A Survey on Internal Defect Detection in Fruits by Non-Intrusive Methods

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Abstract: In food industry, internal and external quality of fruits play an important role, which is evaluated by their colour, texture and defects. In recent years, detection of internal defects in food products is a challenging task. The present research is based on detection of internal defects in fruits during post-harvest period which is being looked along with various remedies that have been suggested and implemented. Our specific focus has been on Mangoes, with all kinds of defects such as, diseases physiological disorders and damage due to pests. However, to understand the various detection techniques, other fruits are also of our interest. Implications of such commercially available non-destructive methods along with comparisons are presented. Some of the challenges being faced by the present researchers along with various standards which are emerging in this area are also discussed. Various performance measures which are being considered by the researchers are enumerated leading to the research opportunities which could potentially exist in this domain. Scope for future research is detailed in conclusion. One such research area would be to use image processing and pattern recognition techniques which can be adopted to non- destructively detect and categorise the mango fruit quality and to reduce post harvest losses during supply chain.

KEYWORDS: Alphonso mango, NIR Imaging, MRI/NMR, X-ray.

I. INTRODUCTION

In India, Horticulture sector has the highest potential for export, owing to the wide diversity of horticultural flora, agro-climatic conditions coupled with efficient low cost labor and advantageous geographic location. India has an edge over other fruit producing countries to expand its export basket[1]. Marketing is an important step in the post-harvest handling of the horticultural produce. It is one of the most complicated issues that requires better understanding of the complexities and identification of the bottlenecks to provide an efficient solution[1]. Marketing these produce plays a major role. An efficient and effective marketing system is a boon to any production system in agriculture and horticulture in particular [2].

India has accelerated the total annual production of Alphonso mango. The internal quality of mango is a concern for consumers and export traders. This variety, however suffers from physiological disorder of spongy tissue which is present in the pulp portion of the mango because of which, its export value and consumer satisfaction are affected[3]. Lack of an automated commercial system based on non-destructive techniques for detection of physiological disorders in Alphonso is a reason for India being still very poor in export of the Alphonso. So far, the causative factor for the spongy tissue has not been identified and there is no proven technology for its control during growth and pre-harvesting period as on today. The internal disorders are not visible to human eye and manually it is not possible to detect the defect-infected mangoes. Till now, certain countries have banned Indian mangoes because of this reason. In such a scenario, the immediate priority is to detect spongy tissue, fruit fly and seed weevil infected mangoes by non-destructive technique for grading and sorting of good quality mangoes for consumption and export[3].

Traditionally, chemical and biochemical methods are available to investigate compositional and metabolic differences between the healthy and the damaged tissue in fruits pulp. The intensity and occurrence of the disorders depends upon factors related to climate, location, and farmers. The symptoms are manifested at the final stage of fruit growth and maturation. Padda et al [4] by using Canonical Discriminant Analysis found that the best tools to assess changes in mango fruit during ripening were firmness, followed by flesh value and total soluble solids (TSS) content. Subedi et al [5] showed that flesh value correlated with maturity of fruit. Colour of flesh was found to be consistent in various farmers and although being a destructive measurement parameter, it is used as a maturity index in several mango producing regions like Maharashtra, Karnataka, Tamilnadu, etc.[6]. Tomas [7] developed an efficient algorithm for detecting and sorting mango based on size properties using image analysis. The features of the mango were extracted from the acquired image and used to identify and sort

the fully defected, partially defected class of the mangoes due to diseases, physiological disorder and pests to large extent.

The characteristics of the texture, whether it is soft, spongy or leathery depending on the severity of damage in the fruit. The peculiarity here is that, the external symptoms of spongy tissue affected fruits are not apparent either at the ripe stage or at the time of picking. The spongy tissue affected is visible only when the ripe fruit is cut into two halves. This necessitates the investigation of various non-destructive techniques for defect detection in Alphonso Mangoes. Also, certain varieties of mango viz., Neelam and Totapuri have seed-weevil or stone-weevil infestation, which can affect the processed pulp[2]. Due to this, the exporters and processors are facing difficulties in providing quality mangoes free from the internal disorders for consumption or making pulp. Various image processing techniques available in the literature for defect detection in fruit can be effectively used in solving such problem that will enhance the export and hence, can improve the export potential for India. Typically, in natural image analysis, texture is the only information that can be used. Thus texture analysis has gained attention in the field of image analysis and pattern recognition for this kind of problem. The work carried out has been divided into three parts for the purpose of presentation in this paper. The first two parts deal with the study of various defects occurring in mango, along with comparative study on various non-destructive techniques. Third part is about the commercially available non-destructive techniques to detect defects in various fruits, not necessarily only mangoes.

II. LITERATURE REVIEW

Some of the aspects which affect the maintenance of mango fruit quality during the supply chain are harvesting practices, adequate orchard management practices, post-harvest treatments, transportation and storage conditions, packing, temperature management and ripening at destination. The Indian mango variety viz. Alphonso is the most important fruit in taste for export. This variety, however suffers from physiological disorder of spongy tissue present in the pulp portion of the mango[2][8]. This malady is caused due to inactivity of ripening enzymes due to high temperature, calcium deficiency, excessive heat and post harvest exposure to sunlight[9-10]. The oriental fruit fly is one of the most serious pests of mango in India, which creates a problem in the export of fresh fruits. The appearance of fruit fly starts from April onwards and the maximum population is recorded during May-July, which coincides with fruit maturity. The population declines slowly from August to September after that it is non-existent up to March [11]. Stone weevil or Seed weevil is a common pest of mango in southern India. Varieties with high Total Soluble Solid (TSS) and sugar such as, Alphonso, Bangalora, Neelum, etc. are more prone to attack by this pest. Female lays eggs under the rind of ripening fruits. Newly emerged grubs bore through the pulp, feed on seed coat and later cause damage to cotyledons. Pupation takes place inside the seed. Pulp is discolored around the affected portion [12]. The internal quality of mango is a concern for both consumers and export traders[2].

Non-invasive defect detection in Alphonso Mango is a new area and very little work has been done in this field. Some of the quality attributes of Alphonso are uniform weight, colour, aroma, firmness, texture, shape and size and also free from external damages such as latex or sap injury, bruises and decay. Post-harvest losses are high in all varieties of Mangoes during the supply chain due to harvesting fruit at improper maturity, sap burn, mechanical damage, spongy tissue, lenticels discoloration, decay, chilling injury, fruit softening and disease and pest damage. The main aim of post-harvest treatments and management practices in the supply chain is to create suitable conditions or environments to extend the storage life and retain the quality attributes, nutrition and functional compositions[13].

III. DEFECTS IN MANGOES

Some varieties of mangoes also suffers from physiological disorders like mango malformation (the disorder caused by factors like, mites, fungal, viral, hormonal imbalance, etc.)[14][15], Biennial Bearing [on-off year cropping-the term biennial, alternate or irregular bearing generally signifies the tendency of mango trees to bear a heavy crop in one year (On year) and very little or no crop in the succeeding year (Off year)][16], fruit Drop (Embryo abortion, climatic factors, disturbed water relation, lack of nutrition, attack of disease and pest and hormonal imbalances are the major factors lead to fruit drop) [17], black tip(the damage to the fruit gets initiated right at marble stage with a characteristic yellowing of tissues at distal end. Gradually, the colour intensifies into brown and finally turns into black)[18], clustering in Mango(A fruiting disorder, locally known as 'Jhumka', is characterised by the development of fruitlets in clusters at the tip of panicles. Such fruits cease to grow beyond pea or marble stage and drop down after a month of fruit set) [19] and zinc deficiency (The major nutritional disorder in mango is *little leaf* caused by the deficiency of zinc)[20], pests like hopper, mealy bugs, inflorescence midge, scale insects, shoot borer, bark eating caterpillar, stem borer, shoot gall psylla, leaf webber[16][21].

Diseases like powdery Mildew (Oidiummangiferae) the characteristic symptom of the disease is the white superficial powdery fungal growth on leaves, stalk of panicles, flowers and young fruits, Anthracnose (Colletotrichumgloeosporioides) causes serious losses to young shoots, flowers and fruits under favorable climatic conditions (like, high humidity, frequent rains and the temperature range of 24-32°C)., Die Back (Botryodiplodia theobromae) is characterised by drying of twigs and branches followed by complete defoliation, which gives the tree an appearance of scorching by fire[16], Phoma Blight (Phomaglomerata) causes the lesions are angular, minute, irregular, yellow to light brown, scattered over leaf lamina. As the lesions enlarge, their color changes from brown to cinnamon and they become almost irregular., Bacterial Canker (Xanthomonascampestrispv. mangiferaeindicae appears as minute water soaked irregular lesions on any part of leaf or leaf lamina.)[16], Red Rust (Cepbaleurosvirescens) attack causes reduction in photosynthetic activity and defoliation of leaves thereby reducing the vitality of the host plant, Sooty Mould(Meliolamangiferae) is common in the orchards where mealy bug, scale insects and hoppers are not controlled efficiently. Diplodia Stem-end Rot (Lasiodiplodiatheobromae)-The fungus enters through mechanically injured areas on the stem or skin. The fungus grows from the pedicel into a circular black lesion around the pedicel[22][23].

IV. NON-DESTRUCTIVE METHODS

There are a number of non-destructive techniques available like X-ray or X-ray CT, NIRS, sonic / ultrasonic, MRI / NMR, etc. for post-harvest defect detection in fruits.

X-RAY

The X-ray or X-ray CT technique uses X-ray source and detectors like photographic plate, X-ray film in a cassette, rare earth screens, photo stimulable phosphors (PSPs) computed radiography or digital radiography, semiconductor. The advantages of this method are convenience, accurate, available as a portable x-ray unit, and is less costly, simple and more reliable than MRI. This method also has certain disadvantages like it requires good image segmentation, more image sample files required, in turn more exposure to harmful X-rays and more work needs to be performed to increase recognition percentage.

NIR IMAGING

The required apparatus for NIRS method are light source, detector (sensor or camera) and wavelength selector. The advantages of this method are its simple working, high resolution, accurate picture, gives quantitative information and further separate sample preparation is not necessary and several constituents of the defects are measured concurrently. Near-infrared imaging techniques (NIR) have effective potentials for identifying and detecting bruises since bruises result in the rupture of internal cell walls due to defects in Mangoes. The disadvantages of this method are that it is not suitable for all fruits and all parameters, expensive, estimation of best wavelength range is difficult, dependent on less-precise reference methods and equipment needs to be calibrated for each situation.

SONIC / ULTRASONIC METHOD

The apparatus required for sonic / ultrasonic method are ultrasound transducer and digital noise corrector. The advantages of this method are portable device, insensitive to fruit mass/size and rapid. This method has disadvantages like acoustic impedance for biological tissues very difficult to determine, theoretically difficult task due to multiple scattering and strong attenuation and not suitable for small and soft fruits.

MRI / NMR

MRI/NMR requires super-conducting magnet, surface coil and imaging coil coupled to a conveyor system. The advantages of the method are ability to image different regions and in any plane, very high level of detail, does not use ionizing radiation, good quality and clarity. The disadvantages of this method are costly than X-ray, NMR response many times not clear, very still object holding required, poses problems when constituents other than water present, machine makes tremendous noise and hardware causes alteration in main magnetic field[2].

Commercially available non-destructive techniques to detect defects in fruits in many countries are listed below [24-30]

Sl.No	Purpose	Type of fruit	Country	Technique
1.	Quality Evaluation	Apple, Pear, Korean Melon, Water Melon, Peach	Korea	NIR Spectroscopy
2.	Quality Evaluation	Apple	Japan and USA	NIR Spectroscopy
3.	Determine soluble solids and skin chlorophyll.	Apple, Peach	Japan	NIR reflected light
4.	Quality Evaluation	Kiwi	New Zealand	NIR Spectroscopy
5.	Determination of Sugar	Dates	Israel	NIR
6.	Top firmness tester	Apple & Pears	Israel	Acoustic Resonance
7.	Determining the starch and dry matter content of immature and mature mangoes[25]	Mango	USA	NIR Technology
8.	Quality Evaluation(sorter)	Pappaya & Avacoda	California	NMR
9.	Detect water core	Apples	Europe	MRI

V. IMAGE PROCESSING OF DIFFERENT FRUITS

In Kiwi fruit, bruises are not visible externally owing to the special physical properties of its peel and so the use of hyperspectral imaging technique to inspect the hidden bruises is adopted. The Vis/NIR (408–1117 nm) hyperspectral image data was collected and multiple optimal wavelength (682, 723, 744, 810,and 852 nm) images were obtained using principal component analysis on the high dimension spectral image data (wavelength range from 600 nm to 900 nm) to effectively detect these bruises [31]. Bennedsen and Peterson [32] developed a multispectral machine vision system for detecting surfaced effects on apples, and other researchers [33] developed a multispectral inspection system for detecting and sorting citrus fruits according to 11 types of external defects by combining the information obtained from four image acquisition systems that are sensitive to NIR, visible, UV and fluorescent images[34].

Investigate the potential of near–infrared (NIR) hyperspectral imaging for detecting bruises on apples in the spectral region between 900 nm and 1700 nm. An NIR hyperspectral imaging system was developed and a computer algorithm was created to detect both new and old bruises on apples[35]. Artificial vision techniques developed for the online estimation of olive quality and to assess the effectiveness of these techniques in evaluating quality based on detecting external defects. This method of classifying olives according to the presence of defects is based on an infrared(IR) vision system. Images of defects were acquired using a digital monochrome camera with band-pass filters on near-infrared(NIR)[36][37]. A nondestructive optical method for determining the internal quality of intact Kiwi fruit was investigated. The method, based upon near-infrared spectrophotometric techniques, was found to be capable of predicting the fructose content (**r** = 0.96, **SEC** = 1.96%), glucose content (**r** = 0.97, **SEC** = 1.68%), soluble solids content (**r** = 0.99, **SEC** = 0.78"Brix), and dry weight (**r** = 0.97,**SEC** = 0.61%) of kiwifruit[38].

An on-line method for detection and removal of infested fruit would thus benefit producers and consumers. An algorithm has been developed to identify spots generated in hyper-spectral images of mangoes infested with fruit fly larvae[39]. A method to sort Jonagold apples based on the presence of defects was proposed. A multi-spectral vision system including four wavelength bands in the visible/NIR range was

developed. Multi-spectral images of sound and defective fruits were acquired tending to cover the whole colour variability of this bicolor apple variety[40]. The maturity index and percentage of defects in olives were objectively assessed on-line by image analysis obtained through machine vision, in which algorithms of color-based segmentation, as well as the main operators to detect edges were used[41].

Near-infrared imaging techniques have effective potentials for identifying and detecting bruises since bruises result in the rupture of internal cell walls due to defects by agricultural materials. In this study, a novel NIR technique, hyperspectral imaging with beyond NIR range of 950–1650 nm, was investigated for detecting bruise damages underneath the pear skin[42]. A non-destructive X-ray inspection method has been developed to detect weevil-infested fruits. X-ray radiographs of infested mangoes show dark areas in the seed corresponding to disintegrated kernel tissue as a consequence of feeding by developing grubs[43]. The effect of season, shelf-life and accuracy of near infrared calibration models for the soluble solids content and firmness of apple was studied based on a large spectral data set based on approximately 6,000 apple fruit from different regions, origins, shelf-life exposure time and seasons[44]. Estimation of the chemical and physical characteristics of one apple cultivar and reduces the number of required wavelengths for prediction using Sparse regression methods-Lasso, elastic-net and fused lasso[45]. Application of NIR spectroscopy like SSC, texture, dry matter, acidity or disorders of fruit and vegetables have been reported[46].

A number of promising technologies exist for non-destructive assessment of mango maturity. Future research topics are proposed, with a focus on the mango cultivars that are currently marketed in the USA (e.g., Ataulfo, Haden, Keitt, Kent, and Tommy Atkins), to address needs for the development of nondestructive methods for objective assessment of maturity in mango[30].

VI. CONCLUSION

In this paper, Mangoes, with all kinds of defects such as, diseases physiological disorders and damage due to pests are discussed and defect detection in some fruits using non-intrusive method has been presented. Some of the challenges and the opportunities existing in this area are highlighted. Especially in the area of image processing and pattern recognition, various gaps and the need to fill those gaps have been identified thus leading to many interesting topics for research. The authors strongly feel that the NIR imaging techniques may be one potential area which can be applied to internal defect tracking in Mangoes thus helping with the export of the same for India.

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