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STRESS RELAXATION CHARACTERISTICS OF WHEAT KERNELS AT DIFFERENT MOISTURE

Jawad AL Aridhee, Grzegorz Łysiak
Uniwersytet Przyrodniczy w Lublinie

Abstract. The study focuses on evaluation of the impact of moisture on the relaxation characteristics obtained through uniaxial compression of single wheat kernels. Polish soft wheat (c.v. Emika) at eight different moisture levels. i.e. 8, 10, 12, 14, 16, 18, 20, and 22% (wet basis) was used in the research. The experiments were made with the help of a Zwick Z020 universal machine. Individual wheat kernels were compressed with constant load value of 50 N between two flat plates. Relaxation time was equal to 300 seconds. Values of the relaxation decay parameter $Y_{(t)}$ were established for the determined relaxation time. Parameters k_1 and k_2 for the model presented by Peleg and Normand were also calculated. Compression work and deformation increased with the moisture rise from 5 to 25 mJ and 0.2 to 1.0 mm, respectively. An increase of kernels moisture caused the load at relaxation time as well as the decay parameter $Y_{(t)}$ to decrease. The values at 22% moisture were more than two times lower that corresponding 8% water level. Coefficients k_1 and k_2 decreased from 3.5 to 1.5, and from 53 to 13, respectively. A linear relation between the two model coefficients was observed. The impact of kernel moisture on the analyzed parameters was described in the form of regression equations.

Key words: wheat, moisture, relaxation, rheological characteristics

INTRODUCTION

The way in which a material reacts to the mechanical loading is closely related to its structure. Hence, studies on rheological phenomena, which are used to be more frequently carried out with the help of relaxation test, are very useful for identification of its state and behavior through processing [Lewicki and Łukaszuk 2000, Lewicki and Jakubczyk 2004, Telis-Romero et al. 2004, Brujić et al. 2005]. They can be used for the fragmentation process, because nature and extent of the damage depends on several

Adres do korespondencji – Corresponding author: Grzegorz Łysiak, Katedra Eksploatacji Maszyn Przemysłu Spożywczego, Uniwersytet Przyrodniczy w Lublinie, ul. Doświadczalna 44, 20-236 Lublin, e-mail: grzegorz.lysiak@up.lublin.pl

mechanical and rheological characteristics of the grains [Cespi et al. 2007, Hernández et al. 2012]. They are also relevant for material quality measurements including interactions to textural sensory attributes [Lewicki and Spiess 1995, Lewicki and Wolf 1995, Bhattachary et al. 2006]. Figueroa et al. [2012] underline its potential for selecting wheat quality, however, more extensive testing is required to be more conclusive [Figueroa et al. 2012].

Stress relaxation represents the value of stress necessary to keep the strain in a material at a constant level. In the case of biological material, the rheological characteristic depends on a lot of factors, like the level and rate of deformation, moisture, and temperature [Bargale et al.1995, Lewicki and Wolf 1995, Khazaei and Mann 2004, Lewicki 2004]. Mechanical properties are often being determined for small strain levels [Karim et al. 2000], however in real processing condition, large deformations (beyond the elastic region) occur resulting to expected material rupture. Peleg and Normand [Steffe 1996] approved that a material subjected to a large deformation usually shows nonlinear viscoelastic behavior, thus a different analysis than in the range of linear elastic deformation is necessary. To approve this, they suggest stress data to be calculated as normalized stress (normalized force is also acceptable).

The research undertaken by the author constitutes a part of studies on the interfaces between material properties and their grinding susceptibility. Hence, the objective of the study was to examine the influence of wheat kernels moisture on their rheological characteristics.

MATERIAL AND METHODS

Material and sample preparation. A Polish variety of wheat (cv. Emika) was used in the studies. The initial moisture content of a batch sample of seeds was determined applying the air oven method. For that, three 5 g samples of kernels were dried for over 3 hours at the temperature of 130°C, in accordance with the Polish Standard PN-86/A74011.

Eight varied levels of kernel moisture content, i.e. 8, 10, 12, 14, 16, 18, 20 and 22% (wet basis) were assigned in the experimental plan. To obtain the levels the batch of known weight and moisture was dried at 40°C until its weight corresponding to 8% of water level was achieved. The batch was then divided into (eight) smaller samples and to each of them, the amount of required water was added. These water amounts were calculated according to simple mass balance equations. The watered samples were stored over 48 hours before mechanical testing.

Measurement of mechanical characteristics. Mechanical testing was carried out with the help of a universal machine Zwick Z020. Akernel was placed with its ventral side on the bottom machine plate and then loaded axially up to 50 N – the constant force value. The constant compression rate during the loading at 10 mm/min was adjusted. The corresponding kernel deformation was held constant for 300 seconds period. For each individual kernel force-deformation characteristics were registered with the help of test Xpert software by Zwick. The experiments were done in 10 replications for each of the moisture levels. On the basis of the force-deformation curves the following were determined:

– deformation up to 50 N load, in mm (L_{50}),

– compression work up to 50 N load, in J (W_{50}),

– decay parameter $Y(t)$ according to the following equation [Lewicki and Spiess 1995, Lewicki and Wolf 1995, Bhattacharya et al. 2006]:

$$Y(t) = \frac{F_0}{F_0 - F_t} \tag{1}$$

where: F_o – maximum loading force at time $t = 0$ in (N),
F_t – force at relaxation time t (N), t – time of relaxation (s)

and

– constants k_1 and k_2 for the model presented by Peleg and Normand (eq. 2) [Steffe 1996]:

$$Y(t) = \frac{F_0 t}{F_0 - F_t} = k_2 + k_1 t \tag{2}$$

The reciprocal of k_2 determines the initial decay rate and k_1 is the hypothetical value of the asymptotic normalized force [Steffe 1996, Bhattacharya et al. 2006]. The constants were obtained by fitting the experimental data to the above formula applying Excel software.

Statistical analyses. Statistical analyses were done with the help of Statistica software by Statsoft (USA). The significance level 0.05 was used for testing statistical hypotheses.

RESULTS AND DISCUSSION

A change of the kernel moisture caused significant differences in its mechanical response. The increased moisture resulted in higher deformations corresponding to the maximum load established at 50 N. This deformation changed from 0.19 to 1.0 mm (fig. 1). The highest increase of the deformation was observed beyond 14% of moisture level. For its lower values the means were not statistically significant. The corresponding relation was described by means of a square polynomial equation with high determination coefficient ($R^2 = 0.786$).

Similar observations were made for inputs of compression work necessary to achieve the assigned load level (fig. 2). The work changed from about 4.5 to 25 mJ. The highest increase of this parameter was characteristic above 14% of moisture level. Below this, slight differences were only observed. The corresponding relation was also polynomial ($R^2 = 0.792$).

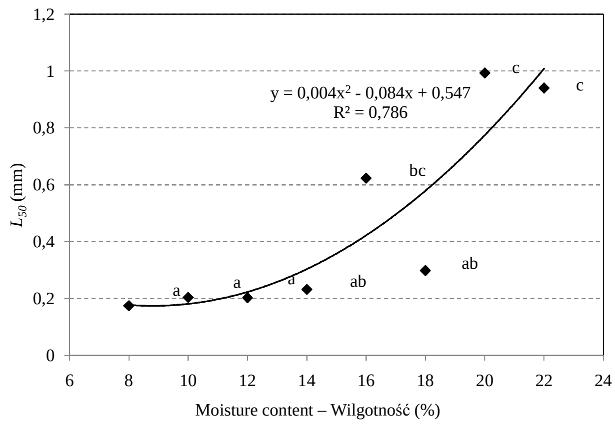

Fig. 1. Deformation of wheat kernelin relation to the moisture (at 50 N load)
Rys. 1. Odkształcenie ziarna pszenicy w zależności od wilgotności (obciążenie 50 N)

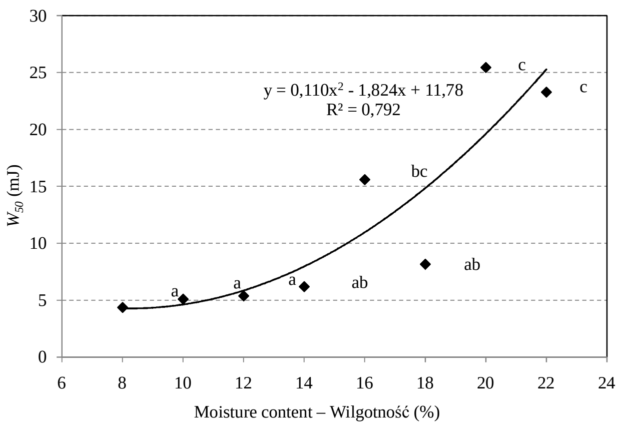

Fig. 2. Compression work of wheat kernelin relation to the moisture (up to 50 N load)
Rys. 2. Praca zgniatania ziarniaka pszenicy w zależności od wilgotności (obciążenie 50 N)

A change in the kernel moisture caused significant differences in the obtained relaxation spectra. Examples of them at different water content levels are presented in Figure 3. It was well noticeable that: 1) at the initial relaxation stage the speed of force relaxation increased with the rise in wheat moisture; 2) the share of the relaxed force increased with water content. The highest value of residual force was achieved at 8% of moisture, while the lowest at 22%.

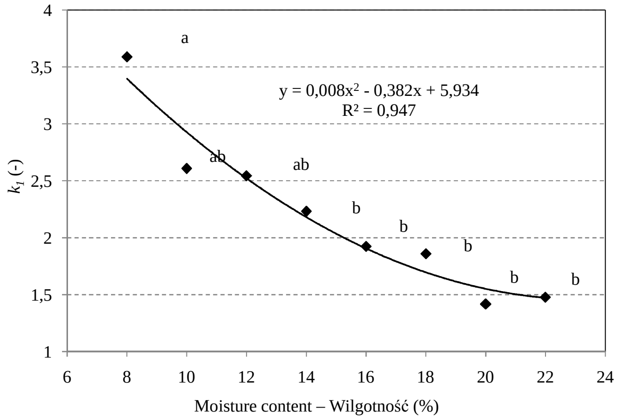

Fig. 3. Examples of relaxation characteristics ofwheat at different moisture
Rys. 3. Przykłady krzywych relaksacji ziarna pszenicy o różnej wilgotności

It was observed that the increase in kernel moisture caused the constants k_1 and k_2 to decrease from 3.5 to 1.5, and from 53 to 13, respectively. This shows that the speed of stress relaxation, which is represented by reciprocal of k_1 increased with moisture. Higher values of k_1 are characteristic for kernels at lower moisture levels. As can be seen from Figure 4 the increase in moisture was followed by lower changes of this parameter. A square equation at a very high determination coefficient (R^2 = 0.947) was used to describe the analyzed influence of water content (fig. 4).

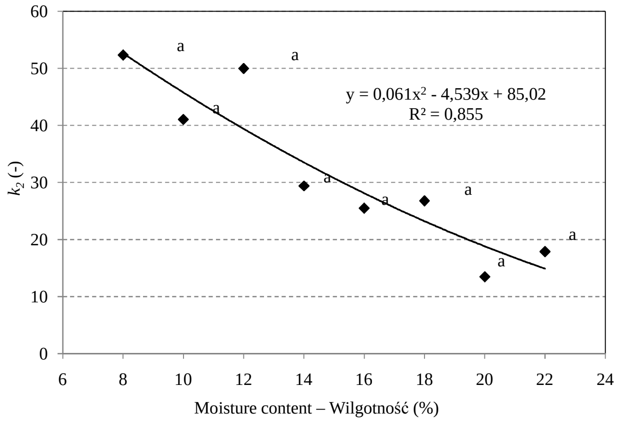

Fig. 4. Influence of wheat moisture on parameter k_1 (according to the model of Peleg and Normand)
Rys. 4. Wpływ wilgotności ziarna pszenicy na wartości współczynnika k_1 (według modelu Pelega i Normanda)

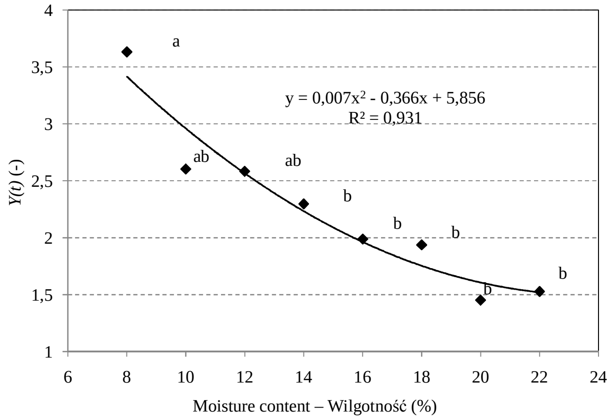

Fig. 5. Influence of wheat moisture on parameter k_2 (according to the model of Peleg and Normand)
Rys. 5. Wpływ wilgotności ziarna pszenicy na wartości współczynnika k_2 (według modelu Pelega i Normanda)

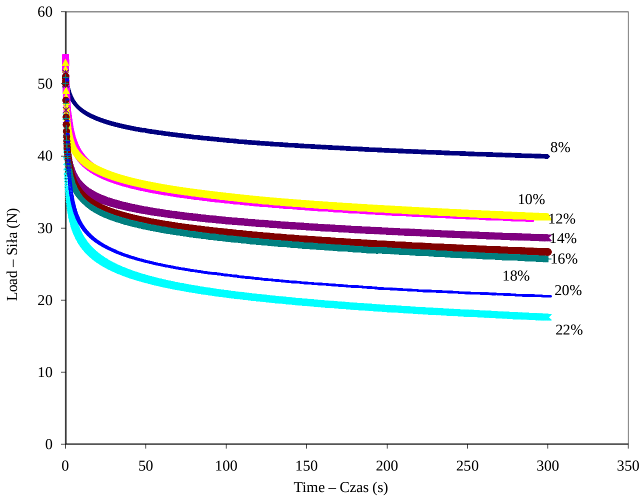

Fig. 6. The dependence of the decay parameter *Y(t)* to the moisture of wheat kernels
Rys. 6. Zależność parametru *Y(t)* od wilgotności ziarna pszenicy

The impact of kernels moisture on values of k_2 is presented in Figure 5. The relatively fast decrease rate of the parameter observed at low moisture levels was diminished for kernels at moisture beyond 14%. This was confirmed by statistical comparisons of means with a help of Tukey test. Two homogenous groups were distinguished (fig. 5). As previously a square equation at $R^2 = 0.855$ was used to describe the corresponding relation (fig. 5).

The decay parameter *Y(t)* changed in the similar range like the coefficient k_1. It was noticed that the values of the parameter decreased with the increase in kernel moisture from 3.5 to 1.5 (fig. 6). The impact of the kernel moisture was described by means of a square polynomial equation presented in Figure 6. It is necessary to note that for all the constants the relations in function of moisture were close to proportional, however the second degree equation better correspond both to the experimental data and expectations. According to equation (1), the decay parameter *Y(t)* tends to infinity for kernels at lower moisture, hence when the force at relaxation time (F_t) is higher. It is additionally caused by little changes of mechanical properties of wheat at low moisture levels.

CONCLUSIONS

1. There was found a positive relationship between moisture of wheat kernels and the deformations up to 50 N, and corresponding energy inputs. Any increase of water level causes these parameters to increase. The higher increase was observed for raised moisture levels.

2. It was observed that the increase of wheat moisture caused the value of residual force (not relaxed) to decrease.

3. The decrease in the coefficients k_1 and k_2 of the model presented by Peleg and Normand due to moisture rise was observed.

4. Observed influence of moisture content on relaxation characteristics was statistically confirmed. However, the lack of differences between means (in some cases) is caused by large variability of results. To overcome this an increased number of replications is necessary.

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CHARAKTERYSTYKI RELAKSACJI NAPRĘŻEŃ ZIARNA PSZENICY O ZRÓŻNICOWANEJ WILGOTNOŚCI

Streszczenie. Celem pracy była ocena wpływu wilgotności ziarna pszenicy na charakter krzywych relaksacji uzyskanych w teście osiowego ściskania. Do badań użyto ziarna polskiej pszenicy zwyczajnej odmiany 'Emika' o wilgotności od 8 do 22%. Pomiary zrealizowano na maszynie wytrzymałościowej Zwick Z020. Pojedyncze ziarna pszenicy obciążano pomiędzy dwiema płaskimi płytami do stałej wartości siły 50 N. Czas relaksacji wynosił 300 s. Wyznaczono wartości parametru *Y(t)* w przyjętym czasie relaksacji. Określono również parametry k_1 i k_2 dla modelu przedstawionego przez Pelega i Normanda. Wraz ze wzrostem wilgotności ziarna zwiększały się praca zgniatania (od ok. 5 do 25 mJ) i wartość odkształceń ziarna (od 0,2 do 1.0 mm). Przyrost udziału wody w ziarnie powodował spadek zarówno średniej wartości siły po pięciominutowym czasie relaksacji, jak i wartości parametru relaksacji *Y(t)*.Wartości te dla wilgotności 22% były ponad dwukrotnie niższe niż ustalone na poziomie 8%. Stałe k_1 i k_2 spadały od 3,5 do 1,5 i od 53 do 13, odpowiednio. Wpływ wilgotności ziarna na analizowane parametry opisano w postaci równań regresji.

Słowa kluczowe: pszenica, wilgotność, relaksacja, charakterystyki reologiczne