Journal of Agricultural and Food Engineering 1 (2020) 0003
Journal homepage: www.myjafe.com
DOI: http://doi.org/10.37865/jafe.2020.0003
e-ISSN: 2716-6236

Mini Review

Quality evaluation of mango using non-destructive approaches: A review

Ong Phey Zhen[a,*], Norhashila Hashim[a,b], Bernard Maringgal[a]

[a]*Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.*
[b]*SMART Farming Technology Research Centre (SFTRC), Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.*

ARTICLE HISTORY

Received: 8 March 2020
Received in revised form: 13 March 2020
Accepted: 23 March 2020
Available Online: 24 March 2020

Keywords
Mango
Tropical fruit
Non-destructive
Postharvest
Quality

Abstract

Mango (*Mangifera indica* L.) is one of the most popular and nutritionally rich fruits. It is also acknowledged as the king of fruits in India. Quality attributes of mango fruit depends on its appearances such as size, shape, skin colour, flesh colour, flavour, sweetness, and aroma. Over the recent years, non-destructive techniques have been garnering the interest of researchers as potential technologies that can be used for quality assessment of fruits in a part of postharvest processing. The present patterns of non-destructive techniques are more efficient, inexpensive, yield faster and accurate results. This mini review paper focuses on some of the previous applications of non-destructive techniques in quality evaluation of mango, focusing specifically on the non-destructive technique based on quality parameters. The future trend of using non-destructive techniques for quality evaluation is also discussed in this review paper.

1. Introduction

Mangoes belong to genus *Mangifera* which consists of about 30 species of tropical fruiting trees in the flowering plant family of *Anacardiaceae*. Mango (*Mangifera indica* L.) is one of the most well-known and nutritionally rich fruits. It is also acknowledged as the king of fruits in India. Mango fruits can be eaten, and it contains high moisture content that is well known for its intense peel coloration, flavourful taste, and high nutritive value of vitamin C, β-carotene, and minerals (Tharanathan et al., 2006). Mango fruits vary in size, shape, colour, flavour, taste, and several other attributes depending upon its variation. The unripe mango fruit has green skin and it will change colour to yellow, orange, purple or red as the mango fruit is ripening. Mature mango fruit has a fragrance smell and is smooth in texture (Barton, 2005).

The largest mango producer in the world is India whereby it consists of nearly 36 % of total fruit plantation area and 40 % of their total fruit production (Sharma & Krishna, 2017). Mango is also one of the well-known fruits in Malaysia for both domestic and global markets. Federal Agricultural Marketing Authority (FAMA) is in charge of the quality of many fruits going into the market in Malaysia as it has propelled Malaysia's Best label which represents the standard for quality fruits. All fruits are required to be classified and examined by Malaysia's Best quality determination under this label, for example, size, appearance and ripening index (Mansor et al., 2014).

Nowadays, consumer demand for high-quality fruit is increasing, the evaluation and identification of fruit quality have become a concern in the postharvest processing. Ripeness, colour, size, external defects such as disease infection and injuries are significant surface quality parameters of mango while sweetness, aroma, internal defects, nutrient and water content are major parameters for internal quality of mango fruits (Gajanan et al., 2015). Physical (size, shape, surface colour), biochemical (acidity, soluble solids content, aroma), and physiological (changes in the skin or flesh colour) parameters are used to interpret the ripening phase for harvesting of fruits (Jha et al., 2010).

In the past, the evaluation of internal and external qualities of fruits was mostly carried out using destructive measurement and the rest are based on the optical appearance and defects of the fruit which could result in imprecise measurement. In addition, evaluation carried out by human sorting depends very much on human labour and is time consuming (Hashim et al., 2012). Non-destructive testing (NDT) is an investigation method utilized in science and innovation industry to evaluate the properties of material, component or system without causing internal damage (Sanchez et al., 2020). Non-destructive technique gives impressive results when used correctly and most importantly it allows the material to be analysed without changing or destroying their usefulness and simultaneously improves the product reliability, prevents accident, and lowers costs as compared to destructive testing.

The intention of this paper is to review the recent research paper on the quality evaluation of mango using non-destructive techniques. The non-destructive techniques discussed in this paper include: Near infrared spectroscopic (NIR), Scanning Laser Vibrometry (SLV), X-ray and Computed Tomography (CT), Computer vision system (CVS) and image processing, Electronic nose, RGB Fiberoptic colour sensor and Ultrasonic.

2. Quality assessment

Quality is known as a marker of the subjective perception of explicit parameters, which can be analysed differently from different prospects (Fukada, 2013). The quality of fruits is described using essentially four attributes which are colour and appearance, flavour (taste and aroma), texture and nutritional value (Barrett et al., 2010). Quality evaluation of mango determines the physicochemical properties and defects of the fruit during storage. The appearance of fruit decides whether it is accepted or rejected by consumers; so it is the most critical quality attribute (Bureau, 2009).

2.1 External attribute and quality of mango

External attribute is necessary and important as it is

*Corresponding author email: pheyzhen@gmail.com

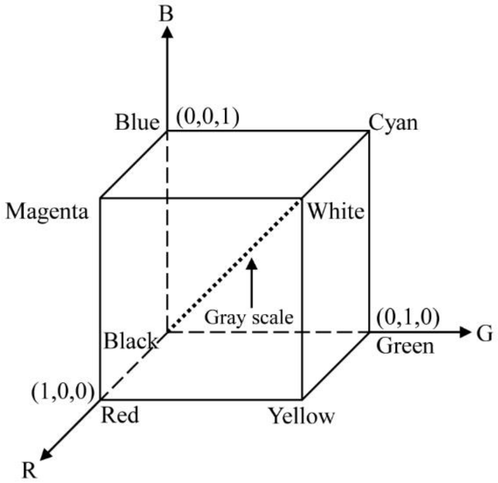

Figure 1. RGB Colour Model

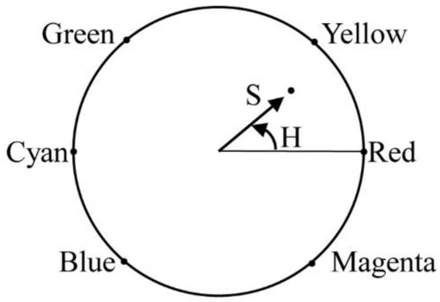

Figure 2. HSI Colour model

considered an immediate explication dependent on the outer surface for most agricultural products (Zhang et al., 2014). Colour is derived from natural pigments in fruits, many of which change as the plant goes through maturation and ripening. In many fruits, during ripening, colour change occurs due to chlorophyll degradation and the increase in the concentration of pigments such as carotenoids or polyphenols (Maringgal et al., 2020). The colour of mango skin is the fundamental external attribute that shows the maturity or ripeness of mango (Penchaiya et al., 2020). Previous studies have been carried out associating the mango quality by its fruit colour, but it is only suitable for some variety of mangoes (Nagle et al., 2016; Ueda et al., 2000).

In order to enhance the consistency of ripening fruits, the harvested mangoes are sorted and graded in packing house according to their maturity phase whereby unripe mangoes are removed and half-matured ones are isolated from fully ripe mangoes. The maturity stage of mango is important to optimize postharvest handling strategy and marketing process of the fruit (Barrett et al., 2010). L*, a*, b*, HIS, and RGB colour model are parameters usually used for grading mangoes.

The L*, a*, and b* colour space is based upon the opponent colour theory of human colour perception (Zele et al., 2018). According to Manasa et al. (2019), L* value represents lightness, a* value represents redness (+a*) or greenness (-a*), and b* value represents yellowness (+b*) or blueness (-b*). The first use of L*, a*, b* colour space was in measuring maturity or defect of fruits and is commonly detected from colorimeter.

Many other colour systems have been developed such as RGB colour model and HSI. In the RGB model, each colour appears in its primary spectral components: red, green, and blue (Ali et al., 2020a). This model is based on the Cartesian co-ordinate system as depicted in Figure 1. HSI stands for Hue (pure yellow, orange or red), Saturation (measure of the degree to which a pure colour is diluted by white light) and Intensity (depends upon colour intensity). Nowadays, colour object is described by its hue, saturation and brightness. The intensity is easily measurable and the results are also easily interpretable. The RGB colour model and HSI colour model are illustrated in Figure 2. Both colour models are also popularly used in measuring the ripeness of fruits. The mango fruits varied in shape: nearly round, oval, ovoid-oblong, and size from few 100s of grams to more than 2.5 kg depending on the variety (Barton, 2005). Fuzzy systems have been investigated for evaluating mango based on its shape and size, which achieved a high accuracy of measurement results (Nandi et al., 2014; Razak et al., 2012; Pandey et al., 2014; Naik et al., 2015).

2.2 Internal attributes and quality of mango

The internal defect, texture, nutrients, and sweetness are parameters of fruit internal quality. Dissimilar fruits typically have different textures, sweetness and nutrient content as well as presence of internal defects (Zhu et al., 2017). Sweetness is one of the important internal quality attributes of mango. Soluble solids content (SSC) or total soluble solids (TSS) and total acidity (TA) are parameters used to measure sugar content of fruits associated with nutrients in fruits (Maringgal et al., 2020). The commonly used technique to determine the sweetness of fruits is destructive method. A strong correlation was found between ripening stage and contents of TSS, TA, TSS/TA ratio and sensory taste, where sweetness of mango fruits increases when the maturity increases (Watanawan et al., 2014).

The concentration of volatile compounds increases when the fruit is ripening (Ali et al., 2020). The release of these volatiles when consuming ripe mango fruit is known as the aroma or fragrance smell. When the fruit is affected by mechanical injury, disease, or fungus infection, the aroma of fruits will be produced (Slaughter, 2009). This shows that the aroma of fruits is one of the parameter to determine the internal defect of fruits and also its maturity stage.

Ripe mango will have soft texture or soft flesh, low acid content and high content of sugars, soluble solids and total solids that gives sweetness to the fruits. Firmness is also one of the indices for ripeness in fruit where it changes during the ripening process, the fruit will become soft after harvest, handling and storage (Pu et al., 2019). Fruit firmness measurement is usually based on a destructive test such as penetrometer and texture analyser (Jantra et al., 2018).

3. Non-destructive measurement

Non-destructive test is pivotal in determining the textural fruit properties, outstandingly in assessing the quality parameters of mango. A summary of non-destructive techniques used for quality assessment or evaluation of mango is shown in Table 1 below.

3.1 Near infrared spectroscopic (NIR)

Near Infrared Spectroscopy (NIR) is a kind of vibrational spectroscopy that employs photon energy (hn) in the wavelength range of 750 to 2500 nm. NIR is based on overtones and combinations of bond vibrations in molecules. The analytical strategies resulting from the use of the NIR spectroscopic region reflect its most significant characteristics of rapid, non-destroy, accurate, non-interfering, with high penetration of the testing radiation beam (Ali et al, 2018).

Over the recent years, the application of near infrared reflectance spectroscopy (NIRS) in agricultural product industries are increasing in terms of instrumental structure or spectra information analysis to measure SSC, fruit firmness, pH,

e-ISSN: 2716-6236

Table 1. Summaries of non-destructive techniques used for mango quality assessment

Technique	Quality parameter	Data Analysis	Reference
NIR spectroscopy	Ripeness	NIRS values	Watanawan et al. (2014) Jha et al. (2010)
	SSC	PLSR-SNV	Munawar et al. (2013)
	TA	PLSR-MSC	Munawar et al. (2013)
Scanning Laser Doppler Vibrometry (SLDV)	Firmness	Signal-to-noise ratio	Santulli & Jeronimidis (2006)
Computer vision system (CVS) and image processing	Colours	RGB values	Nagle et al. (2016)
	External defect	UV-A illumination	Nagle et al. (2012)
RGB Fiberoptic colour sensor	Ripeness	Fuzzy logic	Mansor et al. (2014)
X-ray / Computed Tomography (CT)	Ripeness	Image analysis	Kotwaliwale et al. (2012)
	Defect	Image analysis	Gajanan et al. (2015)
	Internal disorder	X-ray imaging	Sharma & Krishna (2017)
Electronic nose	Ripeness/Aroma	Concentration of volatiles	Nouri et al. (2014) Salim et al. (2005) Zakaria et al. (2012)
Ultrasonic	Firmness	Attenuation	Mizrach (2000)

and TA of fruits (Peng and Lu, 2007; Ali et al., 2018). By using NIR, one mango can be examined in a short period of time without the preparation of sample or chemical application (Mahayothee et al., 2002). NIRS had been used on many varieties of mango (Schmilovitch et al., 2000; Jha et al., 2014; Saranwong et al., 2001; Saranwong et al., 2003). Short wavelength region (700 -1100 nm) was more appropriate for the quality evaluation of Thai mango, Namdokmai mango because its penetration depth into the flesh was higher than that of the long wavelength region (110-2500 nm) (Saranwong et al., 2001).

NIR spectroscopy was also discovered by Jha et al. (2010) to be utilized in mango quality assessment. The authors have predicted sweetness, firmness, ripening index and acidity of 'Dasheri' mango by using visual spectroscopy and colour modelling which gives acceptable results in their research. Texture or firmness of some ripe mangoes had also been determined in Japan with good accuracy (Saranwong et al., 2003). Mango fruit ripeness attributes were effectively examined using NIRS where the values correlated very strongly with firmness and dry moisture content at harvest and TSS was predicted with very high accuracy (Watanawan et al., 2014).

Previous research also shows NIRS works in measuring the TSS and TA of mango fruit and can be examined as one of the fast non-destructive techniques of an automatic sorting and grading system based on imaging technology where principal component regression (PCR) and partial least squares regression (PLSR) were used as calibration models to estimate SSC and TA at the same time by utilizing the treated NIR spectra (Munawar et al., 2013). The authors show that the greatest model for SSC prediction was accomplished when PLSR is applied in integration with standard normal variate (SNV) spectra while PLSR based on multiplicative scatter correction (MSC) spectra alignment model was discovered to be the greatest model in estimating TA.

3.2 Scanning Laser Doppler Vibrometry (SLDV)

SLDV is a delicate and strong characterisation technique based on visual interferometry principle, which is incredibly easy to solve problems on vibration (Hosoya et al., 2017). This technique is capable of precisely measuring surface velocities of grids of points moving at frequencies of up to 30 MHz. SLDV enables vibration measurement reaction and potentially assesses the mechanical properties of highly dampened materials (wood and vegetable tissue) (Santulli et al., 2006).

SLDV is used to measure fruit firmness during ripening of 'Rosa' mangoes (Santulli et al., 2006). They evaluated the probability of using SLDV to calculate the firmness in fruits by observing the frequency spectra and signal amplitudes that are evenly spread on a fruit surface and observed that the resonant frequency of the fruit decreased as the fruits matured. Coherence is used to calculate the value of signal-to-noise ratio where the concept of coherence is related to the stability, or predictability of phase. A higher value of resonant frequency is detected on firmer fruits. For mango, the thicker skin goes about as a highly dampened membrane, almost certainly, the resonant mode detected on firmer fruit mango disappears in the average spectrum for softer fruits. The firmest mango has a less scattered output value, same as the softest one shown in Figure 3 (Santulli et al., 2006).

3.3 X-ray and Computed Tomography (CT)

X-ray radiation is a kind of electromagnetic wave where the wavelength is shorter than the ultraviolet and microwaves. X-ray imaging is a well-established technique to identify strongly attenuating substances and has been used in various assessment applications within the agricultural and food industries (Arendse et al., 2018). X-ray evaluation focuses at the perception of differences in atomic values of substances in its imaging mode, which as a result, is the perception of various electron density within and between substances (Zwiggelaar et al., 1996). Computed Tomography (CT) is related to the X-ray absorption of mango (Kotwaliwale et al., (2012) and the established linear relationships between CT number and biochemical properties which makes CT a non-destructive ripeness indicator (Barcelon et al., 2000; Barcelon et al., 1999b).

X-ray CT has been utilized to image internal quality of apples with different moisture content (Dael et al., 2019). Likewise, it is also used to observe the physiological constituents of peaches for measuring the changes in internal quality of fruit (Barcelon et al., 1999a; Barcelon et al., 1999b). Soft X-ray based imaging techniques are powerful tools for non-destructive internal quality evaluation where it has been developed to detect affected mangoes (Gajanan et al., 2015).

X-ray imaging is also a functional technique to detect jelly seed disorder in mango and this technique can be assimilated into production chain to produce better quality mango and food security (Sharma & Krihna, 2017). The authors found that when using X-ray source of 48Kv, 6.5mA, it produced the greatest images of jelly seed internal disorder in selected mango genotypes. The X-ray images showed dark grey areas around the stone for the fruits susceptible with jelly seed disorder while for good fruits, it is indicated in light grey areas in full mango image as shown in Figure 4.

3.4 Computer vision system (CVS) and image processing

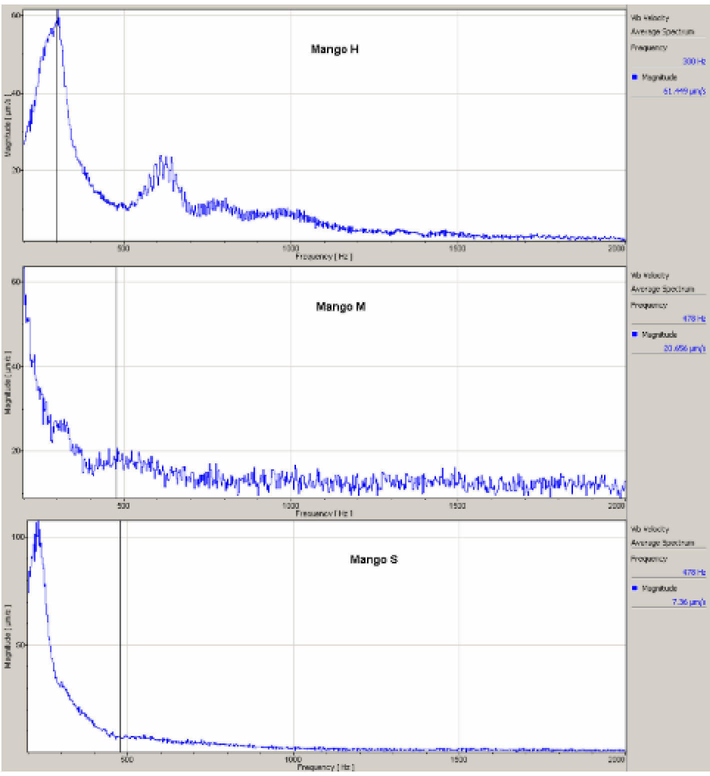

Figure 3. Average spectrum for a hard, medium and soft mango (Santulli et al., 2006)

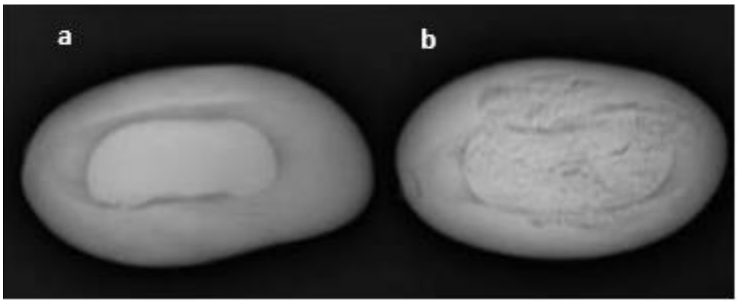

Figure 4. a) Perfect mango fruit b) Affected mango fruit (Sharma & Krishna, 2017)

Over the past few years, there are more sorting application that uses computer vision system (CVS) and image processing. Computer vision is an innovation which gives accurate and significant explanation of physical objects through images (Ali et al., 2020a). The colour of mango is the extensive visible characteristic used to measure maturity or ripeness, and it is the main element in the consumer's purchase decision. Anthracnose disease infection, stem-end-rot, bruises and latex stains that show externally in mango fruits' appearance are frequently harder to detect during hand sorting because of their deferred development until several days after initiation. Image processing is able to provide significant contribution on quality inspection of mangoes by using the new sorting system (Nagle et al., 2012).

Nagle et al. (2012) evaluated the colour of Thai mango using the CVS based on RGB values. L*, a*, and b* colour model were used in measuring the colour of in fruits due to the uniform distribution of colours as well as it is close to human perception of colour (Leon et al., 2006). The image data in RGB colour space acquired using webcams was transformed into L*, a*, and b* colour space. In the research of Nagle et al. (2012), they investigated the CVS colour estimation and it is found that adjustment model is more suitable and accurate for bicolour fruits as they compare the results between 2 varieties of Thai mango which is 'Nam Dokmai' (fully yellow mango) and 'Maha Chanok' (bicolour skin mango).

Besides, anthracnose infection and defect bruises of mango can be effectively detected and data image can be collected by using digital camera as shown in Figure 5 and 6. The implementation of UV-A illumination in hand sorting of mango can improve the accuracy and efficiency of the anthracnose detection as it can be detected clearer (Nagle et al., 2012). They also discovered that the latex stains of mango can be easily identified and assessed under UV-light.

3.5 RGB Fiberoptic colour sensor

RGB Fiberoptic colour sensor had been used by (Mansor et al., 2014) to assemble RGB information from mango fruits that classified are into three categories which are immature, mature and over matured, further determining that data colour features according colour signal and algorithms are developed for choosing functional colour features to classify the maturity phase of mango according to the colour feature sets by using Fuzzy Logic. RGB Fiberoptic Colour Sensor that utilizes high intensity RGB LED light sources separately were used to get measurement results from mango skin and the setup of apparatus is as shown in Figure 8. This research showed that the accuracy of mango grading is more than 85% by using RGB colour sensor and fuzzy logic (Mansor et al., 2014).

e-ISSN: 2716-6236

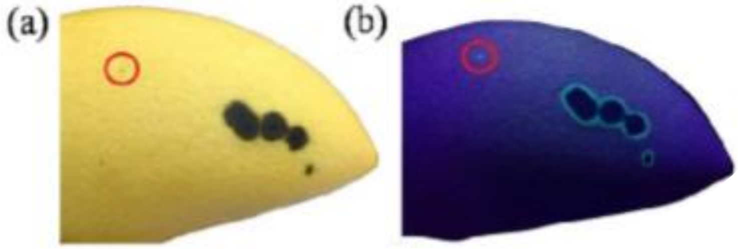

Figure 5. (a) Standard illumination of anthracnose detection, (b) UV-A illumination of anthracnose detection (Nagle et al., 2012)

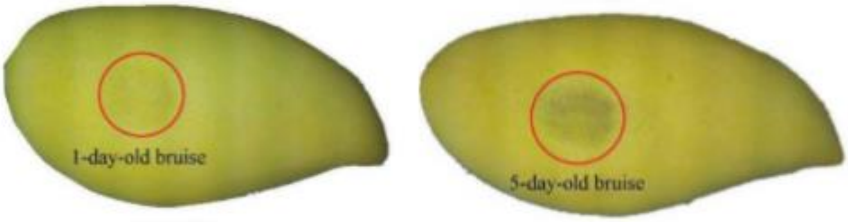

Figure 6. Digital images of bruises on mangos (Nagle et al., 2012)

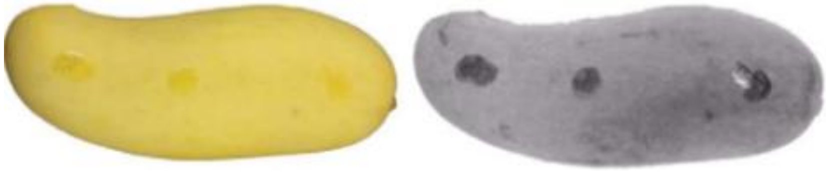

Figure 7. Latex stains under standard (left) and UV illumination (right) (Nagle et al., 2012)

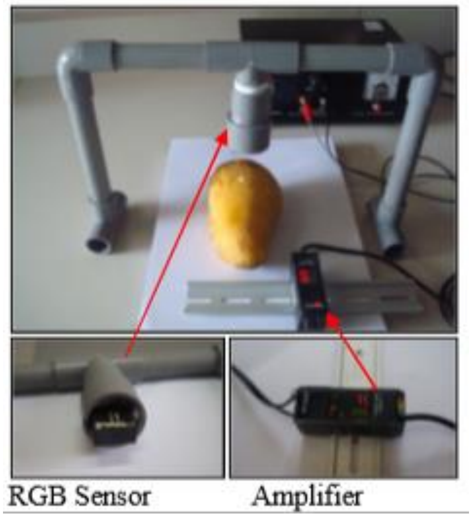

Figure 8. RGB Colour Sensor Data Acquisition Set up (Mansor et al., 2014)

3.6 Ultrasonic

Ultrasonic properties contributed to the fruit tissue which specified the potential functionality of this ultrasonic method for assurance of fruit tissue firmness properties. Ultrasonic waves are transmitted through the peel and the flesh of fruits is able to determine the firmness of fruits and this technique was applied in several investigations where they computed the ultrasonic wave attenuation in kiwifruit (Nowacka et al., 2017), avocado (Mizrach et al. 1999a), and mango (Mizrach et al. 1999b; 1997). Ultrasonic is also used to observe the development of changes in fruit tissue properties, starting from the mangoes on tree, harvest, and storage in different surrounding. In the research of Mizrach (2000), measurements of the chemical changes in harvested mango fruits confirmed that the sugar contents increased while the acidity decreased as the mango matures by

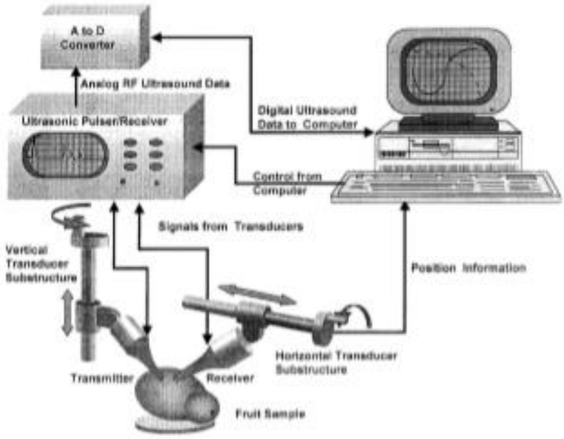

Figure 9. Schematic diagram of the setup for ultrasonic testing of mango and avocado (Mizrach, 2000)

using ultrasonic non-destructive technique through the variations in ultrasound attenuation. The result measured from monitoring will then be processed using statistical, correlation, and modelling procedures which firmly related to growth and duration for the storage of mango fruits as the attenuation of the ultrasonic wave increased with storage time. Figure 9 displays the schematic diagram of the setup for ultrasonic testing of mango and avocado fruits.

3.7 Electronic nose

Electronic nose (e-nose) system is a sensor-based technology, it generates a unique digital image for each composite vapour mixture, which considers the total headspace volatiles and creates a unique smell print (Ali et al., 2020c). E-nose responds to the whole set of volatiles in a unique digital pattern where these patterns are signature of particular set of aromatic compounds (Lim et al., 2016) and by placing a fruit in a fixed compartment or glass container, the aroma profile of a fruit can be measured non-destructively. E-nose has recognizable proof of volatiles for quality control and odour identification in non-laboratory environments. Previous researchers have demonstrated the use of e-nose for observing the ripeness for various types of fruits including peach (Xin et al., 2018; Huang et al., 2017), banana (Sanaeifar et al., 2016; Chen et al., 2018) and citrus (Wen et al., 2019).

E-nose technology also had been utilized to discover internal defects in mango. Salim et al. (2005) was able to classify 'Harumanis' mangos into immature, mature, and over-matured categories using an e-nose where it produced a very strong aroma as compared to other mango cultivars. zNoseTM used in the trend of liberating volatile organic compounds during ripening could potentially be used to predict mango fruit maturity which can help to harvest the fruits at the right maturity stage (Nouri et al., 2014). E-nose and an acoustic sensor were applied to classify the maturity of mangoes and its ripeness stage using Principal Component Analysis (PCA) and Linear Discriminant Analysis (LDA) in order to assess the strength of maturity and ripeness of harvested mangoes based solely on the aroma and the volatile gases released from the mangoes were studied by Zakaria et al. (2012).

4. Future prospects

Evaluating quality parameter of mango is an important consideration to preserve fruits by prolonging its shelf life, supplying quality fruits to the market and meeting the consumer's demand. The implementation of non-destructive equipment is necessary to evaluate both exterior and interior quality of fruits in a sorting or grading system. The non-destructive techniques reviewed in this paper convey the capability, benefits, application and the evaluation of mango fruit quality attributes. Combination of non-destructive techniques such as the X-ray and machine vision techniques has the potential to provide more precise measurement and increase the efficiency of the system but it requires skilled labour for image acquisition and data processing. Automatic sorting and grading of fruits system requires a developed computer vision system. Hence, the extra component equipped for capturing images of the other fruits can be developed in the future.

Besides that, on-line monitoring systems using NIR technology are commercially available. Therefore, the variety, growing place, season and fruit temperature that affect the NIR calibration and its possibility to develop a mobile NIR tools for plantation use should be determined. A limited research investigation of electronic nose exhibited the possibility for the volatile's identification of various sizes and maturity of mangoes. Thus, further additional researches can be carried out in the future to develop the potential of e-nose in mango quality evaluation and develop a technique for instrument institutionalization to permit a dependable and easy-to-use strategy for field calibration or portable e-nose.

5. Conclusion

This review has highlighted the advancement of non-destructive technique in quality evaluation of mango. The approaches have been overviewed to discuss those applications in detail accordingly, including Near Infrared Spectroscopic (NIR), Scanning Laser Vibrometry (SLV), X-ray and Computed Tomography (CT), Computer vision system (CVS) and image processing, RGB Fiberoptic colour sensor, Electronic nose and Ultrasonic.

Author contributions

Ong Phey Zhen carried out the literature review and performed the main writing part. Norhashila Hashim supported the study by providing the concept and the structure of the manuscript and supervised the study as well as giving her advice on the manuscript. Bernard Maringgal edited the final manuscript.

Conflict of interests

The authors declare that they have no competing interests to disclose that might be perceived as affecting the objectivity of this mini review.

Acknowledgments

The authors are thankful to Department of Biological and Agricultural Engineering, Universiti Putra Malaysia for providing facilities in this study.

References

Ali, M. M., Hashim, N., & Hamid, A. S. A. (2020a). Combination of laser-light backscattering imaging and computer vision for rapid determination of oil palm fresh fruit bunches maturity. Computer and Electronics in Agriculture, 169, 105235.

Ali, M. M., Hashim, N., Aziz, S. A., & Lasekan, O. (2020b). Exploring the chemical composition, emerging applications, potential uses, and health benefits of durian. A review. Food Control, 113, 107189.

Ali, M. M., Hashim, N., Aziz, S. A., & Lasekan, O. (2020c). Principles and recent advances in electronic nose for quality inspection of agricultural and food products. Trends in Food Science & Technology, 99, 1-10.

Ali, M. M., Janius, R. B., Nawi, M. N., & Hashim, N. (2018). Prediction of total soluble solids and pH in banana using near infrared spectroscopy. Journal of Engineering Science and Technology, 13, 254-264.

Arendse, E., Fawole, O. A., Magwaza, L. S., & Opara, U. L. (2018). Non-destructive prediction of internal and external quality attributes of fruit with thick rind: A review. Journal of Food Engineering, 217, 11-23.

Barrett, D. M., Beaulieu, J. C., & Shewfelt, R. (2010). Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: Desirable levels, instrumental and sensory measurement, and the effects of processing. Critical Reviews in Food Science and Nutrition, 50, 369-389.

Barcelon, E. G., Tojo, S., & Watanabe, K. (2000). Nondestructive ripening assessment of mango using an X-ray computed tomography. International Agricultural Engineering Journal, 9, 73-80.

Barton, B. (2005). General Introduction: Mango. Theatre Research in Canada-Recherches Theatrales Au Canada, 26, 1-2.

Barcelon, E. G., & Tojo, S., & Watanabe, K. (1999a). X-ray computed tomography for internal quality evaluation of peaches. Journal of Agricultural Engineering Research, 73, 323-330.

Barcelon, E. G, Tojo, S., & Wantanabe, K. (1999b). X-ray CT imaging and quality detection of peach at different physiological maturity. Transaction of the ASAE, 42, 435-441.

Bureau, S. (2009). The Use of Non-destructive Methods to Analyse Fruit Quality. Fresh Produce, 3 (Special Issue 1), 23-34.

Chen, L. Y., Wong, D. M., Fang, C. Y., Chiu, C. I., Chou, T. I., Wu, C. C., et al. (2018). Development of an electronic-nose system for fruit maturity and quality monitoring. Proceedings of

4th IEEE International Conference on Applied System Innovation, 1129-1130.

Dael, M. V., Verboven, P., Zanella, A., Sijbers, J., & Nicolai, B. (2019). Combination of shape and X-ray inspection for apple internal quality control: in silico analysis of the methodology based on X-ray computed tomography. Postharvest Biology and Technology, 148, 218-227.

Fukada, S. (2013). Emotional Engineering, 2, Springer Science & Business Media.

Gajanan, D. V., Ramdas, G. D., & Mahadev, J. S. (2015). Quality evolution of Mangifera Indica using non- destructive method, International Journal of Engineering Research and General Science, 3, 71-76.

Hashim, N., Janius, R. B., Baranyai, L., Rahman, R. A., Osman, A., & Zude, M. (2012). Kinetic model for colour changes in bananas during the appearance of chilling injury symptoms. Food and Bioprocess Technology, 5, 2952-2963.

Hosoya, N., Mishima, M., Kajiwara, I., & Maeda, S. (2017). Non-destructive firmness assessment of apples using a non-contact laser excitation system based on a laser-induced plasma shock wave. Postharvest Biology and Technology, 128, 11-17.

Huang, L., Meng, L., Zhu, N., & Wu, D. (2017). A primary study on forecasting the days before decay of peach fruit using near-infrared spectroscopy and electronic nose techniques. Postharvest Biology and Technology, 133, 104-112.

Jantra, C., Slaughter, D. C., Roach, J., & Pathaveerat, S. (2018). Development of a handheld precision penetrometer system for fruit firmness measurement. Postharvest Biology and Technology, 144, 1-8.

Jha, S. N., Narsaiah, K., Jaiswal, P., Bhardwaj, R., Gupta, M., Kumar, R., & Sharma, R. (2014). Nondestructive prediction of maturity of mango using near infrared spectroscopy. Journal of Food Engineering, 124, 152-157.

Jha, S. N., Narsaiah, K., Sharma, A. D., Singh, M., Bansal, S., & Kumar, R. (2010). Quality parameters of mango and potential of non-destructive techniques for their measurement - A review. Journal of Food Science and Technology, 47, 1-14.

Kotwaliwale, N., Kalne, A., & Singh, K. (2012). Monitoring of mango (Mangifera indica L.) ripening using X-ray computed tomography. Proceedings of the International Conference on Sensing Technology, ICST.

Leon, K., Mery, D., Pedreschi, F., & Leon, J. (2006). Colour measurement in L*, a*, b* units from RGB digital images. Food Research International, 39, 1084-1091.

Lim, J. V. M., Linsangan, N. B., Cruz, F. R. G., & Chung, W. Y. (2016). Temperature compensated electronic nose for fruit ripeness determination using component correction principal component analysis. International Journal of Computer and Communication Engineering, 5, 331-340.

Maringgal, B., Hashim, N., Tawakkal, I. S. M. A., Mohamed, M. T. M., Hamzah, M. H., Ali, M. M., & Abd Razak, M. F. H. (2020). Kinetics of quality changes in papayas (*Carica papaya* L.) coated with Malaysian stingless bee honey. Scientia Horticulturae, 267, 109321.

Manasa, B, Jagadeesh, S. L., Thammaiah, N., & Nethravathi. (2019). Colour measurement of ripening mango fruits as influenced by pre-harvest treatments using L*, a*, b* coordinates. Journal of Pharmacognosy and Phytochemistry, 8, 2466-2470

Mansor, A. B. R., Othman, M., Abu Bakar, M. N., Ahmad, K. A., & Razak, T. R. (2014). Fuzzy ripening mango index using RGB colour sensor model. Journal of Arts, Science & Commerce, 5, 1-9.

Mahayothee, B., Leitenberger, M., Neidhart, S., Mühlbauer, W., & Carle, R. (2002). Non-destructive determination of fruit maturity of Thai mango cultivars by near infrared spectroscopy. ISHS Acta Horticultural, 645, 581-588.

Mizrach, A., (2000). Determination of avocado and mango fruit properties by ultrasonic technique. Ultrasonics, 38, 717-722.

Mizrach, A., & Flitsanov, U. (1999a). Non-destructive ultrasonic determination of avocado softening process. Journal of Food Engineering, 40, 139-144.

Mizrach, A., Flitsanov, U., Schmilovitch, Z., & Fuchs, Y. (1999b). Determination of mango physiological indices by mechanical wave analysis. Postharvest Biology and Technology, 16, 179-186.

Mizrach, A., Flitsanov, U., & Fuchs, Y. (1997). An ultrasonic non-destructive method for measuring maturity of mango fruit. Transactions of the ASAE, 40, 1107-1111.

Munawar, A. A., Hörsten, D. V., Mörlein, D., Pawelzik, E., & Wegener, J. K. (2013). Rapid and non-destructive prediction of mango sweetness and acidity using near infrared spectroscopy. Lecture Notes in Informatics (LNI). Proceedings - Series of the Gesellschaft Fur Informatik, 211, 219-222.

Nagle, M., Intani, K., Romano, G., Mahayothee, B., Sardsud, V., & Müller, J. (2016). Determination of surface color of 'all yellow' mango cultivars using computer vision. International Journal of Agricultural and Biological Engineering, 9, 42-50.

Naik, S., Patel, B., & Pandey, R. (2015). Shape, size and maturity features extraction with fuzzy classifier for non-destructive mango (*Mangifera Indica* L., cv. Kesar) grading. IEEE Technological Innovation in ICT for Agriculture and Rural Development (TIAR), Chennai, 1-7.

Nandi, C. S., Tudu, B., & Koley, C. (2014). Machine Vision Based Techniques for Automatic Mango Fruit Sorting and Grading Based on Maturity Level and Size. Sensing Technology: Current Status and Future Trends II, Springer International Publishing, 27-46.

Nagle, M., Intani, K., Mahayothee, B., Sardsud, V., & Müller, J. (2012). Non-destructive mango quality assessment using image processing: inexpensive innovation for the fruit handling industry. Conference on International Research on Food Security, Natural Resource Management and Rural Development, Tropentag 2012.

Nowacka, M., Tylewicz, U., Romani, S., Rosa, M. D., & Witrowa-Rajchert, D. (2017). Influence of ultrasound-assisted osmotic dehydration on the main quality parameters of kiwifruit. Innovative Food Science & Emerging Technologies, 41, 71-78.

Nouri, F. G., Chen, Z., & Maqbool, M. (2014). Monitoring mango fruit ripening after harvest using electronic nose (zNoseTM) technique. 5th International Conference on Food Engineering and Biotechnology, 65, 8.

Pandey, R., Gamit, N., & Naik, S. (2014). Non-destructive quality grading of mango (*Mangifera Indica* L) based on CIELab colour model and size. IEEE International Conference on Advanced Communications, Control and Computing Technologies, 1246-1251.

Penchaiya, P., Tijskens, L. M. M., Uthairatanakij, A., Srilaong, V., Tansakul, A., & Kanlayanarat, S. (2020). Modelling quality and maturity of 'Namdokmai Sithong' mango and their variation during storage. Postharvest Biology and Technology, 159, 111000.

Peng, Y., & Lu, R. (2007). Prediction of apple fruit firmness and soluble solids content using characteristics of multispectral scattering images. Journal of Food Engineering, 82, 142-152.

Pu, Y. Y., Sun, D. W., Buccheri, M., Grassi, M., Cattaneo, T. M. P., & Gowen, A. (2019). Ripeness classification of bananito fruit (*Musa acuminata*, AA): a comparison study of visible spectroscopy and hyperspectral imaging. Food Analytical Methods, 12, 1693-1704.

e-ISSN: 2716-6236

Razak, T. R. B., Othman, M. B., & Abu Bakar, M. N., Ahmad, K. A., & Mansor, A. B. R. (2012). Mango grading by using fuzzy image analysis. International Conference on Agricultural, Environment and Biological Sciences, 18-22.

Sanchez, P. D. C., Hashim, N., Shamsudin, R., & Nor, M. Z. M. (2020). Applications of imaging and spectroscopy techniques for non-destructive quality evaluation of potatoes and sweet potatoes: A review. Trends in Food Science & Technology, 96, 208-221.

Sanaeifar, A., Mohtasebi, S. S., Ghasemi-Varnamkhasti, M., & Ahmadi, H. (2016). Application of MOS based electronic nose for the prediction of banana quality properties. Measurement, 82, 105-114.

Santulli, C., & Jeronimidis, G. (2006). Development of a method for nondestructive testing of fruits using scanning laser vibrometry (SLV). NDT, 11, 10.

Salim, S. N. M., Shakaff, A. Y. M., Ahmad, M. N., Adom, A. H., & Husin, Z. (2005). Development of electronic nose for fruits ripeness determination. 1st International Conference on Sensing Technology, 515-518.

Saranwong, S., Sornsrivichai, J., & Kawano, S. (2003). On-tree evaluation of harvesting quality of mango fruit using a hand-held NIR instrument. Journal of Near Infrared Spectroscopy, 11, 283-293.

Saranwong, S., Sornsrivichai, J., & Kawano, S. (2001). Improvement of PLS calibration for Brix value and dry matter of mango using information from MLR calibration. Journal of Near Infrared Spectroscopy, 9, 287-295.

Schmilovitch, Z., Mizrach, A., Hoffman, A., Egozi, H., & Fuchs, Y. (2000). Determination of mango physiological indices by near-infrared spectrometry. Postharvest Biology and Technology, 19, 245-252.

Sharma, R. R., & Krishna, K. R. (2017). Non-destructive evaluation of Jelly Seed Disorder in Mango, 1-7.

Slaughter, D. (2009). Nondestructive maturity assessment methods for mango: A review of literature and identification of future research needs. University of California, Davis, 1-18.

Tharanathan, R. N., Yashoda, H. M., & Prabha, T. N. (2006). Mango (*Mangifera indica* L.), "The King of Fruits"-An Overview. Food Reviews International, 22, 95-123.

Ueda, M., Sasaki, K., Utsunomiya, N., Inaba, K., & Shimabayashi, Y. (2000). Changes in physical and chemical properties during maturation of mango fruit (*Mangifera indica* L. 'Irwin') cultured in a plastic greenhouse. Food Science and Technology Research, 6, 299-305.

Watanawan, C., Wasusri, T., Srilaong, V., Wongs-Aree, C., & Kanlayanarat, S. (2014). Near infrared spectroscopic evaluation of fruit maturity and quality of export Thai mango (*Mangifera indica* L. var. Namdokmai). International Food Research Journal, 21, 1073-1078.

Wen, T., Zheng, L., Dong, S., Gong, Z., Sang, M., Long, X., et al. (2019). Rapid detection and classification of citrus fruits infestation by Bactrocera dorsalis (Hendel) based on electronic nose. Postharvest Biology and Technology, 147, 156-165.

Xin, R., Liu, X., Wei, C., Yang, C., Liu, H., Cao, X., Wu, D., Zhang, B., & Chen, K. (2018). E-nose and GC-MS reveal a difference in the volatile profiles of white- and red-fleshed peach fruit. Sensors, 18, 765.

Zakaria, A., Md Shakaff, A. Y., Masnan, M. J., Saad, F. S. A., Adom, A. H., Ahmad, M. N., & Kamarudin, L. M. (2012). Improved maturity and ripeness classifications of *Magnifera Indica* cv. harumanis mangoes through sensor fusion of an electronic nose and acoustic sensor. Sensors, 12, 6023-6048.

Zele, A. J., Feigl, B., Adhikari, P., Maynard, M. L., & Cao, D. (2018). Melanopsin photoreception contributes to human visual detection, temporal and colour processing. Scientific Report, 8, 3842.

Zhang, B., Huang, W., Li, J., Zhao, C., Fan, S., Wu, J., & Liu, C. (2014). Principles, developments and applications of computer vision for external quality inspection of fruits and vegetables: A review. Food Research International, 62, 326-343.

Zhu, Q, Gao, P., Liu, S., Zhu, Z., Amanullah, S., Davis, A. R., & Luan, F. (2017). Comparative transcriptome analysis of two contrasting watermelon genotypes during fruit development and ripening. BMC Genomics, 18, 3.

Zwiggelaar, R., & Bull, C. R., & Mooney, M. J. (1996). X-ray simulations for imaging applications in the agricultural and food industries. Journal of Agricultural Engineering Research, 63, 161-170.

