Slow loading compression of wheat (*triticum aestivum*) kernel

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Abstract
The aim of this study was to acquire data on the mechanical behaviour of three wheat varieties. Two hard wheat culivars and one soft grown under the same agroecological environment were tested on unuiaxial stress-starin compression properties. The maximum value of force at ultimate streinght point is 241.46 N (moisture content 13.3%) for Dragana, 244.30 N (seed moisture content 13.6%) and for NS 40S is 164.90 N at 43.3% of moisture content. The corresponding displacement at ultimate streinght points are 2.28 mm; 2.32 mm and 1.92 mm for Simonida, Dragana and NS 40S varieties. There are no linear correlationship of secant modulus of elasticities neither for hard wheat variteies, nor for soft one.

Key words: *wheat, stress-strain compression test*

Introduction

According to data from the Statistical Office of the Republic of Serbia (www.webrzs.staserb.gov.rs), in 2008, wheat was cultivated on 485,745 ha, and the gross production was 2,095,403 tons. This is the basic crop for the bread-making industry. There are several categories of wheat seed characteristics: mechanical properties relating to the reaction of seeds to stress such as hardness, cohesiveness, viscosity, elasticity or adhesiveness; geometrical properties that define the shape and size of seeds and other properties relating to moisture content, bulk and true density, porosity, thousand-kernel weight and the angle of repose (Mohsenin, 1980; Tabatabaeefar 2003). The stress-strain uniaxial compression test shows the response of biomaterials to an applied external force that deforms the body and induces a change in dimension, shape, or volume (Babić Lj. 2000; Babić Lj, 2001, Babić Lj. et al 2010). This test provides important information about elastic or plastic behavior. The stress-strain curve is a graphical measure of the mechanical properties of a biomaterial.

The stress is an external force (F) upon a cross section area (Ao) of the specimen. An important aspect is not the quantity of force, but rather that it is applied to a cross section area. This is the reason the specimen is a regular shape such as a cylinder or cube. The stress-strain diagram is a graphical presentation of the values simultaneously recorded for stress and strain. The typical shape of this curve is presented in Fig 1.

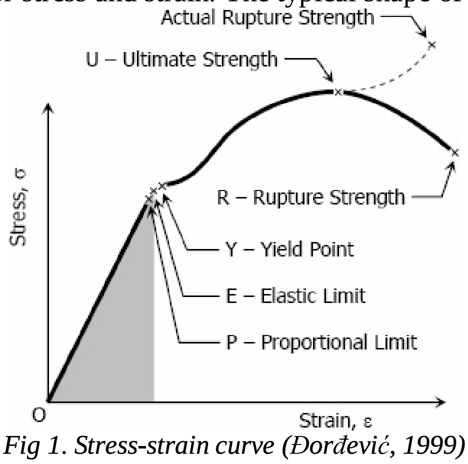

Fig 1. Stress-strain curve (Đorđević, 1999)

Wheat grain stress-strain behavior is a very important physical property in the assessment of kernel quality. The milling industry often uses this factor to classify wheat varieties as hard or soft. This hardness is mechanical property[17] which is useful for objective comparisons between different wheat varieties under varied environmental conditions. Therefore, the stress-strain mechanical properties of an individual wheat kernel will provide information about the changes in volume or dimension.

The objectives of this study were to provide new information describing this physical property of three new domestic wheat seed varieties. The stress-strain uniaxial compression test within wheat kernels as a function of seed moisture content is conducted to identify a correlation. The results of the study were statistically processed using STATISTICA for Windows version 9.0; and Microsoft Office Excel.

Material and methods

Three Serbian wheat seed cultivars were studied; two varieties, Simonida and Dragana, are hard wheat varieties; NS 40S is a soft wheat. These genotypes were grown at the same location and under the same agroecological conditions. The spike of the Simonida cultivar is white and smooth, is medium compact, has red grains and the quality subgroup is A-2. Dragana also has a white spike, absent awns, is moderately dense and belongs to quality subgroup A-1. Cultivar NS 40S has been submitted to the Commission for Varietals Approval. The samples were collected manually in the summer of 2010 from an experimental field approximately 8 km north of Novi Sad. Approximately 5 kilos of each variety were placed in plastic bags and delivered to the Faculty of Agriculture, Department of Agricultural Engineering laboratory. The seeds were manually cleaned to remove all foreign matter and broken and immature seeds. The specimen was divided into three groups that were adjusted to different moisture contents. The seeds were kept in sealed plastic bags and stored in the refrigerator at 4^0C for further use.

The slow loading compression test was performed with all three wheat varieties. Fifteen replicates were conducted for each variety and three different moisture contents for each variety were tested. Testing equipment consists of a loading cell and a PC with the manufacturer's software (Food Technology Corporation, TMS-PRO Texture measurement system). The trigger load was from 0.5 to 450 N. The constant deformation rate before contact with the specimen was 60 mm min^{-1} and during compression it was 30 mm min^{-1}. The range of the load applied by the measuring head was from 0 to 500 N. Each individual seed was placed on the lower plate of the machine such that the crease was in the contact with the bottom plate. The result of each test is presented as a table and as a curve of the force (N) at the ultimate strength point with the loading head displacement (mm) and time (s). The ultimate strength point work (J) was calculated by multiplying the ultimate strength force (N) with the head displacement value (mm). The secant modulus of elasticity Es (N/mm) is the ratio of strength point force F and machine head displacements (mean value- δ_H (mm)) for certain variety and moisture content. All statistical analyses were performed using Microsoft Office Excel.

Results and discussion

The results of the stress-strain compression tests for the wheat are presented in Figure 2. The force values measured at ultimate strenght points for the three wheat seed varieties are plotted as a function of the kernel moisture contents. As has been already emphasized, according to their genetic properties, Simonida and Dragana are hard wheat varieties and NS 40S is a soft variety. The stress-strain compression results confirm this. The measured force at the ultimate strength point varied according to seed moisture content within all the cultivars. The highest values for the ultimate strength forces were observed with the hard varieties at the lower values of moisture contents.

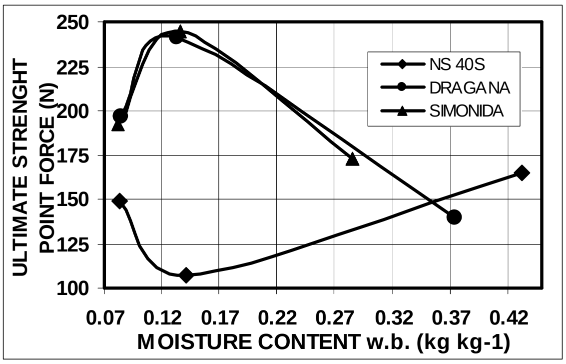

Fig 2 Uniaxial compression curves for three wheat varieties at differentkernel moisture contents.

A force of 241.5 N was recorded at the ultimate strenght point for Dragana (moisture content 0.133 kg kg^{-1}), a force of 244.4 N was recorded for Simonida (moisture content 0.136 kg kg^{-1}) and the force value of 106.8 N (moisture content 0.141 kg kg^{-1}) for the soft wheat cultivar NS 40S. Both hard wheat varieties showed that as the moisture content of seed increased, the force at the utimate strenght point decreased. These results correspond with the conclusions (Dziki, 2006) that higher grain moisture contents cause an increase in seed plasticity.

The opposite result was observed with soft wheat; at higher seed moisture contents, the force values at the ultimate strenght point increased. Similar behaviour has been reported by Saiedirad et al. (2008) and Dziki and Laskowski (2008) for whole wheat kernels during the stress-strain compression test. The results are also correlated with statements of Evers and Millar (2002) in the literature that this behaviour is likely due to larger volumes of air spaces within the soft endosperm, whereas hard endosperm regions have fewer air spaces. According to the same study, soft endosperm has a tendency to fracture randomly and produce irregular pieces, whereas vitreous endosperm produces particles with the starch granules still bound to the protein. It is possible that the differences in fragmentation between hard and soft endosperm are due to cell walls; hard wheat endosperm fragments consist of entire cells or fragments of cells with attached walls.

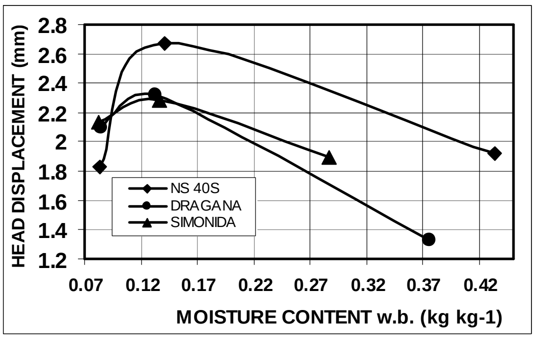

Fig 3 Head displacement versus kernel moisture contents.

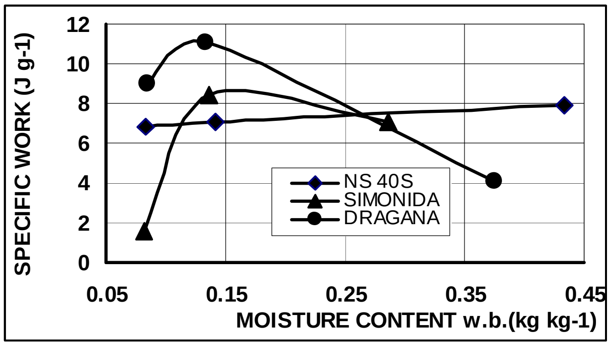

Fig 4 Specific work of three wheat varieties as function of kernel moisture contents.

The displacement of the apparatus head in the stress-strain compression test at the ultimate strenght point is a measure of the change in kernel depth. The results of this test within different seed moisture contents for the three wheat varieties are plotted in Figure 3. The highest value of head displacement is observed in the soft NS 40S variety, 2.67 mm at 14.1% seed moisture content. The head displacements for the hard wheat varieties (Simonida and Dragana) were in a narrow range at similar kernel moisture contents. Simonida's head displacement was 2.28 mm (at 13.6% moisture content) and Dragana's head displacement was 2.32 mm (at 13.3% moisture content). It can be concluded that as the kernel moisture content increases above the lower values, the head displacement decreases.

Specific work (J/per unit of mass) is an amoint of energy necassary to sqeeze the singl wheat kernel, plotted in Figure 4 for all varietis as a function of their moisture contents. The hard cultuvars Simonida and Dragana demontrate highest values of specific work at kernel moisture content around equilibrium values for continental climate. Those values decreasing in the other range of moistrure contents, whith lower and higher values. There were no significant correlation between these two physical properties. On the other side, soft wheat (NS 40S) shows linear correlation between specific work and moisture content of kernel as:

$$y=3.0181\,x + 6.609 \quad R^2=0.9966$$

The results of measurement statistically confirm with a moderate coefficient of regression that there is a linear relationship between the secant modulus of elasticity and seed moisture content only for Dragana variety (Figure 5). An equation is:

$$y=25.332\,x + 95.613 \quad R2=0.41$$

This linear model shows a pretty constant values of secant modulus of elasticity as the moisture content of the kernel increases. There is no such dependence for other hard cultivar (Simonida) or for soft one NS 40S. It is obvious that both hard varieties have high values of secant modulus of elasticity compare to the soft one. Those results indicate how much more energy reguire the milling process of hard wheat, comare to soft wheat. Slow loading uniaxial compression test also shows under drying of hard wheats for this purposes may be take into consideration.

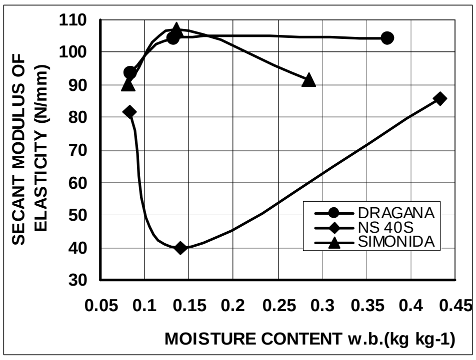

Fig 5 Secant modulus of elasticity of wheat varieties versus kernel moisture contents.

The difference between Dragana and Simonida and NS 40S wheat variety is in the dependence of the modulus of elasticity on moisture contents. This results from the ratio and spatial distribution of the floury and horny endosperm structure in the kernels (Stenvert, 1977; Saiedirad el al 2008). The mechanical properties of the kernel are affected by these two main structural components, their location and quantity, which is the result of the strain's genetic attributes. Thus, every genetically distinct "newborn" wheat variety produced by researchers is likely to show unique compressive loading behaviour.

Conclusion

The ultimate strenth point value of force in stress-strain uniaxial compression tests confirmed the differences in this property between the two hard varieties and the soft variety. The force value for the hard wheat at the ultimate strength point was almost 2.2 times higher than for soft wheat. Head displacement for the three cultivars was in a narrow range (from 2.28 to 2.67 mm) at equilibrium moisture contents. The graphical presentation of specific work at the ultimate strenght point and moisture content show peaks for the two hard wheat varieties, whereas the relationship is linear for soft wheat.

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