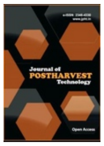

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REVIEW ARTICLE

# Non-destructive techniques for grading of mango: a review

**Chandra Sekhar Nandi**

Applied Electronics and Instrumentation Engineering Department, University Institute of Technology, The University of Burdwan, Burdwan, India

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## ABSTRACT

Postharvest grading of fruits is vital to maximizing the profit, as it offers a variety of choices to the customers. This paper presents the recent developments and future scopes in non-destructive techniques for grading of agricultural products like fruit, especially mango. The significant technologies that associated with non-destructive techniques are machine vision, electronic nose (e-nose), near-infrared (NIR) spectroscopy, and multispectral and hyperspectral imaging. In this paper, different non-destructive techniques to assess the quality and safety parameters of fruits as applied by the researchers in the recent past have been discussed. These techniques work on different fruit characteristics like colour, aroma, firmness, defects and chemical compositions, etc. The limitations, challenges and future scopes of research of these techniques, along with a suitable comparison, are presented in this paper. It is concluded that hyperspectral imaging is a great and promising technique for estimation of quality and safety of fruits and food products. Moreover, machine vision is the most widespread and versatile technique for maturity and visual quality detection of fruit at high speed and low-cost applications.

**Keywords:** Maturity, quality, grading, mango, non-destructive techniques

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## INTRODUCTION

Mango scientifically named as *Mangifera Indica* L. is a tropical fruit commercially produced in various farms for worldwide export along with sales and distribution. Mango is now becoming very important and popular fruit, not only for its flavour, taste but also for its medicinal and nutritional aspect. It is also the essential source of antioxidants like phenolic compounds, total carotenoid, β-carotene and total ascorbic acid (Taing et al., 2015). The carotenoid zeaxanthin and lutein present in mango (16 mole % and 2 mole % respectively), help to protect our eyes from harmful blue light and reduce the prevalence of macular degeneration (Sommerburg et al., 1998). Parts of mango like peel, pulp and seeds contain many bioactive compounds such as polyphenolics, which can protect many degenerative diseases due to their antioxidant activities (Martin and He, 2008). Mango peel and flesh are also able to guard the creation as well as the propagation of cancer cells in the human body (Ribeiro et al., 2007). The

* *For correspondence*: C. S. Nandi (Email: csnandi@uit.buruniv.ac.in)

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nutritional, biochemical and phytochemical quality components also vary with the different mango varieties during the ripening stage (Celis et al., 2019).

During the summer season, mangoes are harvested in different gardens, graded according to their maturity and quality, and then sent for storage at farms or transportation to different locations or various markets by the distributors. Based on the market distance and the quality demand of the market, the distributors require batches of similar maturity and quality level. But the fundamental properties of these agricultural products, especially mango, vary from one cultivar to another (Nandi et al., 2014). Currently, it is seen in the global market that nearly 30% of mangoes are lost after harvesting (Vasconcelos et al., 2019). Thus, proper grading and preservation of fruit like mango are becoming very essential today.

Gum Arabic coating treatment is used for the preservation of mango during storage and transportation, without disturbing the quality parameters. This coating has helped significantly to reduce weight loss, result into higher titratable acidity, delay increase in total soluble solids (TSS) and develop ß-carotene while maintaining ascorbic acid in the mangoes during storage (Daisy et al., 2020). It is shown that the ripening has become slower and shelf life has been increased satisfactorily for gum Arabic-coated mangoes. Thus, with the help of this technique, producers can generate more profit by reducing postharvest losses and losses during transportation. The quality parameters like firmness, TSS, titratable acidity and other biological components vary along with the variation of maturity level during storage at farm and transport vehicle (Penchaiya et al., 2020). Therefore, grading of fruit is crucial before storage and/or transportation.

The grading is to be vendor or distributor specific, as the most matured mangoes are be sent to local markets or may be sent to the food processing industry. The pre-matured mangoes can be shipped to customers over much greater distances to enhance revenue by reducing postharvest loss. Thus, assessing the maturity level of fruit will help the vendor or distributor to decide the distance of the market to be transported. On the other hand, the quality level will help to determine the category of the market. It is seen that proper handling and postharvesting treatment of fruit can significantly increase their quality retention during prolonged storage and transportation (Feygenberg et al., 2014).

Most of the farms in India are still using manual experts for grading of the fruits before storage at the farm and/or transportation. As the mango is a seasonal fruit, so getting a sufficient number of manual experts during the period of harvesting is very difficult. On the other hand, the manual grading process is prolonged, less effective and less accuracy. So, if this task could be performed automatically, then the result would be more objective, and it would also save labour and enhance profit. Moreover, the non-contact detection technique is an inevitable trend in the development of automatic fruit grading systems (Patel et al., 2012).

For grading of fruit, different non-destructive techniques that have been summarized here, consider different fruit characteristics like colour, aroma, firmness, defects and chemical composition etc. This paper also presents the recent developments, trends, limitations, challenges and future scopes of these techniques for automated grading of agricultural products like fruit, especially mango.

## NON-DESTRUCTIVE TECHNIQUES FOR FRUIT ESPECIALLY MANGO GRADING

The demand for good quality and fresh fruits and food products has been increasing in the market, as stated by the World Trade Organization (WTO) (Londhe et al., 2013). Currently, the farmers are looking forward towards having a proper fruit grading machine to relieve from labour unavailability, reduce time and improve quality of grading. Fair grading of fruit is now also becoming a vital task as it fetches high price to the cultivator and improves packaging, handling and carries, thereby an overall improvement in the marketing system. Accurately graded fruits bring more profit when exported to developed countries. As a result, the demand for a low-cost non-destructive method for grading of fruits is increasing day by day.

Presently, several non-destructive techniques have been applied successfully for assessing the quality of fruit and agro-food products. Few non-destructive techniques along with post-harvesting treatments for the estimation of maturity and quality of mango have been reported (Jha et al., 2010). Some potential non-destructive techniques, currently proposed by the different researchers for grading of fruit specifically for mango, along with their limitations, challenges and future scopes of research are discussed in the following sections.

**Electronic nose (e-nose) techniques**

Concentrations of volatile compounds (VOCs) increase during ripening of the fruit. The VOCs of mango fruit can be measured and analyzed non-destructively using gas chromatography and mass spectroscopy (GC/MS). Electronic nose (e-nose) is an intelligent sensing device, has been used during the last decade to identify and analyze the VOCs for the prediction of maturity and quality of fruits. The e-nose system (diagram shown in Fig.1) uses electronic sensors array as the receptor. When a specific sensor contacts with VOCs, the sensor responds by changing its internal electrical properties and transmits a signal to the computer for processing. Proper selection of features from each sensor output signal helps to enhance the performance of e-nose.

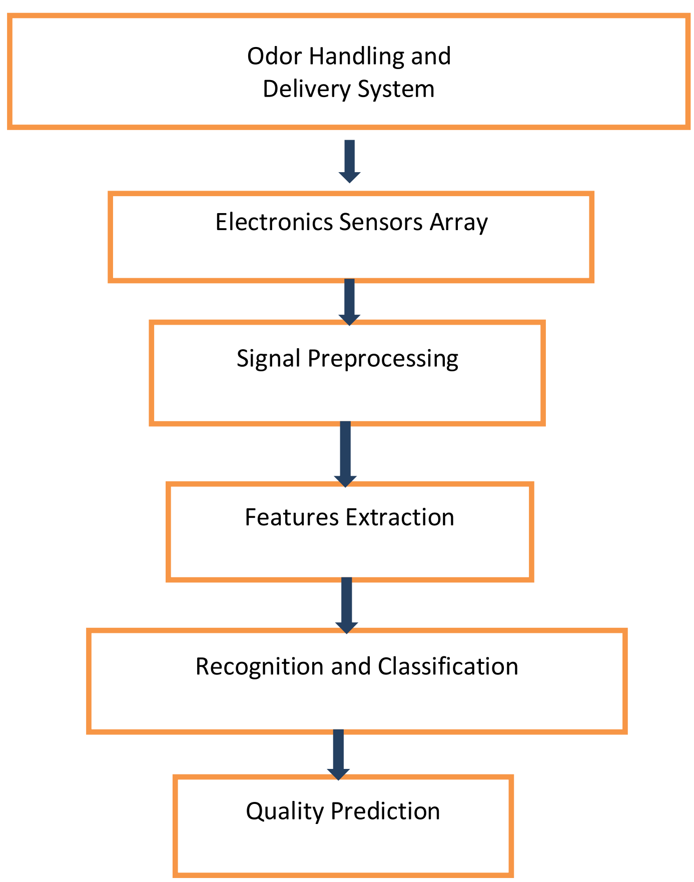


**Fig.1. Flow diagram of electronic nose for estimation of fruit quality**

Using ultra-fast Gas Chromatography (GC) (Li et al., 2009), based on uncoated surface acoustic wave sensor, VOCs are detected to estimate colour, respiration rate and TSS for the prediction of ripeness of mango during shelf life. E-nose technique is carried out to analyze the aromatic volatiles for the estimation of the quality of fruits (Kitthawee et al., 2012; Aghilinategh et al., 2020) and food products (Chilo et al., 2016) by the food processing industry.

**Machine vision techniques**

Machine vision technique is based on the visual appearance of the fruit, which is one of the most critical factors applied by the consumers while purchasing the fruit. The reflectance of light energy from the fruit surface varies due to the presence and concentration of pigments, including carotenoids, anthocyanins, flavonoids and chlorophylls in the skin of the fruit (Gross, 1987). The change in these pigments during ripening of the fruit like mango, affect the perception of skin colour and thus the skin colour of the fruit is commonly used as central attributes of maturity or ripeness.

The machine vision system (diagram shown in Fig.2) is based on the digital camera, hardware, and computer learning algorithms to extract and analyze useful information for the quality estimation of fruit and food products. In most of the fruits the surface colour changes during ripening stage, therefore many machine vision-based techniques have been proposed for the prediction of maturity or ripeness of agricultural products. This technique has been found potentially useful as a non-destructive tool in the agro and food industry for the inspection of quality and safety. Currently, this technique is being used in agricultural, food processing industries and commercial industries during grading, packaging.

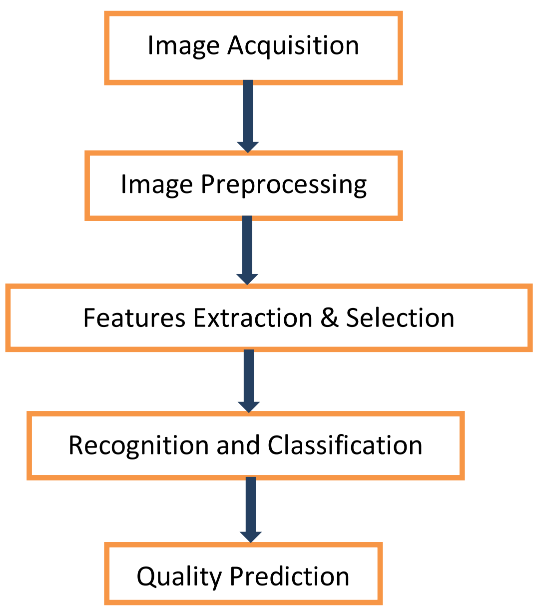


**Fig. 2: Flow diagram of machine vision system for estimation of fruit quality**

This technique has attracted various researchers and business houses due to reduction of computational and camera cost. With the advancement in machine vision technology, grading of fruits and vegetables based on this technique has been developed to detect multi-index simultaneously in real-time applications. Different algorithms and methodologies based on this technique, used by the various researchers for the automatic inspection of quality and safety of fruits and vegetables has been compared (Bhargava and Bansal, 2018). This technique is also being used in the various kind of farming operations related to crop harvestings such as fruit counting and grading (Mavridou et al., 2019). Currently, machine vision and image processing technique is successfully applied for real-time fruit size and maturity estimation within the tree (Bresilla et al., 2019). Some applications of this technique for mango grading are presented in Table 1.

**Table1: Application of machine vision system for estimation of fruit quality**

| Fruit sample | Types of study | Data processing algorithm/ Classifier/Model[1] | Performance accuracy | Ref. |
|---|---|---|---|---|
| Mango | Degree of browning in the skin | LS-SVM | 85-88%. | (Zheng and Lu, 2012) |
| Mango | Grading based on maturity and quality | SVR, MADM and Incremental Fuzzy | 87%. | (Nandi et al., 2016) |
| Mango (Nam Dokmai) | Mass estimation | ANN | 96.7% | (Schulze et al., 2015) |
| Mango | Maturity prediction | RFE-SVM | 96% | (Nandi et al., 2014) |
| Mango | Grading based on geometry and shape | Image processing algorithm | 71% (average) | (Momin et al., 2017) |

[1] LS-SVM: Least square support vector machine, RFE-SVM: Recursive feature elimination support vector machine, SVR: support vector regression, MADM: multi attribute discussion making, ANN: artificial neural network

### Visual and near-infrared (NIR) spectroscopy techniques

Visual and near-infrared (NIR) spectroscopy, having spectrum ranges between 400-750nm and 750-2500nm, can be used as a non-destructive sensing technique for fruit grading in postharvest applications. Regression model based on two different NIR spectral ranges (680-1000nm and 1100-2350nm) has been used to predict the preharvest soluble solids content (SSC) and dry matter contents (DMC) during ripening of fruit (Travers et al., 2014). It is noticed that the performance accuracy is better for longer NIR spectra and may influence by the physiological compositions like stone cells present below the skin of the fruit. These stone cells in fruit, are sources of soluble solids, therefore, additional research work is needed to enhance and qualify the performance accuracy of the model.

Fourier-transform spectrometer in the mid-infrared frequency range has been applied for the quality analysis fruits and processed food products (Bureau et al., 2019). A recently published paper provides important issues significant to the application of visual and NIR technique for the quality analysis of fruit (Walsh et al., 2020). Some applications of visible and NIR spectroscopy in this area are presented in Table 2.

**Table 2: Applications of visible and NIR spectroscopy in mango**

| Fruit sample | Types of study[1] | Wavelength range (nm) | Data processing algorithm/ Classifier/ Model[2] | Correlation coefficients[3] ($R^2$) / Accuracy | Ref. |
|---|---|---|---|---|---|
| Mango | Internal defects like spongy tissue | 673-1100 | FLD | 84.5% | (Raghavendra et al., 2021) |
| Mango | TSS, firmness, TA and RPI | 700-1100 | PLSR | 0.9, 0.82, 0.74 and 0.8 | (Rungpichayapichet et al., 2016) |
| Mango (Nam Dokmai) | DMC and firmness | 700-1100 | LR | 0.96 and 0.67 | (Watanawan et al., 2014) |
| Mango (Osteen) | TSS, firmness and flesh colour | 600-1100, 900-1750, 400-700 | PLS | 0.815-0.896 | (Cortés et al., 2016) |
| Mango | Maturity | 1600-1800 | PLS | 0.74 and 0.68 | (Jha et al., 2014) |
| Mango (Palmer) | SSC and DMC | 699-999, 699-981 | PLSR | 0.87 and 0.84 | (Neto et al., 2017) |
| Mango (Keitt) | Internal disorders | 550-650 | Logistic and LDA | 68% and 70% | (Mogollón et al., 2020) |
| Mango (Keitt) | Internal browning | 400-1000 | ANN and PLSR | 0.57 and 0.53 | Gabriëls et al., 2020 |

[2] FLD: Fisher's Linear Discriminant, PLS: partial least squares, PLSR: partial least squares regression, LR: linear regression, PCA: principal component analysis, PCR: principal component regression, LDA: linear discriminant analysis, ANN: artificial neural network.

[1]SSC: soluble solid content, DMC: dry matter content, SC: starch content, TSS: total soluble solid, RPI: ripening index, TA: titratable acidity.

After grading, the harvested fruit, may need to be preserved at the farms and/or during transportation. Preservation can be done by real-time monitoring and controlling of ethylene production of fruits and vegetables using ethylene analyzer (ETD-300) (Bisson et al., 2016). The detector contains a laser radiation source and a photoacoustic detection system where the ethylene is detected. Detail description for the detection, monitoring and controlling of ethylene production using ETD-300 in the applications of postharvest research is available (Gwanpua et al., 2018). VOCs at fruits can also be analysed by the infrared spectroscopy using a $CO_2$ laser (Popa, 2009).

### Multispectral and hyperspectral imaging techniques

The needs of new sensing technique, for non-destructive quality monitoring of fruit and food products, have become great important today due to economic globalization, increase in awareness and demand. Multispectral imaging technique has been used with amazing capabilities for the quality and safety inspection of fruit and food products. This technology is implemented successfully for detecting certain physical, biological, and/or chemical properties of many fruits and food products.

Hyperspectral imaging technique (diagram shown in Fig.3) has entered as a promising field of research that combines traditional optical spectroscopy and computer vision for quality and safety monitoring of fruits (Li et al., 2019). This technique provides images with spatial and spectral information, which enables it as a powerful technique for the application of internal quality assessment of fruits and food products (Qin et al., 2017).

The spectral reflection from the surface of the fruit depends on the fruit quality attributes such as surface colour, total SSC, moisture content and firmness etc. Hyperspectral imaging technique has achieved extensive recognition as a non-destructive tool for the quality measurement of fruits and food products (Wu and Sun, 2013). This technique has shown its high potential for the inspection of the physical and internal quality parameters of fruits (Ma et al., 2019), textural quality, biochemical components and safety of fruits (Pu et al., 2015), and quality and safety of food products during processing and packaging (Huang et al., 2014). Recently, a large number of research papers and reports are dealing with the applications of hyperspectral imaging technique in the field of agricultural and food processing industries. The study shows that the hyperspectral imaging can be used as a reliable tool for non-destructive detection for grading of fruit based on maturity and quality as well as chemical compositions.

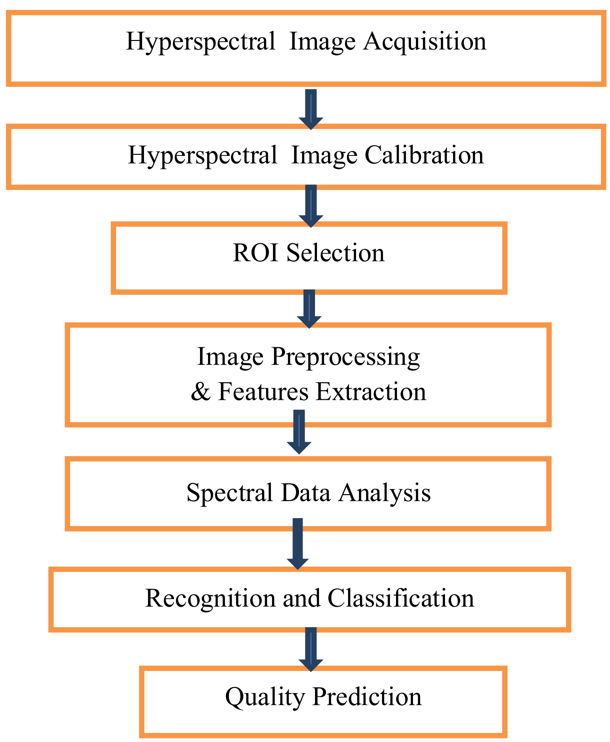


**Fig 3: Flow diagram of hyperspectral imaging technique for estimation of fruit quality**

## LIMITATIONS, CHALLENGES AND FUTURE SCOPES OF RESEARCH

This paper aims to provide the current practices, the latest advancements and future scopes of different non-destructive techniques in fruit grading and food processing applications. The critical factors in international mango trade are quality, safety and maturity of mango at the consumer end. Other factors, such as fruit shelf life, controlled temperature storage facilities available at the farm and during transportation are the significant limitations to this trade.

Practically it is seen that the different maturity levels of fruits like mango may have same average skin colours and this colour variations of different mango cultivars during ripening process are different (Nandi et al., 2014). Due to these variations, a maturity prediction system standardized using one particular variety of mango may not be suitable for other variety. Firmness, one of the grading parameters of mango, can be determined non-destructively, by an optical method (visual/NIR spectroscopy) (Valente et. al., 2009), using acoustic firmness sensor, which also depends on the shape of the fruit (Zhang et al., 2019). Therefore, there is a challenge to the researchers for the development of such a system to assess the maturity and quality of fruits and vegetables in a comprehensive manner.

E-nose techniques are not suited for real-time applications due to the time required both to allow the VOCs to accumulate in the container, and to take the measurement. Also, the performance of the e-nose device to determine the maturity of mango according to their ripening stage is too low to be introduced in the market (Kitthawee et al., 2012). Limited research work has been performed on VOCs using e-nose for the prediction of maturity and quality of mango (Zhen et al., 2020). Therefore, further additional work can be carried out for the development of the potential of e-nose system in mango quality evaluation to permit a reliable and user-friendly method for instrument standardization and calibration.

Since the primary sensing device of machine vision system generally is a digital camera along with associated hardware and software units, it is quite affordable and readily available which has been helped to make this system more ubiquitous and applicable (Shirmohammadi and Ferrero, 2014). This system can provide hygienic, consistent and objective assessment and allows rapid grading of fruits according to their surface colour and visual quality. Moreover, this technique is the most versatile and suitable, as it can meet the challenges of real-time applications and cost constrain. However, for the detection of internal defects such as spongy tissue, seed weevil and fruit fly or internal properties as well as the chemical composition of fruit especially mango, this technique is not suitable.

Using NIR technique for the quality grading of fruit, researchers have proposed diverse solutions with different characteristics; like types of illumination, various cameras and filter combinations, and several classification methods. Furthermore, different absorption properties of fruit skin and selection of spectral wavelength increase their diversity even more. Due to this diversity of the problem, it is challenging to maintain proper grading of fruit by NIR imaging technique. Therefore, future research is required for appropriate calibration of the instrument and adequate classifier architecture to compare and classify them more accurately (Walsh et al., 2020).

Current study reveals that hyperspectral imaging technique has been accepted as an excellent application for online inspection of quality and safety of fruits and food products. This technology has progressed rapidly as computers became faster and more powerful. As in this technique, images contain a large amount of information, therefore, more accurate and precise measurement is possible using this technique (Steinbrener et al., 2019). Further research should be done on developing new or advanced mathematical and/or statistical methods for a better description of spatial scattering profiles to achieve accurate prediction of maturity and internal quality as well as the chemical composition of fruits.

## CONCLUSION

This paper focuses on the recent progress and future trends of different non-destructive techniques in real-time fruit especially mango grading applications. Techniques, such as machine vision, e-nose, NIR spectroscopy and hyper-spectral imaging have shown great potential for use as quality and safety assessment of fruits and food products. Different classification methods available for grading of fruit using these non-destructive techniques and their performance in terms of accuracy, precision, versatility and complexity have been compared. It is clear from this study that hyperspectral imaging is currently the most promising and extensive field of research for qualitative and quantitative measurement of many fruits and agro-food products. Moreover, machine vision is the most useful and versatile technique for maturity and visual quality prediction in real-time applications. There is still scope of research to enhance the performance of the system, by parallel computing and by using very recently developed deep neural networks as a classifier.

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