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Influence of high and low molecular weight glutenins on stress relaxation of wheat kernels and the relation to sedimentation and rheological properties

Z.J.E. Hernández [a], J.D.C. Figueroa [a,*], P. Rayas-Duarte [b], H.E. Martínez-Flores [c], G.V. Arámbula [a], G.B. Luna [a], R.J. Peña [d]

[a] Centro de Investigación y de Estudios Avanzados (CINVESTAV-IPN), Libramiento Norponiente 2000, Fracc. Real de Juriquilla, Querétaro, C.P. 76230 Qro., Mexico
[b] Robert M. Kerr Food & Agricultural Products Center, Oklahoma State University, 123 FAPC, Stillwater, OK 74078-6055, USA
[c] Universidad Michoacana de San Nicolás de Hidalgo, Tzintzuntzan 173, Col. Matamoros, Morelia Mich., Mexico
[d] CIMMYT, km 45, Carretera México Veracruz, El Batán, Texcoco, C.P. 56130, Mexico

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The stress relaxation behaviour of 36 bread wheat kernel lines was studied using the generalized Maxwell model with 4-exponential terms. The data suggested four relaxation phases, two fast phases at shorter times of 1–10 s (τ_1 and τ_2) and two slow phases with longer times of ≈50–450 s (τ_3 and τ_4). The stresses were mainly correlated with kernel mechanical properties. There were differences in spring and stress elements of *Glu-A1* null compared to *Glu-A1* 1 and 2*. The *Glu-B1* and *Glu-D1* showed differences in the stresses. *Glu-A3* only affected kernel mechanical properties while *Glu-B3* showed differences in both quality parameters and mechanical properties. The relaxation times τ_3 were high for genotypes with high SDS-sedimentation volume and long mixing time. Genotypes with 45–60 s of τ_3 usually had good HMW-GS background and LMW allelic combination generally associated with good quality. As expected, genotypes with short relaxation and mixing times and poor sedimentation volume were samples with *Glu-A1* null, *Glu-B3 j* 1B/1R, and with *Glu-A3 e* (null). Differences in stress relaxation were found among HMW-GS and LMW-GS alleles specially *Glu-3* loci and the differences were related to SDS-sedimentation, mixing and alveograph data.

1. Introduction

Wheat gluten proteins are aggregates of high molecular weight- and low molecular weight-glutenin subunits (HMW- and LMW-GS, respectively) and gliadins (prolamins). Several studies have indicated that glutenins exhibit the unusual property of being viscoelastic when hydrated and are responsible for the rheological properties of wheat flour doughs and the quality of bread. Recent reports on the viscoelasticity of wheat kernels with limited amount of water can be found in the literature (Figueroa et al., 2009, 2011a, b; Maucher et al., 2009; Ponce-García et al., 2008). However, despite considerable research done in the past to study the rheological properties of HMW- and LMW-GS of wheat, basic information and data on mechanical and viscolelastic aspects of these glutenin subunits in wheat kernels is very limited (Figueroa et al., 2011c).

Wheat grains, like all other grains, are subjected to a series of static and dynamic loads during harvesting, handling, transport, processing, storage, conditioning and milling. Such loadings cause significant damage to the grains which lead to a decrease in the intrinsic quality associated with specific HMW- and LMW-GS composition and an increase in susceptibility to deterioration during storage. The nature and extent of the damage depends on several mechanical and rheological characteristics of the grains due to the influence of HMW- and LMW-GS composition together with the forces or loading conditions to which grain kernels are subjected. It is, therefore, important to study the mechanical and viscoelastic properties of grains such as the modulus of elasticity, compressive strength and stress relaxation.

The mechanical behaviour of cereals has been found to be time dependent. Viscoelastic materials exhibit stress relaxation phenomena, which are some of the most important factors in characterizing agricultural materials. The measured relaxation time shows how fast the material dissipates stress after receiving

Abbreviations: CIMMYT, International Maize and Wheat Improvement Center; *E*, elastic modulus; GS, glutenin subunits; HMW, high molecular weight; LMW, low molecular weight; SDS, sodium dodecyl sulfate; *W*, work; W_e, elastic work; W_p, plastic work; σ, stress; τ, relaxation time.

* Corresponding author. Tel.: +52 (442) 211 9915; fax: +52 (442) 2119938.
E-mail addresses: jfigueroa@qro.cinvestav.mx, juanded@okstate.edu (J.D.C. Figueroa).

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a sudden deformation. Mechanical damage to agricultural products usually results from compressive loads, thus more data can be found for compression than for tensile tests (Mohsenin, 1986).

In stress relaxation tests, a constant strain is applied and the stress required to maintain the deformation is measured as a function of time. When a stress relaxation test is performed, different behaviours can be observed: ideal elastic materials do not relax whereas ideal viscous materials instantaneously show a relaxation. Viscoelastic solids gradually relax and reach an equilibrium stress greater than 0, whereas for viscoelastic fluids, the residual stress would be zero (Del Nobile et al., 2007; Steffe, 1992).

The Maxwell model, consisting of a Hookean spring and a Newtonian dashpot in series (Mohsenin and Mittal, 1977), is suitable for understanding stress relaxation data, but does not consider the equilibrium stress. For this reason, the viscoelastic behaviour of food can be better described by using a generalized Maxwell model consisting of several elements in parallel with a spring (Steffe, 1992). In a similar model, if the system is subjected to a constant strain, the total stress is the sum of the stress of each element.

Studies by Figueroa et al. (2011a) have shown that the viscoelastic behaviour of wheat kernels can be represented by a generalized Maxwell model. This methodology has proven successful in detecting changes in wheat dough (Matsumoto et al., 1974, 1975) and corn tortilla and masa as a function of time and temperature (Guo et al., 1999). Bargale and Irudayaraj (1995) indicated that a three-term Maxwell model was suitable for describing the stress relaxation behaviour of barley kernels. Several authors (Hassan et al., 2005; Nussinovitch, et al., 1989) studied three stress relaxation terms, namely the generalized Maxwell to fit the experimental data. They indicated that the generalized Maxwell was the best in predicting experimental data.

The present study was therefore conducted with the following specific objectives: (1) to determine the effect of HMW-GS and LMW-GS on the modulus of elasticity, stress relaxation and quality related to SDS-sedimentation volume and mixing data; and (2) to describe the stress relaxation behaviour of wheat kernels when subjected to strain.

2. Experimental

2.1. Plant materials

Thirty-six wheat lines grown by CIMMYT in Sonora, Mexico during the crop cycle 2006–2007 were studied. The sodium dodecyl sulfate-polyacylamide gel electrophoresis (SDS-PAGE) protocol described by Singh and Shepherd (1988) with some modifications indicated by Peña et al. (2004) was used to determine HMW-GS and LMW-GS composition.

2.2. Physical and chemical properties of the various wheat groups

Moisture content was determined by Approved Method 44-15A (AACC Itl 2000). Kernel thickness which represented the highest point of the dorsal part of the grain was measured using a Mitutoyo model CD-6" CS digital caliper (Mitutoyo Corp. Japan). Analyses were done at least in duplicate.

2.3. Flour quality tests

Grain samples were milled into flour in a Brabender Sr. flour mill (C. W. Brabender Instruments, Inc., South Hackensack, NJ). Refined flour was evaluated for SDS-sedimentation according to Peña et al. (1990), dough mixing time in the Mixograph and dough strength (*W*), tenacity, and tenacity/extensibility (*P*/*L* ratio) in the Alveograph according to AACC methodology (54-40A and 54-30A, respectively, AACC Itl 2000).

2.4. Uniaxial compression test

A Texture Analyzer TA-XT2 (Texture Technologies Corp., Stable Micro Systems, Surrey, England) was used to measure the kernel response to compressive loadings using a stainless steel probe TA-510 (10 mm dia.). Kernel samples were placed in a controlled temperature chamber (20 °C) 24 h before the analysis to reduce variance in the measurements. The contact (load-bearing) area of individual kernels during the loading process was determined as follows: individual kernels were slightly pressed on an ink pad and placed crease down in the instrument base. Pieces of bond paper (30 × 30 mm) were placed onto the top of the kernel to record the ink impression of the contact surface of the grain during loading (Ponce-García et al., 2008). The image of the ink impression was digitalized and the area was calculated using ImageJ software (National Institutes of Health). The image analysis reported by Ponce-García et al. (2008) used a scanned picture of the kernel contact area which had challenges including all faint gray regions on the boundary of the bearing area. If this area is not properly accounted for, it will overestimate the modulus of elasticity. In this study, black and white scanned images and black and white threshold were used which improved the accuracy of area measurements.

Settings in the Texture Analyzer were as follows: the load-deformation was recorded from the surface of the wheat kernel and ended after the probe had traveled 0.5 mm (compression), and the clearance was 4 mm. The data was collected using 25 points per second with a loading rate of 0.1 mm/s which is the minimum rate of the Texture Analyzer TA-XT2 equipped with a 25,000 g load cell. Averages were reported from 6 independent kernels per genotype.

2.5. Stress relaxation test

In order to describe the viscoelastic behaviour of a wheat kernel, a massless mechanical generalized Maxwell model was used with the attempt to describe the experimental behaviours to the molecular level events. This model is composed of springs (considered ideal solids, they account for the elastic behaviour of viscoelastic materials) and dashpots (representing ideal fluids, they account for the viscous behaviour) combined in many different ways (Fig. 1).

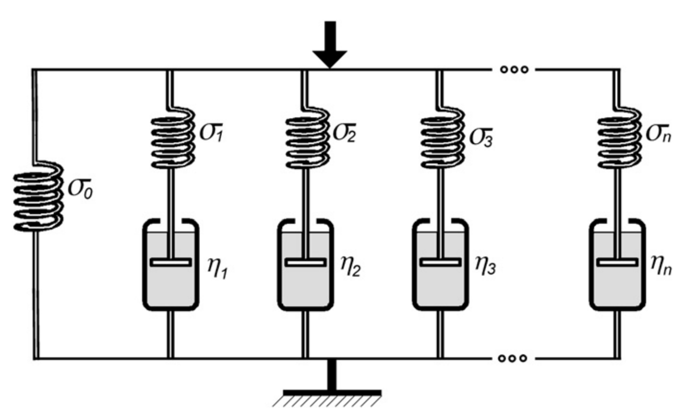

Fig. 1. Representation of the generalized Maxwell model consisting on a single spring constant (σ_0) in parallel to *i*th Maxwell element models of dashpots (η_1 to η_n) accounting for the viscous behaviour and springs (relaxation constant σ_i) for the elastic behaviour.