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Research Paper

Analyzing the pear bruised volume after static loading by Magnetic Resonance Imaging (MRI)

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ABSTRACT

"Dar Gazi" variety of Pear fruit is very sensitive to bruising from mechanical impact and compression. At this study Pear (*Pyrus communis* L.) fruits were loaded in a perpendicular direction to their longitudinal axis. Samples were placed between two solid steel plates and loaded at a constant deformation rate of 0.167 mm/s under five different levels of compressive forces of 40, 50, 60, 70 and 80 N (Loading-Unloading tests), and then kept in cold storage. Propagation of internal bruised volume of fruits was determined by the nondestructive method of Magnetic Resonance Imaging and image processing techniques at different time intervals after loading. This study was carried out based on T_2 type images (based on spin–spin relaxation times) with specifications of Spin-Echo (SE) pulse sequence, echo time (TE): 102 ms, repetition time (TR): 4930 ms, slice thickness: 3 mm, slice-to-slice distance (slice gap): 0.3 mm (center to center), Matrix Size (MS): 288*448, Field of View (FOV): 289*450 mm^2, pixel resolution: 1.003*1.003 mm and Number of Acquisition (NA) of 2. The time intervals between imaging were specified based on the expansion of observed bruised volume on the prior Images. Image processing was performed by ImageJ 1.48 software. To calculate the bruised volume of the pears, a three-dimensional image was modeled for each pear using 3D Viewer plugin. The results indicated the bruised volume expanded linearly against the increase of the applied force, but it expanded non-linearly by time. Indeed, it increased logarithmically for 26 days from loading and then its expansion almost stopped. The effect of force and time, both separately and simultaneously were significant on bruised volume. Also, it was concluded that the optimum time for consumption of the product and appearing the least damage is 12 days after loading/unloading or external impact during harvesting and storage.

1. Introduction

Making sensors is a very intense field of research in agricultural engineering. In recent years there have been attempts to develop non-destructive, non-invasive sensors for evaluation of the quality features of agricultural products (Zion et al., 1995). Since Nuclear Magnetic Resonance (NMR) is known as a tool for describing the physical properties of water in biological materials, Magnetic Resonance Imaging (MRI or NMR imaging) has specific advantages over the other non-destructive technologies. MRI can determine the changes in the internal texture of intact fruits during the whole period of storage and can describe the internal distribution of affected tissues with high resolution (Clark et al., 1998). MRI for fruits requires a quantitative approach. Quantitative MRI can be divided into two groups. The first involves applications which the extraction of morphological characteristics (e.g., volume and surface) is the main goal. In this case, the complete mechanism involved in the contrast is not required. On the other hand, there are applications that require an extensive understanding of mechanisms involved in changes in NMR parameters. This happens when the NMR relaxation time is used as a parameter for the quantification of water or fat content, or for the extraction of information related to changes in microstructure (Mariette et al., 2017). Image contrast in MRI is defined as the intensity difference between several types of tissues. In T_2 images, dark regions correspond to an area with restricted proton mobility and short T_2 values. Regions with high free water content depict high-intensity pixels and a long T_2 value (Lammertyn et al., 2003). Fruit bruising is one of the key factors limiting the mechanization and automation in harvesting, sorting, and transportation of soft fruits (Kabas, 2010). Bruising in fruit is the result of mechanical damages caused by compression or impact forces. Dark spots appearing near the bruised surface are typically due to the previous mechanical contacts of the products with other objects or fruits. The bruises develop in response to two subsequent processes in fruit tissue that take place at the cellular level: tissue disruption with cell wall failure and release of cytosolic components from cells, and enzymatic activities in the disturbed environment of the cells and tissues.

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Nomenclature

T_2	Spin–Spin relaxation time (ms)
V	Pear volume (cm^3)
ρ_t	True density (g/cm^3)
W	Weight of displaced water (g)
P	Water density (g/cm^3)
TE	Echo time (ms)
TR	Repetition time (ms)
MS	Matrix size (Pixel*Pixel)
FOV	Field of view (mm^2)
SE	Pulse sequence (−)
NA	Number of acquisition (−)

Force loading of round fruit can be static or dynamic (Johnson, 2005). A Cell's wall provides mechanical support for the cell and plays a role in its defense as well as fruit ripening. Individual cells receive energy from compression or impact force. This energy is partly redistributed in sound, rebound, regaining the cell structure and cell deformation. Cells respond to external forces based on the stage of ripening of the fruit. The response can be considered elastic when the cells retain their original structure upon removing the external force. At higher levels of stress, the cell wall responds by becoming plastic and as a result, this alters the original structure even after the force has been removed. Mechanical distortion occurs when the wall of the cell and membranes fail which results in the decomposition of cells (Pereira and Calbo, 2000). Bruise extent is usually described in terms of bruised volume. Bruised volume and product quality are intrinsically linked. (Blahovec et al., 1991; Kabas, 2010). Detecting and monitoring of the development of internal defects resultant from methods of storage is possible with MRI and can be monitored over time (Wang et al., 1998). In T_2 weighted images, bruises appear brighter than the normal firm tissues, due to the destruction of the cellular structure caused by bruising (Bowtell et al., 1990; McCarthy et al., 1995). Two non-destructive tomographic techniques, X-ray CT imaging and Magnetic Resonance Imaging (MRI), were applied to study the development of core breakdown disorder in "Conference' pears". Tomographic images of the disordered pears, which were stored for 10 months, were acquired with both techniques and compared with the physical slices. Both X-ray and MRI could differentiate between unaffected tissues, brown tissues, and cavities. It was concluded that the most appropriate method to analyze the core breakdown disorder during postharvest storage is using the MRI technique (Lammertyn et al., 2003). MRI was used for online inspection of fruits to address the suitability of MRI for freeze injury detection in oranges directly during distribution. Undamaged and damaged oranges were conveyed at 50 and 100 mm/s by a specially designed conveyor belt within a 4.7 T spectrometer obtaining fast low-angle shot images. An automatic segmentation algorithm was proposed that allowed the differentiation between undamaged and damaged oranges (Hernandez-Sanchez et al., 2004). MRI was also used as a non-destructive tool to monitor bruise expression over time in avocado fruits. This method was shown as an effective tool in detection of internal injuries in avocado fruits. The physical stress caused by the compression produced an increase in the content of free liquids, and it is indicated by the whitish (brighter) areas in T_2 weighted ^1H MRI images (Snaches et al., 2003; Mazhar et al., 2015). Five mathematical models were used to describe bruised volume in Ankara pears. The bruise volume was ascertained and confirmed with the use of image processing techniques. This allowed for the calculation of the bruised volume (Kabas, 2010).

The main objective of this study was to determine the correlation between bruised volume of 'Dar Gazi' pears across a period of time as well as imposed forces, by processing the MR images.

2. Material and methods

2.1. Selection of fruits

Fifty pear fruits from the variety of "Dar Gazi" have been picked from a farm. Volume (V) and True Density (ρ_t) of whole pears were determined. To ensure the safety of the fruit's tissue, a magnetic resonance image was taken from intact pears in the same range of density. 15 pears with healthy tissues were then selected. The pears were divided into five groups with three random pears per group. A range of five different forces of 40, 50, 60, 70 and 80 N was applied. Immediately after the loading-unloading test, samples were stored in a cold room under +2 °C and 85% humidity. The pears were stored in a wooden box in order to ensure no movement or rattling on pears (Fig. 1).

Fig 1. The wooden box used to keep pear fruit in the magnet during the imaging.

2.2. Physical properties

Volume (V): Was measured when each pear was submerged in a container full of water on a scale. The fruit was kept from touching the sides or bottom of the container by a thin, light rod connected to the stem of pear. The weight of displaced water divided by water density was considered as fruit volume (cm^3) (Mohsenin, 1986):

$$V = W/\rho \tag{1}$$

Where W is the weight of displaced water (g) and ρ, is as water density (1 g/cm^3).

True Density (ρ_t): It was determined for whole pears in terms of (g/cm^3) by the following formula:

$$\rho_t = M/V \tag{2}$$

Where M is the weight of each pear (g).

2.3. Loading–Unloading test

A Universal Testing Machine (UTM) – Santam model STM-5 – equipped with two flat plates was used to apply forces. The fruits were compressed individually between two plates at a constant deformation rate of 0.167 mm/s. The longitudinal axis of the fruits was kept parallel with the compression plates (Fig. 2). After reaching the desired force, the fruit was unloaded at the opposite deformation rate. For each level of forces, three replications were performed. All the loading-unloading tests were performed under usual laboratory conditions (temperature 20–23 °C).