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THE EFFECT OF STORAGE TIME ON SELECTED MECHANICAL PROPERTIES OF POTATOES

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Abstract

This paper describes a the effect of storage time on selected mechanical properties of potatoes, method for determining the impact strength and dynamic shear strength of potatoes on a test stand designed by the authors. The results of preliminary tests examining the effect of storage time on the average impact bending strength and shear strength values of potatoes cv. Irga are also presented. The above parameters and changes in their values during storage time have to be determined to support the optimization of technological processes in the food processing industry, including the production of French fries and potato chips.

List of symbols:

L_u – breaking energy, J;
G_R – pendulum mass reduced to the center of impact, N;
β – angle of the pendulum after fracture, °;
α – angle of pendulum drop or angle of the maximum pendulum bounce, °;
K – dynamic impact energy, $J \cdot cm^{-2}$;
A – cross-sectional area , cm^2;
R_t – dynamic shear energy, $J \cdot cm^{-2}$;
R – radius of pendulum arm, cm.

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Introduction

Potatoes' resistance to mechanical damage and suitability for mechanical harvesting and processing are determined during laboratory tests (BUDYŃ 1993, MOHSENIN 1986, SOBOL 2002, JAKUBCZYK, UZIAK 2005). The mechanical properties of potato tubers have to be determined to minimize damage during harvest and preliminary treatment, and to control and optimize technological processes in the food industry, including during the production of French fries and potato chips. The above is a complex process which requires the identification of strictly correlated factors: plants, machines with specific structural features and machine operating parameters (MOHSENIN 1986). Physical and mechanical parameters are an important set of features that characterize plant materials. Those characteristics are measured and expressed quantitatively to describe the state of the analyzed samples (CIUPAK, GŁADYSZEWSKA 2010, DOBRZAŃSKI, RYBCZYŃSKI 2008, ŻABIŃSKI 2006). The accumulated data support the design of cultivation, harvest, processing and storage devices and computer modeling of those processes (GOŁACKI ROWIŃSKI 2006, STROPEK et al. 2009). The mechanical properties of farm products are affected by various factors, including variety, fertilization, cultivation site, moisture content, and they are characteristic of a given species.

For example, potato tubers density affects the oil content in potato chips and French fries, which suggests potato processing efficiency and quality of the final products (MOZOLEWSKI 2000). Excessive density of tubers causing significant changes in the quality of these products – chips and chips are becoming too hard and have a granular structure, surface texture of fries is too hard and the interior gives the impression of raw, losing the characteristic taste and fragrance of fried foods (LISIŃSKA 2006, RYTEL et al. 2006). The density of potato tubers is a fundamental feature of the distribution used in the separators used in machines to harvest and postharvest processing of potato tubers (MARKS 2004). Potato tuber density tests show the dependence of the characteristics of the variety, weather conditions during the growing season, time of storage. Potatoes belonging to the smaller size fractions and fertilized with mineral fertilizers have a higher density (SOBOL 2006).

Plant materials characterized by high variability require an individual approach to designing and modeling their properties.

The objective of this study was to determine the impact bending strength and shear strength of potatoes used in the production of French fries and chips.

Materials and Methods

The experiment was carried out in a prototype test stand designed and constructed in the Farm Product Separation Laboratory at the Department of Heavy Duty Machines and Research Methodology of the University of Warmia and Mazury in Olsztyn. The developed test stand supports:

– impact bending tests, biaxial shear tests and dynamic mechanical damage tests of root crops using variously shaped hammers at different impact energy values,

– determinations of the energy transferred to the analyzed sample by the hammer.

The experimental materials comprised potatoes cv. Irga with a diameter of 50 to 65 mm and tuber weight of 100 to 200 g. Dried and chilled potatoes were stored indoors at a temperature of 8 ± 1°C and air humidity of 90 ± 5%.

The measurements were performed every seven days over a period of 15 weeks.

Test stand

The developed test stand was a modified Charpy's hammer (Fig. 1). Two brackets were fixed to the main body of the device (*1*). The supports (*3*) were welded to the brackets at the base of the device.

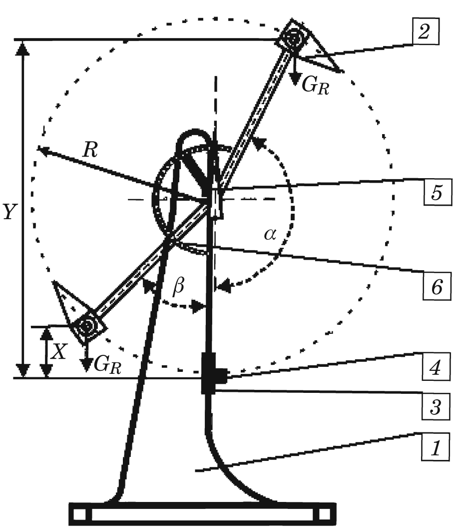

Fig. 1. Test stand: *1* – body, *2* – pendulum, *3* – supports, *4* – specimen, *5* – indicator, *6* – scale, G_R – pendulum mass reduced to the center of impact, Y (or h) – height between the highest and the lowest position of the pendulum, x – height of pendulum bounce after fracture, α – maximum angle of pendulum from the vertical axis, β – angle of pendulum after fracture, R – radius of pendulum arm

The specimen (*4*) subjected to impact bending tests or shear tests is placed between the supports. A pendulum with mounted bearings (*2*) is attached to the upper section of the brackets. Replaceable attachments are fixed at the end of the pendulum with the use of nuts (Fig. 2). A scale (*6*) with an indicator (*5*) is attached to one of the brackets for reading the angle of the pendulum after fracture (shear).

Fig. 2. Replaceable pendulum attachments: *a* – PVC cutting hammer, *b* – PVC flat hammer

The technical specification and structural description of the test stand was provided by (DUBER-SKWARSKA, GÓRKA 2012). The test stand measures the energy required to fracture (shear) the specimen with the accuracy of ± 0.5% of initial hammer impact energy, but not greater than 1 J.

Experimental procedure

Specimens were placed on the supports (Fig. 3) in the test device. The specimen's symmetry plane was located at the mid-distance between the supports where the impact took place.

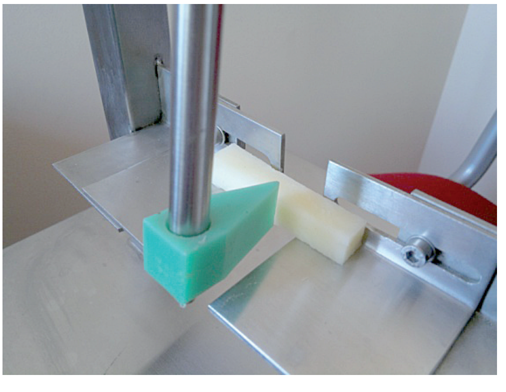

Fig. 3. Specimen positioned on supports during an impact bending test

Prior to the impact test, the specimen's cross-section along the symmetry plane was measured, and the cross-sectional area was determined with the accuracy of ± 0.2 mm. The pendulum moved along a vertical plane that intersected the mid-distance between the supports. The position of the cutting hammer relative to the supports and the distance between the supports were checked before every test series.

In an *impact bending test*, the specimen was fractured by a single impact of the pendulum hammer. The energy needed to fracture the specimen (measured in J) was determined based on the bounce of the pendulum shown on the measuring scale.

The angle of the pendulum hammer α (Fig. 1) without the specimen was read off the scaleto the nearest degree. The same method was used to determine the angle of the pendulum hammer β with the specimen. The impact energy needed to fracture the specimen L_u was calculated using the below formula (1).

$$L_u = G_R(\cos\beta - \cos\alpha) \tag{1}$$

Impact bending strength K was determined with the use of formula (2):

$$K = \frac{L_u}{A} \tag{2}$$

The impact bending test was carried out using a PVC cutting hammer (Fig. 2a) on rectangular specimens of 10 × 10 × 55 mm cut out from the experimental material at a temperature of 22°C. The distance between the supports was set at 26 mm. A pendulum swing test was performed without the specimen before the impact test. The indicator was set at 0, the pendulum was lifted to the angle of 90° and released. The result was read off the scale. The swing test was repeated three times, and the results were averaged. A potato sample was placed on the supports, and the above procedure was repeated.

In a *dynamic shear test* (Fig. 2), a specimen was sheared along two cross-sections transverse to the specimen's longitudinal axis. The result was read off the scale, impact energy L_u was calculated using formula (1), and shear strength Rt was determined based on formula (3).

$$R_t = \frac{L_u}{2A} \qquad (2)$$

A dynamic shear test was carried out with the use of a flat hammer (Fig. 2b). The procedure was identical to that applied in the impact bending test. The distance between the supports was adjusted to the dimensions of the flat hammer, and it was 2 mm greater than hammer length. The results were subjected to analysis of variance (ANOVA) with post-hoc tests (LUSZNIEWICZ, SŁABY 2008), and they were processed with the use of STATISTICA PL v. 10 software. Duncan's test was applied to identify homogenous groups and to determine the significance of differences between means (STANISZ 2006). Differences were regarded as significant at 0.05. The following null hypothesis (H_0) was verified: the average impact bending (shear) strength values of potatoes cv. Irga do not differ significantly during the first 15 weeks of storage. Statistically processed impact strength values are given in Table 1 and are represented graphically in Figure 4.

Table 1

The results of statistical analyses investigating the effect of storage time on the average impact bending strength values of potatoes cv. Irga

Results of analysis of variance	
Value of F-statistics	$F = 6.5003$
Probability of exceeding F-statistics	$p = 0.0004$
Since $p <$ level of significance, – the null hypothesis H_0 should be rejected in favor of alternative hypothesis H_1.	
Homogenous groups (Duncan's test)	
Group I	weeks of storage 8, 10, 11, 9, 13, 12, 14, 15
Group II	weeks of storage 6, 7, 8, 10, 11, 9, 12, 13
Group III	weeks of storage 5, 3, 2, 1, 4, 6, 7, 8, 10, 11, 9
Note: Homogeneous groups at a significance level 0.05	

Results

The results of statistical analyses and that the time of storage can be divided into three principal periods. The average impact bending strength in the first five weeks of storage was relatively stable at approximately 0.135 ($J \cdot cm^{-2}$). The lowest impact strength of 0.125 ($J \cdot cm^{-2}$) was noted on storage weeks of storage 3 and 5. Beginning from week 6, the impact bending strength of the analyzed material increased by approximately 0.015 ($J \cdot cm^{-2}$). Average impact bending strength of 0.15 ($J \cdot cm^{-2}$) was maintained until week 11. From week 12 (experimental day 84) until the last week of the experiment (day 105), the analyzed parameter increased steadily from 0.16 to approximately 0.20 ($J \cdot cm^{-2}$).

The results of statistical analyses of dynamic shear values are shown in Table 2 and are represented graphically in Figure 5.

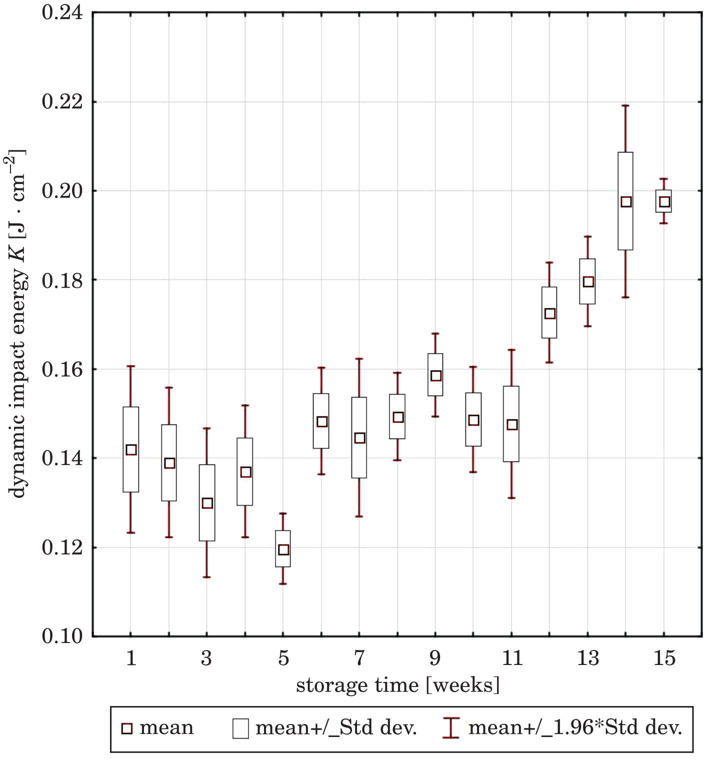

Fig. 4. The effect of storage time on the impact bending strength of potatoes cv. Irga

Table 2

The results of statistical analyses of the effect of storage time on the dynamic shear strength values of potatoes cv. Irga

Results of analysis of variance	
Value of F-statistics	$F = 5.8822$
Probability of exceeding F-statistics	$p = 0.0008$
Since $p <$ level of significance, – the null hypothesis H_0 should be rejected in favor of alternative hypothesis H_1.	
Homogenous groups (Duncan's test)	
Group I	weeks of storage 5, 9, 3, 11, 4, 6, 8, 15, 13, 14, 12
Group II	weeks of storage 9, 3, 11, 4, 6, 8, 15, 13, 14
Group III	weeks of storage 3, 11, 4, 6, 8, 15, 13
Group IV	weeks of storage 1, 2, 7, 10, 5, 9, 3, 11, 4
Note: Homogeneous groups at a significance level 0.05	

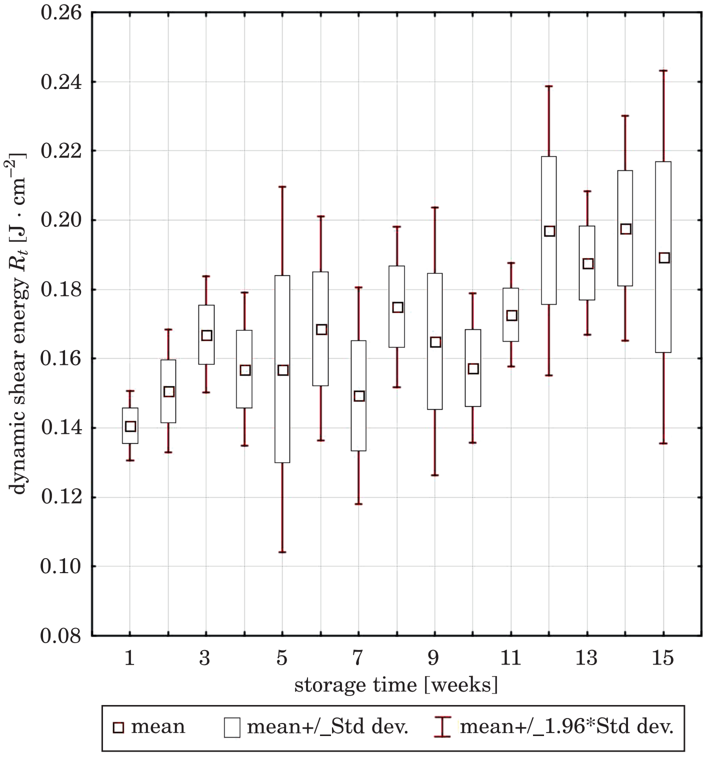

Fig. 5. The effect of storage time on the dynamic shear strength of potatoes cv. Irga

The results of statistical analyses and the observe correlations indicate that the average impact energy required for the dynamic shearing of tubers in the first 11 weeks of the experiment was not stable, with random variations in the estimated range of 0.14 to 0.17 (J · cm^{-2}). Between week 12 (day 84) until the end of the experiment (day 105), a clear increase in dynamic shear strength values was observed in the range of 0.19 ÷ 0.20 (J · cm^{-2}).

Conclusions

The designed test stand supports dynamic shear tests and impact bending tests of farm products in an environment which is similar to the conditions observed during the production of e.g. French fries and potato chips. The results of laboratory analyses performed on edible potatoes cv. Irga revealed fracturing of samples prepared from firm tubers (in the first weeks of the experiment) and deformations with damage of the stretched layer in older potatoes characterized by lower turgor pressure (in the last weeks of the experiment). The energy required to damage potato samples in impact bending tests and shear tests increased with a decrease in the turgor of potato tissue. The results of the analysis indicate that the developed test stand fulfilled experimental requirements. Further work is needed to investigate other farming products, such as root vegetables. The designed test stand should be modified to support calculations of dynamic mechanical damage values during harvest.

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