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INFLUENCE OF MOISTURE CONTENT ON THE STRESS RELAXATION RESPONSE OF AMARANTH SEEDS*

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A b s t r a c t. In the present study relaxation test was used to evaluate the influence of moisture content of amaranth seeds on their mechanical parameters. The first approximation was to assumed linear viscoelasticity of the studied material. A generalised Maxwell model was suggested for the description of seeds reaction to loading. The model took into consideration relaxation that appeared during preliminary deformation. Relation between seed moisture content and the parameters of the model, energy and maximum deformation was considered. Significant differences were found in the course of stress relaxation of the samples in the studied moisture range (9.5-34.8%). A strong influence of moisture content on both energy and maximum deformation was observed in the first phase of the test.

K e y w o r d s: amaranth, stress relaxation, viscoelasticity

INTRODUCTION

Amaranthus cruentus has been known as a plant for breeding since prehistoric times. The family of *Amaranteaceae* consists of about 60 species that can be found on the vast areas of Central and South America, Africa, India, China, and Russia. Valuable properties of these plant made it the subject of numerous research work, and gave it the name of the cereal plant of the coming century. Its main advantages are, first of all, the content of high quality protein that is higher than in cereals and high content of calcium and iron. On the other hand, its lack of gluten content makes it a very useful component of special diets. The content of tocotrienols and squalene in the amaranth seeds makes them useful in the pharmaceutical, chemical and electronic branches of industry.

The above mentioned amaranth properties gave incentive to start studies on the possibilities of amaranth breeding in Poland a few years ago. The natural consequence was to start studies on the harvest technology, after-harvest preparation, and seed storage. In order to do that it became necessary to get to know a lot of mechanical properties of the seeds en masse in the full range of moisture contents that are physiological for them.

Relaxation of stresses is a widely accepted and applied method of determining mechanical features of plant materials. Plausibility of this test has been confirmed by its numerous applications such as: evaluation of maturity, varietal differentiation, determination of resistance to mechanical damage, and suitable conditions for storage, as well was general quality evaluations.

Plant products, not only fruit but also vegetables and grains en masse show viscoelastic properties [1,2,5]. In the present work stress relaxation test was used for the evaluation of the moisture influence on the mechanical parameters of the seeds. Linear viscoelasticity of the amaranth seeds en masse was taken as the first approximation.

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The aim of the present experiment was to determine the course of the value of reaction force as the function of time for the samples placed in a steel cylinder and loaded uniaxially. A generalise Maxwell model was used to the construction of the seed mass model. The model takes into consideration the relation between seed moisture level and the parameters of the model, as well as energy, stress, and deformation at the moment when the plug deforming the sample is stopped.

MATERIALS AND EXPERIMENTAL METHODS

The studied seeds were collected from the field experiment of the Institute of Agrophysics in Lublin. The highest preliminary moisture level was 38.4%, i.e., seed moisture immediately after combine harvesting. Lower moisture levels were obtained by drying seeds that were spread in a thin layer in a well-aired room. Seeds were collected for further testing at a set time intervals. Prior to tests moisture level was checked by means of a drier method.

In the compression and stress relaxation tests, the seeds were placed in a steel cylinder with a diameter of 50 mm. The volume of samples was constant and equal to 250 cm^3. The bottom part of the container had some air outlets. The samples were axially compressed by the spacer plug at the rate of 1.16 mm/s by means of an Instron apparatus model 6022. After the pressure of 100 kPa had been reached, the movement of the plug was stopped and the force of reaction decreasing in time was recorded for 300 s.

Due to the high range of moisture levels of the studied material, high differences in the duration of the initial deformation periods prior to the relaxation test appeared. The values ranged from 2 to 20 s. This situation had to be taken into consideration in the mathematical description of stress relaxation already at the stage of compression that was different for the seed samples with different moisture contents. Chen and Fridley's procedure [3], which uses the relaxation modulus as defined by Ferry [4] was applied. For a linearly viscoelastic body the relaxation modulus is the relaxation stress divided by the value of deformation applied in the time period equal to zero:

$$Y(t) = \frac{\sigma_r(t)}{\varepsilon_o u(t)} \quad (1)$$

where $u(t)$ is the unit step function, ε_0 - relative deformation, σ_r - stress relaxation, $Y(t)$ - relaxation modulus.

By analogy between elastic and viscoelastic bodies [1,6], the reaction force of the viscoelastic material can be described by the following:

$$F(t) = f(\lambda_0)\, Y(t) \quad (2)$$

where $f(\lambda_0)$ is function depending on the sample geometry and deformation resulting from the step function.

For the description of the phenomenon of stress relaxation in the amaranth seed mass a generalised Maxwell model with three elements was applied. A model of the reaction force in the form stated below was obtained after the size of the studied samples and the course of initial deformation was taken into consideration:

$$F(t) = \frac{aS}{l_o} \sum_{i=1}^{3} \frac{E_i}{\alpha_i} \left(1 - e^{-\alpha_i t_x}\right) e^{-\alpha (t - t_x)} \quad (3)$$

where a is velocity of initial deformation, E_i, α_i - parameters of the assumed model, l_o - initial sample height, S - cross-section area of the cylindrical sample, t_x - time period of the initial deformation.

The above equation takes into consideration inaccuracy of the actual realisation of the step function by calculating stress relaxation already during initial deformation.

Curves describing relations between sample reaction force and time were obtained as the result of the present experiment. They have been approximated in the following way:

$$F(t) = \sum_{i=1}^{3} A_i e^{-\alpha_i t} \quad (4)$$

where A_i, α_i are parameters of the approximating function.

Parameters E_i and α_i of the Maxwell's model were obtained by comparing Eqs (3) and (4) that were used for the description of the studied samples.

RESULTS AND DISCUSSION

Considerable differences in the course of stress relaxation in relation to moisture levels were found in the present experiment. Samples with moisture content between 34.8 and 15% showed an abrupt decrease of the reaction force in the first few seconds after preliminary deformation. This course of relation between force and time was more fluid-like. A decidedly higher value of the elasticity remained for the samples with moisture content below 15% proved that the studied material was acquiring the properties of a solid body - Fig. 1.

Strong relation between the E_i parameters of the assumed model and moisture were noted - Fig. 2. At the same time, relaxation times t_i for the individual sections of the model were independent of moisture - Fig. 3. Unchangeability of the relaxation times proved a decrease in the values of dynamic viscosity in the assumed model with the increase in the moisture content. A strong dependency on moisture was exhibited by the remaining parameters determined in the experiments, such as: energy of deformation and maximum deformation - Figs 4 and 5. Ten-fold decrease in the value of sample deformation in the studied moisture range at the constant velocity of loading meant a 10-fold decrease of the time value of preliminary deformation. The above phenomenon justifies the application of

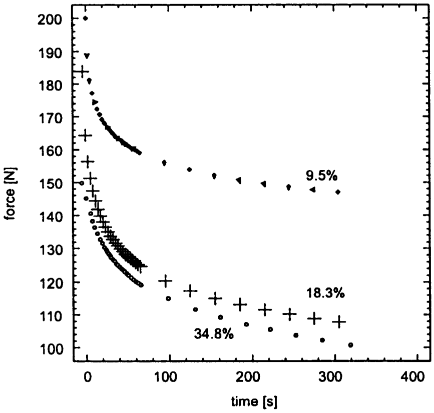

Fig. 1. Force-time response for three different moisture contents of samples.

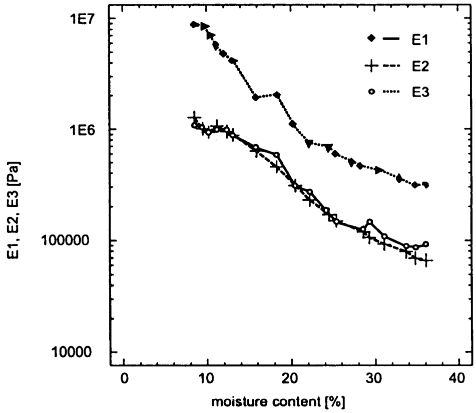

Fig. 2. Parameters of three elements Maxwell model for moisture content within the range used in the experiment.

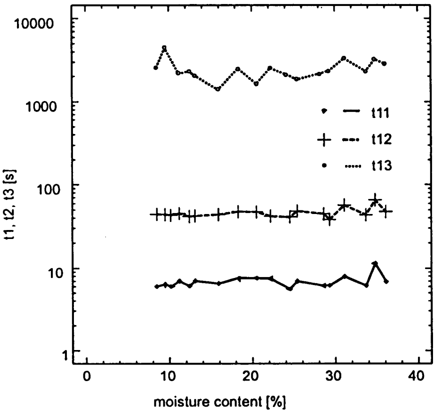

Fig. 3. Relaxation times of the three elements Maxwell model for the moisture content within the range used in experiment.

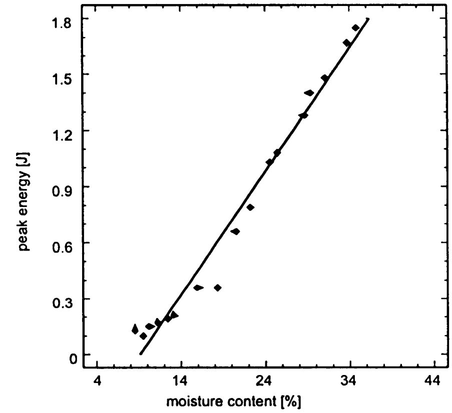

Fig. 4. Influence of moisture content on peak energy of amaranth seeds sample during experiment.

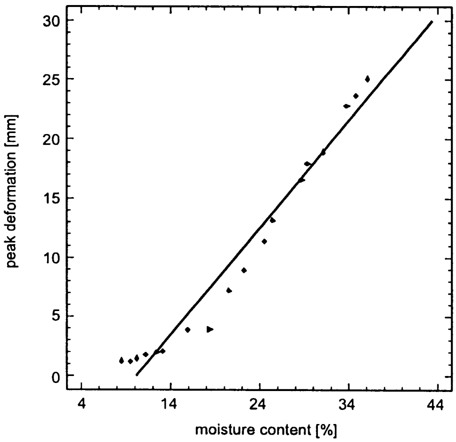

Fig. 5. Influence of moisture content on peak deformation of amaranth seeds sample during experiment.

mathematical procedure taking into consideration relaxations that took place already in the preliminary sample deformation.

The experimental results showed a strong dependency between the energy and the value of deformation at the peak on the one hand, and sample moisture level on the other. The E_i parameters related to the elasticity of the model were correlated with the moisture level to a lesser degree.

The results obtained showed high variation of the studied material and the necessity for a very precise determination of the range of parameters qualifying seeds for further technological processing.

CONCLUSIONS

1. Amaranth seed en masse exhibit prominent viscoelastic properties.

2. Significant differences in the course of stress relaxation was found in the studied moisture range. The differences consisted in the decrease of the elasticity parameters E_i and viscosity E_i/α_i of the assumed model to such a degree that the values of the relaxation time $1/\alpha_i = t_i$ remained at the same level.

3. Parameters, such as energy of preliminary deformation and the value of maximum deformation, that were related to sample compressing preceding proper relaxation tests were the ones that reacted to the moisture changes the strongest.

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