Postharvest Biology and Technology 147 (2019) 100–106

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Impact characteristics of pears

Zbigniew Stropek*, Krzysztof Gołacki

Department of Mechanical Engineering and Automatic Control, University of Life Sciences in Lublin, Głęboka 28, 20-612 Lublin, Poland

ARTICLE INFO

Keywords:
Impact
Bruise
Pear
Restitution coefficient
Maximum stress
High speed camera

ABSTRACT

The effect of impact on two pear cultivars have been studied in terms of maximum force, impact time, maximum deformation, permanent deformation, restitution coefficient and maximum stress. The above mentioned characteristics were related to bruise sizes and the bruise initiation was determined for a given weight and firmness. Bruise initiation was described by the restitution coefficient. The stabilization of mean values of maximum stress at different drop heights confirmed that the pear damage occurred after specified stress values were exceeded. The rate of bruise development was dependent on the fruit firmness. Firmer pears were more resistant to impact and the bruise initiation occurred at a higher impact velocity.

1. Introduction

Mechanized postharvest operations such as sorting and grading require methods to describe responses of fruit and vegetables to impact, and to determine their bruise resistance with greater accuracy. The most common methods to determine impact loading conditions are drop tests (Yu et al., 2014; De Kleine and Karkee, 2015; Gancarz, 2016; Komarnicki et al., 2017; Surdilovic et al., 2018) and pendulum action, either by attaching a fruit to the pendulum (Opara et al., 2007; Polat et al., 2012), or by hitting fixed fruit with a pendulum tipped with a specific shape impactor (Van Zeebroeck et al., 2003; Stropek and Gołacki, 2016a; Zhu et al., 2016; Yao et al., 2017; Stropek and Gołacki, 2018). The main problem with these methods however, is that vibration makes it difficult to record accurately force and deformation during impact. Therefore high-speed cameras, which are not permanently fixed to the measuring stand construction, are more frequently applied in impact research (Lewis et al., 2007; Horabik et al., 2017; Wang et al., 2017; Liang et al., 2018).

Most of the measuring devices in the literature, which are used to determine the displacement in time, have a sensor permanently fixed to an experimental set-up.Sensor fixing in this manner results in mechanical vibrations, which originate from the measuring stand to be transferred to the sensor, due to the longitudinal oscillations of the pendulum arm during the impact. This kind of negative phenomena was reported by Bentini et al. (2005) who found that it was impossible to remove vibration effects in the sugar beet root and pendulum arm completely during the recording of the course of rebound from the steel rigid surface. Abedi and Ahmadi (2013) also identified errors while determining elastic and impact energies caused by friction at the pivot of the pendulum rod and energy losses due to rod vibrations during the rebound. Dintwa et al. (2008) found that energy losses during collision are associated with experimental infrastructure such as friction of the moving parts and vibrations of the apparatus. These factors can never be entirely eliminated and only limited through good experimental design. However, Van Zeebroeck et al. (2003) found that the anvil is rigid enough in this type of pendulum device to assume that its deflection or vibration is insignificant during impact. In an experimental device developed by Scheffler et al. (2018) the pendulum arm was rigid enough to minimize vibration.

The pendulum arm should be of possibly largest stiffness in the impact plane at lowest possible weight and moment of inertia, but it is difficult to meet these two requirements simultaneously. The moment of inertia of a fruit fixed to the end of the pendulum arm calculated along the pendulum rotation axis must be much bigger than that of the whole pendulum. Then the pendulum weight can have a negligible effect on the impact course recording. Unfortunately, to ensure appropriate pendulum stiffness, its weight has to be increased. The use of high speed camera, which is not permanently fixed to an experimental set-up, allowed to eliminate the effect of mechanical oscillations on the measurement of displacement-time and force-time courses during the impact and thus to determine them more precisely. However, pear fixing with a pair of fishing lines of very low mass minimized the effect of mass and moment of inertia of the pendulum.

The aim of this research was to determine the impact characteristics by describing maximum force, impact time, maximum deformation, permanent deformation, coefficient of restitution and maximum stress. Measurements of pear bruise sizes at different impact velocities were then made, and related to other parameters measured in the

---

* Corresponding author.
E-mail address: zbigniew.stropek@up.lublin.pl (Z. Stropek).

https://doi.org/10.1016/j.postharvbio.2018.09.015
Received 18 July 2018; Received in revised form 19 September 2018; Accepted 20 September 2018

experiment. The bruise initiation for a given weight and firmness of fruit was also determined.

2. Materials and methods

2.1. Material

The research was carried out using 'Lukasówka' and 'Xenia' pears that were stored at 4 °C for less than 2 weeks after their harvest. Before the measurements they were kept at room temperature for 24 h. Fruit were selected for weight between 215 to 225 g and maximum diameter of 70–75 mm to reduce the influence of weight and shape (curvature radius) on bruise size. Fruit were dropped from 3, 13, 29, 50, 80, 115 mm with the impact velocities of 0.25, 0.5, 0.75, 1, 1.25, 1.5 m s^{-1} respectively. Ten fruit were used at each impact velocity.

2.2. Flesh firmness

Flesh firmness was measured on pared fruit using a manual Magness-Taylor penetrometer (model FT 327, Facchini srl company, Italy) fitted an 8 mm diameter probe to an 8 mm depth. To ensure linearity of displacement and a constant slope angle of the head, the penetrometer was mounted on a universal drill stand. Fifteen fruit from each cultivar of the same weight and size as for the impact tests were used. Three replicate measurements were made for each pear at every 120° at the largest diameter. The accuracy was 1 N.

2.3. Measuring device

The pendulum principle was used in the measuring stand and a pear was the striking object. The pendulum was composed of a pair of supported fishing lines, each 1 m long to which a plastic plate with two tangs was attached. The pear was fastened to the pendulum by screws. This way of fruit fixing, its distance from the pendulum pivot as well as the pendulum mass caused that the moment of inertia of the pear calculated in relation to the pivot of the pendulum was much larger than the moment of inertia of pendulum elements contributing to the fruit motion. Therefore the effect of pendulum elements on the impact course can be negligible. The pear hit into the titanium plate which was screwed into the force sensor. In turn, the force sensor was screwed into a sliding case clamped to a thick steel plate permanently fixed to a concrete wall. The sliding case and the clamp-joint made it possible to place the fruit (attached to the pendulum) in a position vertical to the plate at the impact moment. In this way a perpendicular direction of the impact force to the impact surface was attained. Jarimopas et al. (1990) attached importance to design the experimental set-up in such a way that the striking force at the pendulum would be exactly horizontal at the moment of contact. The device was also equipped with control screws which allowed positioning of a girder (pendulum rotation axis) so that the impact force direction could go through the fruit mass centre. In that way the central collision conditions in the force sensor axis were satisfied. The drop height was determined by means of a scale with the plotted quantities corresponding to the specified free fall values. The force during the impact was measured by means of a piezoelectric force sensor (Endevco, Sunnyvale, USA), model 2311-100 with a sensitivity of 23.2 mV/N and a measurement range of ± 220 N (Technical Manual, 2013). The sensor measured electric charge generated by the deformed piezoelectric elements. The sensor was of monolithic construction equipped with internal electronic circuits changing the electric charge of piezoelement into the voltage signal.

2.4. Measuring apparatus

Two systems were used for measuring impact. To determine the force response course in time, an LMS SCADAS recorder (Siemens, Munich, Germany) integrated with the LMS Test.Xpress software for data acquisition and analysis was applied. The force response recording frequency was 10.24 kHz and the measurement was triggered when the force exceeded 0.5 N.

The Phanton Miro M320S digital high speed camera (Vision Research, Wayne, USA) and a lens with a constant focal length of 50 mm were used to record the pear impact into a rigid plate. The film of the impact course from the camera was analysed by means of the Phantom Camera Control (PCC-2) software at a resolution of 1024 × 768 pixels and a velocity of 3413 frames/s.

The use of a high speed camera can result in measurement errors due to an inaccurate positioning of the camera at a right angle. The optical axis of the camera should be perfectly perpendicular to the plane in which the pear impact is recorded. The positioning error was minimized by placing the camera on a special head enabling regulation along three planes with an accuracy of 1°. Another source of error is an inappropriate image focus of the observed object which causes its outline not to contrast well with the surrounding background for image edge detection purposes. The large contrast of the apple image against the surrounding background was obtained by LED panel lighting of the object. Errors can also occur during conversion of the image dimensions from pixels into millimetres. In the case of pear impact measurements, the scale factor amounted to 0.138 mm/pixel.

To determine the deformation-time and velocity-time curves, the Tema Motion Version 3.8 software (Image Systems, Linköping, Sweden) was employed which allowed to analyse pear motion in the recorded image. It also allowed to measure the pear contact width in a vertical plane crossing the pear contact plane centre in any impact time point.

2.5. Measurements

Before every test the mass of each pear was measured with an accuracy of 0.2 g and the pear diameter with an accuracy of 0.1 mm. The pear diameter was measured in the vertical plane along which the impact was to take place. The pear was attached to the pendulum by means of two metal tangs. Using control screws, the apple was oriented in such a way that its impact axis crossed the sensor one. In this way the central collision conditions were satisfied (Fig. 1).

After dropping from a given height and recording the impact course with a high speed camera and a force sensor, the pears were left for 48 h at room temperature to allow browning of the bruised tissue. Then the pears were cut along the vertical plane through the pear centre where the bruise was found. The bruise depth d and the bruise width w were measured using a calliper with an accuracy of 0.1 mm.

The research allowed to determine force-time, velocity-time and deformation-time courses. Fig. 2 shows the typical courses of these quantities in time at an impact velocity of 0.75 m s^{-1}. There was also determined the restitution coefficient e being the ratio of the rebound velocity v_{reb} to the impact velocity v_{imp}.

$$e = \frac{v_{reb}}{v_{imp}} \tag{1}$$

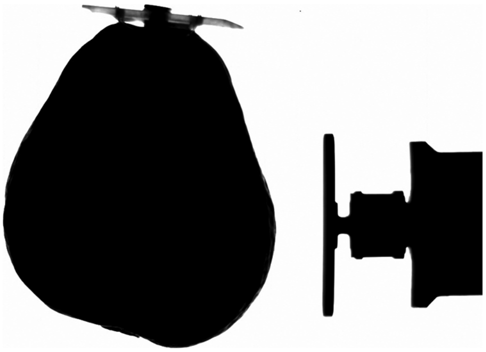

Fig. 1. The picture showing a pear just before the impact into a rigid plate.