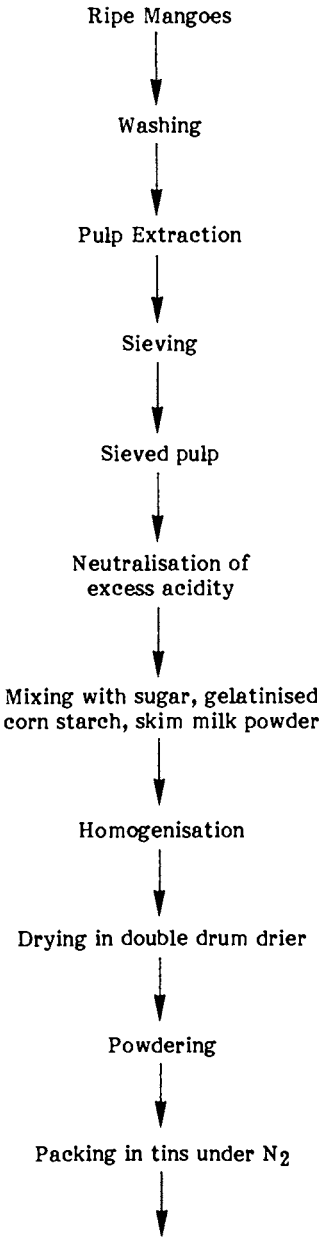


Figure 5. Flow sheet for production of mango custard powder



Mango Powder

Several methods have been studied to dry mango pulp with or without the additives to produce free flowing powder which could be used as a beverage base flavouring agent (115).

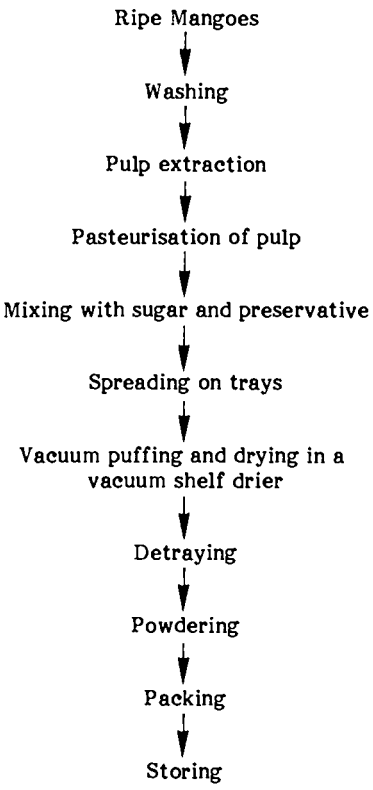
Freeze drying produces dried product with very little loss of flavour or aroma, but cost of production is high. Freeze drying mango pulp (82% moisture) required 11.5 hr to reduce moisture content to approximately 1% (5). The dried product packed in cans under N_2 kept well for about a year and in ambient conditions. Addition of sucrose to the pulp increased the shelf life of the fruit powder (123).

In foam mat drying the pulp is whipped to form heat stable low density foam. The foam is spread on wiremesh trays or a continuous belt in a thin layer and dried with hot air. Glyceride monosterate was found to be a good foaming agent for mango pulp. Drying was accomplished in a cabinet drier at 70-80°C in an hour (42). The powder is reconstituted with cold water. Alphonso mango powder produced by this technique was converted into nectar and the nectar rated poor by sensory evaluation and hence the process is not satisfactory for production of mango powder (22).

Spray drying is accomplished by atomising the diluted or enzyme treated puree into a stream of hot air. The atomised particles are dried to powder as they fall. Alphonso mango is treated with 0.1% (w/v) ultrazyme for 2 hr at 30°C and diluted with water (2:1 v/v). In the drier the inlet and outlet temperatures were maintained at 154°C and 84°C respectively. Taste panel evaluation of nectar made from the spray dried powder rated the colour as bright and attractive but slightly lacking in flavour (12). Addition of skim milk to the pulp at 1:1 and addition of whole milk or curd at 1:2 facilitated spray or drum drying (42). Good quality spray dried powder with a shelf life of one year was reported to have been produced based on the following recipe: Mango pulp (Chausa); 36 kg. sugar: 10.8 kg. concentrated buffalo milk (30% solids): 32.6 kg. cream (40% fat): 14 kg, and 200 gm each of glyceryl monosterate and sodium alginate. The dried product contained 25% moisture (106).

Vacuum puff drying technique has been made use of for preparing sweetened mango powder. It consists of mixing the mango pulp with equal quantity of sugar and the mixed material spread evenly in trays, keeping the tray load at the optimum level of 8 kg/sq. metre. The trays are then transferred to a vacuum shelf drier and dried at 65°C and 27 inch vacuum for about 8 hr. The dried material in the form of spongy mass was detrayed, powdered and packed in hermatically sealed cans (20, 72). Addition of sulphur dioxide at the rate of 200 ppm helped in the retention of colour, ascorbic acid and β-carotene and the retention of these in the dried product was 90%, 80% and 9% respectively. Badami variety was best suited for preparing the powder as compared to Totapuri and Neelum varieties. The powder remained good for about 8 months at ambient condition and less than 4 months at accelerated conditions (72). The proximate composition of mango powder thus prepared is given in Table 10. The flow sheet is shown in Fig. 6.

Figure 6. Flow sheet for production of sweetened mango powder



Mango Concentrate

Concentration by reducing bulk results in the economy of handling, packing, storage, transporation and distribution cost. The demand for mango concentrate in the export market is increasing. Studies conducted in the laboratory has shown the possibility of preparing the concentrate by two methods. In the first method, the pulp is concentrated in a forced circulation evaporator under vacuum up to 30-35° Brix which facilitates easy removal of the concentrate from the evaporator (73,90).

Attempts have also been made to treat the pulp with pectic enzymes, separate the serum from fibrous pulp residue, concentrate the serum and remix it with the fibrous pulp residue and homogenise to obtain 40° Brix mango concentrate (21).

The effect of concentration of Totapuri mango pulp in a forced circulation evaporator on the important constituents is shown in Table 14. During concentration, retention of ascorbic acid, -carotene and total carotenes were found to be 82, 87 and 85% respectively. The concentrated pulp is found to

retain a fairly good amount of volatile flavour as indicated by chemical oxygen demand, and the nectar prepared from it was found to be quite acceptable as evaluated by the panelists. This may be due to retention of less volatile components which contribute much to the mango flavour.

Table 14. Effect of concentration in forced circulation evaporator on the important constituents of Totapuri Mango Pulp.

Constituents	Fresh feed pulp	Mango concentrate
Total soluble solids (%)	17.00	35.00
pH	3.8	3.7
Acidity as citric acid (%)	0.53	1.10
Ascorbic acid (mg%)	10.90	18.60 (82.1)
β-Carotene (mg%)	1.17	2.10 (87.2)
Total carotenoids (mg%) as β-carotene	1.90	3.31 (84.6)
Chemical oxygen demand	1200	300

Figures in parenthesis indicate per cent retention.

Nanjundaswamy (1986) - unpublished data.
Ramteke (1987).

Aroma Recovery and Mango Concentrate

Recent investigations have shown the possibility of stripping the aroma from mango pulp, concentrating it and adding it back to the concentrate prepared from the stripped mango pulp to obtain full flavoured concentrate (90). A total of 16 components were identified in the fresh Alphonso mango pulp. Of these 12 were carbonyls, 3 alcohols, one hydrocarbon myrcene. The aroma concentrate recovered from the same pulp showed the absence of myrcene (90).

Among the various additives studied, addition of sodium sulphite was found to enhance the storage stability of mango aroma concentrate. The shelf life of aroma concentrate was found to be a week without the additive and 2 months with additive when packed in glass bottles and stored at 25°C. At 2°C it was six months without additive and 10 months with additive. At -18°C the shelf life was more than one year even without the addition of any additive. The recovered aroma concentrate was added at various levels to the mango concentrate (30-35° Brix) and the nectar prepared subjected to sensory

evaluation using a fresh sample for comparison. Addition of flavour concentrate at 50% level was found to be quite satisfactory (90). Some authors have reviewed literature on tropical fruit flavours (89).

Alcoholic Beverages

Dry wines and fortified wines prepared from some mango varieties were poor in colour and body. Strong aroma in a few varieties often masked the bouquet. After fortification with sugar and alcohol and madeirization at 50°C for three weeks, the colour, body and bouquet of most varieties were improved (76, 77). Similarly addition of ascorbic acid (0.1% w/v) helped in rapid madeirization. These processes reduced titratable and volatile acidities and increased the pH, volatile esters, aldehydes, colour, brightness and organoleptic scores of dessert wines. Madeirized wines were more acceptable than corresponding dry and dessert wines. Madeira prepared from Totapuri variety was more acceptable than those from Raspuri, Mulgoa, Dushehari and Langra varieties (79).

Production of aromatized wine from mango, designated as Mango Vermouth has been worked out. Herb and spice mixture formulae to produce dry and sweet vermouths with mild aroma and flavour have been developed (78). The composition of mango vermouth is shown in Table 15.

Table 15. Chemical Composition of Mango Vermouths made from Banganapally variety.

Particulars	Mango Vermouth	
	Dry	Sweet
Colour at 420 nm	0.42	0.68
pH	3.4	3.42
Total acidity (gm tartaric acid/100 ml)	0.59	0.59
Volatile acidity (gm acetic acid/100 ml)	0.09	0.07
Alcohol - v/v/100 ml	17.00	17.20
Total aldehydes (ppm)	15.8	26.4
Total phenols (%)	0.06	0.07
Organoleptic score	13.0	15.5

Onkarayya (1985)

UTILISATION OF MANGO WASTE

Seeds (stones) and peels are the important wastes which constitute 35-55% of ripe as well as unripe mangoes (17). Studies have shown the possibility of utilising mango waste for recovering useful products, and simultaneously avoid the serious disposal problem. Peel of Totapuri mango has been found to yield 15.7% pectin. The pectin produced by the alcohol precipitation method, contained 4.9% moisture, 0.94% ash, 8.9% methoxyl, and with jelly grade of 200-220, found to be of good quality (14, 118).

During production of mango pulp, besides peel with adhering puree, pulper waste pulp is also obtained. The chemical composition of these materials are shown in Table 16. Studies have shown the possibility of treating these with pectic enzyme, expressing the juice and utilising this juice in the preparation of nectar and vinegar (15).

Table 16. Chemical Composition of Mango (Totapuri) Peel and Waste pulp from Pulper

Particulars	Peel	Waste pulp from pulper
FRESH MATERIAL		
Total soluble solids (%)	21.0	12.5
Moisture (%)	68.5	83.2
pH	3.1	3.2
DRIED MATERIAL (Moisture 3-4%)		
Sugars - Total (%)	48.1	51.3
Acidity (%)	2.6	2.3
Pectin (%)	12.9	10.6
Starch (%)	2.9	5.2
Nitrogen (%)	0.26	0.53
Crude fibre (%)	8.4	6.00
Tannins (%)	2.3	Trace
Total ash (%)	2.9	2.4

Beerh et al. (1976b)

The stone content is found to range from 9-23% with an average of 15% for 29 varieties (82). Mango seed kernel contains protein, fat, carbohydrates including starch, fibre and ash as major constituents (83) as shown in Table 17. Due to its blandness, plasticity and absence of toxic substances it enjoys a potential use as edible fat in sweet meats (74). It can also be used as a substitute for tallow in the preparation of quality soaps and cocoa butter (13). No difference was noticed in the texture, taste and flavour of toffee prepared from mango seed oil and cocoa butter (66).

Table 17. Important Chemical Constituents of Mango Seed Kernels

Constituents	Range
Moisture (%)	8.2-8.7
Protein (N x 6.25) (%)	5.6-9.6
Fat (%)	9.3-16.1
Total carbohydrates (%)	69.2-79.8
Fibre (%)	0.14-2.95
Total ash (%)	0.35-3.11
Total tannins (%)	10.0-11.0

Parmar et al. (1984); Bhatnagar & Subramanian (1973)

Mango seed kernel also contained 47-63% starch of which 19-22% was Amylose (94). Gelatinisation characteristics, temperature, paste clarity, retrogradation and swelling power and solubility of mango seed starch have been studied (84) and the starch is recommended for food use (17). But the major problem is in the collection of peel and stones so as to enable its economic commercial use (17).

PROBLEMS IN PROCESSING OF MANGOES

Processing of mangoes presents several problems to the industry and to the market expansion. Irregular and alternate bearing, non-uniform ripening and short storage life of ripe fruits affect the regular production schedule. Large number of varieties with their variable attributes affect the quality and uniformity of the processed products. The lack of simple, reliable methods for determining the stage of maturity of various varieties for processing also affects the quality of the finished products. Presence of weevil within the fruit of some varieties of mangoes affects the quality and so far no successful method has been developed to prevent this insect problem. Quite often, mangoes are required to be peeled and sliced for production of certain products and lack of mechanised equipment is the bottleneck in increasing their utilisation (17,121). Variation in flavour in many varieties and non-availability of information on

blending as a means of adjusting flavour (129) is a disadvantage. The cost of processed mango products is also prohibitive to the common man in the areas where most mangoes are grown. There is considerable export potential to richer countries, but in these countries the processed mango products must compete with other established processed fruits of uniform quality and relatively low price (121). As a result of these problems there is very low input into the processing industry (0.2% of world production). Hence, concerted research and development efforts are needed to find a solution to these problems and thus give fillip to the processing industry especially in the countries where mangoes are the major fruit crop.

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INDEX

Mango is a tropical crop whose economic utilisation could be greatly improved. This fruit represents a great proportion of the agricultural production of many developing countries and is in increasing demand in western countries. The development of a sea transportation system that could provide fruit of a consistently high quality would help to realise the potential of this commodity. This requires research and development of pre- and post-harvest technologies to improve yield, quality, disease control and fruit storage.

In this volume, research carried out worldwide concerning mangoes is presented as a series of comprehensive reviews.

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