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Research Application Summary

Application of X-ray micro-computed tomography to detect bruise damage of pomegranate (cv. Wonderful) fruit

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Abstract

The key to extending the storage life and maintaining the quality of fresh fruit could rely on early detection and separation of fruit with mechanical damage such as bruising. A non-destructive technique was developed to detect bruise damage in bruised pomegranate fruit using a commercial X-ray micro-computed tomography (X-ray µCT) system. Pomegranate fruit harvested at commercial maturity were dropped from 100 cm onto a flat ceramic surface to simulate poor postharvest handling technique. Image acquisition with X-ray µCT was performed at 0 h (immediately after drop impact), 48 h and 7 days (d) after impact bruising. Non-dropped pomegranate fruit were scanned as control to allow for a good comparison of results. The X-ray radiation from the source operated at 245 kV voltage and 200 mA electron current produced optimal µCT and was used to generate two-dimensional (2D) radioscopic images, which were reconstructed into three-dimensional (3D) images for the detection of bruise damage. Two-dimensional images of X-ray µCT of pomegranate fruit scanned at 0 h and 48 h after impact bruising showed no evidence of bruise damage. Bruise damage manifestation was visualised by X-ray µCT after 7 d of impact bruising. Overall, application of X-ray µCT was not successful in detecting bruise damage of pomegranate fruit at early stage (immediately or 48 h after impact bruising).

Keywords: Bruising, drop impact, images, image analysis, pomegranate fruit, X-ray micro computed tomography

Résumé

La clé pour prolonger la durée de conservation et maintenir la qualité des fruits frais pourrait reposer sur la détection précoce et la séparation des fruits présentant des dommages mécaniques tels que des ecchymoses. Une technique non destructive a été mise au point pour détecter les dommages causés par les ecchymoses dans les fruits de grenade meurtries à l'aide d'un système commercial de tomographie micro-informatique aux rayons X (rayons X µCT). Les fruits de grenade récoltés à maturité commerciale ont été déposés de 100 cm sur une surface plate en céramique pour simuler une mauvaise technique de manipulation après récolte. L'acquisition d'images par rayons X µCT a été réalisée à 0 h (immédiatement après l'impact de la goutte), 48 h et 7 jours (d) après l'impact des ecchymoses. Les fruits de grenade non lâchés ont été scannés comme témoins pour permettre une bonne comparaison des résultats. Le rayonnement X de la source qui fonctionnait à une tension de 245 kV et à un courant d'électrons de 200 mA a produit un µCT optimal et a été utilisé pour générer des images radioscopiques bidimensionnelles (2D), qui ont été reconstruites en images tridimensionnelles (3D) pour la détection de des ecchymoses. Des images bidimensionnelles de rayons X µCT de fruits de grenade scannés à 0 h et 48 h après l''impact des ecchymoses n'ont montré aucun signe de dommage par ecchymose. La manifestation de dommages de ecchymoses a été visualisée par rayons X µCT après 7 jours d'impact d'ecchymoses. Dans l'ensemble, l'application de rayons X µCT n'a pas réussi à détecter les dommages causés par les ecchymoses sur les fruits de la grenade à un stade précoce (immédiatement ou 48 h après les ecchymoses).

Mots clés: Ecchymoses, impact de chute, images, analyse d'images, fruits de grenade, tomodensitométrie à rayons X

Background

Pomegranate (*Punica granatum* L) fruit undergoes several postharvest operations throughout the cold chain; ranging from harvest, sorting, packaging, storage and transportation. As a result of increasing use of mechanised operations at harvest and during postharvest handling, minor mechanical damages on fruits have become a very important problem to detect (Ergun, 2017). Preharvest factors, harvesting and postharvest handling operations predispose fruit to varying levels of dynamic forces that eventually lead to mechanical damage (Hussein *et al.,* 2018). Bruising is the most common type of mechanical damage resulting from such forces (Opara and Pathare, 2014). Bruise damage is caused by failure of subcutaneous cells when the loading pressure exceeds the failure stress of the fruit tissue (Diels *et al.,* 2017).

Bruise damage is not always immediately visible after its occurrence, at least for most of the affected fruit (Van Linden *et al.,* 2006). Unlike other types of fruit such as apples, tomatoes and banana, the presence of bruising on pomegranates is hardly detectable by flattening or softening. The peel surface of bruised fruit may or may not be characterized by discoloration resulting from enzymatic reactions of polyphenol oxidase enzyme. Hence, since the damage on fruit is not apparent until a later stage in the handling chain, bruised fruit are easily overlooked and usually neglected during manual sorting and grading (Ergun, 2017). Consequently, symptoms of internal bruise damage become severe and potentially hasten quality deterioration of affected fruit over time, leading to serious postharvest losses (Brosnan and Sun, 2004). Detection of bruise damage on fresh fruit is thus critical both to researchers and to the industry personnel in quest for developing procedures to reduce consequent postharvest losses (Samim and Banks, 1993).

The key to extending the storage life and maintain quality of fresh fruit could rely in early detection and separation of fruit affected by bruise damage and other quality defects. Application of accurate and cost-effective non-destructive assessment methods for field and laboratory measurement as well as in-line sorting and grading could be a viable option. X-ray micro-computed tomography (X-ray µCT) is one the non-invasive techniques that have been explored to detect several kinds of internal defects in agricultural produce. Diels *et al*. (2017) successfully applied X-ray computed tomography to detect and quantify the bruise damage of different apples cultivars at a range of impact levels. Herremans *et al.* (2013) investigated the microstructural changes *in vivo* during development of internal flesh browning of 'Braeburn' apples by means of X-ray micro-tomography and classified fruit tissue as healthy and disordered. Little is known about the potential of X-ray µCT to detect and classify bruises on fruit with thick and hard rind such as pomegranates (Arendse *et al.,* 2017). The aim of this study was to evaluate the feasibility of X-ray µCT in detection and characterization of bruise damage on pomegranate fruit.

Study description

Pomegranate fruits (cv. Wonderful) were handpicked at commercial maturity from an orchard in the Western Cape Province, South Africa. Fruit sorting was performed to ensure that only sound and healthy fruit were used (free from cracks, sunburn, husk scald or internal decay). Individual fruit were subjected to impact by letting them to fall from 100-cm height onto a flat ceramic surface. All drop tests ensured that fruit hit the impact surface only once on each of the two opposite cheek positions along the fruit's equatorial region. Image acquisition of bruised and non-bruised (control) fruit was performed at 0 h (immediately), 48 h and 7-days after drop impacts (after incubation at 21 ± 3^0C and 86 ± 5 % relative humidity). A commercial X-ray micro computed tomography (X-ray µCT) system (V|Tome|XL240, General Electric Sensing and Inspection Technologies GmbH, Phoenix, Wun-storf, Germany) located at the Central Analytical Facility (CAF) of Stellenbosch University , South Africa, was used to obtain the CT images. Scanning was performed for each individual pomegranate fruit (bruised or non-bruised) mounted on a translation stage at a fixed physical distance of 210 mm from the X-ray source (245 kV voltage and 200 mA electron current) and 600 mm from the detector, with a scanning resolution of 70 microns. Image slices were acquired using a fully automated data acquisition system and saved onto a processing workstation, operated by system-supplied reconstruction software (Datos|x®2.1, General Electric Sensing and Inspection Technologies GmbH, Phoenix, Wunstorf, Germany). X-ray µCT image processing and analysis was performed using volume graphics software (VG Studio Max 2.2 software, Heidelberg, Germany). Image processing and analysis was done independently for only one of the two opposite bruise damaged sides of each fruit using similar procedures (Image processing and analysis procedures not shown).

Results

Two-dimensional X-ray µCT images of fruit scanned at 0 h (immediately) and 48 h after impact bruising showed no clear evidence of bruise damage (Figure 1a and b). However, changes in bruise-damaged tissue characterised by a darker appearance were observed in pomegranate fruit scanned after 7 days of impact bruising. Bruise damage in the impact region of the fruit was evidenced by the presence of darker region, which was distinguishable from the rest part of non-bruised fruit characterised by a brighter appearance (Figure 1c).

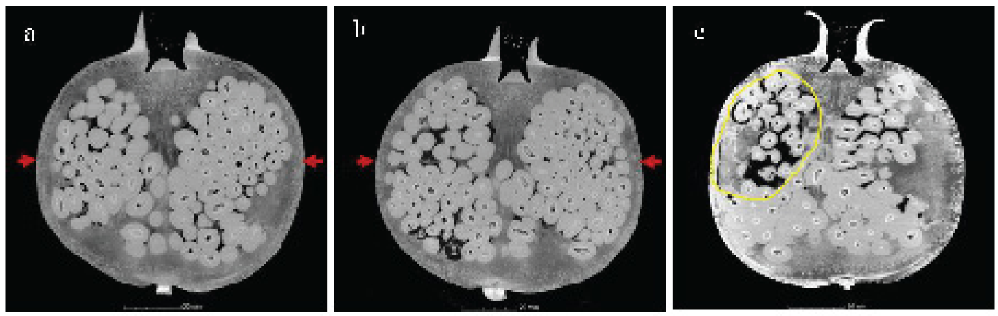

Figure 1. Two-dimensional X-ray micro computed tomography images for a single pomegranate (Cv. Wonderful) (a) 0 h (immediately) after bruising (b) 48 h after bruising (c) 7 days after bruising - bruised area identified (circled) based on visual appearance on the impact region. Arrows point the direction of drop impact.

Discussion

In principle, visualization and characterization of internal structures within the biological material rely upon the ability of X-ray CT to differentiate between structures with different densities (Lembe and Opara, 2014). The dearth of evidence for the presence of bruise damage on 2D μCT images of pomegranate fruit scanned at 0 h (immediately) and 48 h after impact bruising could be due to lack of density change in bruise-damaged tissue. It has been established that the μCT images of fruit are characterised by the grey level of a pixel that depends on the density of the sample (Jiang *et al.,* 2015), such that the lack of differences in density within the biological sample result in no changes in X-ray attenuation. We presume that the physical changes which occurred within the bruise-damaged tissue in 0 – 48 h after drop impact were not sufficient to affect the X-ray absorption of the fruit tissue.

The evidence of bruise damage was observed in fruit scanned after 7 d of impact bruising (Figure 2a-c). Two-dimensional μCT image slices showed that non-bruised region of the fruit was characterised by high levels of X-ray attenuation (brighter region) corresponding to high density of non-damaged tissues. In contrast, bruise-damaged regions were typically darker, which could be attributed to lower absorption of X-ray radiations, similar to that of voids (air space). Hence, on the basis of changes in structural component within the fruit, bruised or non-bruised tissues were distinguished by the X-ray absorption of the respective tissues, with the brighter (higher intensity) and darker (lower intensity) regions corresponding to non-bruised and bruise-damaged part of the fruit, respectively. It can be hypothesized that bruise damage due to drop impact lead to the development of more voids and cracks that are characteristically lower in density and X-ray absorption. In addition, higher moisture loss from the bruise-damaged tissue in the period between bruising and scanning of fruit could have led to lower X-ray absorption in comparison to non-bruised tissue of fruit (Herremans *et al.,* 2013).

These results are in agreement with the observation of Diels *et al.* (2017) who concluded that the time interval between bruising and scanning was significant in quantifying bruises in apple fruit cultivars by means of X-ray CT. According to the authors, time lapse allowed for sufficient fluid displacement from the bruise to its surrounding tissue.

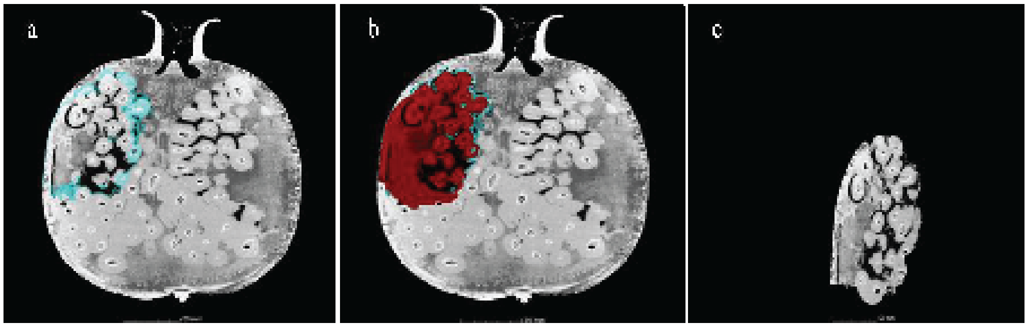

Figure 2. Two-dimensional X-ray micro computed tomography images for a single pomegranate (Cv. Wonderful) fruit after 7 d of impact bruising at different stages of image analysis. A raw representative X-ray image slice of a bruised fruit, background (external air and styrofoam) removed; (a) bruised area selected and manually segmented slice by slice based on its region of interested (ROI) using the drawing tool (b) area colour-coded (red) and (c) bruised region extracted using surface determination.

Conclusion

This study has shown that the potential of X-ray CT for inline application to detect bruise damage of fruit with hard rind such as pomegranate is limited by its inability to detect bruises at early stages of development (young bruises). Hence, improvement of X-ray CT to develop algorithms that could exploit the properties of fruit with hard rind to detect and segment the bruises is a crucial requirement. In addition, the need for future studies to explore alternative non-invasive techniques such as hyperspectral imaging system for detection of young bruises on fruit with hard rind such as pomegranate is of utmost importance.

Acknowledgements

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