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.

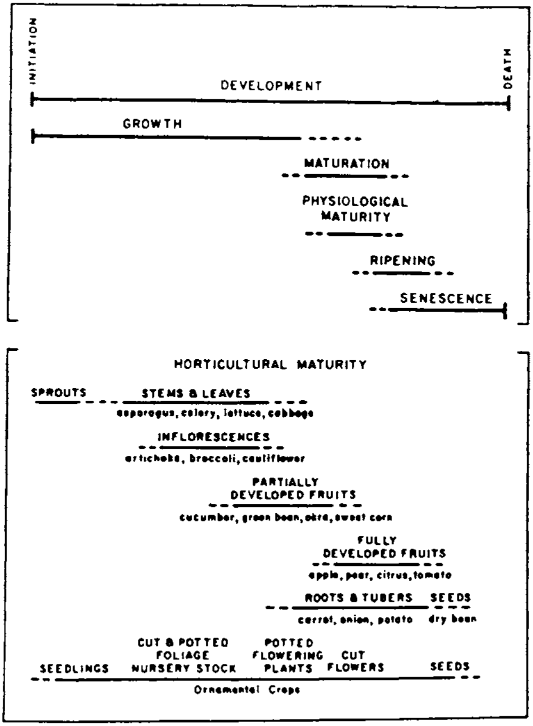

Figure 1: Horticultural maturity in relation to developmental stages of the plant (Watada et al. (45)).

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 inacccurate 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.

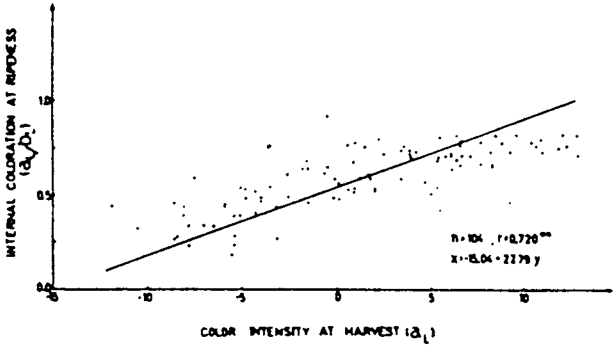

Figure 2. Relationship between the maximum initial red colour intensity at harvest (Hunter a_L and the maximum internal yellow colour intensity at ripeness Hunter a_L/b_L)

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

Harvesting
↓
Washing and Fungicidal Treatment
↓
Sorting
↓
Sizing
↓
Packing
↓
Fumigation
↓
Ripening

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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