# Relationships between Traditional and Fundamental Dough-testing Methods

S. UTHAYAKUMARAN[1*], R.I. TANNER[1], S.-C. DAI[1], F. QI[1] and C.W. WRIGLEY[2]

[1]School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, Mechanical Engineering Building, NSW 2006, Australia
[2]Queensland Alliance for Agriculture & Food Innovation, The University of Queensland, St Lucia, Qld, Australia

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**Summary**

Two fundamental test systems were used to evaluate the visco-elastic properties of doughs from wheat samples of three varieties grown at four distinct sites. For comparison, tests were also performed with traditional equipment, namely, the Mixograph, an extension tester and a Farinograph-type small-scale recording mixer. Uniaxial dough elongation (with an Instron) produced results similar to the conventional extension tester, except that results were provided in fundamental units (Pascals), the critical value recorded being the elongational stress at maximum strain. Stress relaxation measurements were performed following a small initial shear strain. With this method, it was possible to distinguish between the viscosity and the elastic components of dough visco-elasticity. In all the tests the extra dough-strength properties were evident for the variety (Guardian) that had the 5+10 glutenin subunits, in contrast to the other two with the 2 +12 combination of subunits.

**Keywords:** wheat dough, rheology, genotype, environment

## Introduction

Dough quality is an important aspect of wheat product quality at all stages of the grain chain – when the breeder is selecting elite lines, when the miller is attempting to meet flour-quality specifications and when the baker is producing the end product. Strong dough is needed for many types of bread and pasta. In contrast, weaker, extensible dough is needed for cakes and cookies (Ross and Bettge 2009).

For up to 80 years, cereal chemists have been served well with various forms of dough-testing equipment, mainly the Mixograph, Farinograph, Extensigraph and the Alveograph – all described in AACC Methods (AACC 2002). More recently, other types of equipment have been devised for similar purposes (reviewed by Dobraszczyk 2004, and Young 2012). In addition, small-scale versions of the traditional equipment have been developed, especially for breeding and research purposes (Bason et al. 2007; Cavanagh et al., 2010; Békés, 2012). Most of these instruments produce the results of dough properties in various 'arbitrary units'.

Nevertheless, cereal chemists have learnt the significance of these units, such as Brabender Units (known just as 'BUs'), as well as merely recognising the shape of the resulting traces, irrespective of the units involved. However, such empirical methods do not lend themselves

*Corresponding author; E-mail: surjaniu@gmail.com; Phone: + 61 2 9351 2252; Fax: + 61 2 9351 7060

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well to valid comparisons of results from different laboratories; a better basis is the use of methods based on absolute units.

Dobraszczyk (2004) has criticised conventional rheological tests as relying ‘on descriptive empirical measurements of the deformation behaviour of the dough during mixing, compression, or extension’, claiming that these conditions differ markedly from the baking process. In preference, he has advocated tests ‘based on modern polymer rheology principles’.

*Table 1.* Glutenin alleles of the varieties used, and the protein content and the composition of the samples

| | **LongReach Guardian**[a] | **Janz**[b] | **EGA Gregory**[b] |
|---|---|---|---|
| *Glu-1* alleles | a, u, d | a, b/u, a | a, u, a |
| HMW-GS subunits | 1, 7*+8, 5+10 | 1, 7+8/7*+8, 2+12 | 1, 7*+8, 2+12 |
| *Glu-3* alleles | b, b, b | b b b | c b c |
| Payne Score [c] | 3+3+4=10 | 3+3+2=8 | 3+3+2=8 |
| Protein content (%) Means | 13.2 | 13.6 | 13.4 |
| Ranges | 10.1-17.3 | 10.7-17.7 | 10.2-17.2 |
| Glu/gli ratio Means | 1.28 | 1.27 | 1.22 |
| Ranges | 0.96-1.45 | 1.12-1.42 | 1.11-1.33 |
| UPP% Means | 66.30 | 63.80 | 64.35 |
| Ranges | 65.07-66.76 | 62.66-65.50 | 61.50-65.80 |

[a]Personal communication with LongReach Breeding staff.

[b]From Wrigley et al. (http://www.aaccnet.org/initiatives/definitions/Pages/Gluten.aspx)

[c]From (Payne et al. 1987)

Results from two fundamental test systems are compared in this paper with results from more traditional dough testing for a diverse set of wheat samples, derived from three Australian varieties (Janz, EGA Gregory and LongReach Guardian) grown in four locations. The three varieties were chosen because of the similarity of their low-molecular-weight glutenin subunits (LMW-GS) (Table 1) and the similarity of their high-molecular-weight glutenin subunits (HMW-GS) in the A and B genomes (Uthayakumaran et al. 2012; Wrigley et al. http://www.aaccnet.org/initiatives/definitions/Pages/Gluten.aspx). Importantly though, they provided a contrast in the HMW-GS of the D-genome. Janz and EGA Gregory have the allele (*Glu-D1a*) for subunits 2+12, whereas LongReach Guardian (distinct from the U.K. variety named Guardian) has the allele (*Glu-D1d*) for subunits 5+10, reputed to confer greater dough strength. As a result, Guardian has the highest quality score of these varieties (Table 1), based on the system of Payne et al. (1987).

The initial purpose for this set of experiments was to examine the possibility of breeding varieties for tolerance to the effects of growth conditions on dough quality. Indeed, it was found that one of these varieties (Guardian) showed stability of dough quality irrespective of growth conditions. This aspect of these results has already been published by Uthayakumaran et al. (2012).

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The present article describes the distinctly different aspect of comparing the results of conventional and fundamental dough testing.

## Materials and Methods

The three varieties listed in Table 1 were grown as part of Australia's 2008 National Variety Trials at Coolah, Canowindra, Spring Ridge and Wagga Wagga in New South Wales. Full details of growth conditions and flour-sample preparation are provided by Uthayakumaran et al. (2012).

*Dough-test methods*

Three traditional dough-test methods were used.

(1) A Farinograph-type small-scale recording mixer – the micro-dough-LAB four-gram Z-arm mixer (Perten Instruments, Macquarie Park, NSW, Australia) (Bason et al. 2007). Water absorption values were determined as a percentage, based on the amount of flour and water for the dough to achieve a mixing resistance up to the 115 mN mark. Results have been demonstrated to correlate closely with those from the full-scale Farinograph (reviewed by Békés 2012).

(2) A Mixograph$^{TM}$ (TMCO, Lincoln, NE, USA) (Cavanagh et al. 2010), suited to a dough sample consisting of about ten grams of flour. The small-scale mixer uses the same mixing action as the original equipment (Rath et al. 1990). Mixing time (*MT*, in minutes), the time to reach peak dough development, has been traditionally regarded as a measure of dough strength (reviewed by Békés 2012). Results were analysed using MixSmart software, version 1.0.484 (AEW Consulting, Lincoln, NE, USA).

(3) The dough-extension testing involved the equipment and method according to Cavanagh et al. (2010). The dough piece for testing was obtained from the Mixograph (mixed to peak dough development). Results were expressed as maximum force (dough strength, as *Fmax* in Newtons) at the point of dough breakage and as the distance to this point (extensibility, as *Dist* in mm).

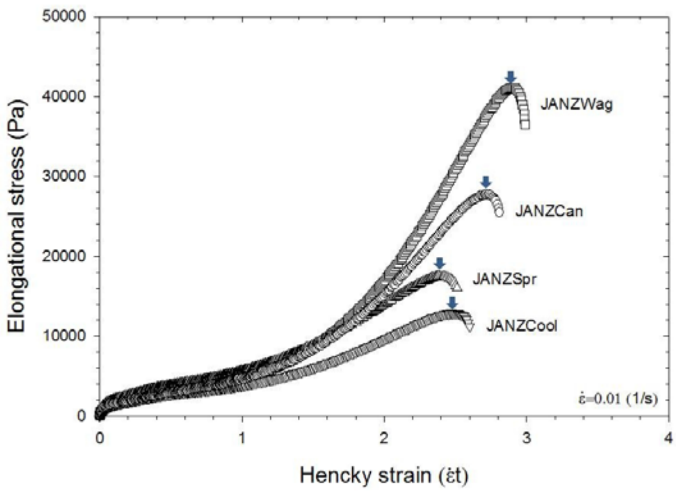


*Figure 1*. Uniaxial dough elongation of doughs from Janz variety from the four growth sites indicated

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*Fundamental rheological tests*

Two fundamental rheological tests were used.

(1) Uniaxial dough elongation involved elongation measurements with an Instron 5564 Universal Testing Machine at a constant elongation rate of 0.01 $s^{-1}$ (Tanner et al. 2007; Uthayakumaran et al. 2012). The dough piece, also from the Mixograph (at peak dough development), was stretched between two parallel plates mounted on the Instron. The mounted sample was compressed to 10 mm, and allowed to relax for a further 20 min to allow any built-up residual stress to decay. During testing, the sample was stretched until it was physically broken. The specimen diameter (and thus the cross-sectional area) was measured using a digital camera that downloaded the results to a computer as a movie. Fig. 1 shows traces from some elongation tests.

The elongational stress (in Pascals, vertical axis of Fig. 1; 1Pascal = 1 $N/m^2$) at any Hencky strain (HS, horizontal axis) was calculated by dividing the load applied by the area measured. It is an indication of the resistance of the dough to stretching. The critical value recorded was the elongational stress at maximum strain.

The Hencky strain ($\varepsilon_H$) is a logarithmic strain indicating the extent of dough stretching. In simple elongation, it is given by the equation (where, ln = logarithm to base *e*):

$$\varepsilon_H = \ln \text{[final length/initial length]}$$

The critical value recorded was the Hencky strain at maximum stress just before the dough piece breaks.

(2) Stress relaxation measurements (Safari-Ardi and Phan-Thien 1998; Uthayakumaran et al. 2012) required a 3-gram dough piece from the Mixograph (at peak dough development) to be inserted between parallel plates (25 mm diameter) with a gap of 2 mm in a Paar Physica MCR301 shear rheometer. In addition to experiments with the dough pieces, tests were conducted with an elastic rubber band (as an example of a material with very little relaxation) and with a Newtonian liquid (a polydimethylsiloxane or silicone), having significant viscosity, but little elasticity). Relaxation tests were conducted at a small initial shear strain ($\gamma$) of 0.1% applied rapidly in about 20 ms as a relative twist of the platens. The magnitude of the relative twist is directly proportional to the shear strain. For a shear strain of 0.001 (0.1%) at the rim, with 25mm diameter platens and a sample thickness of 2mm, the angle of twist is 0.001x2/12.5 radians , or about 0.009 degrees. The relaxation of the stress following this shear was recorded as a function of time (Fig. 2). Essentially, from Fig. 2, rubber relaxes very little, while the Newtonian liquid relaxes instantaneously: doughs lie between these extremes. The derived results (Fig. 3) were expressed as the variables shear modulus at 1 second, G(1), and the decay slope, p, which were calculated as follows (adapted from Uthayakumaran et al. 2012).

The resistance of the dough to deformation could be described by the damage function model (Tanner et al. 2007). For small strains, of the order of 0.1%, the model gives the complete linear viscoelastic behaviour in terms of only two parameters: the shear modulus at 1 second, G(1), and the decay slope, p. To explain these parameters, suppose a small shear strain of magnitude $\gamma$ is suddenly applied to the sample at the initial time (t = 0), and that the decay of the shear stress ($\tau$) (“stress relaxation”) is then measured. To a close approximation, we find, for t>0,

$$\tau (t) = \gamma G(1) t^{-p} \quad \text{……………. Equation 1}$$

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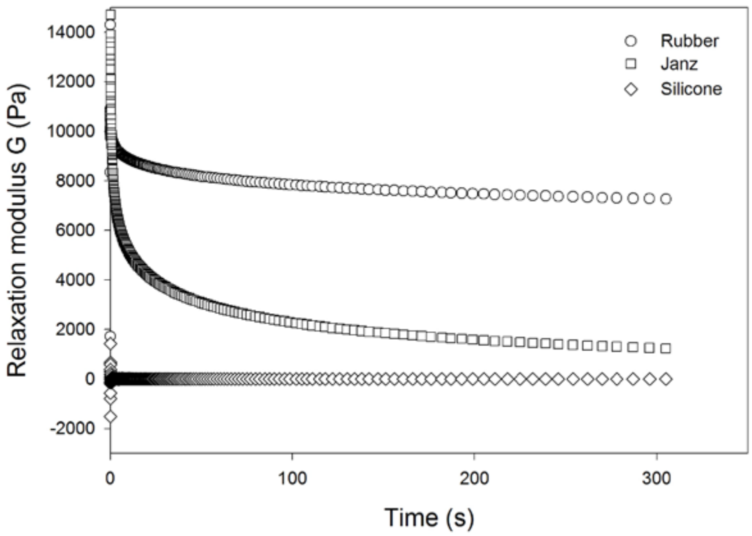


*Figure 2*. Shear relaxation measurements for Janz wheat dough, for silicone liquid and for an elastic rubber band. Relaxation modulus, G(t), and time are charted on linear scales

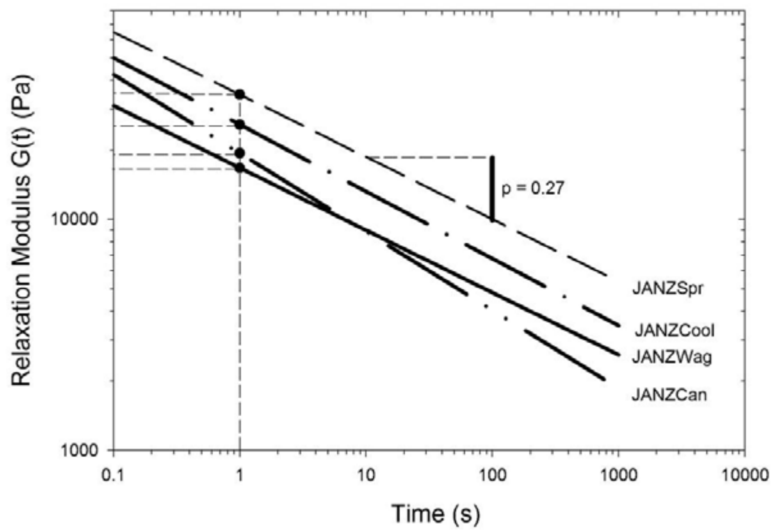


*Figure 3*. The shear relaxation modulus [G(t)] at one second was derived from the shear relaxation measurement plots for wheat doughs in Fig. 2. The slope of the lines gives us the parameter ‘p’

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From the measured shear stress response, for a fixed, small $\gamma$, we can find G(t) and p, plotted in Fig. 3. The G(1) is the shear modulus (equal to $\tau/\gamma$) of the dough when t = 1 second. Thus this test is a direct measure of the initial stiffness of the dough mix. The relaxation modulus, G(1), is large for a stiff dough and small for a slack dough. The decay slope, p, describes the slope of the logarithmic plots of the decay of $\tau$ versus time. The larger p is, the quicker is the decay of stress.

The compositional analyses of glutenin-to-gliadin ratio and % unextractable polymeric protein (%UPP) were performed according to the methods of Batey et al. (1991) and Gupta et al. (1993). All results represent the means of four replicates. Data were submitted to analysis of variance (ANOVA) using GENStat Software (Release 13, PA, USA).

## Results

*Traditional test systems*

Samples of the three varieties, grown at multiple sites, provided a good range of dough qualities, as indicated by the plots in Fig. 4. In particular, the set of samples covered a relatively wide range of protein contents (10.1 to 17.7%) and protein compositions (Table 2, Fig. 4a). The range of Mixograph mixing times was rather narrow. The mix times for all the Guardian samples were higher (stronger) than for the other two varieties, as would be expected for Guardian, having the 5+10 combination of HMW glutenin subunits, compared to the 2 +12 subunits of the other varieties. Dough strength, as indicated by maximum force (*Fmax*) in the extension tester, was also greater for all samples of the 5+10 variety Guardian than for the other varieties (Fig. 4c).

*Fundamental dough-test systems*

Two fundamental rheological test systems were studied to provide opportunities to ‘measure the forces required to produce controlled deformations’ (Uthayakumaran et al. 2012).

*Uniaxial elongation*

Uniaxial elongation curves are illustrated in Fig. 1 for one of the varieties (Janz) grown at each of the four sites. Each dough sample was stretched progressively with increasing stress until it eventually broke, just after the elongational force fell off. The two resulting parameters recorded were elongational stress (ES, height at maximum elongational stress, Fig. 4e) and Hencky strain (HS, $\varepsilon_H$, at maximum stress, expressed as the natural logarithm of the degree of elongation, Fig. 4f).

As this test operates by a principle similar to the Extensograph elongational stress correlated strongly (r = 0.86) (Table 2) with the corresponding parameter *Fmax* (height of the extension curve). The correlation of elongational stress was almost as great to *Dist* (the distance to peak extension) (r = 0.74). (This last distance differs from that used for the Extensograph for which the overall curve length is used.) Elongational stress was also correlated to the maximum Hencky strain at break (r = 0.69), but the Hencky strain was not related to *Fmax.*

Visual examination of the four elongational curves in Fig. 1 indicates a positive relationship between elongational stress and Hencky strain for these four dough samples. For the full set of samples, these parameters were correlated positively (r = 0.69) (Table 2). Elongational stress was relatively elevated for the 5+10 variety (Guardian) at low protein content (Fig. 4e), and Hencky strain was lower for this variety at higher protein levels (Fig. 4f).

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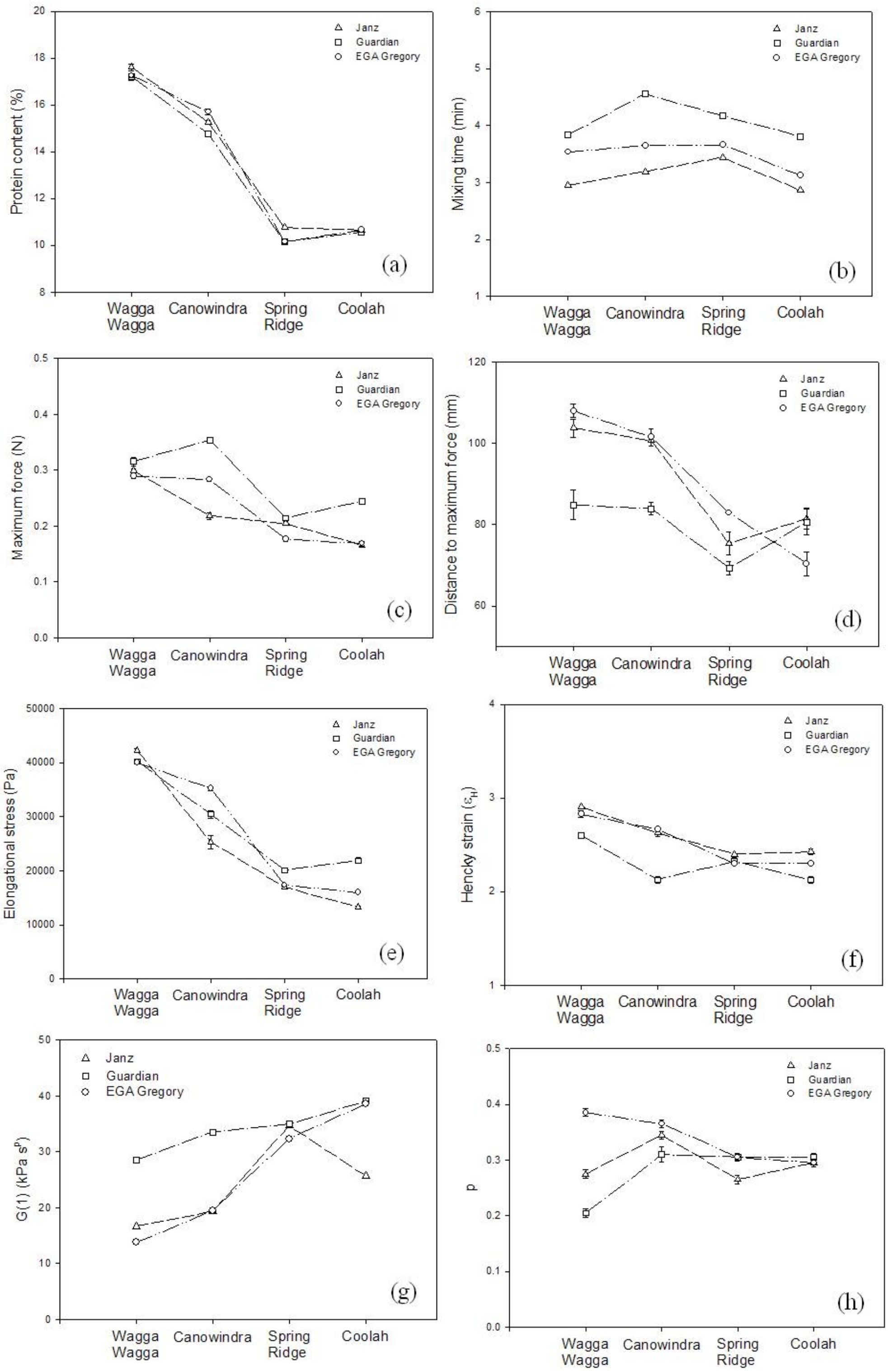


*Figure 4*. Plots of results for the three varieties from the four growth sites as indicated

*Table 2.* Correlations between traditional and fundamental results for dough quality

| | **Protein %** | **Elongat'n Stress** | **Hencky strain** | **G(1) Shear modulus** | **Decay slope, p** |
|---|---|---|---|---|---|
| **Protein %** | | 0.95*** | 0.76*** | -0.77*** | 0.07 |
| **Water Absorption %** | 0.92*** | 0.81*** | 0.88* | -0.93*** | 0.29 |
| **%UPP** | 0.30 | 0.45* | 0.01 | -0.01 | -0.13 |
| **Glu/Gli ratio** | -0.87*** | -0.80*** | -0.69*** | 0.64*** | 0.09 |
| | | | | | |
| **Mixing Time** | -0.02 | 0.14 | -0.50** | 0.39 | -0.00 |
| **Strength *Fmax*** | 0.78*** | 0.86*** | 0.28 | -0.34 | -0.05 |
| **Distance at *Fmax (Dist)*** | 0.80*** | 0.74*** | 0.79*** | -0.90*** | 0.43* |
| **Elongation Stress** | 0.69*** | | 0.69*** | -0.67*** | 0.04 |
| **Hencky Strain** | 0.76* | 0.69*** | | -0.92*** | 0.19 |
| **G(1) Shear modulus** | -0.77*** | -0.67*** | -0.92*** | | -0.42* |
| **Decay slope, p** | 0.07 | 0.04 | 0.19 | -0.42* | |

Glutenin-to-gliadin ratio was strongly correlated to both uniaxial elongation (r = -0.80) and to Hencky strain (r = -0.69) and both relationships were negative. This result presumably reflects the role of gliadin in conferring extensibility on dough. Neither uniaxial elongation nor Hencky strain related to %UPP, the proportion of very large glutenin polymer. Again a higher glutenin content and lower gliadin contribution would be expected to increase strength-related parameters and decrease extensibility.

*Shear stress relaxation*

In the second approach to the study of fundamental rheology, the shear-relaxation process was used to monitor the relaxation of a dough sample with time after an imposed rotational strain. The two main parameters derived from the shear-relaxation testing are the shear modulus, designated G(1) and the decay slope (p). Example results for these parameters are shown in Fig. 2 (linear axes) and Fig. 3 (axes are logarithmic scales). At one second after the sudden strain (vertical line in Fig. 3), the value of the shear stress, divided by the shear strain magnitude in radians, gives the modulus G(1).

Fig. 2 also shows the extreme contrasting results obtained when stress-relaxation tests were performed on two contrasting materials, namely, an elastic rubber band, which exhibits nearly complete elasticity with little viscous component to slow its relaxation *versus* a Newtonian fluid (silicone) with high viscosity, but little elastic tendency to return to its original position.

The shear modulus, G(1), an indicator of dough stiffness, correlated closely and negatively with traditional indicators of extensibility – *Dist* (r = -0.90) and elongational (Hencky) strain (r = -0.92), but not to indicators of elastic dough strength – Mix time (r = 0.39) or *Fmax* (r = -0.34) nor with the decay slope, p (r = -0.42). The negative relationships between extensibility parameters (e.g. *Dist*) and G(1) are consistent with the concept that shear modulus, as G(1), quantifies how stiff a dough is and thus how inextensible it is. Accordingly, G(1) correlated strongly with protein content (r = 0.77), but p did not.

The slopes of the lines in Fig. 3 provide the second stress-relaxation parameter, p, which indicates the rate of decay of the initial stress. Thus a large p denotes a rapid decay of stress. The decay slope, p, showed no significant correlations with any of the other parameters (Table 2) and the patterns of the p results in Fig. 4 are distinct from all others.

At high protein content, Guardian doughs (5+10) showed opposite values for these two parameters, namely, high shear modulus values and low decay slopes.

## Discussion

These observations offer for the first time, the novel opportunity of distinguishing the 'visco' aspects from the 'elastic' components (respectively) of dough as a visco-elastic substance, based on the extreme traces in Fig. 2 – mainly elastic and mainly viscous. The derived parameters, G(1) and p, were very high and nearly zero, respectively, for the rubber band, and zero and very large, respectively, for the silicone.

The behaviours of dough samples were intermediate between these extremes. Furthermore, it should be possible to assess one dough sample as having a higher elastic component and lower viscous component than another dough. For example, if high G(1) values can be attributed mainly to the elastic component, then the samples of Guardian (Fig. 4) would be interpreted as being more elastic (higher shear moduli, Fig. 4g), with relatively lower viscosity (lower decay slopes, Fig. 4h). This conclusion is consistent with the concept of the 5+10 subunits of HMW glutenin conferring stronger dough properties.

According to Bloksma (1990), for production of a loaf of bread, viscosity has to be large enough to prevent gas cells from ascending, thus to provide an increase in the final loaf height. On the other hand, excess elasticity may squeeze gas cells and restrict their need to expand adequately so that they increase in volume and contribute to final loaf volume. Thus elasticity and viscosity must be in an appropriate balance, as maintained by Wrigley et al. (2006). Despite the importance of these two balancing factors, it has not previously been possible to perform fundamental testing to evaluate the factors separately. This distinction is now possible.

Overall, these results indicate that the extensional testing and shear viscometry methods can bring out subtle differences in dough properties, which are normally undetectable by other methods. Fundamental rheological tests produce results with absolute units in contrast to the results from most traditional methods. This facilitates the comparison of test results across laboratories.

However, of greatest significance to the individual scientist, is the decision about which of the many dough-testing methods is best suited to the user's needs. That consideration is generally the prediction of dough behaviour during subsequent processing, such as the many forms of baking and extrusion. These needs differ through a wide range of requirements depending on the restrictions of time, costs, operator-skill and equipment available. This description of two fundamental dough-test methods adds to the range of available methods. They have the possible advantage that they can be applied to relatively small dough samples.

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