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Development of multiple regression model to estimate the apple's bruise depth using thermal maps

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ABSTRACT

Thermography is a useful technology for non-contact two-dimensional temperature measurement of the material's surface that requires nondestructive evaluation. It is also considered as a non-destructive method to determine quality attributes of agricultural products. In this study, the surface temperature of bruised apples was determined using thermal maps and the bruise depth during a set of factorial experiments in the form of a completely randomized design with two factors, namely impact location (bottom, middle, top) and impact energy at three levels (200, 700, 1200 mJ). Then, the relationship between bruise depth and surface temperature was investigated using multiple regression analysis. The results of analysis of variance showed that impact energy and the interaction of impact energy and location of impact region had a significant effect on temperature. The results of the multiple regression model showed that the surface temperature measured from a region can be used to predict the bruise depth in that region. The residual analysis confirmed the prediction adequacy of the proposed model.

1. Introduction

For most fruits including apples bruising is the most common postharvest mechanical damage (Wilson et al., 1999). Bruising means damages occurred to fruit tissue by an external force that causes physical changes in the texture and chemical changes in the color and flavor. This phenomenon is one of the main reasons that led bruised apples be placed in lower quality grades in inspections (Xing and Baerdemaker, 2005). A large amount of fruits are destroyed or degraded due to bruise and other mechanical damages during harvesting, transporting, storage and packaging. More than 30% of apples are damaged during picking, handling and storage operations (Kupferman, 2006). Based on the US grading standard, existence of the damaged area in 16 mm diameter and 1.6 mm depth will exclude get out the apples from high degreeindicators (USDA, 2002). In a study, the economic depreciation of apples resulting from mechanical damage was estimated in Belgium. They found that the percentage of bruised apples in 2000 and 2001 was equal to 15% and 8%, respectively. They concluded that a reduction of only 10% of the amount of bruised apples resulting from mechanical damage can increase revenues with 892 million dollars in 2000 and 595 million dollars in 2001 (Van Zeebroeck et al., 2003).

One of the non-destructive methods that can be used to detect damages in fruit is thermal imaging. Thermography is a useful technology for non-contact two-dimensional temperature measurement of the material's surface that requires nondestructive evaluation (Kheiralipour et al. 2013). This technology is able to detect the subjects and objects that their surface temperature is different from background (Meola and Carlomagno, 2004). Thermography and using thermal maps are used as non-destructive methods to detect defects that can be implemented in two common modes: passive and active thermography. Passive thermography insists on measuring the heat emitted by natural variations in temperature between normal and bruised tissues. This is while in active thermography an external heat source is used for heating the area of study first before being thermally imaged (Meola and Carlomagno, 2004). Thermal images are capable of providing a thermal map from the product surface. Infrared thermography is evolved as a non-contact means for monitoring conditions to display the surface temperature of objects (Bagavathiappan et al., 2013). Varith et al. (2003) used thermography for detection of bruise in apples when 48 h after dropping for the bruises to develop fully. The results show the 1–2 °C difference between normal and bruised tissues, which is due to the difference in thermal penetration capabilities in these

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tissues. Baranowski et al. (2009) used passive thermography to distinguish crushing in three varieties of apple, namely Janagold, Ligol, Gloster. Temperature change patterns of bruised fruit's surface revealed that the temperature difference between normal and bruised tissues changes between 0.5–1.5 °C. This experiment was performed at room temperature of about 25 °C. The results also showed that in passive thermography bruised tissue can be detected 48 h after impact. The most temperature difference is observed in Janagold variety and the least temperature difference is observed in Gloster that may be due to differences in their tissue integrity (Baranowski et al., 2009).

In another research, thermography method was used to the diagnosis of watercore in apple. Obtained temperature of apples is considered as an appropriate parameter to evaluate the differences in thermal properties between patients and healthy apples. The rate of temperature rise in the initial stages of heating for apples with watercore defects, were significantly lower than healthy apples. The results showed a good correlation between the changes in the temperature and density of the fruit tissue (Baranowski et al., 2008). Zarifneshat et al. (2010) reported that the size of bruising occurred in upper and lower portions of fruit was lower than other parts. The reason for the difference in bruising rate is expressed in differences in the radius of curvature of the fruit in different parts (Zarifneshat et al., 2010). In another research, Siyami et al. (1998) reported that the radius of curvature of an apple has a significant effect on the size and diameter of bruised area in apple, so that by increasing the radius of curvature of the fruit, the diameter of bruising decreases. Van Zeebroeck et al. (2007) evaluated the effective factors on bruise in apple and reported that the apples' harvest time is effective on bruise. Much research has been done to investigate the important factors on bruising is important today is that to realize the actual contribution of the bruising indicators such as depth and volume of bruise with a non-destructive method. Bruise depth can be considered as an appropriate parameter for grading bruised apples. Thus, the purpose of this study is to determine the relationship between the recorded temperature in depth and surface of bruised tissue using thermal imaging system.

2. Materials and methods

2.1. Simulation of bruise

To perform this test, 45 samples of Golden Delicious apples were prepared with an average weight of 119 g. While preparing samples, the apples were selected. These apples had no prior decay. To simulate the bruise of apple's tissue, three points were identified on each apple in three areas include the middle, upper and lower zones (Fig. 1), where the lower zone is located close to the calyx, the upper zone close to the stem and the middle zone on the equator.

Bruising simulation was performed by impact application and in a completely randomized design form in three levels of energy and three locations of apples and each level with five repeats in the form of the factorial experiment. A pendulum (with the flat-surface head with a mass of 0.796 kg and its arm length of 0.196 m) was used to apply impact force on the samples. The impact energy E (J) is determined by:

$$E = mgh(1 - \cos\alpha) \quad (1)$$

with E the impact energy (J), m the mass of the pendulum (kg), g the acceleration due to gravity (m s^{-2}), h the distance from rotation center to center of gravity of the pendulum in meters, α the rotational angle (°).

Based on this relationship, the three energy levels of 200, 700, and 1200 mJ were implemented with rotational angles of 25°, 60.8° and 78.5°, respectively (Sadrnia and Emadi, 2012). In order to avoid damage to other parts of the apples, the apple was covered with wax. After hitting and crushing simulation, samples were kept at a temperature of 5 °C for 624 h.

2.2. Thermal imaging

Thermal imaging system included a thermal camera (NEC Avio Infrared Technologies InfRec G100Ex, Japan) that was able to image in the temperature range of −40 to 1500 °C, with the resolution of 0.08 °C and thermal image of 240 × 320 pixels. The camera's spectral range was 8–14 µm. Also, the imaging system had a camera bracket, an insulated compartment and a computer system (Fig. 2). The emissivity of apples was determined to be equal to 0.94. Thermal imaging was done in early afternoon at about 2–4 pm.

2.3. Measurement of bruise depth

In order to measure the bruise of each sample, the bruised area in each sample was cut by metal blade and the bruise depth was measured using a digital caliper with an accuracy of 0.01 mm (Fig. 3).

2.4. Extraction of desired characteristics from thermal images

After imaging of samples during the specified period in visible and infrared spectral ranges, visible images and thermal maps were analyzed using the software MATLAB version R2011a (Mathworks Inc., US) and InfRec Analyzer NS9500 (NEC Inc., Japan). The thermal maps were transfered to InfRec Analyzer software and the temperatures of all points were saved in the form

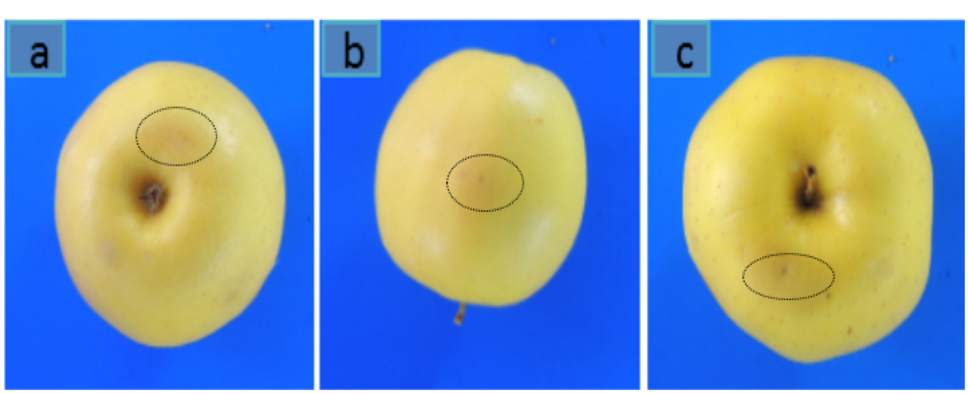

Fig. 1. Bruising in three regions on an apple surface: lower (a), middle (b), upper (c) region.