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REVIEW ARTICLE

Quality parameters of mango and potential of non-destructive techniques for their measurement – a review

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Abstract The king of fruits "Mango" (*Mangifera indica* L.) is very nutritious and rich in carotenes. India produces about 50% of the total world's mango. Many researchers have reported the maturity indices and quality parameters for determination of harvesting time and eating quality. The methods currently used for determination of quality of mango are mostly based on the biochemical analysis, which leads to destruction of the fruits. Numerous works are being carried out to explore some non-destructive methods such as Near Infrared (NIR), Nuclear Magnetic Resonance (NMR), X-ray and Computed Tomography (CT), electronic nose, machine vision and ultrasound for quality determination of fruits. This paper deals with some recent work reported on quality parameters, harvesting and post-harvest treatments in relation to quality of mango fruits and reviews on some of the potential non-destructive techniques that can be explored for quality determination of mango cultivars.

Keywords Mango · Maturity indices · Physical properties · Biochemical properties

Introduction

Mango (*Mangifera indica* L.) is the most important fruit of India. The ancient records mention the cultivation of mango in Indian subcontinent for well over 4000 years. One can also find in the mentions of travellers beginning from Hiun Tsang (632–645 AD) who was the first foreigner to bring mango to the notice of world outside India (Bose and Mitra 2001). Ibn Haukal (902–908 AD) and Ibn Batuta (1325–1349 AD) have written about the delicious fruit. Amir Khusrau, the great sufi poet, praised the mango fruit during the time of Mohammed Tughlaq. The greatest tribute to this fruit was paid by Emperor Akbar who established the *Lakh Bagh* (a mango orchard having 100,000 plants) in Darbhanga (Bihar) when large orchards of fruit trees were unknown. Abul Fazl in *Ain-I-Akbari* has mentioned in detail the cultivars, cultivation and quality of mangoes (Bose and Mitra 2001).

There has been a growing demand for traditional varieties of mango in Western markets. However, mangoes are yet to realize their maximum potential as an export oriented commodity due to their localized production and potential markets located across the globe. There are more than thousand mango varieties in India. However, only about 30 varieties are grown on commercial scale in different states. Important mango varieties cultivated in different states of India are presented in Table 1. Post-harvest loss of mango in India has been estimated to be 25–40% from harvesting to consumption (Rekha and Goswami 2007), mainly because of lack of improved technology and instrumentation for getting right information for harvesting during ripening and transportation. Restricted import particularly to developed countries is mainly because of their quarantine needs and lack of instruments and techniques to meet their requirement. Stone weevil, fruit fly, spongy tissue etc are internal defects in some varieties of mangoes, which need to be detected before making consignment for export.

The quality parameters such as size, shape, colour, total soluble solids (TSS), acidity, pH, physiological weight, juice, pulp and moisture content are important for the table purpose and value addition. The objective of this paper is to review the recent work reported on quality parameters of mango, effect of harvesting and post-harvest treatments in relation to quality of mango and to explore the potential of available non-destructive techniques for determination of maturity, physical, biochemical, viscoelastic and rheological quality parameters and internal disorders in mango fruits.

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Table 1 Major varieties of mangoes grown in different States of India

State	Varieties grown
Andhra Pradesh	'Allumpur Baneshan', 'Banganapalli', 'Bangalora', 'Cherukurasam', 'Himayuddin', 'Suvernarekha', 'Neelum', 'Totapuri'
Bihar	'Bathua', 'Bombai', 'Himsagar', 'Kishen Bhog', 'Sukul', 'Gulab Khas', 'Zardalu', 'Maldah/Langra', 'Chausa', 'Dashehri', 'Fazli', 'Kalkatia'
Goa	'Fernandin', 'Mankurad'
Gujarat	'Alphonso', 'Kesar', 'Rajapuri', 'Vanraj', 'Jamadar', 'Totapuri', 'Neelum', 'Dashehri', 'Langra'
Haryana	'Dashehri', 'Langra', 'Sarauli', 'Chausa', 'Fazl'
Himachal Pradesh	'Chausa', 'Dashehri', 'Langra'
Jharkhand	'Jardalu', 'Amrapalli', 'Mallika', 'Bombai', 'Langra', 'Himsagar', 'Chausa', 'Gulabkhas'
Karnataka	'Alphonso', 'Bangalora', 'Mulgoa', 'Neelum', 'Pairi', 'Baganapalli', 'Totapuri'
Kerala	'Mundappa', 'Olour', 'Pairi'
Madhya Pradesh	'Alphonso', 'Bombay Green', 'Langra', 'Sunderja', 'Dashehr', 'Fazli', 'Neelum', 'Amrapalli', 'Mallika'
Maharashtra	'Alphonso', 'Mankurad', 'Mulgoa', 'Pairi', 'Rajapuri', 'Kesar', 'Gulabi', 'Vanraj'
Orissa	'Baneshan, 'Langra, 'Neelum, 'Suvarnarekha, 'Amrapalli, 'Mallika
Punjab	'Dashehri', 'Langra', 'Chausa', 'Malda'
Rajasthan	'Bombay Green', 'Chausa', 'Dashehri', 'Langra'
Tamil Nadu	'Banganapalli', 'Bangalora', 'Neelum', 'Rumani', 'Mulgoa', 'Alphonso, 'Totapuri'
Uttar Pradesh	'Bombay Green', 'Dashehri', 'Langra', 'Safeda Lucknow', 'Chausa', 'Fazli'
West Bengal	'Bombai', 'Himsagar', 'Kishen Bhog', 'Langra', 'Fazli', 'Gulabkhas', 'Amrapalli', 'Mallika'

Source: Anon (2006)

Quality parameters of mango

The quality of a fruit which is free from internal and external disorders is judged by various parameters such as size, shape, weight, colour, specific gravity, acidity, pH, TSS, carotenoids, vitamins and other trace elements and volatile compounds responsible for their aroma. Viscoelastic, rheological properties and TSS of mango are important from processing point of view.

Quality parameters of mango change almost daily and consumer cannot measure them during purchase. It is therefore essential that all the major quality parameters be correlated in such a manner that size, shape, colour or aroma should reveal the overall quality of fruit. The major changes in biochemical parameters that occur during ripening of mango fruits are increase in TSS, pH, sugar to acid ratio, and carotenoids; whereas acidity, starch, and vitamin C decrease (Tandon and Kalra 1986, Gowda and Huddar 2001, Ueda et al. 2001). Application of coatings can retard water loss and drop the sensory attributes, increase the soluble solid content, titrable acidity and ascorbic acid content in mango (Po-Jung Chien et al. 2007). Irradiated mangoes show no major changes in carotenoid HPLC profiles but indicated a delay in ripening compared to non-irradiated fruits. However, irradiation dose greater than or equal to 1.5 kGy induced flesh pitting due to localized tissue death (Reyes and Cisneros-Zevallos 2007) which may not be liked by the consumer.

Many researchers have worked in the field of identification of constituents of various cultivars of mango. The composition of fruit generally varies with the cultivar. The unripe green mangoes have nearly 90% moisture, 8.8% carbohydrate, 0.7 % protein, 0.1% fat, 0.02% P, 0.01% Ca, 4.5 mg/100 g Fe, 6.3–20.2 mg/100 g carotene as vitamin A, 30 mg /100 g riboflavin and 3 mg/100 g ascorbic acid (Bose and Mitra 2001), while constituents of ripe mangoes vary distinctly (Table 2). Supriya et al. (2007) studied the β-carotene content and its bio-accessibility in six locally available varieties of mango 'Badami', 'Raspuri', 'Mallika', 'Malgoa', 'Totapuri' and 'Neelam'. β-Carotene content in ripe mangoes ranged from 0.55 ± 0.03 mg/100 g in the 'Malgoa' variety to 3.21 mg/100 g in the 'Badami' variety. The amount of bioaccessible β-Carotene was highest in the 'Mallika' variety (0.89 mg/100 g), followed by 'Badami' (0.79 mg/100 g). Addition of milk generally brought about a significant increase in the bioaccessibility of β-Carotene from mangoes, the increase ranging from 12 to 56%.

The enzymes of mango, such as magneferin, katechol oxidase and lactase, clean the bowel of the "filth" within and are ideal antidotes for all toxic effects inside the body. They provide sufficient resistance to fight any germs and afflictions. Mango is an excellent natural source for pro-vitamin A. Total 145 volatile compounds, including 8 novel compounds were observed in 9 cultivars of Colombian mangoes (Quijano et al. 2007). Terpenoids are the major aroma compounds present in all varieties, with differences in dominant compounds in some varieties. Delta-3-Carene was the major terpene in varieties 'Haden', 'Manila', 'Irwin' and 'Tommy Atkins', alpha-pinene predominated in

Table 2 Biochemical composition of ripe mango

Moisture, %	73.0–86.7
Carbohydrate, %	11.6–24.3
Protein, %	0.5–1.0
Fat, %	0.1–0.8
Fibre, %	1.1
Lipid, %	0.8–1.36
TSS, °Brix	12.0–23.0
Total sugars, %	8.7–17.9
Acidity, %	0.12–0.38
Total phenol, %	1.2–7.8
Vitamin A, µg/100g β-carotene	6375–20750
Vitamin B, mg/100g	40
Nicotinic acid, mg/100g	0.3
Riboflavin, mg/100g	50.0
Ascorbic acid, mg/100g	6.8–38.8
N, %	0.46
P, %	0.195
K, %	0.88
Ca, %	0.412
Mg, %	0.082
S, %	0.542
Cu, ppm	24
Zn, ppm	11.5
Mn, ppm	10.0
Fe, ppm	50.0

Source: Bose and Mitra (2001)

varieties 'Hilacha' and 'Vallenato', terpinolene and alpha-phellandrene predominated in variety 'Yulima' and 'Van Dyke', respectively, whilst the variety 'Springfield' had no dominant terpene. Total concentration of volatiles in mangoes ranged from 17 to 75 mg/kg fresh wt (Quijano et al. 2007). Schieber (2007) reviewed the classification, analysis and functional properties of phenolic compounds, phenolic acids, flavonoids, xanthones, tannins, and phenolic lipids. Most of the phenolic compounds were found in the seed and peel which are barely consumed.

Maturity indices: There is no particular parameter for judgment of fruit maturity. Physical, biochemical, and physiological parameters are used to define the maturity stage for harvesting of fruits (Jha and Matsuka 2002a, Jha et al. 2006). Useful biochemical parameters are acidity, soluble solids content, phenolic constituents, and carbohydrate content. Physical parameters are size, shape, surface colour, pit around the pedicel, lenticels and specific gravity (Ketsa et al. 1999). Physiological maturity shows changes in the pulp colour, breaking to yellow. Hence, it can be tested by slicing a fruit before harvesting. An ancient advice for mango harvesting says that, when first fruits begin to drop, the crop is ready for picking. At the time when mango is fully grown and ready for picking, the stem will snap easily with a slight pull. If a strong pull is necessary the fruit is still fairly immature and harvesting should be delayed (Ram 1998).

There are number of indices such as shoulder growth and TSS:>7 (Kudachikar et al. 2001), acidity (Lakshminarayana 1980) and specific gravity 1.00–1.04 (Tandon et al. 1988) which used to determine the fruit maturity at harvest. Another approach is to count days after fruit set (Saranwong et al. 2004) and it varies from variety to variety such as for 'Dasheri' and 'Langra' 84 days (Anon 2006) and for 'Chausa' and 'Mallika' 105 days. Mango harvested at optimum maturity develops good flavour, aroma with uniform ripening (Tandon and Kalra 1986) and firmness but inconsistency in these parameters of mango varieties restricted its use as a criterion to predict maturity (Tandon and Kalra 1986). A maturity index using TSS has also been used to determine maturity of mango (Jha et al. 2006). TSS at 8°Brix and acidity of about 1% have been taken as indices for full maturity of some varieties of mango.

Mango harvesting and its effect on mango quality

Mangoes are usually harvested green. Harvesting usually takes place after 15–16 weeks of fruit set when they are physiologically mature. Late harvesting may result in uneven ripening, and can lower sugar to acid ratio. Usually fruits are picked with ~10 cm stem to avoid the spurt of milky/resinous sap, because in some cultivars it causes sap burn on skin of fruit with which they come into contact. The fruits are then placed in field crates and desapping involves breaking off the fruit stalk and placing stem-end-down till flow of sap stops. After desapping, the fruits are packed and graded according to their size and colour. To prevent fruits from bruising they are packed in single or double layered cartons, which contain protective cushioning material.

Post-harvest treatments in relation to mango quality

Low temperature: Highly perishable nature, susceptibility to post-harvest diseases and injuries during handling are major constraints, which are impeding the growth of international trade of fresh mango. Mangoes are still considered as a luxurious and expensive item in the markets of many developed countries, where mangoes are not grown on large scale. Mangoes are tropical fruits and are therefore sensitive to chilling when stored below a critical minimum temperature (Chaplin et al. 1991 Lizada 1991). If stored at low temperatures for prolonged time, storage could have an effect on ripening and causes chilling injuries. Recommended temperatures for majority of varieties are in the range of 10–15°C and lead to storage life of 2 to 3 weeks. 'Langra' and 'Dasheri' however, can safely be stored at 7–8°C for 25 days. The best ripening temperature ranges from 21–24°C, but at high temperature of 32°C, the ripening process is retarded. Other essential factors with temperature for safe storage are 98–100% relative humidity (RH) and 76 or 152 mm Hg atmospheric pressure.

Controlled and modified atmosphere: Controlled atmosphere (CA) can provide an effective storage environment for different fruits and vegetables (Gariépy et al. 1991, Bender et al. 2000, Raghavan et al. 2003). Modified atmosphere (MA) is referred to as a relationship between product respiration and gas exchange within any form of structural enclosure. MA storage can be used to maintain the post-harvest quality of different fruits (Meir et al. 1996, Ding et al. 2002, Illeperuma and Jayasuriya 2002, Rodov et al. 2002). If mango fruits are stored at 1% O_2 and 15% CO_2 level, off-flavour and skin discolouration occur. MA packaging inhibited the mango ripening process (Sornsrivichai et al. 1992). Film perforation delayed the softening and reduced the weight loss of mango cv. 'Nam Doc Mai'. Market acceptability of fruit was found to be greater in case of 'Tommy Atkins' and 'Kent' cultivars stored at 13°C, 76–152 mm Hg pressure and 98–100% RH for 3 weeks as compared to the storage under normal pressure (Spalding and Reeder 1997).

Ionizing radiation: Irradiation includes application of ionizing energy such as 13 gamma rays, electrons, X-rays and microwaves during storage. For safe storage of fresh fruits and vegetables, the US Food and Drug Administration approved the use of irradiation at a dose of 100 Krad (USDA 1986). Percentage of decayed mango is minimized when they are exposed to 750 Gy or higher energy level, but fruit peel shows scald-like symptoms with irradiation doses over 500 Gy (Spalding and Von Windeguth 1988). Ripening process got also affected because of change in biochemical processes due to exposure of radiation. Gamma irradiation (30 Krad) caused ripening delay of 7 days in comparison to mango stored at room temperature (35±2°C). According to Spalding and Reeder (1986) combination of irradiation and hot water treatment (53°C) or 0.2 % hot imazalil (53°C) was more effective for storage.

Chemicals: Treatment efficiency varies with infection level and storage regime. The shelf life depends on cultivar, injury, maturity at harvest, Ca spray, and exposure to ethylene (Coates et al. 1993). A dip in 4–6% $CaCl_2$ can increase the shelf life of some cultivars (Singh et al. 1993). Prochloraz also provides good protection from anthracnose and alternaria rot in mango (Johnson and Coates 1993). Gibberellic acid spray prior to harvest can retard mango ripening at ambient temperature for up to 6 days of storage (Khader 1991). $CaCl_2$ treatment resulted in low ethylene production, low respiration and reduced storage decay.

Storage methods and post-harvest treatments to mangoes affect colour, ripening level, TSS, acidity and reduce the decay level and increase the shelf life, which in turn affect the market acceptability.

Post-harvest heat disinfestation treatments

Heat treatments are used to control post-harvest diseases and insect pests (Couey 1989). Although heat has fungicidal and insecticidal action, it often has detrimental effect on the product quality. The fruit is heated for a specific period of time to ensure that the energy gets transferred from the heating medium, usually hot air or water to fruit. The temperature and treatment duration depend on commodity and cultivars and must be precise so that it only kills pests without affecting the commodity. Nowadays 3 heating methods are commonly used for mangoes, (i) Vapour heat-treatment (ii) Forced hot air-treatment and (iii) Hot water-treatment.

Vapour heat-treatment: This is a conductive way of heat transfer and also called as high humidity air heating. In this process, saturated moist air is passed across the fruits when the temperature of fruit is at or below the dew point; condensation of moisture appears on the fruit surface. The heat from surface of fruit is then transferred towards the fruit centre. It has been noted that water droplet transfers heat more efficiently than air and allows faster fruit heating. But in this case risk of physical injury increases. Nowadays Japan requires mangoes from India to be treated with vapour heat at 46–47°C for 10 min.

In ripe fruits, vapour heat-treatment can induce internal breakdown of the inner mesocarp, which is characterized by the presence of white, starchy and tough lesions. In severe cases, this results in damage of the product because there is depletion of internal oxygen level, which gives undesirable fermented by-products (Esguerra and Lizada 1990).

Forced hot air-treatment: It is also called non-condensing air heating. Under this treatment hot air is passed through a bed of fruits at a specified temperature, which leads to transfer of heat from hot air to cooler fruit via the skin and to the centre of fruits. In this treatment the fruit surface remains dry and the RH of the passing air is 30%. This method has been developed in USA for mango quarantine treatment (Mangan and Ingle 1992). They reported that hot air-treated fruit whose pulp temperature is over 47°C is able to kill all stages of West Indian fruit flies. The disadvantage of this treatment is fruit weight loss and shrivelling which occurs due to low air humidity.

Hot water-treatment: Hot water is an effective heat transfer medium and within a short time a uniform temperature profile will be maintained (Couey 1989). The additional benefit of this is that it can control post-harvest diseases such as anthracnose and stem end rot (McGuire 1991). This treatment is commonly used for disinfestation of mango from fruit flies. This treatment is cheaper than any other heat-treatment and is also effective on commercial scale in USA. Recommended temperature ranges are 43–46°C. Above 46°C the fruit experiences excessive damage. Usually a single dip procedure is used either in batch process or continuously for 65–90 min depending on fruit size and cultivar.

Physiological responses to heat-treatment: Physiological response to heat treatment in the fruits has been summarized (Jacobi et al. 2001) as below:

i) Heat-treatment increases fruit heat tolerance which depends upon a number of factors including species, stage of fruit maturity, fruit size and exposure to different environmental factors, time, duration and type of application.

ii) When harvested fruits are transferred from ambient growth temperature to an elevated temperature, stress is induced and the impact depends upon length of exposure and temperature difference.

iii) Heat-treatment also develops external or internal heat injuries in many cultivars.

iv) Heat-treatment can affect fruits ripening either inhibiting, promoting or disrupting the ripening process.

v) Heat-treatment accelerates yellowing of mango fruit skin and uniformity of skin colour is also observed. However, in many cultivars fruit becomes soft due to heat-treatment. Actual mechanism by which heat treatment accelerated mango fruit ripening is not yet known but it has been hypothesized that it is associated with increased synthesis of carotenoid, degradation of chlorophyll and synthesis of cell wall degrading enzymes (Jacobi et al. 2001).

vi) Immature mangoes have lower heat tolerance compared to mature ones. When immature mangoes get treated with vapour heat treatment at 46°C for 10 min internal breakdown has been noted by Esguerra and Lizada (1990) in the form of spongy white starch tissue in fruit mesocarp however, no external damage was noted.

vii) If fruits and vegetables treated with hot water before storage at low temperatures, the treatment reduces the incidence of cold injuries (CI) (McCollum et al. 1993 González-Aguilar et al. 2000).

Physiological and physical disorders

During ripening, mango fruits are susceptible to several physical and physiological post-harvest disorders, which affect fruit quality. Some disorders are inherent while some are induced. The inherent physiological disorders include spongy stem-end disorder, soft nose, and spongy or soft tissue. Best example of induced disorder is CI when commodity is exposed to low temperature.

Sap burn: The stem of picked mango exudes large quantities of latex/sap which has low pH and high oil content and has tendency to burn the fruit skin. According to Joel (1980) latex repels fruit flies. Terpinolene is the main ingredient responsible for skin burn and high nitrogen levels in the fruit cause more severe sap-burn.

Spongy tissue: In the flesh of ripened fruit, a desiccated sponge-like tissue is found which is called a spongy tissue (Amin 1967). The fruit flesh remains unripe and due to physiological and biochemical disturbances a deposition of non-hydrolyzed starch occurs. Mechanical injury can also be responsible for spongy tissue like symptom in fruits. Spongy tissue in 'Alphonso' mango was traced near the seed, which is due to its recalcitrant nature, switches over to germination mode during fruit ripening phase and drawing nutrients from the mesocarp (Ravindra and Shivashankar 2006). It has been noted that the affected fruit pulp has higher acidity, low pH, low ß-carotene content, sugar and ascorbic acid. The amylase and invertase activity is also reduced. In 'Alphanso' the incidence of spongy tissue may be reduced if fruits are harvested earlier and ethylene is used for subsequent ripening. The affected fruit has no external symptoms either at the time of picking or ripening. The affected portion is visible only after the fruit is cut. There is thus a need to develop some non-destructive technique to sort the affected fruit out from a lot to be marketed and exported.

Black-tip: In black-tip disorder, the distal end of fruit becomes yellow, and mesocarp and seed are unaffected in early stage, while later on the entire tip of fruit turns brownish black (Ram 1989). The affected portion becomes hard and its growth is retarded. The fruit becomes unattractive and loses its quality. Sprays of sodium carbonate, sodium hydroxide and borax can prevent the incidence of black tip in mango.

Soft-nose: This disorder may be related to Ca deficiency. Cultivars 'Kent' and 'Ameeri' from Canary Island were found more susceptible to this disorder (Galan Sauco et al. 1984). The fruit, which has low in Ca content, is the most affected one.

Chilling injury (CI): To maintain the quality of harvested horticultural crops, temperature is one of the most predominant factors. Lowering the temperature can reduce rate of metabolic processes of the commodity. When tropical and subtropical crops are stored at low temperatures, certain physiological disorders such as CI have been observed. Due to this phenomenon, storage life of product is reduced and leads to significant degradation of quality. The primary cause of CI is thought to be the damage of cell membrane that initiates a cascade of secondary reactions. CI is a time and temperature dependent phenomenon. Mango fruits are subjected to CI when stored below 10°C. The symptoms include greyish scald like discoloration of skin, skin pitting, uneven ripening and reduction in the levels of carotenoids, aroma and flavour during ripening (Thomas and Oke 1983). In CA storage enhanced CO_2 accumulation alleviated CI symptoms while low O_2 has no significant effect (O' Hare and Prasad 1993). Peroxidase, invertase and cellulase activities in the peel of fruit increased while amylase activity decreased during the development of CI. Freezing injury is different from CI as ice crystals are formed in frozen tissues. When fruits are stored below their freezing point, ice crystals are formed which causes cell damage. It has been thought initially CI damaged the cell membrane, which initiated a cascade of secondary reactions including ethylene production, toxic compounds accumulation, reduction in photosynthesis, increased respiration and cellular structural alteration. CI symptoms are not only due to storage of fruits at low temperatures but also depend on the maturity of harvested fruits and duration of exposure of commodities to low temperatures and protective packaging of fruits while they are stored at low temperatures (Medlicott et al. 1990). Short heat-treatment at 38°C is effective in reducing CI in various fruits including tomato (Lurie and Klein 1991) and avocado (Sanxter et al. 1994, Woolf et al. 1995). Heat-treatments such as hot air, hot water also reduced CI symptoms in mango although they failed to retard the ripening process (McCollum et al. 1993).

Quality parameters of ripened mangoes

Physical parameters: 'Chausa' variety has maximum fruit weight and length whereas it was lowest for 'Dasheri' (Table 3). The major changes that occur in physical parameters during ripening of mango are reduction in fruit weight, volume, length, thickness, and firmness (Gowda and Huddar 2001). The specific gravity ranges from 0.99 to 1.10. Based on the studies on fruit weight, length, volume, diameter, fibre percentage and juice percentage using 8 mango cultivars, Zaied et al. (2007) showed that the 'Langra' posseses the maximum length and weight (717 g, 180 mm, 696 ml) followed by 'Dabsha' and 'El-Kobbaneia' (424 g, 11.73 mm, 452 ml), while 'El-Madam' and 'Khade El-Gamel' were found to be the small fruits. The fiber percentage was lowest in 'Alphonso' (2%) and highest in 'Langra' (6%). The highest fruit juice percentage is reported in 'Langra' (420%), while the 'Hendi Meloky' (133%) had the lowest. The review of literature showed that most workers recorded length and diameter of fruit instead of length, width and thickness. As the fruit has 3 distinct dimensions, it is necessary to measure all 3 dimensions to have better understanding of fruit size.

Biochemical parameters: Biochemical parameters like others also varied with cultivar (Table 4). The TSS of ripe mangoes varies from 16.5 to 24.0 °Brix depending upon the variety. 'Mallika' shows maximum TSS whereas 'Banganpalli' the minimum. An increase in TSS content was observed in all 'Irwin' mango fruits cultured in a plastic house and stored at 7–25°C. The sucrose and fructose levels increased relatively in all fruits with storage (Ueda et al. 2001), whereas, the polysaccharides content, particularly starch decreased dramatically. A study on 8 cultivars of mango by Zaied et al. (2007) showed that the average TSS was highest in 'Langra' (13.6°Brix) fruit followed by

Table 3 Physical parameters of ripened mango cultivars grown in India

Varieties	Weight, g	Length, mm	Width, mm	Volume, ml	Specific, gravity	References
'Dashehri'	165.0	9.1	4.7	157.0	–	Gowda and Ramanjaneya 1994
'Neelum'	249.0	11.2	–	–	1.0	Nandani and Oommen 2002
'Alphonso'	216.0	7.8	6.6	225.0	–	Gowda and Ramanjaneya 1994
	299.3	10.2	7.8	–	1.0	Kudachikar et al. 2003
	231.9	9.1	7.2	212.6	1.1	Badhe et al. 2007
'Langra'	217.0	8.7	6.0	213.0	–	Gowda and Ramanjaneya 1994
'Chausa'	419.0	13.4	–	–	1.0	Nandani and Oommen 2002
'Banganpalli'	329.0	10.5	8.2	228.0	–	Gowda and Ramanjaneya 1994
	307.5	13.2	–	–	1.0	Nandani and Oommen 2002

Table 4 Biochemical parameters of ripened mango cultivars grown in India

Variety	TSS, °Brix	Total sugars, %	Acidity, %	Ascorbic acid, mg/ 100 g of pulp	Reference
'Dashehri'	21.8	11.1	0.2	42.5	Gowda and Ramanjaneya 1994
	19.3	12.5	0.1	9.2	
'Neelum'	18.0	16.4	0.3	31.0	Singh et al. 1976
'Amarpali'	22.8	17.2	0.1	35.0	Singh et al. 1976
'Mallika'	24.0	18.6	0.3	19.0	Singh et al. 1976
'Ratna'	23.0	16.8	0.2	25.0	Salvi 1983
'Alphonso'	19.0	15.8	0.3	33.5	Salvi 1983
	19.0	12.3	0.4	51.4	Gowda and Ramanjaneya 1994
'Langra'	17.1	10.3	0.2	131.7	Gowda and Ramanjaneya 1994
	19.3	13.4	0.3	136.5	
'Chausa'	23.0	16.7	0.1	26.5	Gowda and Ramanjaneya 1994
'Banganpalli'	16.5	15.2	0.4	28.9	Nandani and Oommen 2002
	17.8	12.0	0.2	4.2	Gowda and Ramanjaneya 1994

'Alphonso' (11.2°Brix) and lowest was in 'Mabrouka' (7.8 °Brix).

Acidity: The percent acidity (citric acid) ranged from 0.12 to 0.41 for the cultivars (Table 4). 'Alphonso' cultivar had maximum acidity whereas 'Amrapali' had minimum. The highest titratable acidity was in 'Dabsha' (2%) fruit, but the lowest one was detected in 'Langra' (1.5%), 'El-Madam' (1.8%) and 'Alphonso' (1.5%) fruits (Zaied et al. 2007).

Viscoelastic and rheological properties: Viscoelastic properties have long been recognized for studying the fruit maturity at harvest, ripening level, storage and transport, and also for the prediction of potential shelf life of marketable fruit (Jha and Matsuoka 2002b,c). These are also related to human perception of fruit texture, a major factor affecting consumer acceptability (Shewfelt 1999). The rheological properties are essential for the design and evaluation of food processing equipment such as pumps, heat exchangers and evaporators (Dodeja et al. 1990, Jha and Matsuoka 2002a,b,c, 2004a,b,c) for making concentrates of fruit juice, dried slices and powders. The power law model has been extensively used (Vitali and Rao 1984, Manish et al. 2007) to relate the shear rate with shear stress for these foods. The study on time-independent and time-dependent properties using co-axial cylinder rheometer showed that mango pulp is a pseudoplastic liquid with yield stress and exhibits thixotropic properties. It was found that yield stress calculated using Casson or Bingham plastic models had markedly higher values than those determined by stress- strain plots. The time-dependent model of Weltman was more suitable (Bhattacharya 1999). In a study on rheological properties of 'Chausa' variety, the consistency coefficient showed exponential correlation with pulp concentration. The consistency coefficient followed the Arrhenius temperature relationship and the magnitude of activation energy was 8.9 to 11.8 kJ/g mole (Khandari et al. 2002).

Measurement of various quality parameters of mango

The measurement of quality parameters involves the application of various scientific principles such as chemical reactions of different constituents and their behaviour during the reactions, physical principles such as reflection, refraction, absorption, transmittance and scattering. The viscoelastic and rheological behaviour involves the measurement of internal resistance to flow. Majority of parameters presently are determined by wet chemistry method which destroys the samples and make them unfit for consumption. Another method which also injures the sample either partially visible or invisible is use of mechanical methods comprising dynamic force-deformation, impact and sonic principle. Firmness of apples and other fresh fruits using these principles have been determined (Galili et al. 1998, Ozer et al. 1998, Stone et al. 1998, Sugiyama et al. 1998, McGlone et al. 1999, Zude et al. 2006, Peng and Lu 2007). These mechanical methods differ in the instrumentation setup and the properties measured and their correlation with destructive measurement techniques. Firmness measurement for apple fruit using this technique is still unacceptable for the purpose of sorting and grading (Lu 2003). Considerable research therefore is being conducted worldwide to develop non-destructive methods to determine various quality parameters of fruits (Lee 1981). The most recent non-destructive techniques used for quality determination of fruits and vegetables are NMR, X-ray and computed tomography, NIR spectroscopy, electronic nose, machine vision, and ultrasound. Instruments along with their operating principles used for measuring quality parameters are presented in Table 5. Since reported work on non-destructive techniques for mango is scanty, some of the techniques reported for other fruits that can also be tried for quality assessment of mango are briefly discussed hereunder.

The measurement of physical parameters such as length, width, thickness and weight requires equipment like vernier calliper and weighing machine which are accessible in all laboratories. Vernier callipers are generally having least count of 0.001 cm. As the 'Chausa' cultivar has maximum fruit weight of around 420 g (Table 3), a weighing balance having maximum capacity of 500 g with least count of 0.001g is needed for mango fruit.

Determination of physico-chemical quality parameters using non-destructive techniques is enumerated in Table 6. These techniques have already been applied (Diwan et al. 2006) for defect detection on cherries (Guyer and Yang 2000), apples (Kim et al. 2001, 2002a,b, Kavdir and Guyer 2002, Mehl et al. 2002, 2004, Lu 2003), citrus (Aleixos et al. 2002), cucumbers (Cheng et al. 2004) and tomatoes (Polder

Table 5 Instruments and their operating principle

Operating principle	Instruments
Reflection	Glossiness and colour measurement, ultrasound, NIR spectroscopy
Refraction	Optical density, NIR spectroscopy
Absorption	X-rays, MRI, NIR spectroscopy, computed tomography
Transmittance	NIR spectroscopy
Scattering	NIR spectroscopy
Internal resistance	Rheometers, firmness measurement
Differential adsorption	High performance liquid chromatography

Table 6 Non-destructive techniques and their use in quality assessment

Techniques	Food material	Measurable parameter	Reference
NIR	Wheat	Protein	AACC 1983
	Melon	TSS	Dull and Birth 1989
	Peach, Orange	Sugar	Kawano 1994
	Milk	Fat	Chen et al. 1999
	Tomato juice	Acid-Brix ratio	Jha and Matsuoka 2000
	Kiwifruit	Dry matter	Osborne and Kunnemeyer 1999
X-ray, CT	Apple	Interior region	Tollner et al. 1992
	Peaches	Physiological constituents Density variation	Barcelon et al. 1999a, b MacFarlane et al. 2000
MRI	Fruits	Moisture	Steinberg and Richardson 1996
	Food materials	Ice formation during freezing	Kerr et al. 1998
	Avocado	Maturity	Chen et al. 1993
Electronic nose	Orange	Maturity	Di-Natale et al. 2001a, b
	Melons		Benady et al. 1995
	Pears		Correa et al. 2001
Machine vision	Apple	Concavities	Yang 1993
	Citrus fruits	Differentiate the calyx and stem	Ruiz et al. 1996
	Apple	Blemishes and colour	Leemans et al. 2002

et al. 2002). Hunter colour values have also been correlated with the maturity index, defined as TSS of 'Dasheri' mango divided by 8 and multiplied by 100 (Jha et al. 2005).

A method based on liquid chromatography-mass spectrometry (LC-MS) was developed to identify and quantify carotenoids and tocopherols in 7 mango cultivars grown in Mexico (Ornelas-Paz et al. 2007). Browning disorders in apple can be detected by X-ray imaging (Schatzki et al. 1997), NIR absorption spectroscopy (Upchurch et al. 1997, Choi et al. 2001) and magnetic resonance imaging (MRI) (Clark and Burmeister 1999, Gonzalez et al. 2001). The main difficulty however, is that apart from NIR others are not suited to routine online use in packing situations (Clark et al. 2003).

Nuclear magnetic resonance (NMR) technique: This technique is often referred as MRI and involves resonant magnetic energy absorption by nuclei placed in an alternating magnetic field. The amount of energy absorbed by nuclei is directly proportional to the number of a particular nucleus in the sample such as the protons in water or oil. The theory of NMR is presented in detail elsewhere (Farrar and Becker 1971). There are many applications of NMR in agriculture (Rollwitz 1984). The simplest amongst them is the determination of moisture and oil content (Mousseri et al. 1974, Leung et al. 1976, Miller et al. 1980, MacMillan et al. 2008). Ice formation during freezing can be examined by MRI method as ice formation has been seen to reduce the spatially located MRI signal. The characteristics can be better controlled as MRI can serve to assess freezing times and the food structure during the freezing process (Kerr et al. 1998). The secondary processing changes almost all characteristics of a food, such as physical and aerodynamic (Jha and Kachru 1998), thermal and hygroscopic properties (Jha and Prasad 1996, Jha 1999), which in turn change its key acceptability factors, i.e. sensory texture and taste. A device consisting of super-conducting magnet with surface coil and 150 mm diameter imaging coiled coupled to a conveyor system was reported for imaging MRI spectra of avocado fruits (Kim et al. 1999). These spectra were used to measure the oil/water ratio in avocados and this ratio is correlated with percent dry weight. Although MRI is being explored for many foods, yet no work on mango has been reported. This technique should be explored for dry matter content determination, internal bruises, fruit fly, soft tissue, and maturity assessment of mango fruits.

X-ray and computed tomography (CT): X-ray imaging is a well established technique to detect strongly attenuating materials and has been applied to a number of inspection applications within the agricultural and food industries. In particular, there are many applications within biological sciences where we wish to detect weakly attenuating materials against similar background material. Qualitative and quantitative X-ray evaluations have been used by food-scientists and agriculturists, medical scientists, nanoparticle and material physicists, chemical analysts, airport security for non-destructive testing (Storm 1972, Zwiggelaar et al. 1996, Schatzki et al. 1997, Wallin and Haycock, 1998, Barcelon et al. 1999a, b, Gibaud et al. 2001, Gashaw et al. 2004). The main matter/X-ray photon interactions that cause attenuation of X-rays passing through material objects take different forms, namely, photoelectric absorption, elastic (coherent/Rayleigh) scattering, and inelastic (incoherent/Compton) scattering. All of these interactions depend upon photon energy and the materials in question. In its imaging mode, X-ray evaluation is aimed at the detection of differences in atomic numbers of materials and/or the difference in density within a material, which in effect is the detection of differences in electron density within and between materials (Zwiggelaar et al. 1996).

X-ray CT has been used to image interior regions of apples with varying moisture and to a limited extent density states (Tollner et al. 1992). Similarly, the physiological constituents have been monitored in peaches and were expressed as CT number, which was used later as an index for measuring the changes in internal quality of fruit (Barcelon et al. 1999a,b). Relationships between CT number and physiological contents were determined and it was concluded that x-ray CT imaging could be an effective tool in the evaluation of peach internal quality. One may investigate the potential of x-ray and CT scanning for detection of internal defects in mangoes such as stone weevil, soft tissue, fruit fly, etc.

Near-infrared (NIR) and visual spectroscopy: Recently, NIR spectroscopy has become a useful technique for measuring soluble solids content (SSC), fruit firmness, acidity etc (Peng and Lu 2008). Lu (2003) developed a technique for estimating fruit firmness based on analyzing scattering images from fruit at multiple wavelengths in the visible and NIR region. Radial scattering profiles were extracted and analysed using neural network prediction model, which gave good firmness prediction for apple (Jayas et al. 2000). They further proposed a Lorentzian distribution (LD) function with three parameters to characterize the multispectral scattering profiles of apple fruit. In analyzing hyperspectral scattering images for peach fruit, utilized a two-parameter LD function for prediction of peach fruit firmness.

The use of NIR spectroscopy as a rapid and often non-destructive technique for measuring the composition of biological materials has been demonstrated for many commodities. An official method to determine the protein content of wheat was established long ago (AACC 1983). In Japan, NIR as a non-destructive method for quality evaluation was started for determination of sugar content in intact peaches, 'Satsuma' orange and similar other soluble solids (Kawano 1994).

Now various NIR spectrometers are available and are being used commercially. Some modifications in these spectrometers, especially for holding the intact samples, are reported (Kawano et al. 1992, 1993). In the same sample holder a test tube for holding liquid foods such as milk was also used to estimate fat content (Chen et al. 1999). Jha et al. (2006a) have identified the quality parameters of mango to be used for their determination using visual and/or NIR spectroscopy. Using visual spectroscopy and colour modelling, they have predicted sweetness, firmness, yellowness index and acidity of 'Dasheri' mango non-destructively (Jha et al. 2005, 2006a, 2007) with reasonable amount of accuracy. Eating quality of some ripe mangoes has also been determined in Japan with good accuracy (multiple correlation coefficient 0.92) (Saranwong et al. 2004). Numerous works for quality evaluation of other food materials using NIR spectroscopy have been reported but are beyond the scope of this paper (Jha and Matsuoka 2000, 2004a).

Electronic nose (EN): Recent technological developments in chemosensory technology have enabled researchers to develop a class of instruments known as ENs, which generate a unique digital image for each complex vapour mixture. EN system is a sensor-based technology, which considers the total headspace volatiles and creates a unique smell print. Unlike gas chromatography, EN does not resolve the samples volatiles into its individual components, but responds to the whole set of volatiles in a unique digital pattern. These patterns are signature of particular set of aromatic compounds. For each process or application of interest, a database of such digitized patterns is created, called the training set. When an unknown sample is exposed to EN sensors, the EN first digitizes the samples volatiles and then compares it with the existing training set. Currently, EN technology is being investigated to study its applicability to a wide variety of problems including the evaluation of apple maturity (Young et al. 1999, Saevels et al. 2003) and tea taster. Young et al. (1999) demonstrated that EN technology using metal oxide sensors could be used as a potential maturity indicator to predict the harvest date for 'Royal Gala' apples. However, the sensors used were sensitive to moisture and were also associated with sensor drift and they performed their experiments on apple tissue (destructive methods). Saevels et al. (2003) demonstrated that EN with quartz microbalance sensors could be used to evaluate the optimal harvest date for 'Jonagold' and 'Breaburn' apples. Commercially available ENs use an array of sensors combined with pattern recognition software. There have been several reports on electronic sensing in environmental control, medical diagnostics and the food industry (Keller et al. 1995, Schaller et al. 1998, Hai and Wang 2006). Some authors reported positive applications of EN technology for discriminating different fruits' quality and many experiments were performed including testing orange (Di Natale et al. 2001a), melons (Benady et al. 1995), blueberries (Simon et al. 1996), pears (Oshita et al. 2000, Correa et al. 2001), peaches (Molto et al. 1999, Brezmes et al. 2000, Di-Natale et al. 2001b), bananas (Llobet et al. 1999), apples (Hines et al. 1999, Brezmes et al. 2000, 2001, Saevels et al. 2003) and nectarines (Di-Natale et al. 2001b). These studies showed that EN has greater potential for non-destructive quality evaluation of mangoes, which emanate different strong aromatic compounds at different stages of maturity and ripening.

Machine vision: Size, which is the first parameter identified with quality, has been estimated using machine vision by measuring either area (Tao et al. 1990, Varghese et al. 1991), perimeter (Sarkar and Wolfe 1985) or diameter (Brodie et al. 1994). Colour is also an important quality factor that has been widely studied (Singh et al. 1992, Dobrzanski and Rybczynski 2002, Hahn 2002). Some fruits have single colour uniformity distributed on the skin surface, which we call primary colour. The averaged surface colour is a good quality indicator for these fruits. However, other fruits (peaches, apples and tomatoes) have a secondary colour that can be used as a good indicator of maturity.

In this case, it is not possible to rely only on the global colour as a quality parameter. In oranges, peaches and apples there is an interest in detecting long stems in order to avoid damage to other fruit or because their absence could imply a quality loss. Several solutions have been proposed to determine position of the stem, such as the use of structured lighting to detect concavities in apples (Yang, 1993) colour segmentation techniques to differentiate calyx and stem in citrus fruits (Ruiz et al. 1996) or study of light reflection in apples (Penman 2002). Sometimes, stem can be confused with defects or blemishes on the skin. Damage and bruise detection is a crucial factor for quality evaluation. One of the first approaches for bruise detection in apples was based on the use of interferential filters (Rehkugler and Throop 1986). Other studies treated blemishes together with colour estimation (Miller and Delwiche 1989, Leemans et al. 2002). More recent techniques combine infrared and visible information to detect blemishes (Aleixos et al. 2002) or use hyperspectral imaging. The use of machine vision was mostly reported for apple and other fruits, therefore its use for quality assessment of mango need to be studied for development of online quality detection systems.

Ultrasound: There has been interest of late in using ultrasound to investigate factors such as physical change and contamination in food products (Javanaud 1998, Zhao et al. 2003, Bamberger and Greenwood 2004). One reason for this is that changes in acoustic properties can be related to density changes in the food product (McClements 1995, Gan et al. 2001). Ultrasound has the ability to differentiate between both propagation of velocity within various media and differences in acoustic impedance between different regions within a given volume (Gan et al. 2002). Thus, using the usual contact or immersion techniques, ultrasound can be used to measure the moisture content of food products (Steele 1974) and for liquid level measurement. However, to date these techniques require a coupling medium between the test sample and the transducer surface. The use of a couplant such as water may not always be suitable for certain inspection situations, especially when the material property might change, or where contamination or damage would result. For these reasons, X-rays have been widely used to detect anomalies or foreign objects present in food (Dearden 1996, Penman 1996) usually through-transmission. Other techniques such as MRI can be used to study the temperature distribution in food samples (Nott et al. 2000), although this is an expensive and complicated method already discussed. In the past, researchers have successfully applied the non-contact ultrasonic system to measure and image the properties of food in the food containers thus this technology may be explored for detection of internal defects in mango such as spongy tissue, stone weevil and fruit fly which changes the density of the fruits.

Summary

Mango fruits are rich source of carotenes, ascorbic acid and have very good medicinal value. The physical and biochemical quality parameters of mango fruit vary with the cultivar. The changes that occur during growth and ripening are TSS, acidity, size and colour of fruit. There are various methods of maturity judgement but most prevalent ones are related to days after fruits set, TSS and acidity of fruit. Currently used wet chemistry methods are destructive in nature that make the sample unfit for consumption. The non-destructive methods thus are being explored for their use as a tool for determination of quality parameters of various fruits. A very few are reported in literature. The non-destructive methods, though indirect in nature could, prove economic and time saving. Techniques such as MRI, X-ray and CT, NIR, ultrasound, machine vision, and EN have great potential for use as quality assessment of mango. There is a need for a concerted effort by various research institutes and business houses together for accelerated development of non-destructive methods for quality evaluation of major fruits of India in general, and mango in particular, for having major share in the world market.

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