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TEXTURE PROFILE ANALYSIS – HOW IMPORTANT ARE THE PARAMETERS?

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ABSTRACT

A starch-glycerol gel was subjected to a two-bite compression test using two sample-instrument geometries, various speeds of compression and strain levels, both with lubrication or not. Results were interpreted using the primary characteristic terminology previously defined in Texture Profile Analysis.

Compression speeds from 0.1 to 10 m/s showed a logarithmic relationship with hardness, cohesiveness, corrected cohesiveness and adhesiveness. Gels survived compression to strains of 0.90 without failing, strain levels from 0.25 to 0.90 resulted in an exponential rise in hardness with increasing strain and linear reduction in corrected cohesiveness. Lubrication had no significant influence on any of the measured parameters and an application of force with different sample-instrument geometry revealed that parallel plates and plungers only had an influence on gel hardness.

Caution is urged when researchers modify the test protocol from 75% deformation with parallel plates. A minimum crosshead speed of 2 mm/s is recommended.

PRACTICAL APPLICATIONS

Texture Profile Analysis has been widely applied to test solid and semi-solid foods; however, some researchers deviate from the original test protocol. This article attempts to show how modifying the parameters in the test protocol can influence the apparent properties of the sample.

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INTRODUCTION

In 1963 Friedman, Whitney and Szczesniak, at the General Foods Corporation, published a procedure that made measurements of food texture accessible to anyone with an appropriate instrument (Friedman *et al*. 1963). Five years later, Bourne (1968) adapted the method to operate on an Instron Universal Testing Machine (IUTM), and in so doing, he overcame some instrumental limitations of the General Foods Texturometer (GFT); however, in the adaptation, changes in the experimental protocol occurred. These changes are summarized in Table 1.

The GFT had two key problems with its operation. It had been designed to mimic the action of the human jaw, and as such, the force was applied in an arc whereby a plunger mounted on a lever moved towards a base plate at an average rate of 42 bites per minute, and in so doing, the food sample was deformed. However, the arc motion meant that as the plunger touched the food the area of contact changed with the rotation of the lever, resulting in differing stresses within the food with progressive deformation. Moreover, the direction of the stresses in the food changed as the lever swept through its arc. The second problem with the GFT was that stresses were measured by strain gauges mounted on the lever and consequently some flexibility in construction existed, consequently instrumental readings were not exclusively due to deformation and stresses resulting from the food.

TABLE 1.
SUMMARY OF DIFFERENCE BETWEEN OPERATING CONDITIONS PROPOSED BY FRIEDMAN *ET AL*. (1963) AND BOURNE (1968)

Test Protocol	Friedman *et al*. (1963)	Bourne (1968)
Instrument	GFT	IUTM
Motion of deforming force	Arc	Vertical
Sample height	12.75 mm	10 mm
Start height above sample	3.175 mm	0 mm
Deformation	75%	75%
Probe to sample diameter ratio	<=1	>1
Speed of compression	17.78 mm/s*	0.83 mm/s

* Speed of compression is an average velocity based on 42 bites per minute.

In contrast to the GFT, the IUTM used a load cell mounted on a crosshead, which was driven vertically up and down by rotating screw threads. The vertical motion ensured that with a plane surfaced food sample, the stresses would be normal to the sample surface and that contact between the instrument and the sample would be less variable.

In addition to overcoming the design faults inherent in the GFT, changes were made to the test geometry. In the original protocol, the food sample was "$^1/_2$ inch in height and an area at least that of the plunger base," (Friedman *et al.* 1963, p. 392).[1] At the start of a test the plunger was 3.175 mm above the sample and during the test, it followed an arc at an average rate of 17.8 mm/s. In adapting the technique to the IUTM, "A flat horizontal plate, approximately 15 cm diameter, was attached to the inverted load cell which was bolted to the moving crosshead. The crosshead was set to cycle with a vertical reciprocating movement at a constant speed of 5 cm per min and a stroke length of 7.5 mm" (Bourne 1968, p. 324). The speed difference was probably dictated by the fixed gearing ratios available to the IUTM. The improved crosshead maneuverability in relation to the sample meant that dead space between the sample and the instrument could be eliminated from the test procedure. Less easy to explain was the change in the probe to the sample diameter ratio. On the face of it, Friedman *et al.* were actually measuring stress within the sample as the force that the instrument measured could be related to the area of the food that was being deformed. However, Bourne (1966) had previously shown that during puncture tests both compression and shear elements existed and that the magnitude of the perimeter and surface area of the probe affected the proportion of each element, possibly complicating interpretation. By squashing the sample between two parallel plates, both substantially larger than the food sample, shear forces were eliminated, at the expense of not knowing the contact area.

In the period since these two pioneering papers, over 400 articles have used one of the two test protocols or variants on them. A number of reviews show the extent of the difference in the test protocol such as Pons and Fiszman (1996) who compared the influence of some of the test parameters used to test gels; Mittal *et al.* (1992) who looked at the effect of test parameters on meat products; or Yuan and Chang (2007), working with tofu. To an extent the diversity in methodology was justified by limitations of the instrument available to do the test, thus the speed of operation or maximum load cell capacity have forced experimenter to change the operating conditions to those that yield values. However, sometimes, the shape of the food has forced a change in protocol (e.g. testing whole grains of rice or noodles).

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[1] Dimensions originally given in imperial inches but with the exception of quotes they are converted to SI units in this paper.

The two bite test procedure has become known as Texture Profile Analysis (TPA). From the output of the instrument, one is able to measure five primary characteristics (hardness, cohesiveness, adhesiveness, elasticity [also called springiness] and brittleness [also called fracturability]), there are also several derived characteristics. The extent to which the test parameters actually affect the results of the test are the subject of this paper. A model gel system, based on Turkish Delight (but with glycerol instead of sugar to make it easier to handle) was used because of its ability to withstand high levels of strain without breaking and moderate levels of cohesiveness. While TPA was intended as a large deformation test – to mimic mastication, from a comparative point of view, we are better off testing a system that does not fail during testing, as if a gross structural failure occurs during the first bite, subsequent data is less comparable.

MATERIALS AND METHODS

The model gel system contain 60% (m/m) glycerol (Fisher Scientific G/0650/17, Batch 0926653), 10% (m/m) acid thinned starch (National Starch, Flojel 60, batch AJS1040) and 30% (m/m) water. The mixture was prepared by mixing the water and the glycerol and then suspending the starch powder. The mixture was then boiled in a microwave with intermittent stirring for about 1 min until a clear paste was formed. The hot mixture was reweighed and water added to compensate for evaporative losses. The paste was then thoroughly mixed before being poured into 12.8 mm diameter syringe bodies (with the nozzle end removed). Gels were allowed to set and retrograde for 2 days at room temperature (18–25C).

Gels were extruded onto a glass plate by squeezing the syringe plunger into the syringe body. Gel cylinders were then cut into constant lengths with a cutting guide and a razor. Gel cylinders were placed with one of the parallel flat surfaces on a glass plate and transferred to the platform of an LFRA Texture Analyser model LFRA1500 (Brookfield Viscometers Ltd., Harlow, UK) and compressed under various conditions (see further discussion). All tests were carried out at room temperature (18–25C). The instrument base position was determined with just the glass plate in place and the sample lengths were measured with an instrument trigger of 39 N.

Unless otherwise specified, the following instrument test protocol conditions were used.

(1) samples were compressed with an acrylic probe 38 mm in diameter;
(2) compression was 75% of the sample length with no delay between the first and second compressions;

TABLE 2.
VARIATIONS IN TEST PROTOCOL

Test	Conditions
Speed of compression	0.1, 0.3, 0.7, 1, 3.3, 6.6 & 10 mm/s
Percentage deformation	90, 85, 75, 65, 55, 45, 35, & 25%
Sample-instrument geometry	12.8 mm diameter gels working with a 38 mm diameter plate or 12.8 mm diameter probe against 18.5 mm diameter gels
With or without Lubrication	Lubrication was achieved with liquid paraffin on the glass support plate and on the top of the sample

(3) the speed of the crosshead was 1 mm/s; and
(4) the samples were lubricated with liquid paraffin (BDH, Spectrosol, 14017, batch 0355970K) applied to the glass plate before the sample was placed upon it and on top of the sample.

Table 2 shows the variation in test protocol, this was achieved by varying just one of the parameters above at a time.

To overcome variability between batches of gels and ambient temperature – when any particular test parameter was being investigated, only one batch of gel was used. Thus, all the speed comparison gels came from one batch while all the tests looking at the affect of lubrication came from another single batch of gel, etc.

At least five replicates were carried out for each test condition.

The primary TPA characteristics of Hardness, Cohesiveness (Corrected Cohesiveness [Peleg 1976]), Adhesiveness and Springiness (originally called elasticity by Friedman and co workers) were determined.

Under all the test conditions employed in this study, the model gel did not visually rupture and gave measurable values on the texture analyzer.

Data were analyzed using Microsoft Excel 2003.

RESULTS AND DISCUSSION

A typical force–time plot for the test protocol and gel system employed in this study is shown in Fig. 1. Apart from background noise (evident at the low loads), the LFRA texture analyzer produces a smooth curve to a sharp peak with a maximum load at 5.15 s. The absence of shoulders suggests no point of rupture or gross mechanical failure. Having said this, the second peak is

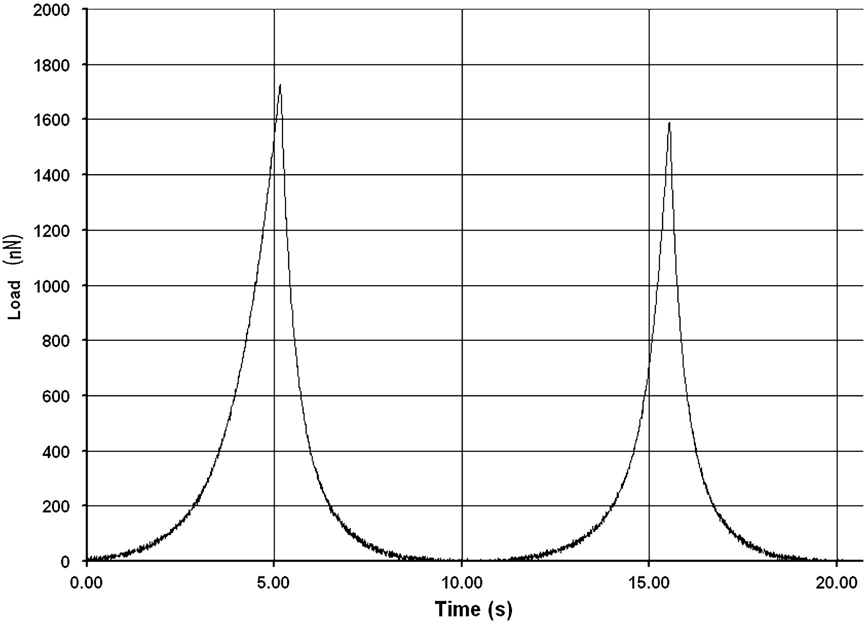

FIG. 1. A TYPICAL FORCE-TIME CURVE

smaller than the first indicating some weakening of the internal structure. This behavior is consistent with TPA as a technique.

Since the LFRA 1500 texture analyzer measures the sample height, we were able to confirm with one way analysis of variance that there was no significant difference between the lengths of the samples being analyzed. A similar one-way analysis of variance was carried out to consider the effect of lubrication and the influence of sample-instrument geometry. Table 3 summarizes the probability level of difference for hardness, cohesiveness, corrected cohesiveness, adhesiveness, springiness, arising from the effects of lubrication versus no lubrication and whether a probe or a platen was used to deform the sample.

Lubrication with liquid paraffin seems to make no difference to any of the parameters measured. Having said this, barreling was observed in the nonlubricated samples. It is possible that the moist surface of these gels provide adequate lubrication to prevent friction being of any consequence, thus the additional lubrication of paraffin contributes nothing.

The effect of the sample-instrument geometry of the test seems less clear-cut. As far as corrected cohesiveness and springiness are concerned, it makes little difference whether the sample is compressed with a platen or a

TABLE 3.
SUMMARY OF PROBABILITY OF DIFFERENCE (P VALUES) BETWEEN THE TEST CONDITIONS

	lubrication versus no lubrication	Sample – instrument geometry
Hardness	0.154	<0.001
Cohesiveness	0.167	0.043
Corrected cohesiveness	0.304	0.100
Adhesiveness	0.588	0.047
Springiness	0.481	0.242

plunger. However, there are weak associations between the sample-instrument contact geometry with both the cohesiveness and the adhesiveness, and a highly significant relationship with the hardness parameter. On the face of it, we should not be surprised, for we know that a plunger will reveal both compressive and shear resistances to deformation; however, what is odd is that the samples compressed with a platen actually show higher levels of hardness (mean of 880 mN) than those compressed with a plunger (mean of 541 mN). The reason for this may be that as the sample is compressed it spreads below the contact surface, in the case of the plunger, it is squashed beyond the contact area, whereas with the platen, it continues to be stressed as it can not escape the contact.

Reviewing the literature on different sample-instrument geometries is quite revealing, some workers, particularly with semisolid foods (such as yoghurt) have actually performed a variant of TPA in a container with a close fitting plunger that effectively gives a measure of back extrusion as the sample is compressed and forced to flow through the annular gap between the plunger and the container (for example Rawson and Marshall 1997; Sandoval-Castilla *et al.* 2004). Some other researchers have used a spherical or hemispherical-ended probe to make contact (e.g. Sikora *et al.* 2004; Kotwaliwale *et al.* 2007; Otegbayo *et al.* 2007), others have used conical probes reminiscent of penetrometers (Ahmed, El Soda *et al.* 2005; Cheret *et al.* 2005; Laneuville *et al.* 2005). Other less traditional geometries include a star-shaped "cherry pitter" probe used on beef steak (Caine *et al.* 2003). In the case of noodles and pasta, several workers have laid the sample across the base plate and brought a "blade" like probe (typically 3 mm wide) down to compress the sample (e.g. Baik *et al.* 1994; Kadharmestan *et al.* 1998; Lee *et al.* 1998; Kadan *et al.* 2001; Setiady *et al.* 2007). Of course, such a test geometry has both portions where the strands extend beyond the plunger and other portions where the plunger extends beyond the sample. Other instances of multiple samples being compressed include the compression of several rice grains simultaneously (Moretti *et al.* 2005; Bello *et al.* 2006)

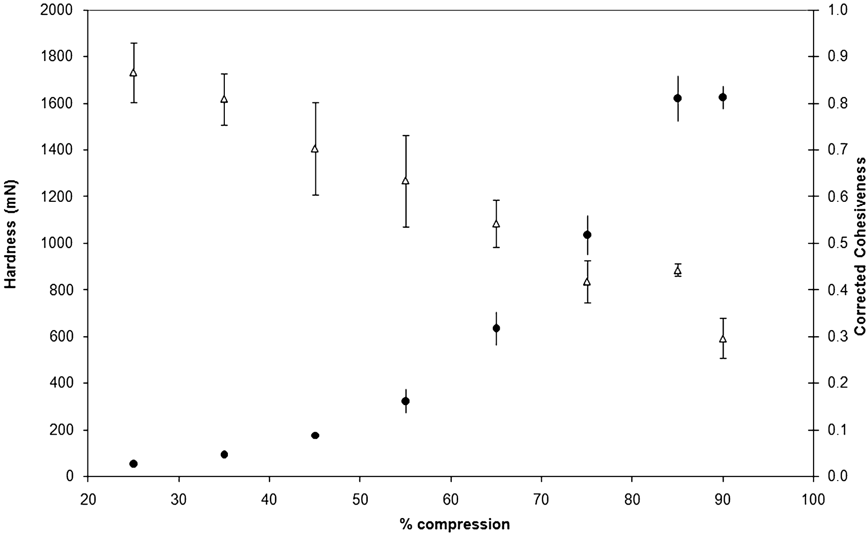

FIG. 2. EFFECT OF COMPRESSION ON HARDNESS (●) AND CORRECTED COHESIVENESS (△) ERROR BARS SET TO ONE STANDARD DEVIATION

Of course, these less usual sample-instrument geometries are valid in their own right as means of comparison, however whether one can treat compression with a pointed cone or a blade as a measure of hardness is perhaps questionable.

When comparing the percentage deformation that is applied during the test, useful readings were obtained in a range from 25% to 90%. Below 25%, the noise to signal ratio prevented useful data being collected and at deformations above 90% the gel ruptured during compression showing a break in the first peak. Figure 2 shows the effect of varying percent deformation (maximum Cauchy strain), there is a good exponential relationship for hardness ($R^2 = 0.99$) whereby

$$\text{Hardness (mN)} = 15.337\ e^{0.0545\%\text{compression}}$$

and a linear relationship for corrected cohesiveness ($R^2 = 0.97$), such that

$$\text{Corrected Cohesiveness} = -0.0084 \times \%\text{compression} + 1.0855$$

Cohesiveness appears to follow an exponential trend though the fit is poor. Adhesiveness seems to be unaffected by the percentage compression up to about 75%, but higher levels result in a marked increase along with a greater variability between replicate samples. Springiness, on the other hand, seems to increase progressively to 75% before leveling off.

The originators of TPA describe cohesiveness (and, by extension, corrected cohesiveness) as "a direct function of the work needed to overcome the internal bonds of the material" (Friedman *et al.* 1963, p. 393), and in this respect, one might anticipate that if the structure is deformed more, the internal bonds might be broken to a greater extent, thus giving less recovery for the second bite. In such situations, one might anticipate the result obtained.

The literature shows a vast range of percentage deformations being used with TPA. For example, Gupta and Sharma (2007) compressed *chikki*, a sunflower confectionary product, by 10%, while Birkeland and Skara (2008) compressed smoked salmon by 90%. If the relationships identified for the gel system in this study were to be used predicatively, with the wide range of percentage compression seen in the literature, one would observe corrected cohesiveness that ranged from unity to one-third and predicted hardness's covering two orders of magnitude! Clearly, the results are highly dependent on the test protocol.

Just as the literature shows a wide variety in the percentage compression, the speed of compression also varies from 0.02 mm/s (Ravi and Susheelamma 2004) to 100 mm/s (Allais *et al.* 2006). Experimental data from this study shows a logarithmic relationship between speed of compression and hardness as shown in Fig. 3, a best fit logarithmic curve ($R^2 = 0.92$) has the equation:

$$\text{Hardness (mN)} = 774 + 103 \times \log_e [\text{Speed of compression}]$$

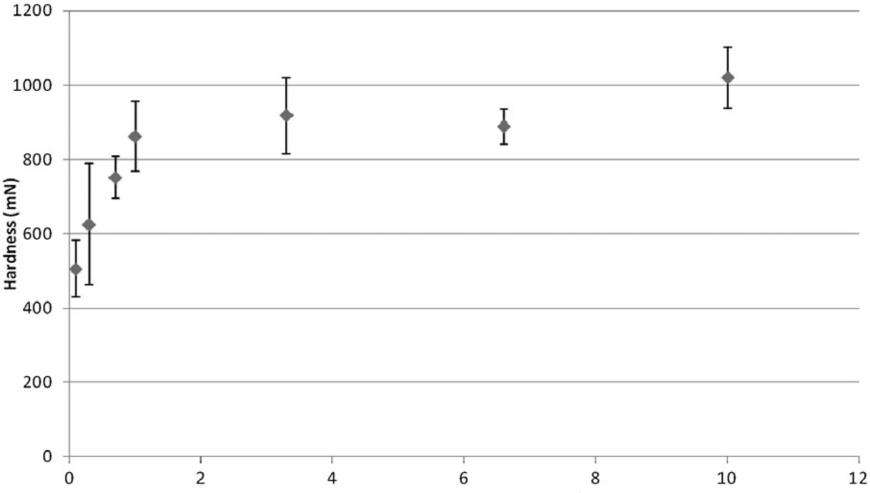

FIG. 3. EFFECT OF SPEED OF COMPRESSION ON HARDNESS

Such a relationship is in keeping with Pons and Fiszman's (1996) review of TPA in gelled systems in which there is general agreement that increasing the speed of compression leads to an increase in the hardness. They conclude that the slower the speed of compression, the more time the sample has to relax and dissipate the applied force. As relaxation generally falls exponentially with time, such an idea would corroborate the logarithmic curve fit to the data above, thus justifying the use of such a model.

TPA was created as an imitative test, resembling what goes on in the human mouth. It has been suggested that such test should operate at a similar speed to that of the human jaw (Rosenthal 1999). A number of studies have looked into the speed of biting such as Tornberg (Tornberg *et al.* 1985) who estimated the jaw to move at speeds of between 33 and 66 mm/s. Pons and Fiszman (1996) reported better sensory correlations with tests which ran at higher speeds. From Fig. 3 we can appreciate that once the speed of compression is in excess of about 2 mm/s increases in speed of compression make little difference to the hardness.

While these relationships maybe specific to the gel system being used in this study, the dramatic impact of both speed of compression and percentage compression on measured parameters does illustrate the importance of sticking to an established protocol. This is particularly the case if TPA parameters are to be compared between different foodstuffs. Szczesniak *et al.* (1963) correlated the instrumental results with well defined products from the General Foods Corporation manufacturing range with the intention of creating standard rating scales. For example, sensory hardness was measured on a nine point scale with products ranging from Cream Cheese to Rock Candy, and a curvilinear instrumental response was observed, suggesting the potential of a calibration between the GFT and standard food specimens. Perhaps this aspect of an apparent absolute, indubitable instrumental measure of texture is what makes TPA so attractive. From the literature, it is clear that some researchers report TPA parameters in their papers as if the results are absolute and comparable directly with others. The data from this study suggests that comparisons between TPA results are only likely to be valid if identical test protocols including test geometry, speed of compression, percentage compression are all kept constant. Thus the differences between the two key papers summarized in Table 1 are likely to invalidate Szczesniak, Brandt and Friedman's correlations, as are modifications made by other researchers.

The apparent accessibility of TPA as a technique for easy texture measurement is perhaps why after almost 50 years, the number of publications year on year continues to rise. However, this popularity has, in some cases, been accompanied by a misappropriation of data yielded. To this end, the originators of the technique have expressed concerns over both terminology

(Szczesniak 1996) and interpretation of the results (Bourne 1998; Szczesniak 1998). Implying that researchers wishing to use the technique should, rather than treating it as a "black box", think through and apply the test protocol appropriately. With this in mind, the platen geometry introduced by Bourne (1968) has generally become the standard, as have deformations of 75%. Care should be taken in selecting the speed of compression, which should be equal or greater than 2 mm/s.

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