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Development of a machine vision system for determination of mechanical properties of onions

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ABSTRACT

In this research, a machine vision system was developed to measure the contact area and dimensions of agricultural samples in mechanical properties testing. Two probes were made of aluminum and round glass panes. The Universal Testing Machine was equipped with these probes. One camera was positioned inside the probe to monitor the contact area between probe and samples. Other camera was located outside of probe to measure dimension of samples during the test. Onions were selected as study products and those mechanical properties were measured using this machine vision system. Also, to verify the results of this system, the mechanical properties were calculated using conventional methods. The effects of onion cultivars (red and yellow), loading direction (polar and equatorial) and loading speed (15 and 25 mm/min) on the size of contact area, the stress and strain, elasticity modulus and Poisson's ratio were examined. The results showed that there was no any statistically significant differences between conventional method and our presented method at 99% confidence level. Therefore, a machine vision system can be replaced with conventional method. It was possible to assimilate the shape of contact area to a near perfect circle. The effect of loading direction on Poisson's ratio and the loading speed on stress and elasticity modulus were significant. Red onions under polar loading with speed 15 mm/min had maximum Poisson's ratio, stress and modulus of elasticity. The stress was obtained as 0.281 ± 0.044 MPa. The values of elasticity modulus were obtained as 2.56 ± 1.4 and 2.77 ± 1.8 MPa for yellow and red onions, respectively. The Poisson's ratio along x and y axis were obtained as 0.393 ± 0.05 and 0.375 ± 0.07, respectively. Polar loading samples were easy to deform laterally compared to equatorial loading samples. The contact area, stress and Poisson's ratio increased with increasing deformation while the modulus of elasticity decreased.

1. Introduction

A high percentage of food losses mainly due to poor handling techniques which are importantly underscored in the post-harvest management (Shitanda et al., 2002). The physical and mechanical characteristics are vital in its standard classification for storage, marketing and consumption. The major problem encountered in the food supply chain is loss during storage due to rotting, sprouting and weight loss. In many cases, the physically damaged skins of stored products will be affected by microorganisms and the resulting physiological changes may accelerate higher deterioration of these products. The assessment of textural characteristics of cultivars appears to be crucial for their selection and commercialization, since they affect the consumer choice (Steenkamp, 1997). In fact, exported agricultural products are normally inspected for the presence of defects, appearance and fruit firmness (Pallottino et al., 2011). Since such properties are vital for the design of effective and efficient product handling facilities, estimates must be made to minimize physical damage and injury during processing.

Among all mechanical properties, Poisson's ratio and modulus of elasticity, which are determined from stress-strain test, are of important and commonly used ones to describe the mechanical behaviour of any object. Poisson's ratio is the ratio of transverse strain to axial strain. The strain refers to any changes in axial or lateral dimension of an object going under mechanical stress. The change in size (deformation) is measured with a caliper in the conventional method. The elastic modulus of an object is defined as the slope of its stress–strain curve (the ratio of stress to strain) in the elastic deformation region. "Stress" is defined as the force applied by the probe divided by force application area. The force measured using a loadcell. However, the shape of contact area between the probe and sample is uncertain. On the other hand,

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unlike engineering materials out of which samples can be made in a cylindrical shape so the circular contact area would be constant and known, it is not possible for most agricultural products. Thus, determining the size of force-application area, or probe-sample contact area, during the stress-strain test is challenging. In this project, we examined and developed an alternative method based on vision system to measure this area accurately. In the following, first the studies of mechanical properties and used conventional methods were investigated, next the knowledge gap and aim of research were mentioned.

There are many published literature on Poisson's ratio and elasticity modulus of fruits and vegetables (Timbers et al., 1965; Chappel and Hanman, 1968; Rong et al., 1999; Sagsoz and Alayunt, 2001; Emadi et al., 2005, 2009; Cakir et al., 2002). Knowledge of elastic modulus allows researchers to compare relative stiffness of various materials. Timbers et al. (1965) estimated the modulus of elasticity for cylindrical cores of potato tuber, loaded with rigid plates of various diameters; Chappel and Hanman (1968) determined the Poisson's ratio and Young's modulus of apple flesh under compressive loading; Rong et al. (1999) analyzed the cracking of macadamia nutshells under the load between two rigid plates; Ojijo et al. (2000) determined the viscoelastic properties of soybean cotyledons subjected to accelerated storage; Sagsoz and Alayunt (2001) compared several methods used for determining the modulus of elasticity of some onion varieties; Emadi et al. (2005 and 2009) studied the mechanical properties of three varieties of squash and melons and mechanical properties of pumpkin, respectively.

Shitanda et al. (2002) studied the compressive strength properties of rough rice considering the variation of contact area. They determined contact area during compression at 0.2 mm intervals by placing a pressure sensitive paper on the compressing surface of the stress–strain tester before the test started; Cakir et al. (2002) determined the Poisson's ratio and elastic modulus of some onion varieties.

Presently, fruit firmness evaluation is carried out manually via the so called Magness–Taylor (MT) test (Shmulevich et al., 2003), that uses a hand-held penetrometer, also known as fruit pressure tester (Magness and Taylor, 1925), and provides a direct measure of the peak force at rupture. Such a force has been used as an index of maturity and firmness for several different fruits, especially for apples (DeLong et al., 2000). In citrus fruits and vegetables, the relationship between puncture force and firmness is, however, concealed by the differences in the tissue types directly under the puncture probe (Pallottino et al., 2011).

Similarly, other techniques based on visible or near-infrared spectroscopy (NIRS), impaction or acoustic impulse resonance frequency (AIF) have so far exhibited inaccurate results (Garcia-Ramos et al., 2005; Ruiz-Altisent and Ortiz-Canavate, 2005). In particular, it is worth citing their use in combination with nondestructive flesh color readings (Valero et al., 2003), as successfully tested to determine the optimum harvest date and quality characteristics of apples (Menesatti et al., 2009; Zude et al., 2006) or mandarin fruits (Hernandez Gomez et al., 2006), or combined with artificial neural networks to predict kiwifruit firmness (Ragni et al., 2010). Pallottino et al. (2011) assessed the mechanical compressive properties of orange fruits and precisely determined the probe's instant contact area on each fruit's surface during the test by approximating its outline to a polygon and reconstructing the contact area outline by the Elliptic Fourier Analysis, or by inscribing an ellipse in the contact area's bounding box. They estimated the apparent Poisson's ratio and the modulus of deformability of the whole orange fruit as 0.16 ± 0.09 and 353 ± 3 kPa, respectively, using image analysis.

To date, there have been several methods used for determining mechanical properties of round or nearly round agricultural products using destructive stress-strain curve analysis. In almost all these methods, deformation is measured with a ruler, caliper, and digital caliper that it is difficult and very time-consuming. Also, the contact area of such samples was assumed to be geometrically circle. However, it is not true for all cases and this assumption produces error in calculation of the applied stress. On the other hand, determining actual stress requires knowing the true area under load. There has been little knowledge and effort determining actual contact area, as it has not been a straightforward task.

In this research, we developed a novel methodology using an imaging system and image processing techniques to determine instantaneous and actual contact area and dimensions of samples under loading. We tested our developed methodology on onions as case study samples. However, we believe our developed system can be used for other volumetric fleshy fruits.

2. Materials and methods

2.1. Materials

2.1.1. Raw material

Onion samples of two cultivars, namely cultivar 1 and cultivar 2, which are commonly known as Red and Yellow onions, used in this research as case study samples. The onions were harvested in autumn, 20 days before conducting the tests. Onion samples were kept at room temperature (21 °C). Forty onions of each cultivar were randomly selected. Diameters of samples were measured by a digital vernier caliper (Fig. 1). Shape factor was calculated as described by Abd Alla (1993). The moisture of the onions was determined using the standard hot air oven method; samples were dried in an oven at 100 ± 1 °C for 24 h. The onions were loaded either axially or laterally until rupture occurred. Some measured physical properties of the studied onion samples, grouped under on their cultivar names, are given in Table 1.

2.1.2. Fabrication of probe and machine vision system

Two cylindrical probes were made out of aluminum (Fig. 2). Probes were made such that to be able to attach to the upper and lower grips on the testing machine on one side. A circle cut out of glass pane was pasted on the other base side of the cylindrical probes. Also, a series of RGB LED lights were placed around the glass circle-cut for illumination and to increase the contrast between the contact area of sample and the glass base.

Two cameras (Farassoo 2370, Farassoo Inc, Iran) were positioned along the axis lines y and z so as to collect the projection images of the sample under testing. One camera was positioned at one end inside cylinder looking towards the glass pane at the other end (along the Z-axis, Fig. 2). The images of this camera were used to monitor the instantaneous contact area between probe and samples, the samples deformation along the Y-axis and sample size. The other camera was located outside of the probe along the Y-axis. The images obtained from the latter were used to measure the samples deformation along the X-axis or Z-axis (the displacement of the probe, i.e. vertical distance between fixed and moving plate).

The cameras were connected to a computer and acquired images were taken and stored in this computer controlled by a program written in MATLAB (ver 2015a, Mathworks Inc, US). The acquired images were processed and the relevant information were extracted through a process explained in Section 2.2.2.