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An efficient laser sensor system for apple impact bruise volume estimation

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ABSTRACT

Fruit are subjected to several external loads during processes from the orchard to the market, which result in bruising and therefore, quality loss. In this study, we developed a system based on a line laser light source and light detector for a rapid and efficient estimation of the bruise volume of apples (*Malus domestica* Borkh L. cv. Starking Delicious) dropped from a certain height onto a steel impact plate. We measured two parameters, namely rise time and dwell time, extracted from response signals generated by the proposed system during the impact test. These parameters are related to contact time, showing how long the fruit remains in contact with the impact plate. The experiments were conducted at six different drop heights and two different temperatures. It was found that there was a strong relation with coefficients of determination of more than 0.93 between bruise volume and dwell/rise time, in which the bruise volume decreased with the increasing rise time/dwell time as a power function. Furthermore, the results showed that warm apples developed greater bruise volume than cold fruit, and the estimated regression lines and curves for cold fruit had higher coefficients of determination than those of warmer fruit.

1. Introduction

Apples are mechanically damaged in several processes such as harvesting, sorting, storage, packaging, handling and transport, within the period from harvest to marketing of the product. During these processes, fruit are subjected to several types of external forces (Mohsenin, 1986). Bruising is defined as damage to the tissue of fruit and vegetables caused by external forces resulting in changes in color, flavor, and texture (Mohsenin, 1986). Bruising is also the most common type of mechanical damage limiting mechanization and automation in harvest and postharvest processes for all fruit including apples, and has the potential to reduce the market value of fresh fruit (Hung and Prussia, 1989; Blahovec and Paprstein, 2005). Major symptoms of bruising are browning and softening. The amount of bruise is usually described in terms of bruise volume, and therefore, bruise volume is usually used as a measure for fruit bruising (Blahovec, 1999; Blahovec and Paprstein, 2005).

A dropping impact test is widely used in various studies to understand the mechanism of bruising of apples, since it is a good simulation for the actual effect of forces with various controllable parameters such as dropping height, temperature, variety, etc. In these experiments, the true bruise volume is estimated by a method in which the bruised area is manually extracted from the apple and several geometric shapes are fitted to this area to calculate the extracted volume. A number of researchers (Schoorl and Holt, 1982; Klein, 1987; Brusewitz and Bartsch, 1989; Brusewitz et al., 1991; Marshall and Burgess, 1991; Pang et al., 1996; Studman et al., 1997; Yuwana and Duprat, 1997; Blahovec, 1999) have estimated bruise volume using this method. Bollen et al. (1999) and Kabas (2010) summarized and compared different geometric shapes and bruise size dimensions in estimating bruise volume. More recently, several researchers have also used this approach to estimate bruise volume (Yurtlu and Erdoğan 2005; Lewis et al., 2007; Opara, 2007; Van Zeebroeck et al., 2007a; Kabas, 2010).

Although the manual based method gives accurate estimation results, its estimation procedure is relatively difficult and time-consuming. To overcome these difficulties, several researchers have proposed rapid and easy automatic bruise volume estimation methods, and they have compared their results with those of the manual based method, which are considered ‘true’ or ‘measured’ bruise volume values. Some of these studies have used various types of force transducers to estimate bruise volume (Brusewitz and Bartsch, 1989; Brusewitz et al., 1991; Zarifneshat et al., 2012; Ahmadi et al., 2010). They measured several parameters related to bruising, such as impact peak force, absorbed energy, contact time, contact area, and time-to-peak force, and showed how these parameters were related to bruise volume and how they could be

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Nomenclature

D	bruise diameter, cm
h	drop height, cm
P	bruise depth, cm
R^2	coefficient of determination
t_d	dwell time, s
t_{pp}	peak to peak time, s
t_r	rise time, s
W	bruise width, cm
V	true bruise volume, cm^3
$\hat{V}$	estimated bruise volume, cm^3

used to estimate bruise volume automatically. Lewis et al. (2007) also developed engineering design tools based on a high speed video camera to estimate bruising automatically. In their method, they measured the rebound heights after impact of apples dropped from a certain height, and related energies (energy before and after impact, which are calculated using the measured heights) to estimate bruise volume in an efficient method.

In this study, we propose an efficient method to estimate the bruise volume of apples bruised during a dropping impact test. In the experiments the apples were dropped from a certain height onto an impact plate located between a laser light source and a light detector. During impact, the laser light is obstructed by the dropped apple, and therefore, the amount of light on the light detector decreases. Changing the amount of light on the light detector produces a response signal which is recorded by a computer. Using a response signal, we measured two parameters related to contact time in which the apple remains in contact with the impact plate. These parameters are called rise time and dwell time, and they are used in estimating the bruise volume of the apple. In the proposed system, the recording process is handled by means of a sound card of the computer, and hence an external data acquisition system is not required. Furthermore, the software to record the process is free. Therefore, the total cost of the proposed system is considerably lower than for systems which use a force sensor or high speed video. The experimental results obtained from this study showed that the proposed system accurately and reliably estimates the bruise volume of apples.

2. Materials and methods

2.1. Sample preparation

Apples (*Malus domestica* Borkh L. cv. Starking Delicious) were used in the experiments, and were supplied from the cold storage of a local supermarket, selecting non-bruised apples with uniform mass 157 ± 13 g These apples were separated into two equal groups; one group was refrigerated at 1 °C and the other held at a room temperature of 19 °C for 24 h prior to the dropping experiments. Similar temperatures have been chosen in the literature: Klein (1987) used 1 and 18 °C temperatures for apples and Ahmadi et al. (2010) 3 and 20 °C for peaches. The dropping impact tests were conducted for six drop heights of 20, 40, 60, 80, 100, and 120 cm against a steel impact plate at two temperatures (1 and 19 °C). Ten apples were used for each test and each apple was dropped once, and a total 120 individual apples were tested. All tests were carried out at the Biological Material Laboratory in Agricultural Machinery Department of Atatürk University, Erzurum, Turkey.

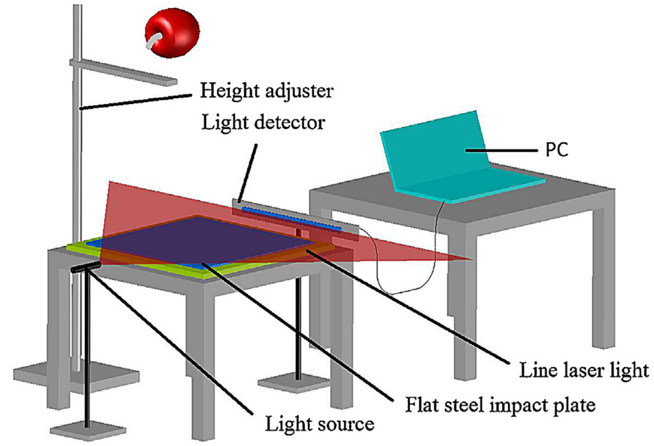

Fig. 1. Graphical representation of measurement setup for the dropping impact test.

2.2. Test apparatus and procedure

The measurement setup for the dropping impact tests consisted of three main parts as shown in Fig. 1(a) a base frame equipped with a vertical rod to control the drop height and a height adjuster connected to the rod by means of a clamp to adjust the drop height, (b) a flat steel impact plate with a square area of 300 mm × 300 mm and a thickness of 3 mm, and (c) the laser sensor system including a line laser light source, a light detector and a recorder. Each apple was carefully oriented and released by hand onto the impact plate to ensure that the impact point occurred on the cheek of the fruit. After the first impact the fruit was caught by hand to avoid a second impact due to fruit rebound. During the first impact of the apple, the laser light was obstructed by the dropped apple and the amount of laser light on the light detector was changed and these changes produced a signal recorded by software to be utilized for estimating bruise volume.

2.3. Proposed system

In this study, we developed an efficient laser sensor system to estimate the bruise volume of an apple dropped from a certain height. During apple dropping experiments, the system measures two parameters which are related to contact time, giving how long the apple remains in contact with the impact plate and the bruise volume is estimated using these parameters. A graphical representation of the developed system is shown in Fig. 1. The system has three main parts: a line laser light source, a light detector and a recorder. The light source (HUANIC LC650-5-3-F with 650 nm wave length 0.4 mrad divergence 5 mW output power) produces a red color line laser light. The light detector was a set of light dependent resistors (LDR). A total of 28 LDRs, each of them of 10 mm diameter, were mounted adjacent to each other on a frame and the frame was located in front of the light source to capture the line laser light easily. In terms of electrical circuit, the leads of LDRs were connected to each other in a parallel way. As shown in Fig. 1, this circuit was supplied with a 9 V battery and connected to the recorder. The recorder was a computer that recorded the current changes on the main branch of the circuits with the aid of Audacity, the well-known free sound editor software tool, through microphone input (SONY VAIO VPCF13M1E/H with sound card Intel® HD Audio, Eight channels, 192 kHz/32-bit) at 44.1 kHz sampling frequency.

The sensing principle of the proposed system can be explained as follows. When an apple is dropped from a certain height, it hits the impact plate and it remains in contact with the impact plate for a short time, which is known as the contact time. During contact time, the laser light is obstructed by the apple and the amount of light