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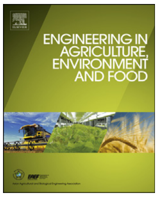

Effect of mechanical treatments on creep behavior of potato tubers

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ABSTRACT

The effect of surface type and angle, drop height, and number of impacts on the creep behavior of Lady Rosetta potato cultivar was studied. Instrumented sphere (impact recording device) was used to obtain the coefficient of restitution and to calculate the absorbed energy for steel sheet, steel rods, rubber-coated steel rods, and two-layer potato surfaces. The four-element model (E_o, E_r, η_o, and η_r) was used to simulate the creep behavior of samples. Results showed that there is significant effects of drop height, surface angle, and number of impact on the creep parameters ($P < 0.05$). Higher parameters values, i.e. lower incident strain, were associated with steel rods and steel sheet surfaces, dropping tubers from 100 cm, and dropping tubers for 5 and 10 times. Moreover, the two-layer potato surface was found to cause the lowest strain values to the dropped tubers compared to other tested surfaces. Non-linear regression analysis was conducted between the absorbed energy and creep parameters. Low regression performance was obtained for E_o, η_r with determination coefficient (R^2) best values falling in the range of 0.40–0.69, while E_r and η_o showed fair regression. Results of this study could be used for improving storage facilities of potatoes by accurately estimating the strain affecting stored tubers and consequently the appropriate height such that strain values in the bottom layers do not negatively affect quality and shelf life of potato tubers.

1. Introduction

Mechanical properties of agricultural materials can be classified into three groups: basic mechanical, viscoelastic behavior, and texture profile analysis. These properties are typically generated from three instrumental measurements; stress, strain, and time (Mohsenin, 1986). The behavior of an agricultural commodity that undergoes a compression stress eventually measures several basic mechanical properties of food such as modulus of elasticity, plasticity, stiffness, toughness, bioyield point, and rupture stress. Such properties have been used for quality assessment of perishable produce. Tuber skin strength is a major factor affecting damage occurrence. Results obtained by Muir et al. (1990) indicated that there were changes in skin strength after harvesting and during storage. Fekete and Sass (1994) examined the use of coefficient of elasticity (ratio of compressive or tensile force to the resulted deformation) as a measure of fruit firmness. A good correlation between the coefficient of elasticity and other mechanical properties was obtained.

Mechanical properties of agricultural commodities were extensively studied. The bioyield, rapture stress, and work required for deformation were investigated for six apples cultivars by Zana et al. (1994) and results showed that the rapture stress is a distinguishing value for each cultivar. Yuwana and Duprat (1996) studied the trend of the modulus of elasticity (E) for apple fruits during storage and it was found that values of E decreased during the first two months of storage. Dobrzanski et al. (1995) studied the elastic behavior of apple skin under different storage temperatures using the tensile strength and found that skin firmness did not change in the storage range of 0–2 °C. Fruits, vegetables, and grains affected by a dead load during storage may suffer from an excessive compression stress that leads to permanent damage or accelerates the infection by harmful microorganisms such as black heart in potatoes, browning in fruits, and mycotoxin in wheat (Mohsenin, 1977).

Viscoelastic characteristics of food products were studied using the creep and relaxation tests. In the creep test, strain is recorded as

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a function of time under a constant stress. While in relaxation experiment, the stress is obtained as a function of time at a constant strain. Varshney and Siripurapu (1985) developed an instrumentation to study the creep behavior of apple flesh. Samples were exposed to 2 and 7 Kg of compression loads and the creep compliance data was represented using the four-element model (Burger's model). The deviation between the observed and predicted values was as low as 2%. Thus, apple was considered as a viscoelastic material which agreed with the results obtained by Lu et al. (1988) who found apple flesh properties to be nonlinear viscoelastic.

Burger's model was also successfully implemented to fit creep data for plantain (Ajibola, 1986), tomato (Jackman and Stanley, 1995), and apple cortex (Mittal and Mohsenin, 1987). Solomon and Jindal (2007) studied the effect of storage temperatures (5, 15, and 25 °C) on the rheological properties of potatoes. Cylindrical samples (30 mm thickness and 15 mm diameter) were subjected to a dead load and the Burger's model was used to simulate the creep behavior. Results showed that elasticity and viscosity values significantly decreased over the storage time. In addition, relationships between creep parameters and both storage temperature and storage time were feasible using polynomial model with R^2 values of as high as 0.99.

Measuring the impact severity for perishable products during harvest and handling operations is important for evaluating the efficacy of mechanizations used in such processes. Instrumented sphere (IS) or impact recording device (IRD) was first developed and calibrated by Tennes et al. (1986; 1988a; 1988b) in Michigan State University, East Lansing, MI, USA. Tennes et al. (1990) used the IS to evaluate five apple packing lines. Results were helpful in locating points where excessive impacts were encountered which could cause fruit bruising. Later, several researchers used IS for assessing impact damage in fruits and vegetables (Timm et al., 1989; Chen and Yazdani, 1991; Hyde et al., 1992; Molema, 1999).

During harvesting and subsequent handling operations, potato tubers are subjected to compression and shear forces that cause internal or external mechanical damage. Tubers are then stored in 4–6 m height stalks or in bins to a height of up to 1.5 m. Such practices promote internal and external bruises due to pressure or compression forces (Gottschalk and Ezekiel, 2006). Consequently, it is important to simulate the creep trend of potato tubers that were pre-affected by impact forces. Thus, the objective of this work was to study the effect of different impact parameters during the falling test on creep behavior of potatoes.

2. Materials and methods

2.1. Raw materials

Lady Rosetta potato cultivar, commonly used in chipping, was selected for conducting the experiments. Samples were brought from a commercial farm in El Sharqia Governorate, Egypt in the 2003–2004 season. Samples were grown in sandy soil with a considerable percentage of clods. After mechanical harvesting, tubers were gently washed by water to remove soil and clay and then left for drying at room temperature for 6 h. Moreover, tubers with cuts, skinning, splitting, rot, and greenish were discarded. Tubers were then stored at 15 °C and 90% relative humidity for 2 weeks for curing (Burton et al., 1992). Experiments were then conducted over a period of 6 weeks and the sampling was taken place every week at which 48 samples were tested. The instrumented sphere was used to evaluate impact features for the studied surfaces and such experiments were carried out in the commercial farm site. A complete representation of the experimental design is shown in Fig. 1.

2.2. Physical characteristics

Several physical characteristics were measured or calculated for a set of tubers. Tuber weight and dimensions (length, width and thickness) were measured using laboratory scale and digital caliper, respectively. Apparent density is the mass divided by the volume of an individual sample only (Wilhelm et al., 2005). Apparent tuber volume (V_p) was measured based on water displacement technique illustrated by Mohsenin (1986). Each tuber was weighed, suspended using a thin copper wire, and then placed in a previously-weighed 500 mL glass beaker filled with 300 mL water. The change in weight was then recorded which represented the displaced water weight. The apparent volume was then calculated using equation (1):

$$V_p\left(cm^3\right) = \frac{Weight\ of\ displaced\ water,\ g}{Water\ denisty,\ g/cm^3} \tag{1}$$

Apparent density (ρ_p) was then calculated by dividing the tuber weight by the apparent volume. Bulk density is the mass of a group of samples divided by the occupying volume including pores between samples (Wilhelm et al., 2005). Bulk density was measured by filling a 30 × 30 × 30 cm^3 wooden box with tubers and then weighing the filled box. Bulk density was then calculated as the ratio between the weight of tubers only divided by the internal box volume (9000 cm^3). Moisture content (wet base) was measured using the air convection oven technique (Ghadge et al., 1989) using 10 × 10 × 10 mm^3 samples that were weighed, placed in a foil dish, and then placed in the oven that was set at 130 °C for 4 h. Moisture content (MC_{wb}) was calculated using equation (2):

$$MC_{wb}(\%) = \frac{Weight\ of\ sample\ \ before\ drying(g) - Weight\ of\ sample\ after\ drying(g)}{Weight\ of\ sample\ before\ drying(g)} \times 100 \tag{2}$$

The total soluble solids (TSS) were measured using RHB-32ATC digital portable refractometer (Spectrum technologies, Inc., Plainfield, IL, USA). Tuber roundness (T_r), a measure of the sharpness of object corners, was also assessed following the Curray equation (Mohsenin, 1986) as following:

$$T_r = \frac{Largest\ projected\ area\ of\ the\ object\ in\ natural\ rest\ position,\ m^2}{Area\ of\ the\ smallest\ circumscribing\ circle,\ cm^2} \tag{3}$$

Round object tend to have roundness values closer to 1. Finally, tuber sphericity (T_s) was calculated as following:

$$T_s = \frac{Diamete\ of\ the\ sphere\ whose\ volume\ is\ equal\ to\ tuber\ volume,cm}{Diameter\ of\ the\ smallest\ circumscribing\ sphere,\ cm} \tag{4}$$

For spherical objects, sphericity value gets closer to 1.