BIOSYSTEMS ENGINEERING 147 (2016) 17–25

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Drop test of pear fruit: Experimental measurement and finite element modelling

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ARTICLE INFO

Article history:
Received 11 January 2016
Accepted 14 March 2016
Published online 23 April 2016

Keywords:
Pear fruit
Dropping test
Bruised area
Finite Element Method

Pear fruit has a soft tissue that must be protected against mechanical bruises. In this paper, the bruised area of pear fruit was determined by experimental dropping tests and then was predicted by the Finite Element Method (FEM). Three dropping heights (200, 500 and 1000 mm), two impact surfaces (steel and wood) and two fruit orientations (vertical and horizontal) were studied. In order to simulate the fruit in the ANSYS 14 software, volume, density and elasticity modulus of unripe, ripe and overripe fruits were determined experimentally using standard methods. The minimum bruised area was occurred for unripe pear falling on the wood surface at vertical orientation and 200 mm dropping height whereas the maximum value was obtained for overripe pear falling on the steel surface at horizontal orientation and 1000 mm dropping height. The minimum and maximum error for prediction of bruised area by finite element modelling was 0.00 and −60.50%, respectively.

1. Introduction

Mechanical impacts have been known for many years as a major factor causing post-harvest losses (Sitkei, 1987). Bruising results from processes that do not appear immediately, but they reduce the quality of fruit within a short period (Li, Li, & Liu, 2011). Impact areas become discoloured due to the release of enzymes from damaged cells (Gonzalez, 2009; Jiménez-Jiménez, Castro-García, Blanco-Roldán, Agüera-Vega, & Gil-Ribes, 2012, Jiménez-Jiménez et al., 2013; Li, Yang, & Liu, 2013; Opara & Pathare, 2014).

Mechanical damages are ocurred when the magnitude of exerted external forces exceeds a fruit breaking threshold and leads to the break-up of fruit tissues (Mohsenin, 1986). Dynamic loads are more effective at causing bruising than static loads (Azadbakht, Aghili, Asghari, & Kiapey, 2015) and predicting the injured surface, deformation and stress distribution of fruit has been an important issue in post-harvest studies of agricultural products (Celik, Rennie, & Akinci, 2011; Topakci et al., 2010; Van linden, De Ketelaere, Desmet, & De Baerdemaeker, 2006).

Different methods have been applied to study the amount of stress, bruise characteristics and stiffness of agricultural products (Dintwa, Van Zeebroeck, Ramon, & Tijskens, 2008; Jackson & Harker, 2000; Miranda, Pajares, & Guiberteau, 2008). Finite Element Method (FEM) is a numerical procedure that has been widely used for solving complex and extensive engineering problems. Chen and De Baerdemaeker (1993) studied the watermelon stiffness and pear stiffness was determined by Dewulf, Jancsók, Nicolai, De Roeck ,and

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http://dx.doi.org/10.1016/j.biosystemseng.2016.03.004
1537-5110/

Table 1 – Characteristics of material used for modelling.

Material		Area (mm^2)	Volume (ml)	Density (g ml^{-1})	Elasticity Module (MPa)	Element type
Pear fruit	Unripe	–	105.21	0.91	8.74	Solid 168 3D
	Ripe	–	117.11	0.97	6.46	Solid 168 3D
	Overripe	–	127.10	1.12	2.64	Solid 168 3D
Steel surface		62,500	–	7850.00	200,000	Solid 164
Wood surface		62,500	–	681.63	8890	Solid 164

Briassoulis (1999). The static simulation of fruits under load was investigated by Wu and Pitts (1999) who developed and confirmed the simulation of an apple cell. Nourain, Ying, Wang, Rao, and Yu (2005) estimated the firmness of melon, Lu, Srivastava, and Ababneh (2006) studied the stiffness of apple fruit, Lewis, Yoxall, Canty, and Romo (2007) researched on apple bruises, Li, Yang and Liu (2013) predicted mechanical injury in tomato under compression tests and Pieczywek and Zdunek (2014) modelled the mechanical behaviour of onion epidermis by FEM.

Dynamic tests and FEM simulations were carried out by Chen, De Baerdemaeker, and Bellon (1996) to analyse pineapple behaviour association with its stiffness. Lu and Abbott (1997) investigated the apple unstable responds to stimulating the fruit impacts, Kabas, Celik, Ozmerzi, and Akinci (2008) modelled the tomato drop test, Dintwa et al. (2008) analysed the dynamic impact on apple fruit, Celik et al. (2011) investigated on the deformation behaviour of apple fruit in dropping test, Petrů et al. (2012) studied the mechanical behaviour of jatropha under compression loading. These research papers showed thatFEM is an appropriate method for the calculation and prediction of some the properties and deformation behaviour of fruits and vegetables.

However, to date there has not been reported research modelling pear fruit in a dropping test. The objective of this research was to determine bruised area of pear fruit under different dropping conditions and modelling this by FEM for the prediction of bruise characteristics. FEM appears to offer a low-cost method for determining and predicting of pear bruise characteristics.

2. Material and methods

2.1. *Experimental tests*

About 50 pear fruits of Natanz variety, one of the most famous pear fruit in Iran, were selected in this study. There are many factors influencing the amount and severity of imposed injuries during harvest and post-harvest operations. These factors consist of dropping height, impact energy, contact surface and size and ripeness stage of fruits (Ahmadi, Ghassemzadeh, Sadeghi, Moghaddam, & Neshat, 2010; Zarifneshat et al., 2010). In this study different dropping conditions including fruit ripeness levels (unripe, ripe and overripe), several dropping heights (200, 500 and 1000 mm), various orientations (horizontal and vertical) and different contact surface materials (steel and wood) were considered and investigated in the experimental and modelling tests.

The samples were categorised into three groups as unripe, ripe and overripe fruits. The fruits were weighted using a digital balance (Model: AND-GF-6100, Bradford, MA, USA) with the accuracy of 0.01 g. Average volume of the categories was determined using the water displacement method (Mohsenin, 1986). Then fruit density for each category was calculated (Table 1).

The elasticity modulus of 9 pears was obtained using a universal test machine (Zwick Roell, Model: z0.5, Ulm, Germany) using a compression test. The test was performed by placing a 20 × 20 × 20 mm pieces of pear between the flat plates.

Three compression tests were carried for each ripeness category with loading speed of 20 mm min^{-1}. The average amount of elasticity modulus for unripe, ripe and overripe pear fruits has been presented in Table 1.

To conduct drop tests, the contact surfaces were put in a balance condition on the ground. Three horizontal lines were drawn on a vertical wall at distances of 200, 500 and 1000 mm from the surface and a fruit was dropped for each test condition. The experiments were conduct at a constant room temperature to reduce variable environmental effects (Abedi & Ahmadi, 2013; Boydas, Ozbek, & Kara, 2014). The bruised area was measured using an image processing algorithm in MATLAB 2010a Software (Mathworks Inc., Natick, MA, USA). Firstly, the bruised area was painted by black colour (Fig. 1) and then an image of the fruits was acquired by a camera. The

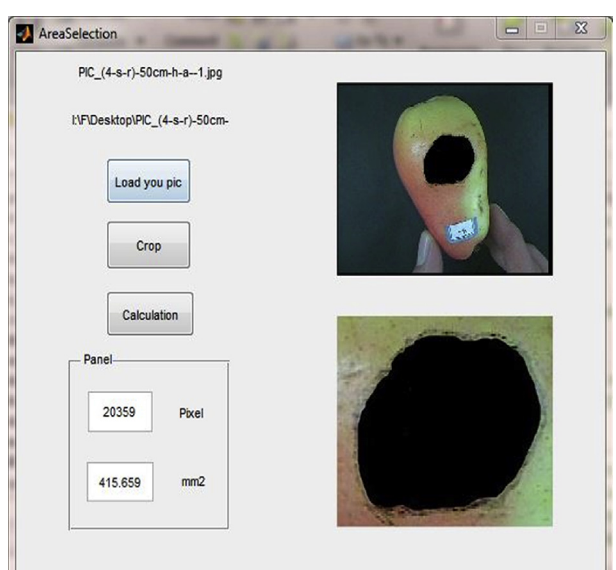

Fig. 1 – Determination of the bruised area.