

## A food quality application using dynamic shear rheometry

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The production of wheat dough is a process in which raw materials (mainly flour, water, and yeast) are mixed and subjected to a large range of strain situations. Dough is a complex mixture of starch, protein, fat, and salts. Rheological properties change during every stage of bread making as the dough is processed. Stress conditions are high when the dough is mixed in high-speed mixers, at which point it becomes an elastic and coherent mass. When the dough is subjected to lamination and rolling, the stress conditions are intermediate. Finally, stress conditions are lowest during proofing. In theory, knowledge of the fundamental rheological properties of any dough can be an indication of how the dough is going to behave under various processing conditions. For the miller, fundamental properties are an indication of the characteristics of the flour and its composition.<sup>1</sup>

Wheat dough is usually tested using standardized empirical procedures, including the Mixograph, Farinograph, Extensograph, and Alveograph. The tests subject the dough to medium-to-high deformations with results in empirical units. A correlation of these results with fundamental properties such as the elasticity modulus or the complex modulus is difficult to make.<sup>1</sup>

The use of small strain rheometry, particularly oscillatory dynamic rheometers,<sup>2</sup> has been proposed as a method to determine the fundamental properties of dough. The use of oscillatory dynamic rheometers has been investigated by several authors; advantages include 1) the tests use small samples, 2) the results act as a tool in calculating the optimal absorption of water, 3) the optimal mixing time can be determined, and 4) the behavior of the dough in several stages of the bread-making process can be analyzed. On the other hand, the equipment can be expensive and some stickiness issues need to be addressed. The use of sandpaper on the surface of the parallel plates or the cone and plate was found to solve this problem.<sup>3</sup>

The measurement of the storage modulus ( $G'$ ) and the loss modulus ( $G''$ ), together with the phase angle ( $\delta$ ), is a good indication of the stiffness and extensibility of the dough. A high value of  $G'$  and a low  $G''$  will indicate a stiff dough, while a lower  $G'$  will indicate a softer and more extensible dough.<sup>2</sup> The amount of mixing of dough is a very important parameter and oscillatory tests could indicate under- and overmixing.<sup>4</sup>

The presence of salt is known to affect the properties of dough; salt toughens the protein and helps in conditioning the dough by improving its tolerance to mixing.<sup>5</sup> Galal et al. and Wehrle et al. have investigated the effect of acid and salt content on the rheological properties of dough, and found that the addition of salt produced a more stable and stiff dough. Dough is considered to be more stable when its structure does not break if the mixing time runs longer than is ideal. The complex modulus ( $G^*$ ) also increases and  $\delta$  decreases compared to a basic formulation.<sup>6</sup>

The Dynamic Shear Rheometer Quality



Figure 1 DSR QC rheometer.

Control (DSR QC) rheometer (ATS RheoSystems, REOLOGICA Instruments, Bordentown, NJ) (Figure 1) is a quality control instrument that was specifically designed to meet the requirements of the asphalt industry ([www.njcc.com/~ats/spectech-dsv.htm](http://www.njcc.com/~ats/spectech-dsv.htm)). The DSR QC also has potential for the analysis of foods, pharmaceuticals, polymers and solutions, and paints and coatings ([www.njcc.com/~ats/applications.html](http://www.njcc.com/~ats/applications.html)). The objective of this experiment was to determine the feasibility of using the DSR QC as a device for dough quality assurance assessment. To make this determination, doughs of different salt contents were tested and analyzed using the DSR QC and the VOR Controlled Strain Rheometer (CSR rheometer [Bohlin, Cirencester, UK]).

### Materials and methods

Three formulations of doughs were prepared using the following measurements: 1) 100 g wheat flour, 60 g deionized water, and 2 g salt; 2) 100 g wheat flour, 60 g deionized water, and 6 g salt; and 3) 100 g wheat flour, 60 g deionized water, and 10 g salt.

A KitchenAid (St. Joseph, MI) mixer with a dough hook was used. The dry ingredients were blended while water was slowly added during the first minute of mixing, and the ingredients were mixed at speed 5 for a total of 10 min. Samples were then loaded into the DSR QC and the VOR CSR rheometers for analysis.

The three dough formulations were first tested on the DSR QC. After each sample was mounted on the lower plate, the upper plate was moved down and the sample was trimmed. Mineral oil was used to seal the outer edges of each sample so dehydration would not compromise test results. Strain sweeps were performed using parallel plate geometry with a diameter of 25 mm. The gap was set at 1.0 mm and 25 steps were measured between the strains, using the instrument's

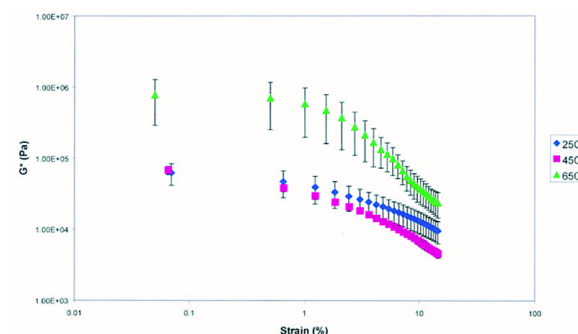


Figure 2 Percent strain vs complex modulus for 10 g dough.

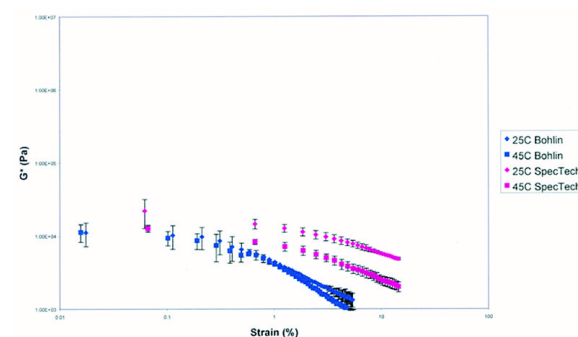


Figure 3 Percent strain vs complex modulus for DSR QC and VOR rheometer comparison.

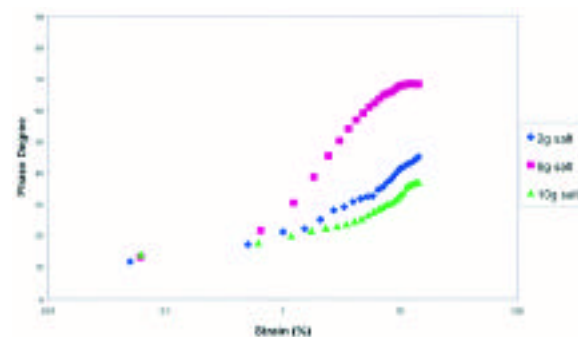


Figure 4 Salt effects on LVR at 65 °C.

strain limits of 0.01–15%. Each sample was tested in triplicate at 25, 45, and 65 °C. The data were copied onto an Excel (Microsoft, Redmond, WA) spreadsheet and graphs of complex modulus ( $G^*$ ) and phase degree were plotted against percent strain for comparison.

The third formulation was also tested in triplicate on the VOR CSR. Strain sweeps were tested using parallel plate geometry with a diameter of 30 mm. The gap size was 1.0 mm. Strain was measured in 50 steps with a range of 0.001–15%. Again, the data were copied onto a spreadsheet (Excel) and complex modulus ( $G^*$ ) was plotted against percent strain.

### Results and discussion

The DSR QC provided data for linear viscoelastic range (LVR) determination as well as evidence of temperature effect on dough formation. The LVRs of doughs in this experiment fell within a strain range of 0.1–1% (Figures 2–4). At strain levels greater than approx. 1%, the ratio of stress to strain was no longer constant, and the relationship between complex modulus and percent strain was no longer

linear. Among replicates there was little deviation within the LVR.

As temperature increased from 25 to 45 °C, there was little difference in LVR or the magnitude of complex modulus over the percent strain range (Figure 2). At 65 °C however, the LVR was extended slightly and the complex modulus increased by an order of magnitude. This temperature effect is most likely due to the gelatinization of starch granules and disulfide interchange within the gluten proteins. These effects are induced in dough within the temperature range of 65–85 °C. An increase in the magnitude of  $G^*$  with temperature was thus expected, since these physical and chemical changes typically help to create a stronger, more solid-like dough network. Additionally, DSR QC data were similar to VOR CSR data (Figure 3), reinforcing the fact that fundamental rheological parameters are independent of the instrument used.

Figure 4 shows the effect of salt on dough mechanical properties at 65 °C. Phase degree was plotted against percent strain. As salt content increased, the percent strain of the LVR increased slightly, revealing that salt helped to create a stronger, more elastic dough matrix, probably by aiding disulfide interchange and cross-linking.<sup>5</sup> Error bars outside of the LVR were large because equations for phase degree, like all small strain calculations, assume that the material was tested in the LVR.

The results show that knowledge of dough's LVR can be helpful to a baker in a quality control setting. Using a machine like the DSR QC allows a baker to understand how strong or elastic the dough is in addition to how reproducible the dough-making methods are. For example, if the linear relationship of complex modulus and percent strain is seen to extend only into low strain ranges, the gluten matrix may not be fully developed. In this situation, dough may not be strong enough to hold water vapor and carbon dioxide bubbles. Therefore, the dough may not properly rise or it may eventually fall. Alternatively, if the LVR is

found to be too large, the dough may be too strong and elastic to obtain the desired bread texture. In this case, water vapor and carbon dioxide bubbles would not be able to form because the dough matrix is too tough. By understanding the relationship between the LVR and the dough's physical properties, a baker can use the DSR QC to quickly test new formulations and predict their strength and performance during proofing and baking. In addition, a baker can use knowledge of the LVR to test the reproducibility of dough within a single mixing method or between several methods.

The evidence of temperature effect on dough formation obtained from the DSR QC could also be helpful to a baker. As dough is heated, starch granules undergo gelatinization and the gluten matrix undergoes disulfide interchange. The result of these two chemical and physical changes is a stronger, more elastic dough matrix. An increasing complex modulus roughly correlates to this textural effect. Therefore, a baker can produce different dough formulations and test them at a range of temperatures using the DSR QC to compare how the formulations perform at different temperatures.

In its application to quality assurance purposes in the baking industry, the DSR QC provides numerous advantages. For example, the test is quick and easy; it takes only 5 min to test one sample, and only a few buttons must be activated. The actual strain test is already programmed as well. Loading and cleanup are also relatively fast and simple. In addition, a small amount of sample is needed for each test. The DSR QC can give reproducible LVR data that will help bakers assess dough quality or mixing method reproducibility. Dough formation at various temperatures can be evaluated. Finally, the test truly measures fundamental rheological properties.

Since the operational software for the DSR QC was configured to meet the single-point testing requirements of the Strategic Highway Research Program's (SHRP) TP5 for Asphalt Binders, the need for multipoint testing analy-

sis for foods was not addressed. Several simple enhancements to the DSR QC software would allow the DSR QC to be utilized as an all-around quality performance indicator for food products. For example, presently only one gap is possible on the DSR QC; therefore, foods with large aggregates cannot be tested. In addition, the software supports only one frequency, 10 rad/sec, and step change rather than gradient temperature profiling. Testing at only one frequency and temperature precludes developing an understanding of rheological properties during cooking. Modifying the DSR QC software beyond the SHRP testing specification to allow for more complex frequency/temperature profiles will expand the capability and usefulness of the rheometer and eliminate the user having to resort to more expensive research-grade rheometers.

### Conclusion

The DSR QC could be a useful instrument for quality assurance purposes in the baking industry. The instrument measures fundamental properties that may assist bakers to better predict bread quality and texture. Also, the instrument permits assessment of mixing method reproducibility. It does in one test what might require several individual empirical tests to measure, providing a quick and easy means of obtaining dough strength, stability, and elasticity in a quality-type setting. In this experiment, the effectiveness of the DSR QC was seen. As salt level increased in dough, the resulting LVR was also increased, indicating the dough was stronger and more elastic with salt.

In the future, a standard method of testing dough on the DSR QC could be developed for the industry. An instrument with varying gaps might be more useful to a wider application of food products. The ability to probe lower strain ranges may also be helpful in understanding the LVR. In addition, the ability to test at several frequencies would allow a baker to do frequency ramps and therefore obtain better fingerprints of dough mechanical spectra.

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