Rheological Behavior of Undeveloped and Developed Wheat Dough

DANILO T. CAMPOS,[1] JAMES F. STEFFE,[1,2,3] and PERRY K. W. NG[3]

ABSTRACT

Cereal Chem. 74(4):489-494

Undeveloped wheat dough is essentially wheat flour that has become fully hydrated without being deformed. The rheological properties of this material were compared to dough (developed dough) made using the standard method involving a farinograph. Flow behavior of undeveloped and developed dough samples made from hard and soft wheat flours were tested using creep tests, frequency sweep oscillatory tests, and temperature sweep oscillatory tests. All experiments showed that the undeveloped dough requires less resistance for deformation than developed dough. The differences are due to the energy input received by the developed dough and the influence of this factor in forming the protein matrix associated with developed dough. To attain a comparable state as the dough made in the farinograph, an energy input must be applied to the undeveloped dough material. Understanding the differences between undeveloped and developed dough may lead to new products, equipment, and processes in the bakery industry.

Traditionally, dough is made by combining flour, water, and energy through mixing. The addition of sufficient mechanical energy provides the distribution and hydration of flour particles, allowing the formation of a continuous protein matrix (holding starch and other components). The dough thus formed, a developed dough, has a unique viscoelastic behavior (Schofield and Scott Blair 1932) which is a result of the complex reactions between the sulfhydryl (S-H) and disulfide (S-S) bonds found in gluten (Eliasson and Larsson 1993). Undeveloped dough is a homogeneous, fully hydrated wheat flour where the energy input phase of dough development has not been initiated (Campos et al 1996).

The rheological characterization of wheat flour dough is essential. It gives valuable information concerning the quality of the raw materials, the textural characteristics of the finished products and properties needed for the design and development of new equipment. Published literature on dough rheology is very extensive, and various summaries have been published in recent years (Faridi 1985; Bushuk 1985; Faridi and Faubion 1986, 1990; Bloksma and Bushuk 1988; Castell-Perez and Steffe 1992). Typically, methods used to evaluate dough rheological behavior are classified as empirical, imitative (descriptive), and fundamental (Menjivar 1990). Investigations on flour and dough characteristics (Swanson and Working 1933, Bloksma 1957, D'Appolonia 1984, Casutt et al 1984) have been conducted using traditional instruments (e.g., farinograph, mixograph, alveograph, extensigraph), which provided practical information for the bakery industry.

Many dough studies have also been conducted (Schofield and Scott Blair 1933, Launay and Bure 1973, Sharma 1990, Amemiya and Menjivar 1992) using basic rheological procedures (steady shear, creep, stress relaxation, extension, and dynamic tests). Results indicated that dough development is a function of many factors: composition, moisture content, degree of energy input, temperature, and flour quality. Past work has been very useful but limited by the fact that dough samples were prepared in a farinograph, a mixograph, or a similar mixing system before fundamental rheological measurements. Preparing dough in these systems does not provide the well-defined rheological parameters required to understand the actual process of dough development.

The problem with dough prepared using the traditional mixing systems is that the distribution and energy input functions are combined, so limited fundamental information on dough development can be obtained. Lack of basic knowledge in this area is one factor limiting technological advancement in the baking industry. This problem can be overcome by working with the undeveloped dough concept, where the hydration and energy input phenomena of dough formation are decoupled.

Undeveloped dough introduced by Campos (1996) and Campos et al (1996) was investigated in this study. Dough preparation involved a unique procedure in which ice and flour particles were mixed under freezing conditions and then warmed, allowing hydration of flour without mechanical energy input. A similar concept was reported earlier (Olcott and Mecham 1947, Davies et al 1969), however, the focus of their investigations was on lipid binding in the dough matrix. A recent patent (Kageyama and Torikata 1993) presented a method of making bread dough by mixing powdered materials (flour, yeast, sugar, fats, and oils) and ice particles. Our work is the first study to decouple the hydration and energy input factors related to dough formation. Future work will focus on the use of controlled deformation in dough development.

The overall goal of this study was to evaluate the fundamental rheological properties of undeveloped wheat dough subjected to pure shear (creep and oscillatory) deformation. The specific objectives were to: 1) investigate the effects of wheat flour type and temperature on the rheological behavior of undeveloped dough, and 2) compare rheological behavior of undeveloped and developed doughs.

MATERIALS AND METHODS

Wheat Flours

Two different types of commercial flours with distinct physicochemical characteristics were studied: soft white winter and hard red winter wheat flours (King Milling Co., Lowell, Michigan). Protein content, moisture content, falling number, ash content, and farinograph characteristics were determined using Approved Methods 46-13, 44-15A, 56-81B, 08-01, and 54-21, respectively (AACC 1995).

Preparation of Undeveloped Dough

A method of blending powdered ice and flour in a walk-in freezer at –8°C, described by Campos et al (1996), was used in preparing the undeveloped dough. The ice was prepared in the presence of solid carbon dioxide (dry ice) which was required to absorb the heat generated in breaking the ice into smaller particles. Breaking or crushing the ice without using the CO_2 caused some of the ice particles to melt and others to clump together, making the material difficult to handle. Solid CO_2 and ice parti-

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[1] Dept.Agricultural Eng., Michigan State University, East Lansing, MI 48824-1323.
[2] Corresponding author. E-mail: steffe@egr.msu.edu Phone: 517/353-4544. Fax: 517/353-8982.
[3] Dept. Food Sci. and Human Nutrition, Michigan State Univ., East Lansing 48824-1323.

Publication no. C-1997-0618-07R.

cles were sieved, and those with a particle size (150–250 µm) similar to flour were collected for further use. The powder mixture was then held inside a freezer at a temperature of –8°C, undisturbed, allowing sublimation of the solid CO_2 while keeping the ice particles intact.

The blending of flour and ice particles was performed inside the –8°C walk-in freezer. Materials were carefully weighed (to control the moisture content), placed into a centrifuge tube, and distributed uniformly using a vortex mixer. The resulting flour and ice mixture was placed in a moisture barrier container and kept frozen until needed. Before rheological measurement, the flour and ice mixture was held for at least 3 hr at room temperature (≈25°C). The preset holding time was essential because it allowed the ice particles to melt, and the water thus produced diffused into the system resulting in the hydration of flour, forming an undeveloped dough. This novel procedure of blending and thawing was the critical step that allowed the uniform distribution of ingredients, and flour hydration (Campos et al 1996) without the sample deformation (shear or extensional flow) traditionally considered essential for the formation of a protein matrix associated with the farinograph method of making dough. For convenience, 6 g of flour was used for each sample. The amount of ice added to each flour sample depended on the target dough moisture content (76% db or 43% wb) considered in this study.

Preparation of Developed (Farinograph) Dough

For comparison purposes, doughs were made using the farinograph with a 50-g bowl and standard preparation procedures (AACC 1995). A known amount of water was added rapidly to produce a dough of predetermined moisture level similar to that of undeveloped dough (76% db or 43% wb). The dough was mixed for a period equivalent to the development time of the flour as depicted in Table I. In this work, dough produced in the farinograph is considered a fully developed dough system.

Rheological Measurements

Rheological tests of both undeveloped and developed dough samples were made using a controlled-stress rheometer (model RS100, Haake, Paramus, NJ) with a 5 N-cm torque capability. All measurements were conducted using a 20-mm diameter parallel plate configuration with a 2-mm gap between the plates. Each test required a dough sample of ≈2 g. Excess dough protruding at the edge of the sensor was trimmed off carefully with a thin blade. To prevent drying of the edge, a thin layer of petroleum jelly was applied to cover the exposed dough surfaces. For the oscillatory temperature ramp tests, a high-melting-point food-grade grease was used. Before starting any measurement, the dough was rested for 5 min, allowing any normal stresses induced during sample loading to relax.

Only shear deformations created by the rotational, parallel-plate rheometer were used to generate rheological data. These included both creep and oscillatory measurements. Steady shear measurements of the first normal stress coefficient and viscosity function were not included due to instrument limitations (normal stresses could not be measured with this instrument) and complicating material behavior. Preliminary tests indicated difficulty in obtaining reliable steady shear data because dough samples would not stay in the gap during the entire test: dough started to leave the gap after a quarter turn of the sensor and then climbed upwards on the outer rim of the upper plate, which seemed to be rolling away from the gap. This problem may be caused by the normal forces resulting from the elastic response of the dough sample. Similar problems were encountered by Muller (1975) and Amemiya and Menjivar (1992). Except for the oscillation temperature ramp, all measurements were made at a 25°C.

TABLE I
Physicochemical Characteristics of Flours

	Hard Red Winter	Soft White
Moisture content, % db	14.2[a]	14.8[a]
Protein content, % mb	12.4	10.7[a]
Ash content, %mb	0.52[a]	0.45[a]
Falling number, sec	478[a]	260[a]
Farinograph		
Water absorption, % wt basis	59.8	54.8
Arrival time, min	1.25	0.75
Dough development time, min	2.5	1.25
Stability time, min	10.0	2.75
Mixing tolerance index, BU	40	140
Departure time, min	11.5	3.5

[a] Data are averages of four samples.

All rheological measurements were performed in three replicates and results given here are averages. The coefficient of variation for the results of creep tests (J) were, at most, 8.6% of the mean value, while that of the dynamic oscillatory tests (G^*) were, at most, 8.1% of the mean value. Results show that the measurements are reproducible.

Linear Viscoelastic Region

Ideally, dynamic oscillatory experiments are to be conducted within the linear viscoelastic range of a material. With a controlled stress rheometer, the sample is subjected to a sinusoidal applied stress and the resulting sinusoidal strain is measured. In the linear viscoelastic region, the amplitude of shear strain has a proportional response to the applied stress amplitude. Also, the dynamic moduli (G' and G'') are independent of the applied stress and, therefore, of the shear strain response as well. Most viscoelastic materials, including wheat flour dough, behave linearly only at very low stress or strain levels. The level at which nonlinearity occurs can be quite variable and depends on many factors such as material structure and composition.

To determine the linear viscoelastic region of the undeveloped dough, a dynamic oscillatory experiment was performed in which the applied stress was ramped from 2 to 100 Pa at an angular frequency of 6.28 rad/sec (1 Hz). Storage moduli and strain response data were collected and plotted as a function of the applied stress. Results show that dynamic moduli decreased slowly with increasing stress, indicating that a clear linear region could not be established in the dynamic responses of the dough. However, the strain response was reasonably proportional to the applied stress up to 50 Pa, which corresponds to a strain amplitude of 0.2%. In previous investigations, strain amplitudes of up to 0.2% (Dus and Kokini 1990), 0.22% (Hibberd and Wallace 1966), 0.25% (Weipert 1990), 0.5% (Amemiya and Menjivar 1992), or 0.8% (Lindahl and Eliasson 1992) have been reported to include the linear region. Accordingly, all dynamic oscillatory experiments conducted in the current study were performed using 50 Pa as the applied stress. The same stress value was also used to evaluate creep behavior of developed (farinograph) dough samples.

Slip

One of the major sources of error in the rheological measurement of food materials is wall slippage. This phenomenon was evaluated for undeveloped wheat dough applying the technique introduced by Navickis and Bagley (1983). Tiny particles of sand were glued into the surfaces of the parallel plates and the rheometer was operated using a standard Newtonian fluid. Results indicated an error (lower viscosity) of 34%. The preset effective gap between the plates was controlled automatically by the instrument assuming smooth plates were used. However, this distance was altered by the glue and sand particles adhering into the plates, causing an erroneous calculation of viscosity. Also, the weight of the adhesive and sand particles may have altered the sensitivity of the instrument adding further measurement error. Navickis and Bagley (1983) also experienced problems in testing wheat starch gels using sanded plates to prevent slip. They found that slip between plate and gel could occur "even on rough, freshly sanded surfaces . . . ." The method developed by Yoshimura and Prud'homme (1988) for evaluating slip was also tested. Experimental results for creep tests of undeveloped wheat dough using three gaps between the plates showed similar values. It was also observed that dough samples were very sticky and adhered to the surfaces of the plates when separated, an indication that slip is not present.

Creep Measurement

Creep measurement for each dough sample used a constant stress of 50 Pa. Each test lasted for a period of 10 min, and data were calculated as creep compliance (J) versus time (t). Creep behavior was characterized using the six-parameter Burgers model as described by Steffe (1996):

$$J = J_0 + J_1[1 - \exp(-t/\lambda_{\text{ret1}})] + J_2\,[1 - \exp(-t/\lambda_{\text{ret2}})] + t/\mu_0 \quad (1)$$

where J is the creep compliance, J_0 is the instantaneous compliance, J_1 and J_2 are retarded compliance values, λ_{ret1} and λ_{ret2} are retardation times, t is time, and μ_0 is the Newtonian viscosity. A four-parameter Burgers model was also evaluated but gave a poor fit of experimental data.

A simple semi-empirical model, developed by Peleg (1980), was also used to characterize creep behavior of dough samples:

$$t/J = k_1 + k_2 t \quad (2)$$

where k_1 and k_2 are empirical constants.

Dynamic Oscillatory Measurement

Dynamic oscillatory tests of dough samples were conducted using the frequency sweep mode by applying a constant sinusoidal shear stress of 50 Pa over an angular frequency range of 0.60–380 rad/sec. The measured responses of the material were the maximum amplitude of the strain, and the phase difference (or phase angle) between the applied stress and the resulting strain wave. Data were simultaneously converted into frequency-dependent material parameters used to characterize viscoelastic properties: storage modulus (G'), loss modulus (G''), and complex modulus ($G^*=[(G')^2 + (G'')^2]^{1/2}$).

Oscillatory Temperature Ramp Measurement (25–95°C)

Under this measurement scheme, a dough sample was subjected to a constant stress (50 Pa) and a frequency (6.28 rad/sec) with a superimposed temperature sweep of 25–95°C. This test allowed simulation of some of the chemical changes (i.e., starch gelatinization and protein denaturation) that take place during baking. A heating rate of 1°C/min was used in all temperature ramp experiments. Complex moduli, storage moduli, and loss moduli versus temperature, were determined and analyzed.

RESULTS

Physicochemical Characteristics of Flours

The results of the physicochemical tests of flours used in this study are presented in Table I. These numbers show that differences in physical and chemical characteristics existed in the flours tested.

Creep

Fig. 1 shows creep curves of the undeveloped and developed wheat doughs (soft vs. hard flour) at 76% db (43% wb) moisture content level. The data indicate that undeveloped doughs have lower creep compliance values over time when compared with developed doughs. This behavior is manifested by the different values of parameters of Burgers equation used to model the creep data (Table II). The Newtonian viscosity (μ_0) and retardation times (λ_{ret1}, λ_{ret2}) are bigger for undeveloped doughs than for developed doughs. Shear compliance values (J_0, J_1, J_2) for undeveloped doughs are smaller when compared with developed doughs. Fig. 1 shows that hard wheat dough (undeveloped and developed) has a structure that is more resistant to deformation than the soft wheat dough. Usually, hard wheat flours possess gluten proteins that are responsible for producing a stronger dough. This observation is confirmed by the values of parameters of the Burgers model. The viscosity parameter (μ_0) for the hard wheat doughs are higher than for the soft wheat doughs denoting a more viscous behavior; hence, greater resistance to flow. Retarda-

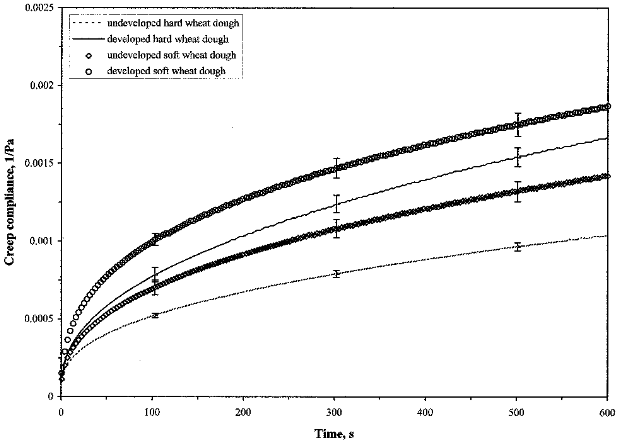

Fig. 1. Creep behavior of undeveloped and developed dough using soft and hard wheat flours. Error bars are ± standard deviation.

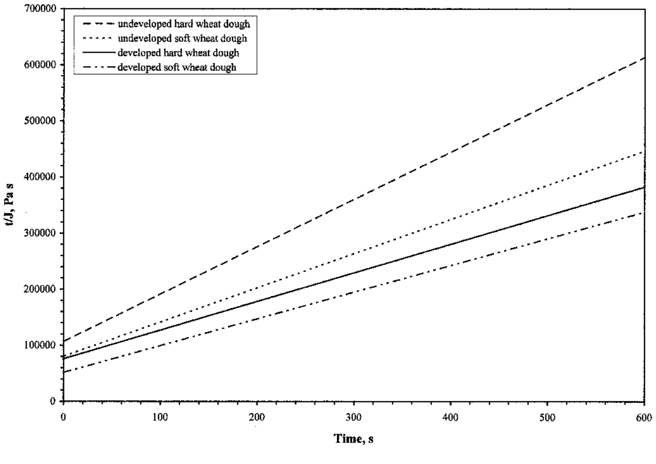

Fig. 2. Linearized curves of semi-empirical Peleg model of creep data for undeveloped and developed wheat doughs. *t/J* = time/creep compliance.

TABLE II
Values of Six-Parameter Burgers Model for Creep Behavior of Wheat Doughs

Sample	J_0 (1/Pa)	m_0 (Pa sec)	J_1 (1/Pa)	λ_{ret1} (sec)	J_2 (1/Pa)	λ_{ret2} (sec)
Undeveloped hard dough	1.02×10^{-4}	1.50×10^{6}	3.50×10^{-4}	1.43×10^{2}	1.50×10^{-4}	1.27×10^{1}
Undeveloped soft dough	1.13×10^{-4}	1.04×10^{6}	4.30×10^{-4}	1.50×10^{2}	1.87×10^{-4}	1.37×10^{1}
Developed hard dough[a]	1.23×10^{-4}	8.87×10^{5}	6.03×10^{-4}	1.53×10^{2}	2.37×10^{-4}	1.23×10^{1}
Developed soft dough[a]	1.30×10^{-4}	8.38×10^{5}	6.73×10^{-4}	1.20×10^{2}	3.40×10^{-4}	1.05×10^{4}

[a] Farinograph.

tion compliance values (J_0, J_1, J_2) for soft wheat doughs are higher than for hard wheat doughs, indicating a more compliant characteristic behavior.

Analysis of creep data using the semi-empirical linearized model proposed by Peleg (1980) is shown in Fig. 2 and Table III. The model yields a good fit and Eq. 2 would be adequate in most cases for characterizing creep behavior of dough. The greater the values of the intercept (k_1) and the slope (k_2) of the linearized creep curves (t/J vs. t), the smaller the creep compliance differential over time. Results indicate that undeveloped dough parameters (k_1 and k_2) are larger than developed dough parameters for both hard and soft wheats (Table II), denoting a stiffer (less deformable) dough structure. Values of creep parameters reported here are averages of three replicates. An ANOVA to establish statistical difference of these parameters between doughs was conducted. Results showed that the parameters are statistically different at $P < 0.05$.

Dynamic Test

The effect of frequency on the viscoelastic behavior of undeveloped and developed wheat dough show a strong dependence of complex modulus on frequency (i.e., G^* increased as the frequency was increased) for both hard (Fig. 3) and soft (Fig. 4) wheat doughs. The figures also indicate that developed doughs have greater G^* values when compared with undeveloped doughs throughout the frequency range for both soft and hard wheat samples. The storage modulus G' (elastic property) is greater than the loss modulus G'' (viscous property) for all samples investigated; an expected behavior for highly structured materials such as wheat dough. Earlier studies (Hibberd and Wallace 1966, Smith et al 1970, Cumming and Tung 1977, Szczesniak et al 1983, Faubion et al 1985) on traditionally prepared doughs reported that G' and G'' were affected by frequency in a similar manner.

Oscillatory Temperature Ramp

During the oscillatory temperature ramp experiment, the volume of the sample increased due to a well-known phenomenon called oven-spring (Hoseney 1994). The rheometer used in this study is equipped with a microprocessor that automatically adjusts the plate to the original preset gap, thus avoiding problems caused by volume changes of the sample. Hence, it can be assumed that this phenomenon is not a factor in obtaining a reliable data. In addition, any problem caused by oven-spring would similarly influence developed and undeveloped dough but not influence a comparison between them.

Figs. 5 and 6 show typical results of oscillatory temperature ramps for undeveloped and developed wheat dough samples. Results indicate that developed doughs obtain greater complex modulus (G^*) values than undeveloped doughs at the low and high temperatures considered. During the initial heating, the complex modulus (G^*) decreased slowly as the dough temperature increased from 25 to 60°C, suggesting initial softening of the dough. At ≈65°C, G^* began to increase rapidly, reaching a peak at ≈80°C. These changes are evidently caused by heat-induced reactions such as starch gelatinization and protein denaturation. Others have also reported that the rheological properties of wheat dough are highly sensitive to temperature (Launay and Bure 1973, Hibberd and Wallace 1966, Dreese et al 1988).

Figs. 5 and 6 also indicate that hard and soft wheat flour doughs have different gelatinization-denaturation temperature ranges. Soft wheat dough has a gelatinization-denaturation temperature range at ≈70–80°C, while the hard wheat dough has this range at ≈63–82°C. At low temperature, the hard wheat doughs exhibit stiffer structure but became less resistant to deformation than soft wheat doughs when the gelatinization temperature was reached. This suggests that, during the initial stages of heating, the effect of protein

TABLE III
Values of Parameters of Linearized Peleg Model for Creep Behavior of Wheat Doughs

Sample	k_1 (Pa sec)	k_2 (Pa)	r^2
Undeveloped hard dough	106,743	845	0.97
Undeveloped soft dough	80,402	610	0.98
Developed hard dough[a]	75,875	511	0.97
Developed soft dough[a]	51,606	477	0.98

[a] Farinograph.

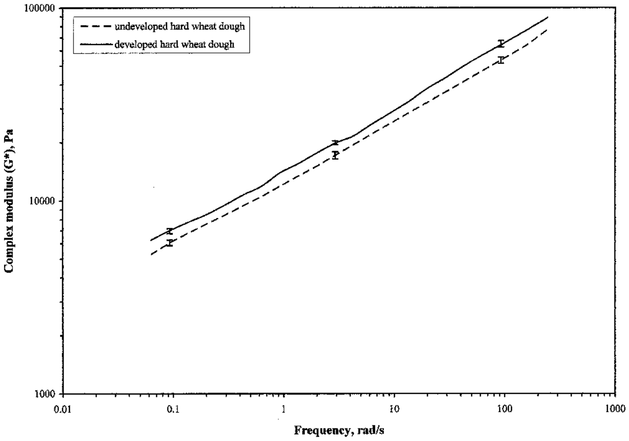

Fig. 3. Dynamic oscillatory behavior of undeveloped and developed hard wheat dough. Error bars are ± standard deviation.

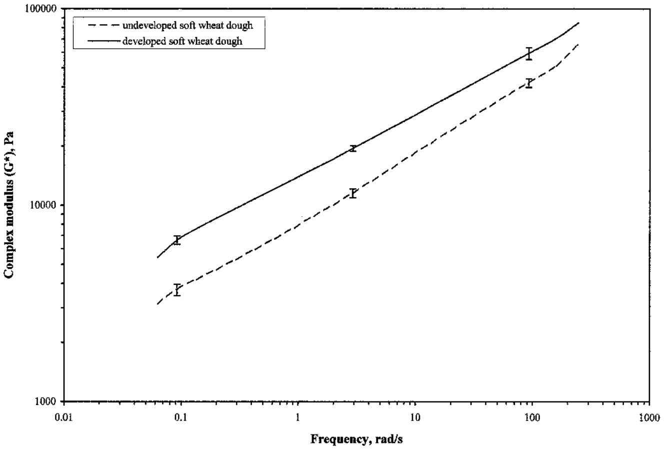

Fig. 4. Dynamic oscillatory behavior of undeveloped and developed soft wheat dough. Error bars are ± standard deviation.

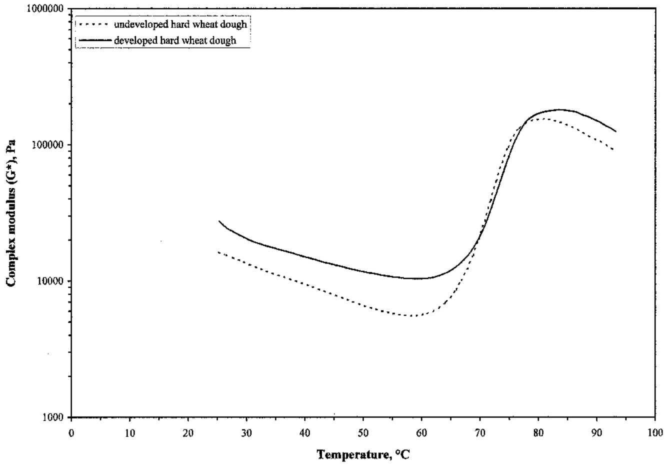

Fig. 5. Oscillatory temperature ramp of undeveloped and developed hard wheat dough.

content predominates and has a strong influence on the heat-induced rheological changes of wheat doughs (hard wheat flour has higher protein content with stronger gluten strength than soft wheat flour). However, when the gelatinization-denaturation temperature is reached, the effects of gelatinized starch in dough dominates, as indicated by the sudden increase in storage modulus. Wheat flours in general, have high concentrations of starch, and the soft wheat dough used in this research had a higher starch content than the hard wheat dough. When gelatinization temperature is reached during heating, more starch in soft wheat dough is available for gelatinization, resulting in a dough becoming more elastic and causing a greater response of G^* values as compared with hard wheat dough. Although the presence of protein has a strong influence on heat-induced rheological changes in dough (Weipert 1990, LeGrys et al 1980), the effect is perhaps masked by the changes caused by the relatively high concentration of gelatinized starch molecules.

DISCUSSION

Results depicted in Figs. 1 and 2 indicate that undeveloped doughs are more difficult to deform than developed doughs, showing lower creep compliance values over time for both soft and hard wheat. This can be explained by considering the undeveloped dough as material that has not reached the same level of development as the farinograph dough (i.e., the developed dough). Farinograph doughs were mixed to a point corresponding to the development time based on their farinograms, thus producing fully or optimally developed dough systems.

Preston and Kilborn (1984) suggested that a fully developed dough has a well-organized, weblike (laminar) gluten protein structure, stabilized by interactions between individual proteins and the formation of well-established intermolecular bonds (hydrogen and disulfide bonds), suggesting a strong and a firm dough structure. Results of the creep tests, however, indicated that undeveloped doughs seem to portray a stiffer dough structure than comparable farinograph doughs. To resolve these seemingly contrary descriptions, it should be noted that creep testing involves shearing (or deforming) of a material in one direction (in this case, a deformation of up to ≈10% strain was obtained). The orderly alignment of laminar structure of protein network in farinograph dough allows more easy deformation during creep testing compared with the undeveloped dough. Hence, the farinograph doughs offer less resistance to the stress, resulting in greater strain. The undeveloped dough is a fully hydrated system where the flour particles and, particularly, protein fibrils are collectively unorganized and thus incapable of forming a weblike or laminar protein network. During creep testing, these particles rub against each other resulting in more resistance to the applied shear stress and, consequently, less creep.

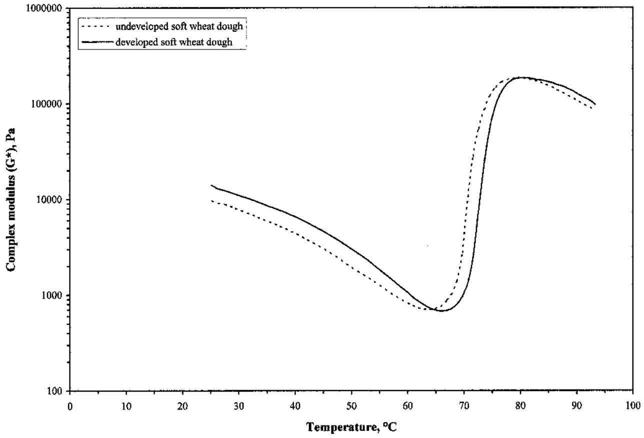

Fig. 6. Oscillatory temperature ramp of undeveloped and developed soft wheat dough.

Results on dynamic oscillatory experiments show that developed doughs have higher complex moduli (G^*) than the undeveloped doughs. These data suggest that, as the weblike structure of gluten network is created through mixing in the farinograph dough, interparticle interactions increase, resulting in more bonding which contributes to the increased elastic behavior of the dough. The undeveloped dough has not reached the same level of development as the farinograph dough, and an appreciable work input (in the form of mixing and shearing) can be added to increase firmness.

As indicated in Figs. 5 and 6, the results of the heat-induced rheological changes show that developed dough has greater resistance to deformation than undeveloped wheat dough during most of the heating process. Data also suggest that the developed dough has higher onset of gelatinization-denaturation and higher peak value of G^*, over the same temperature range, than the undeveloped dough. The gelatinization-denaturation temperature range of developed dough appears to be wider than that of undeveloped dough. This finding suggests that the extent of dough development has an influence on the heat-induced rheological behavior of wheat doughs. It is well established that wheat flour dough is predominantly composed of starch. Upon heating, starch molecules take up water and swell substantially, causing a change in rheological properties. This starch gelatinization phenomenon is essential in transforming dough into a baked product. With continued heating starch granules become distorted, and soluble starch is released into the system (Pyler 1988). Soluble starch and the continued uptake of water by the remnants of the starch granules are responsible for the change (increase) in storage modulus. Also, the protein present in the dough denatures at this stage. The onset of starch gelatinization and protein denaturation starts at the temperature corresponding to the rapid increase in G^* and ends upon reaching the peak value. Dreese et al (1988) found that heating doughs to 45°C caused no irreversible changes in either G' or the tan δ; however, when heating was increased to 55°C, G' and the tan δ, were irreversibly increased and reduced, respectively. These changes were caused by various heat-induced reactions in the dough such as starch gelatinization and protein denaturation (Bloksma and Nieman 1975, Weipert 1990). LeGrys et al (1980) indicated that the increase in G' can also be attributed to the increased gluten cross-linking that occurs when dough is heated.

It is unclear how dough strength is related to hydration and energy input resulting from material deformation. This study on the rheological behavior of undeveloped dough is unique because these phenomena (hydration and energy input) are decoupled. Results indicate that differences in rheological behavior between undeveloped and developed wheat doughs can be attributed to deformation; however, much work remains to evaluate how the amount of the energy input and the nature of the deformation (shear or extensional flow) influence dough development. This information may lead to significant improvements in the engineering design of dough processing equipment by introducing a controlled deformation to manipulate the level of dough development. The undeveloped dough concept also suggests the possibility of using powder processing technology to make frozen dough products such as bread dough, pizza dough, cookies, and low-fat crackers.

CONCLUSIONS

The undeveloped wheat dough is a viscoelastic material which exhibits linear behavior at low levels of stress (up to 50 Pa), corresponding to low strain levels (up to 0.2%). Creep behavior of undeveloped wheat dough can be modeled accurately using the six-parameter Burgers model or the Peleg empirical model. The complex moduli (G^*) of undeveloped wheat doughs are strong functions of frequency in dynamic oscillatory tests. In general, hard wheat dough is more viscous and can be described as having a dough structure that provides greater resistance to deformation than soft wheat dough for both undeveloped and developed wheat doughs. The heat-induced rheological response of the wheat dough is affected by flour type and the method of dough preparation (farinograph vs. undeveloped dough). Undeveloped and developed wheat doughs exhibit unique rheological behavior. Understanding the role of energy input and deformation (shear vs. extension) in establishing these differences may lead to new products, equipment, and processes in the bakery industry.

ACKNOWLEDGMENTS

Partial support of this research from Michigan Agricultural Experiment Station, from the Crop and Food Bioprocessing Center, Michigan, and from the United State Department of Agriculture (NRI Program) is gratefully acknowledged.

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[Received December 16, 1996. Accepted April 18, 1997.]