Lubricated Uniaxial Compression of Fermenting Doughs[1]

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ABSTRACT

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Lubricated uniaxial compression was used to obtain stress relaxation curves of fermenting wheat flour doughs. Linear transformation of the normalized curves allowed the calculation of constants directly related to the extent of stress relaxation *a* or rate of stress relaxation *b*. Standard deviations for *a* constants were less than 5%. Comparison of the *a* constant values showed that doughs containing oxidant ($KBrO_3$) were significantly more like a solid, and doughs with reducedferementation time were significantly more like a liquid than their controls. Furthermore, the *a* values of undermixed and overmixed doughs were significantly different. Overmixed doughs exhibited more solid behavior. Because of large standard deviations, *b* constant values could not be used to differentiate the dough treatments tested.

The rheological changes taking place in dough as it ferments affect its machinability and, ultimately, the quality of the finished product. These changes are empirically evident but (unlike the changes in nonfermenting doughs) have proven difficult to study with fundamental rheological principles. Hoseney (1985b) reviewed the problems inherent in assessing the rheology of fermenting dough. The "spread test" (Hoseney et al 1979) has provided useful information on the relationship of viscous and elastic properties in fermenting doughs but is incapable of providing the fundamental rheological constants that characterize the stress-strain behavior of the material.

A potential alternative is parallel plate, uniaxial compression testing. While this group of related techniques is commonly used as a means to obtain force-deformation data in food texture studies (Olkku and Sherman 1979), frictional effects between the platen and sample can have significant adverse effects on the resulting data (Culioli and Sherman 1976). Recently, Bagley et al (1985) reported the utilization of Teflon-coated plates, lubricated with paraffin or silicon oil as a means to effectively eliminate those frictional effects and obtain reproducible force-deformation curves. Using this technique, Bagley and Christianson (1986) studied the response of chemically leavened dough to uniaxial compression. Stress relaxation was determined and was used as a means to compute an apparent biaxial elongational dough viscosity.

DeMan (1976) noted that one of the greatest difficulties in food rheology is the problem of relating practical test conditions to basic units of stress and strain. In most cases, it is difficult to interpret results in terms of fundamental units and principles. This is due, in part, to the fact that most foods exhibit nonlinear viscoelastic behavior. Consequently, material properties depend both on deformation level and time as well as sample history.

Peleg (1980) developed a mathematical technique for interpreting force relaxation curves of foods. In this procedure, the raw data, i.e., relaxation curves, are normalized, and a decay parameter $Y(t)$ is calculated as:

$$Y(t) = [F_0 - F(t)]/F_0 \quad (1)$$

where $F(t)$ is the residual force after *t* min of relaxation.

Because sample deformation, for the most part, is maintained as a constant, the parameter $Y(t)$ represents the decay of the force. A plot of $Y(t)$ versus *t* demonstrates the rheological behavior of

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various materials during relaxation. The typical shape of the function $Y(t)$ versus t may be converted to a mathematical form suggested by Mickley et al (1957):

$$Y(t) = abt/(1+bt) \tag{2}$$

where a and b are both constants. The constant a describes the level to which stresses decay during relaxation. If $a = 0$, the stress does not relax, and the material is behaving as an ideal elastic solid. If $a = 1.0$, the stess level approaches zero, as in an ideal liquid. The constant b represents the rate at which stresses relax. If $b = 0$, the stress does not relax at all (ideal elastic solid behavior). For viscoelastic solids, the lower the value of b, the slower the stress relaxation.

A linear relationship may be obtained by a combination of equations 1 and 2 as in

$$t/Y = 1/ab + t/a \tag{3}$$

where $1/ab$ is equal to the intercept, and t/a is equal to the slope. Equation 3 not only offers a simplified way to describe a curve with two constants, but also offers an explanation for curve shape characteristics of solid food relaxation studies.

The purpose of this study was to apply the repeatable technique developed by Bagley et al (1985) to a series of dough treatments and express the resulting physical changes in the system, utilizing the simplified mathematical relationship developed by Peleg (1979).

MATERIALS AND METHODS

Dough Preparation and Testing

All doughs were prepared from a hard wheat flour containing 11.4% protein (14% mb). The flour was obtained from Ross Industries (Division of Cargill, Inc., Wichita, KS). Doughs were prepared using a slight modification (Fig. 1) of the procedure employed in the analytical bake test (Finney 1984). Full formula doughs consisted of the following ingredients (flour weight basis): flour, 100%; sucrose, 6.0%; sodium chloride, 1.5%; shortening, 3.0%; nonfat dry milk, 4.0%; and active dry yeast, 0.76%. Formula water was added at 62% (flour weight basis), the optimum as determined with the mixograph. In all cases, instant dry yeast (Fermipan, Gist-Brocades, Charlotte, MN) was added to the dry flour and dispersed prior to addition of liquid.

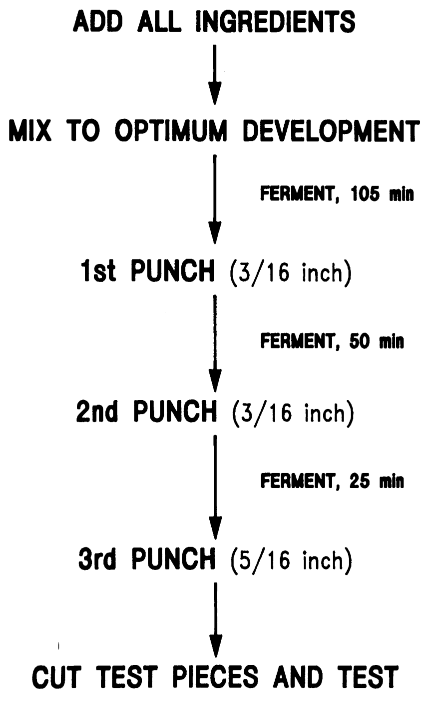

Fig. 1. Dough preparation procedure. Values in parentheses represent the roll gaps used in each punching step.

After the last punch, two to three disk-shaped dough pieces were cut from each dough with a cookie cutter (diameter, 1.90 cm). The resulting test pieces were immediately immersed in heavy mineral oil (Hunt Products Co., Dallas, TX) for 30 sec on each side. Prior to testing with the universal testing machine, the individual test pieces were reimmersed in oil for 15 sec/side. Uniaxial compression tests were performed with an Instron universal testing machine (model 1130-C4) equipped with a 2,000-g load cell. The metal platen surfaces were covered with adhesive-backed Teflon sheeting (Bagley et al 1985), and the sample-platen interfaces were liberally lubricated with heavy mineral oil (Bagley and Christianson 1986).

Prior to testing, dough heights were measured with calipers, and that measurement was used to determine the time necessary to deform the sample to a predetermined strain level of 50% at a crosshead speed of 2.5 cm/min. Once this strain level was reached, the crosshead was stopped, and stress relaxation curves were obtained. Relaxation time was calculted at 10× the time to achieve 50% deformation. The resulting data were used to calculate the a and b constants (Peleg 1979) for each dough.

The doughs tested included full fermentaton (FF), overmixed (OM), undermixed (UM), oxidized (OX), reduced (RD), and short (105 min) fermentaton time (SFT). The OX doughs were full-formula doughs plus 20 ppm $KBrO_3$ (Aldrich Chemical Co., Milwaukee, WI). The RD doughs were FF with 50 ppm of L-cysteine HCl (Sigma Chemical Co., St. Louis, MO).

Optimum mixing time for full-fermentation doughs was 4 min, 25 sec. The OM and UM doughs were mixed 90 sec more and 90 sec less than optimum, respectively. The mixing time of the RD sample was decreased to 2 min 20 sec.

Statistical Methods

A simple, one-way analysis of variance (ANOVA) was performed on the data (Steele and Torrie 1960). Four replications were done per treatment, with two repetitions per experimental unit (dough). Treatments were randomized between days, and one dough treatment was done per day. The effect of blocking on a day-to-day basis was assumed not to be significant ($P > 0.05$). Statistical calculations were carried out on an HP-41CV calculator (Hewlett Packard Inc., Palo Alto, CA) with a statistical package.

RESULTS AND DISCUSSION

Relaxation curves of the various dough treatments obtained at a deformation of 50% were normalized and plotted as $t/Y(t)$ versus t in Figure 2. Table I shows the mean and standard deviations of a and b constants for each treatment. The standard deviations of the calculated a values did not exceed 5%, whereas those of the b constant were larger, ranging from 5 to 20%.

It is not possible to conclude that values for b constants were affected by the various treatments listed in Table I. The b value represents a rate of relaxation rather than an extent. It may be that subtle differences in actual relaxation rate, coupled with small errors in measurement, resulted in standard deviations that obscured differences.

As Table I and Figure 2 show, differences in the a constant existed among the various treatments. The oxidized doughs

TABLE I
Means and Standard Deviations of Constants Calculated for Each Dough Treatment

Treatment	Constant a	Constant b
Full formula	0.49 ± 0.02	11.24 ± 0.91
Overmixed	0.46 ± 0.01	11.74 ± 0.57
Undermixed	0.51 ± 0.01	10.94 ± 0.58
$KBrO_3$	0.40 ± 0.02	11.63 ± 2.00
Short fermentation time	0.60 ± 0.01	13.22 ± 0.84
Cysteine	0.51 ± 0.01	11.25 ± 1.13

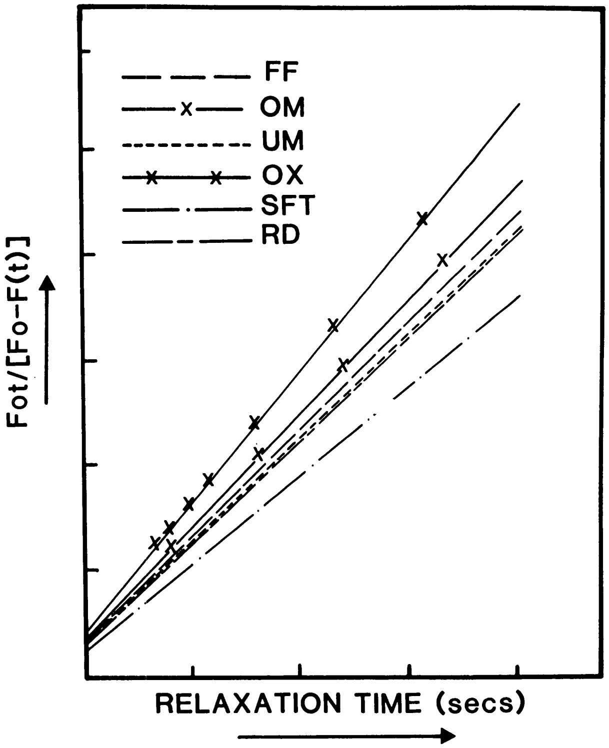

Fig. 2. Linear transformations of stress relaxation curves obtained from fermenting doughs. The doughs tested included full fermentaton (**FF**), overmixed (**OM**), undermixed (**UM**), oxidized (**OX**), reduced (**RD**), and short fermentaton time (**SFT**).

behaved more like solids than full fermentation controls (higher *a* value). In contrast, the *a* constant of the short fermentation time dough was higher than that of fully fermented controls, indicating a more elastoviscous, liquid behavior.

These data are consistent with previous reports using the spread test (Hoseney et al 1979), which showed that oxidized doughs (with or without yeast) had spread ratios lower than those of unoxidized controls. The data also offer quantitative support for the often-reported, empirical observation that oxidized doughs are "stiffer" than their unoxidized counterparts.

Comparison of the *a* constants of optimally mixed doughs given full or partial fermentation (FF vs. SFT) indicates that partially fermented doughs relax to a greater extent than their fully fermented controls. Again, this provides quantitative data consistent with previous reports that doughs become more elastic as a result of fermentation (Hoseney et al 1979).

The fact that *a* values for undermixed and fully fermented doughs were not significantly different was, at first, surprising. However, the hydration and protein interaction that characterizes dough development (Hoseney 1985b) can continue during the 180 min of fermentation. Therefore, it is likely that undermixed doughs are, in fact, "fully developed" by the time fermentation is complete. Recent studies (Dreese 1987) on the dynamic rheological properties of wheat glutens showed that undermixed glutens have dynamic storage moduli (G') and tangents equivalent to their fully mixed controls if the former are pressed for 90 min prior to testing.

Finally, *a* constant values for fully fermented and reduced doughs were not significantly different (Table I). This was not expected, because cysteine is a reducing agent known to cause dough to become slack or extensible. A possible explanation for this result can be found in the fact that yeast exerts a rheological effect on doughs that is similar in many ways to that of oxidants (Hoseney et al 1979). Specifically, fermentation makes doughs less extensible and more viscous. Studies using the spread test (Kivett 1987) show that although cysteine increases the initial spread ratio of yeasted doughs, fermentation acts to partially overcome that effect (i.e., reduces spread ratio). The data presented above may reflect a similar phenomenon, measured in a different way. In this case, fermentation for 180 min effectively overcame the effects of cysteine.

These results suggest that the *a* constant can be employed as a practical index to quantify differences in relaxation patterns between different dough treatments. The technique is not only simple and descriptive but also appears to be sensitive to ongoing rheological changes in dough systems.

LITERATURE CITED

BAGLEY, E. B., AND CHRISTIANSON, D. D. 1986. Response of chemically leavened doughs to uniaxial compression. Pages 27–36 in: Fundamentals of Dough Rheology. H. Faridi and J. Faubion, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.

BAGLEY, E. G., CHRISTIANSON, D. D., AND WOLF, W. J. 1985. Frictional effects in compressional deformation of gelatin and starch gels and comparison of material response in simple shear, torsion, and lubricated uniaxial compression. J. Rheol. 29:103.

CULIOLI, J., AND SHERMAN, P. 1976. Evaluation of Gouda cheese firmness by compression tests. J. Text. Stu. 7:353.

DEMAN, J. M. 1976. Mechanical properties of foods. Pages 53-80 in: Rheology and Texture of Foods. J. M. DeMan, P. W. Voisey, V. F. Rasper, and D. W. Stanley, eds. Avi: Westport, CT.

DREESE, P. C. 1987. Dynamic Rheological Studies of Flour and Gluten Doughs. Ph.D. dissertation. Kansas State University, Manhattan, KS.

FINNEY, K. F. 1984. An optimized straight-dough, bread-making method after 44 years. Cereal Chem. 62:20.

HOSENEY, R. C. 1985a. The mixing phenomenon. Cereal Foods World 30:456.

HOSENEY, R. C. 1985b. Rheology of fermenting dough. Pages 177–191 in: Rheology of Wheat Products. H. Faridi, ed. Am. Assoc. Cereal Chem. 56:141.

HOSENEY, R. C., HSU, K. H., AND JUNGE, R. C. 1979. A simpe spread test to measure the rheological properties of fermenting dough. Cereal Chem. 56:141.

KIVETT, C. L. 1987. Studies on Dough During Fermentation and Overmixing. M.Sc. thesis. Kansas State University, Manhattan, KS.

MICKLEY, H. S., SHERWOOD, T. K., AND REED, C. E. 1957. Applied Mathematics in Chemical Engineering. McGraw-Hill Co.: New York.

OLKKU, M., and SHERMAN, P. 1979. Compression testing of cylindrical samples with an Instron universal testing machine. Pages 157–175 in: Food Texture and Rheology. P. Sherman, ed. Academic Press: New York.

PELEG, M. 1979. Characterization of the stress relaxation curves of solid foods. J. Food Sci. 44:277.

PELEG, M. 1980. Linearization of relaxation and creep curves of biological materials. J. Rheol. 25:451.

STEELE, R. G. D., and TORRIE, J. H. 1969. Principles and Procedures of Statistics. McGraw-Hill: New York.

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