Potential of reflected UV imaging technique for detection of defects on the surface area of mango

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Revised: 30 December 2018 / Accepted: 18 January 2019 / Published online: 7 February 2019
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Abstract Surface defects such as mechanical damage, black lesion, latex stains and shriveling of mango fruit are very common and responsible for lowering of market prices as well as postharvest losses. Current research, thus, focused on the study of reflected ultraviolet imaging (UV) technique, its potential of detecting defected mangoes and to develop a computer vision system which could find the reflected area on injured or defected mango's surface. The visual visualization of the bruised areas was noticed different when viewed under 15 W fluorescent UV tube (100–400 nm) light by UV camera. Hidden defects on fruit's surface detected just after the image acquisition by UV camera and brightness enhancement. Defected or injured surface of mangoes recognized easily by reflected UV imaging at 400 nm band-pass filter. The seriousness of injuries which were not detected by RGB color camera, detected by reflected UV imaging technique exactly.

Keywords Ultraviolet · Reflected imaging · Non-destructive · Mango defects · Computer vision

Introduction

Mango (*Mangifera indica* L.) is an oldest, tropical, attractive and the most popular climacteric fruit of India. Mango is very nutritious and rich in carotenes and is considered as the king of fruits of India (Jha et al. 2010). Cultivation of mango in Indian subcontinent is recorded for well over 4000 years. Mango is native to Southern Asia, especially Burma and Eastern India (Jagtiani et al. 1988). Later on, mango spread to the outside of India, especially to Africa, Brazil, Caribbean and Central America, during 632–645 AD. India is producing more than thousand mango varieties and its share is about 50% in total world's production (Jha et al. 2010).

Though India is the world's largest producer of mango fruit, but surprisingly, it accounts for less than one percent of the global trade because of lack of rapid, non-destructive and precision sorting methods for quality and safety assurance. Defects such as mechanical damage, black lesion, latex stain, shriveling, etc. are responsible for the lowering of market prices. Major pre-and-post-harvest disease of mango, among them, is anthracnose (black lesion) caused by fungus *Colletotrichum gloeosporioides* (Arauz 2000). Mango latex, in contrast, is a transparent, viscous and clear or slightly milky fluid which causes undesirable skin blemish or burn. Mechanical damage defined as plastic deformation, superficial rupture and tissue destruction due to external forces, however, is more common during fruit handling (Sanches et al. 2008). Physical impact is of the most common cause of mechanical damage. According to Garcia et al. (1988) fruits and vegetables are more exposed to impact and vibration than to compression forces during packing. Impacts are transitory movements caused by sudden acceleration or deceleration causing great dissipation of energy and consequent

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s13197-019-03597-w>) contains supplementary material, which is available to authorized users.

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damage to the fruit (Vigneault et al. 2002). Thus, to minimize the losses and to satisfy the increased awareness, sophistication and greater expectation of consumers, it is necessary to improve the sorting and grading technique of mango (Patel et al. 2012b).

Several non-destructive defect detection techniques have now been emerged potentially in the field of agriculture. Computer vision system (CVS) among them being an objective, consistent, quantitative, rapid, real-time, non-contact and non-invasive quality evaluation tool has attracted much research and development attention (Patel et al. 2012a). Camera among the five basic components (illumination, a camera, an image capture board (frame grabber or digitizer), computer hardware and software) of CVS has very crucial role in defect detection of agricultural produce.

Moreover, this technology also opens up the possibility of studying mangoes in electromagnetic spectrum in which the human eye is not sensitive. According to researchers UV imaging could be as important in investigating of hidden injuries for agricultural produce as in forensic. UV radiation has a shorter wavelength and higher energy than visible light. Scientists classify UV radiation into three bands—UVA (320–400 nm), UVB (290–320 nm), and UVC (100–290 nm). Standard optical glasses absorb light and cannot be used for imaging in the region below 290 nm while UVB scattered more than the UVA and visible light. In reflected-UV imaging; UV illumination reflects off a scene and is recorded by a UV sensitive camera while in UV fluorescence imaging; UV illumination stimulates fluorescence at a longer wavelength than the UV excitation source. The resulting fluorescence is typically in the visible band (Richards 2010).

In this context, few research on the UV camera based CVS has also been carried by the researchers. For instance, Nagle et al. (2012) have built a simple CVS for detection of anthracnose infection and latex stain by using a low-cost webcam under UV-A illumination. Ozluoyamak (2014) developed a system for detection and separation of aflatoxin contaminated dried fig at 365 nm illumination. Similarly, freeze-damaged oranges were also detected using ultraviolet (UV) fluorescence method by Slaughter et al. (2008) at 365 nm. Various defects on inside surface of the fruits and vegetables which can't be recognized by so-called available conventional systems (Kleynen and Destain 2004), thus, can be identified by reflected UV imaging technique. But, the main drawback in the developing of UV camera-based CVS is the lack of knowledge of power of reflected-UV imaging to reveal hidden defects of agricultural produce (Patel et al. 2012b). Except some studies on UV fluorescence imaging, research on reflected UV imaging is still lagging. Considering the above facts, main aim of this research was to develop an algorithm

which could detect the defected/injured area on the surface of mangoes.

The first aim of present work is to find its ability of illumination and camera setup which can work efficiently to capture the reflected UV image and to study the potential how this detected the defected/injured surface area of mango which lessens the market value and shelf life.

Materials and methods

For the current research, Chausa variety mangoes, ovate to oval oblique and light yellow, grown in Bihar and Uttar Pradesh state of India selected owing to peel color more suitable for the image processing. The 60 fruits (fresh ripe and with different defects and blemishes/injuries) procured from each state in the spring. Thus collected, 60 fruits - brought to the laboratory and stored in a cold room maintained at 20 °C, 95% RH, during the experimentation period.

Image acquisition system

An imaging system fabricated in Division of Post Harvest Technology in Indian Agricultural Research Institute, New Delhi (India), was used for nondestructive quality analysis of mangoes (Fig. S1). The system mainly consists of an illumination chamber, image acquisition system (different lighting arrangements and camera setup), frame grabber, image processing and analysis software/hardware.

Black painted chamber fabricated from iron sheet was used to protect the objects from the natural (or external) light and to give diffuse illumination over the fruit's surface with the aim of avoiding highlights and light reflections. As the image processing technique is very sensitive to illumination, the constant environment condition is very important to achieve a robust performance of the algorithm. Lighting of the inside of illumination chamber controlled with the nine fluorescent bulbs (50 W, 220 V) fitted in a cylindrical lighting system. The illumination angle was maintained at 45° to achieve uniform illumination. In addition to visible lighting arrangement, the illumination chamber has also been equipped with four 15 W fluorescent UV tube (100–400 nm). Although, before capturing of the fruit's images using UV camera in UV light, it assured that visible lighting system (cylindrical) was off and taken it outside and vice versa.

The UV camera (XC-EU50/60; Sony, Japan) with resolution (768 × 494 pixels) placed at the top of the illumination chamber manually at about 200 mm from the top of the fruit. However, the distance between UV camera and bottom of the chamber was 60 cm. The camera fastened at the camera stand and then acquired the images of manually

placed mangoes on the sample holding platform. Similarly, for color image capturing, UV camera was removed from the camera stand, switched off the UV light and switched on the cylindrical lighting system after fitting it inside the chamber. Now, visible RGB color (u Eye) camera (U1-1225LE-C-HQ; Imaging Development System, Germany) with resolution (752×480 pixels) was used and acquired the images. All thus acquired UV and color images were stored in computer hardware memory in BMP form.

These cameras were connected through Gigabit Ethernet port on the PC via Cat5e Ethernet cable and FALCON/EAGLE Frame Grabber (Falcon PCI board). Industrial computer (PC type) and IMAQ Vision software (version 10.0) were used for image processing and analysis.

Image acquisition and processing for defect detection

First, fruit is illuminated in chamber and then, its six images, in different postures (four by rotating 90° , one each from top and bottom), were captured using UV and visible camera setups one by one. Thus acquired 720 images from each camera setup were stored into the computer for further processing. The defected surface area of fruits detected using the reflected UV imaging techniques just after the image acquisition and brightness enhancement. Five band pass filters of 200 nm, 250 nm, 300 nm, 350 nm and 400 nm wavelengths were tested for the defect detection. The results, thus, obtained have been discussed below:-

Results and discussion

The band-pass filter of 400 nm wavelengths was found more suitable to detect the defected or ruptured tissues of mangoes. It might be due to the high photographic value of UV-A band and since, the reflected UV photography well performed over 360 nm (Cosentino 2015). Similar results were also reported by Nagle et al. (2012) working with mango fruit.

Detection of mechanically injured fruit

Figure 1a shows an example of target fruit presenting non-detectable defects with the standard RGB color camera but well detectable with the new proposed reflected UV imaging method. The target fruit has injuries at four locations because of impact/vibration/or compression during harvest, transportation, packing, etc. These locations are presented as 'a₁', 'b₁', 'c₁', and 'd₁' in the color image while in UV image these are shown as 'a₂', 'b₂', 'c₂', and 'd₂'. The visualization of mechanical injuries in reflected UV image is much distinct and clear than in the color

image. In UV image, injuries were found darker, rough and upside down (i.e. open disk) in their surface topology. The injury at 'b₁' location in colour image is unidentified by colour camera. UV camera, in contrast, revealed that the defect at relevant region 'b₂' is very serious and looks like as a burnt paper in reflected UV image. Such type of visualization might be due to injury just below the peel by impact possibly having rupture of internal tissues. Traditional visual inspection and color camera based computer vision system (CVS) often missed such injuries which later on may have caused the exposure of the acid content to oxygen, accelerating degradation. The effects of impacts usually do not cause serious external symptoms immediately observable but their effect causes internal injuries (Moretti et al. 1998).

Detection of black lesion and stem-end rot

Black spots d₁ and d₂ (in Fig. 1a) are the visualization of black lesion on mango fruit's surface in color and UV image, respectively. The actual defected area noticed by reflected UV imaging was seen larger than the area detected by colour camera. As the disease severity can be defined either by size (diameter) (Smoot and Segall 1963) or by number of spots (Koomen and Jeffries 1993). The information of correct diameter of defected area is very useful during the sorting of mangoes into different classes/grades (such as fresh, minor and major defected). Thus, the observation of such type of defect can be enhanced by reflected UV imaging.

Similarly, Fig. 1b shows the color (RGB) image of fruit with multiple defects having severe anthracnose (black lesion) and its corresponding visualization in the reflected UV image. Furthermore, the visualization of stem-end rot by colour imaging (d₁) and reflected UV imaging (d₂) is presented in Fig. 1d. The reflected UV images in Fig. 1c, d revealed that the visualization of severely defected fruits is very dark might be due to the pathogen which produced melanized appressorium. The appressoria of certain pathogenic fungi appears darkly pigmented due to a discrete cell wall layer of melanin (Howard and Ferrari 1990) absorbs UV light strongly. In addition, the UV light tends to be absorbed strongly by many organic materials and makes possible to visualize the surface topology of an object without the light penetrating into the interior parts (Richards 2010). Unlike the area with dry anthracnose, the visualization of wet anthracnose was darker.

The observation of defected and fresh area by the reflected UV technique was very different and distinct in terms of surface topology, darkness/pixel intensity and inconsistencies. Severely defected fruits, thus, can be recognized easily from the piled mangoes on the basis of these observations. As UV lights have a short wavelength,

Fig. 1 Visualization of mechanical damage (a), fungal stricken with anthracnose and dehydrated area (b), severe anthracnose (c) and severe stem-end-rots (d) on the surface of mangoes in color and reflected-UV image

smaller inconsistencies and rough surfaces can be identified. This finding is almost an agreement to the UV light principle reported by Richards (2010) working with forensic application.

Detection of shriveled fruit and latex stain

Visualization of the textures of dehydrated area of fruit in the reflected UV image (Fig. 1b) was seen alternatively bright and dark might be due to the fruit's salt

accumulation and dried tissues/cells/flesh. As the inorganic matter like salt causes reflection and standout as bright, simultaneously, the UV light is highly absorbed by many commonly encountered organic materials appears as dark. In addition, the wrinkles/inconsistencies on the shrivelled area in the UV image found were more clear and distinct than in the colour image (Fig. 2a).

In contrast, visualization of fungus on the fruit surface (Fig. 1b) was also seen brighter. This observation was might be due to the strong reflection of UV light from the fungal stricken area. The brightness of the fungal stricken area noticed more than shrivelled fruits in reflected UV image. Similar results have also been reported by Slaughter et al. (2008) for citrus fruit when viewed under long wave UV light.

Furthermore, the UV camera was found to be enough and capable for collecting image information required for

the detection and evaluation of the latex stains. The latex stains were easily detected and overlooked under UV-A (400 nm) illumination (Fig. 2b). Colour images and their corresponding reflected UV images are shown in the Fig. 2b. The visualization of latex stains on fruit surface is dark in reflected UV images might be due to the absorption of UV light by terpinolene like organic element in mango sap. As the primary cause of mango sap burn is entry of volatile components of the sap such as terpinolene through the lenticels, resulting in tissue damage and subsequent enzymatic browning. Similar findings have also been given by Nagle et al. (2012).

Visualization of fresh fruit

Visual appearance of fresh fruit's image (Sr. No. 9, Table 1) acquired by the UV camera was a light dark in

Fig. 2 Visualization of shriveled mango fruit (a) and latex stains on fruit's surface (b) in color and reflected-UV image

(a) Shriveled mangoes (UV, color and cut away) image

(b) Latex stains on fruit's surface in color and UV image

Table 1 Various defects and their visualization in UV and color images

S. No.	Bruise /objects type	Visualization	Image acquired by colour (RGB) and UV camera
1.	Latex stain on surface	Dark spot
2.	Dry tissues beneath the peel surrounding the defects	Bright
3.	Fungal area	Brighter
4.	Scratch on surface	Dark as adjacent area
5.	Anthrachnose (black lesion)	Dark surface with bowl shape topology and rough surface
6.	Partially dehydrated whole mango (Shriveled)	Bright and dark sign
7.	Bruised mango	Deep dark, rough surface and upside down topology
8.	Crack or cut on surface or beneath the peel of fruit	Dark and wider cracks
9.	Fresh mango surface	Light dark smooth surface
10.	White or black background	Brighter or darker background	

color and free from inconsistencies, upside down topology, absurdness, etc. might be due to the absorbance without diffusion of UV light by the biological tissues. Further, various defects and their visualization in UV and color image have also been summarized and presented in Table 1. Latex stain on surface (Sr. No. 1), dry tissues beneath the peel (Sr. No. 2), fungal stricken area (Sr. No. 3), partially dehydrated/shriveled fruit (Sr. No. 6) and rupture in tissues beneath the peel (Sr. No. 8) are easily detectable while the detection of anthracnose and bruised mangoes can be enhanced by reflected UV imaging technique in terms of actual defected area and its seriousness inside the fruit (Table 1). But, the application of reflected UV imaging was inefficient to detect the scratches/bruises (Sr. No. 4, Table 1) on the surface. Only severe/old (in days) scratches on mango fruit could be detected by the proposed technique (Nagle et al. 2012).

Need of further research

As in this research the potential of reflected UV imaging technique was studied for defects detection just after image

acquisition and brightness enhancement. Investigation on segmentation of defected area and algorithm development is still required. Thus, to achieve this goal, the image processing for segmentation will be repeated and an algorithm will be developed for real-time inspection of mangoes and successively the UV camera based CVS will be developed.

Conclusion

Potential of UV imaging technique, for the recognition of hidden defects/ruptured tissues, etc. just below the peel of mangoes, has been confirmed by this research. The distinction between RGB colour and reflected UV imaging is very clear. An image acquisition system was designed and evaluated for acquiring reflected UV images for online mango fruit inspection. Algorithm, thus, for defect segmentation can be developed and CVS could combine with a UV camera and a software algorithm to detect injuries as minuscule in a surface. Since UV technology is still an emerging area of research in the agriculture sector. Current study could be the basis of future research and for the developing of automated UV camera based image processing techniques and electronic eye.

Acknowledgements This work was supported by the National Agricultural Innovation Project, Indian Council of Agricultural Research through its subproject entitled “Development of non-destructive system for evaluation of microbial and physico-chemical quality parameters of mango” (C1030).

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