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Applications of texture analysis to dough and bread

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Abstract: The assessment of product quality through texture analysis is an essential tool for both bread products development and production. This chapter describes the terms used in texture analysis of the intermediate product (dough) and the final baked product and includes the practical relevance of testing methods to these products. The principles connected with the measurement of the rheology of the dough for the processing steps, e.g. mixing, moulding, etc., and examples of the instrumentation used are illustrated. For the final baked product the texture of the crust and crumb structure along with freshness, volume and appearance are all important criteria by which the product is judged. The tests and instruments used for these tasks are described. The application of texture analysis to dough and bread is explained. Finally future trends in potential instrumentation and measurement techniques are discussed.

Key words: texture analysis, texture profile analysis, dough, bread, instrumentation, rheology, mixing energy, elasticity, extensibility, resistance, stickiness, softness, firmness, resilience, freshness, crumb structure, crumb density, loaf volume, texture analysers, C-Cell, crumb scoring.

22.1 Introduction

Conversion of flour, water, yeast, salt and other functional ingredients into the palatable product called bread has been undertaken using different processing methods around the world for centuries (Gould, 2007). The end products have different structures, different eating qualities and different flavours. The way the bread is used, whether for sandwich making or as an accompaniment to a fine meal, has resulted in varied shapes, sizes and internal and external textures. Each of the end products has a unique 'signature'. Part of this signature is the product's texture and is important because of its link to eating qualities, flavour and shelf life. Along with appearance, taste and flavour, the perception by the consumer of the texture of the product governs how often the product might be purchased.

Combining the ingredients in a mixer and applying mixing energy results in an intermediate dough product destined to become bread. The method and timings of the process along with the conditions in baking can affect both the final product appearance and its texture. Assessing the dough quality at different steps in the process can give some indication of how it might react or be affected downstream in the process. The dough quality can be a pointer to the final product's appearance and eating qualities, and is important for the consistent production of breads.

Instruments have been developed to meet the needs of the baker in understanding what is happening during the product's journey to becoming a consistent baked product with the eating qualities sought by the consumer. The results from such instruments can be linked to sensory analysis (in the case of the finished product) thus giving an objective measure of product quality.

22.1.1 Definitions

It would be remiss to omit some definitions of texture in a chapter on texture analysis. For the finished bread product these include:

- hardness
- firmness/softness
- springiness/resilience
- adhesiveness
- cohesiveness
- fracturability
- gumminess
- chewiness.

These terms were defined by Szczesniak *et al.* (1963).

Hardness is commonly a positive character sought in low moisture content products such as rusk-style bread products. In breads it might be used to describe the crust but should not be confused with crispiness. Crisp crusts are expected to be hard and to break or shatter readily.

Firmness and softness are terms generally used to describe a loss of softness in the breadcrumb.

Softness is seen as a positive attribute for breadcrumb and for the crust of a sandwich loaf. However it is seen as a negative attribute for the crust of 'crusty' bread products, e.g. baguette and oven bottom breads.

Springiness and resilience describe the way a product's crumb springs back and returns to its un-deformed state after a compressing force has been removed. During storage this attribute is lost as the staling process advances.

Adhesiveness is the force necessary to separate food from any surface with which it has contact.

Cohesiveness is generally seen as a positive character in all types of baked products. Where products form a ball readily in the mouth and require some effort in chewing, this character is controlled in part by moisture content and in part by the strength of the network surrounding the holes (cells) in the crumb. Where there are no 'cells' in the crumb, e.g. biscuits, the loss of moisture contributes to *crumbliness*, as does the underlying staling process.

Fracturability is the force necessary to crumble/crack or shatter product.

Gumminess describes the energy required to disintegrate food ready for swallowing.

Chewiness is the length of time to masticate food ready for swallowing.

For the intermediate dough product, an indication of the rheology of the dough (i.e. how the dough reacts under stresses and strains) is important (Stauffer, 2007). Rheology of dough includes:

- extensibility
- elasticity
- resistance to deformation
- stickiness.

Extensibility is a measure of how far the dough can be stretched before it breaks or snaps. *Elasticity* is a measure of how well the dough springs back to its original shape when stretched. *Resistance to deformation* is a measure of the degree of force required to change the shape of the dough. *Stickiness* – when doughs are compressed and/or sheared they may stick to surfaces with which they have contact so that when the compression is reversed an adhesive force is manifest before the dough parts from the surfaces.

22.2 Principles and types of instrumental analysis as applied to dough

Because of its molecular structure containing glutenins and gliadins, dough is a visco-elastic material. The 'texture' of dough is not usually measured as such during mixing and processing but its rheological properties are used as a guide to the machinability of the dough and its influence on final baked product structure. The rheological properties listed above change depending on ingredient composition, e.g. water addition, emulsifiers, fats, type of mixing equipment and the conditions applied. In further processing after mixing the yeast activity and the relaxing of the dough play an important part in changing the rheological characteristics and development of the dough. For example, a resistant and elastic dough immediately ex-mixer commonly becomes more extensible and less resistant if allowed to rest between processing stages. This in turn can affect the structure and texture of the finished loaf, e.g. a longer first proof results in a more 'open' texture in the final product. Also the stickiness that is often associated with dough pieces after immediately dividing and leaving moulders and other dough processing equipment may quickly disappear with exposure to the atmosphere or further 'gentle' processing and this makes it difficult to measure.

22.2.1 Assessing dough rheology during mixing

The major property assessed during mixing is the resistance of the dough – primarily the ingredients flour and water at laboratory-scale and the full recipe for plant mixers. The type of equipment used for both situations measures the torque on the mixer blades, which is related to the changing resistance of the dough as mixing continues. The torque data are continuously recorded during the appropriate mixing time and are displayed as a graph. It should be noted that the resulting data and curves are specific to the equipment used and are unlikely to be identical with other machines and methods employed. However since in general they are measuring torque over a time period there may be some similarities in curve shapes. With much of the laboratory-scale equipment involving mixing the curves displayed are similar to those created with commercial-scale mixers. Both sets of curves show the maximum energy followed by the weakening of the system and some broad indication of the performance of the flour might be deduced from the laboratory-scale curves. Figure 22.1 shows the curves obtained from a laboratory-scale mixer and Fig. 22.2 shows the curve obtained from a plant-scale mixer.

Examples of the laboratory-scale equipment are:

- Brabender® Farinograph®
- Newport Scientific (now Perten) DoughLab
- Chopin Mixolab.

Figure 22.3(a), 22.3(b) and 22.3(c) illustrate some of the instruments available.

In plant production the energy curves from the mixing cycle will vary as the resistance of the dough varies. During the short period when the ingredients are being dispersed the energy used is low but as water is added and mixing starts in

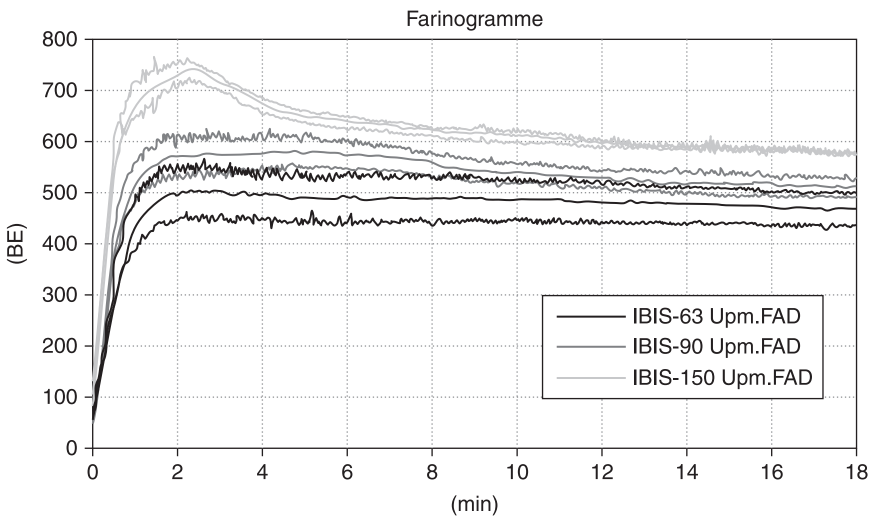


Fig. 22.1 Curves obtained from a laboratory-scale mixer.

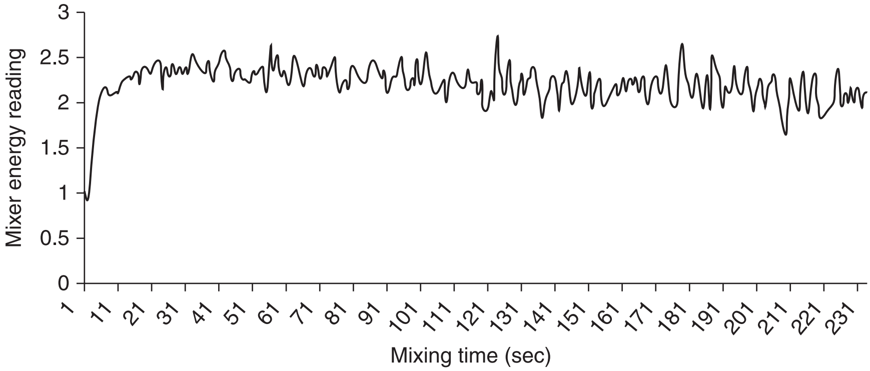
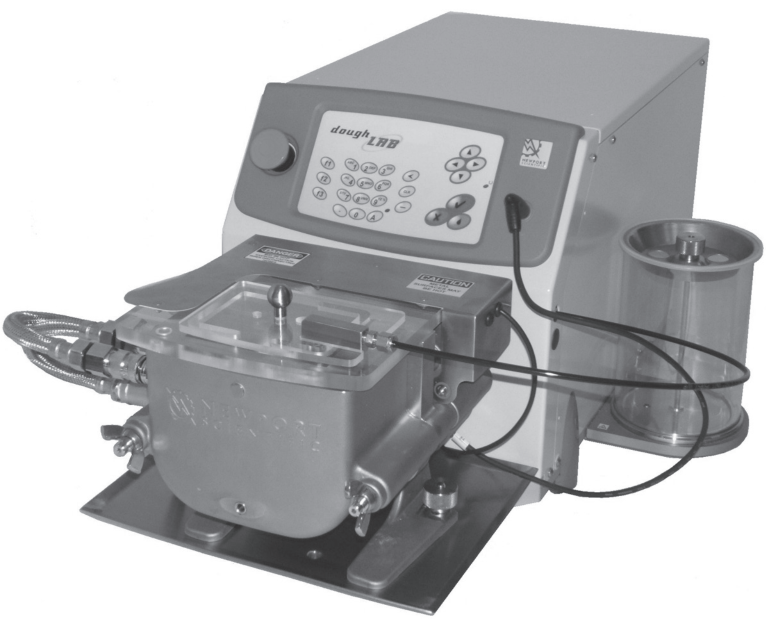


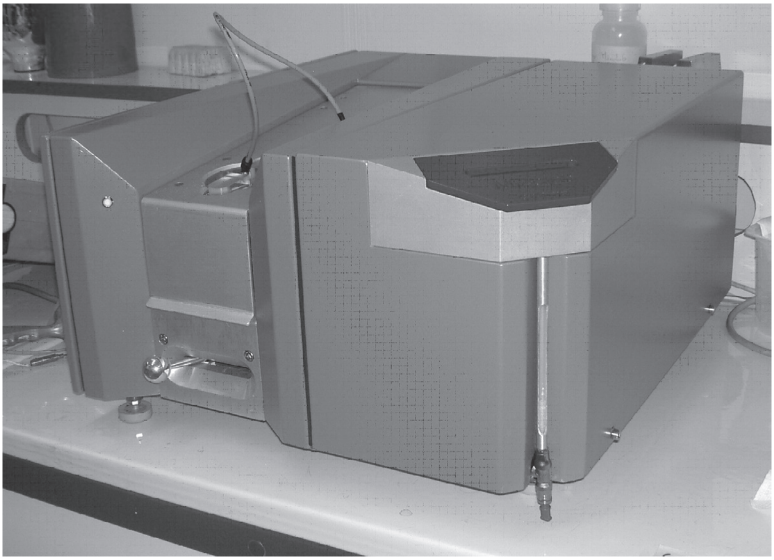
Fig. 22.2 Curve obtained from a plant-scale mixer.

earnest the dough becomes more resistant and viscous. The energy level needed rises to a maximum and then drops off as the dough becomes slightly less viscous. Recording and displaying the collected energy data over time from the mixer is undertaken in large plant bakeries. Modern mixers have the facility built-in, and the peaks and energy given over a period of time can be seen on the display and can be related to the final product quality.

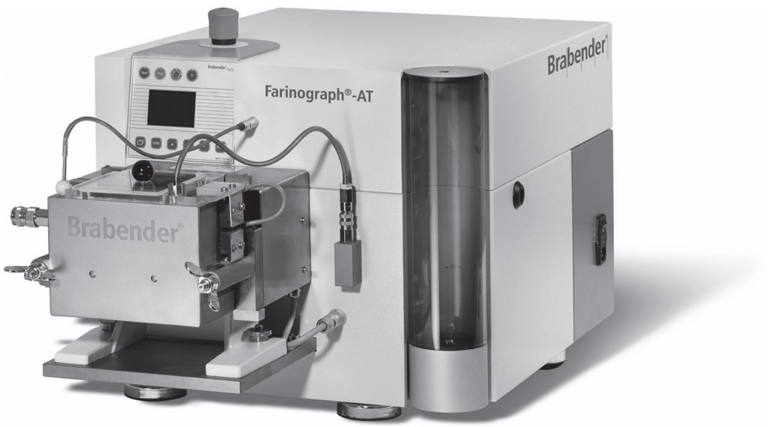


(a)

Fig. 22.3 Some of the instruments available: (a) Chopin (reproduced with permission from Chopin Technologies®).



(b)



(c)

Fig. 22.3 Continued (b) Perten (reproduced with permission from Perten Instruments of Australia Pty, Ltd.), (c) Brabender (reproduced with permission from Brabender® GmbH & Co. KG).

Extensibility is an important characteristic in the moulding of bread doughs. It is one of the characteristics that bakers use to relate the sensory properties of a dough piece to its probable performance in processing and to possibly predict the end product quality. A soft extensible dough can pass through the moulding heads on sheeting equipment and will curl easily when creating configurations for

Fig. 22.4 Moulder damage manifest in final loaf made from a stiff non-extensible dough.

panning. Easily mouldable doughs and correct settings on the moulding equipment will minimise damage in the end product, e.g. unwanted holes in the bread slice (Cauvain and Young, 2009a). Figure 22.4 shows how moulder damage can be manifest in a slice from a loaf made from a stiff non-extensible dough.

The instruments available for assessing extensibility and elasticity mimic the actions of the expert baker (who might stretch or pull a piece of dough). Examples of equipment are:

- Brabender® Extensograph®
- Chopin Alveograph
- Dobraszczyk–Roberts Dough inflation system
- Kieffer dough and gluten extensibility rig.

All of the above instruments are designed for laboratory trials but can be adapted to full recipe bakery formulations, though this is not common practice. Dough pieces are rested for a period of time before testing, and in some cases are re-moulded before being rested and then re-tested. One method is to stretch vertically a dough piece restrained between two attachments and record the load/extension curve during stretching. Figure 22.5 shows the Brabender Extensograph close-up – stretching the dough:

Fig. 22.5 Brabender Extensograph close-up – stretching the dough (reproduced with permission from Brabender® GmbH & Co. KG).

Another method for assessing extensibility is to force pressurised air at a constant rate from the underside of a flat dough sheet to form a bubble, e.g. the Alveograph, which measures the pressure inside the bubble and a curve (alveogram) shows this pressure plotted against time. The inflation continues until the dough bubble bursts. This test attempts to mimic the stresses and strains experienced by a dough piece in proof and the early stages of baking (Cauvain, 2009). Another instrument functioning along similar lines is an attachment to SMS Texture Analyser system – the Dobraszczyk–Roberts Dough inflation system. With this instrument the bubble is inflated by use of a piston and volume displacement of air. The pressure during inflation is measured by a pressure inducer, and the volume of air is calculated from the piston displacement. The dough's rheological properties are then calculated directly from pressure, volume and time (Cauvain and Young, 2009b). Figure 22.6 shows a typical inflation curve using the Dobraszczyk–Roberts dough inflation system.

For use in research laboratories where there may only be a small sample available the Kieffer dough and gluten extensibility rig attached to an SMS Texture Analyser can be employed to determine the small forces required for extending the dough. The maximum force (resistance to extension) and the distance to the elastic limit when the sample breaks (extensibility) are measured and plotted. Figure 22.7 shows a typical extensibility curve using this rig.

Elasticity is a more difficult parameter to assess because it is related to the molecular structure of dough and in some of the tests briefly referred to above it is difficult to separate effects of time, temperature and cumulative shear damage.

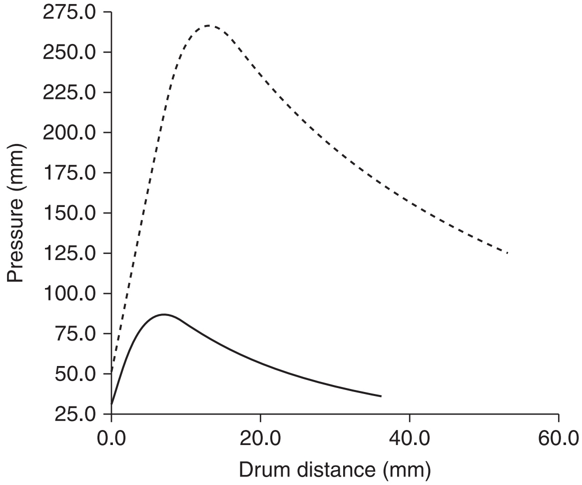


Fig. 22.6 Inflation curve using Dobraszczyk–Roberts dough inflation system (reproduced with permission from Stable Micro Systems).

More fundamental testing methods observing stress–strain relationships are helpful in this context. For example, the relationship between resistance and extensibility can be measured using the Bohlin Rheometer and similar equipment. In such instruments the dough pieces are subjected to relatively small deformations, which are not likely to change the rheological properties of the dough significantly,

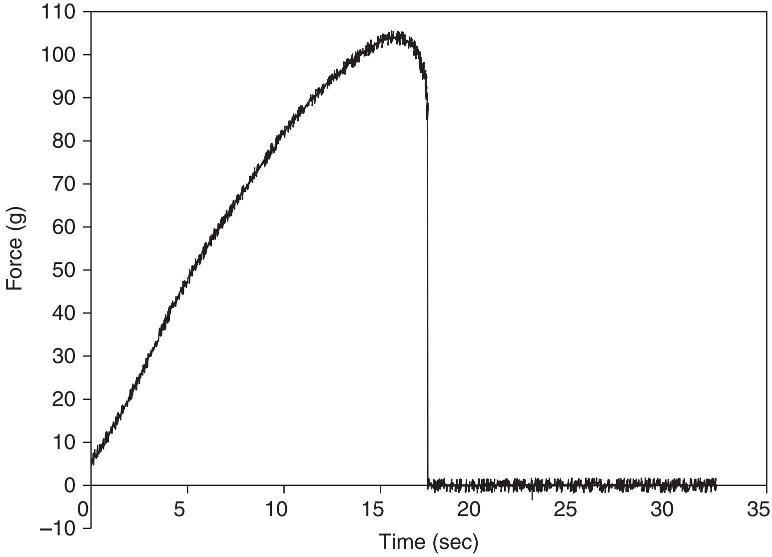


Fig. 22.7 Extensibility curve from Kieffer dough and gluten extensibility rig.

i.e. the dough sample is not destroyed during testing. The forces applied in such tests are considerably less than would commonly be experienced in a commercial bakery environment, e.g. during moulding and shaping. Stickiness is another parameter that is difficult to measure. The SMS/Chen–Hoseney Dough Stickiness Rig is used for laboratory samples by means of an attachment for the SMS Texture Analyser. Here a ball of dough is compressed and then the force is released to assess its stickiness.

Many of the instruments and tests developed can only be comparative tests performed on a particular instrument. They are often fundamental measurements of a property and give little information about the actual behaviour of doughs in a commercial environment. One of the challenges in developing instruments for commercial use is to be able to successfully mimic the actions of stretching and squeezing the dough by hand or machine for a variety of different dough textures. Currently the tests developed are at best just comparative ones. The other significant challenge for developing new dough testing methods is to devise ones that do not require manipulation of the dough in preparation for testing in such a manner that the dough property of interest is modified; it is precisely this issue which has limited a number of tests designed to evaluate the stickiness of dough.

A third challenge for new dough testing methods concerns the length of time over which the dough is evaluated; the times involved with many dough compressing and stretching tests are considerably longer than the processing times of dough on the plant. For example, during final moulding a dough piece is subjected to compression between sheeting rolls, relaxation after leaving the sheeting rolls and curling in a matter of a few seconds before being recompressed under the final moulding board. In some case there may be further stress applied to the dough before it reaches the pan, e.g. four-piecing (Cauvain and Young, 2001). Currently there are no dough testing techniques that approach the degree of compression, shear and general 'abuse' of a dough piece, let alone measure it and deliver a practical assessment in less than 5 seconds, yet this is what an expert baker must do.

22.3 Principles and types of instrumental analysis as applied to bread

When assessing the quality of bread products the physical measurements for softness, resilience, etc., are easier to achieve and be meaningful than for the intermediate dough product. The textural properties are described in terms of their sensory properties using the terms defined at the beginning of this chapter. The sensory terms used are often subjective descriptors rather than objective measures. Whichever way the textural quality is assessed it is important to define a base line from which all future quality assessments are made. Any changes in quality need to be assessed in terms of both the direction of change and the magnitude of the differences. It is possible to relate the subjective assessment and objective measurement. This relationship paves the way for future quality assessments to be made by objective measurements alone and negates the need for expensive human assessments. For example, when assessing bread slices (and therefore the loaf) by giving scores for the parameters defined (e.g. cell size), and then an overall score for the slice, it is possible to link these scores to the measured values given by an instrument such as C-Cell (see below).

22.3.1 Assessing softness and resilience in breads

Softness and resilience are two of the key characteristics linked to freshness of the bread product. These characteristics are the two that the consumer is attempting to assess when squeezing the packaged loaf as it sits on the supermarket shelf, when the loaf is cold and there is no aroma to indicate that it is freshly baked. Many of the objective tests that are used to assess product texture are designed to mimic the approach that consumers and experts use in their assessment. Commonly some form of controlled compression is applied to the sample. A typical compression test will either subject the product to a standard force applied for a fixed time or compress the sample though a given distance and measure the force required to achieve a given percentage thickness compression. Both techniques provide useful information on the softness of the sample. Resilience data or sample springiness can be determined by removing the compressing force and measuring the degree to which the sample recovers, usually after a fixed time. To some degree the ability of the sample to recover depends on the level of compressing force that was first applied. The greater the compressing force, the less likely the sample is to show significant resilience. Figure 22.8 shows a typical texture profile analysis curve for breadcrumb from a double compression test. These tests are done using the inner surfaces of the loaf (slices of specified depth). However the ‘squeeze test’ by the consumer is mimicked by the instrument Bread V Squeeze Rig (Community Registered Design) – an attachment to the SMS Texture Analyser machine (Fig. 22.9). It is a non-destructive test and requires no sample preparation. The loaf can be packaged or unpackaged. Figure 22.10 shows two typical curves obtained using this attachment.

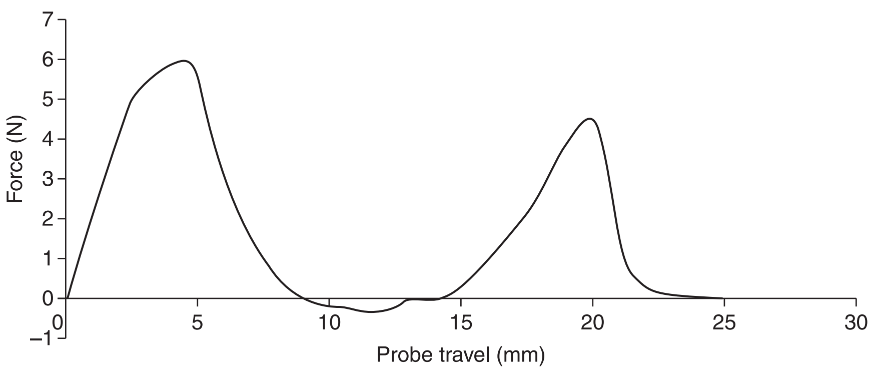


Fig. 22.8 Typical texture profile analysis curve for breadcrumb from a double compression test.

Fig. 22.9 Bread V Squeeze Rig (reproduced with permission from Stable Micro Systems).

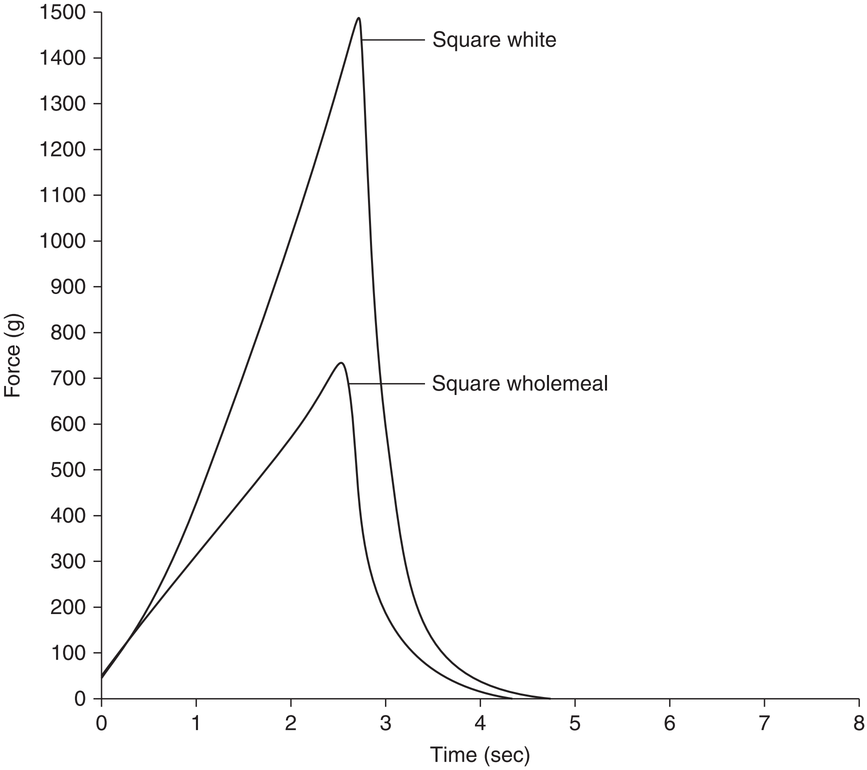


Fig. 22.10 Typical comparative curves from Bread V Squeeze Rig (reproduced with permission from Stable Micro Systems).

22.3.2 Assessing freshness in bread

Loss of 'oven-freshness' encompasses a number of different changes in the product. These are:

- Crumb firmness increase (starch retrogradation, described below, see Chapter 23).
- Loss of crust crispness, particularly in wrapped products.
- Loss of crumb and crust moisture, especially in unwrapped products.
- Increases in product crumbliness, commonly related to moisture content.
- Changes in taste, commonly loss of.
- Changes in aroma, commonly loss of.

Assessing firmness can give an indication of the amount of physical 'staling' that has occurred in the product and is measured using a single compression test as described above. The type of equipment and results obtained are shown in Fig. 22.11 and Fig. 22.12. Briefly, physical staling is the intrinsic firming of the breadcrumb and is caused by the changes in the crystalline structure of the starch component of the product (Pateras, 2007) irrespective of its moisture content. This change in the starch crystallization in wheat flour is known as 'retrogradation'. The magnitude and rate of the retrogradation process depend on a number of

Fig. 22.11 Bread firmness rig (reproduced with permission from Stable Micro Systems).

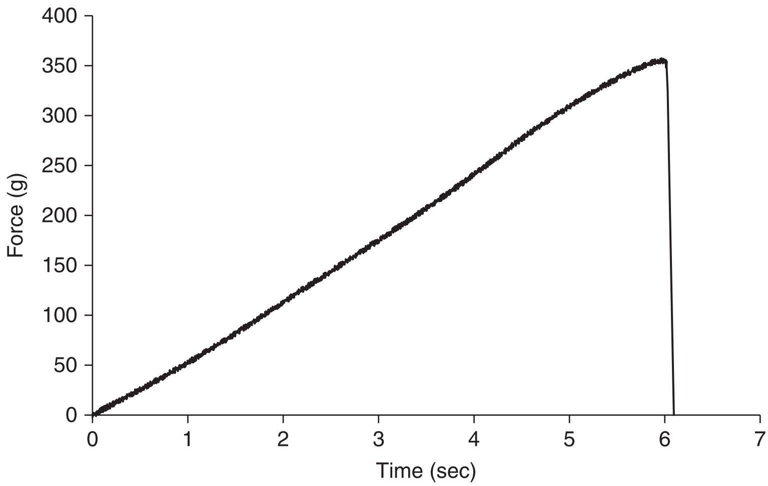


Fig. 22.12 Typical bread firmness curve.

formulation factors and the conditions of storage. In addition a firmness test can be used to assess the effect that different ingredients might have on the staling process.

The hardness or crispness of bread crusts may be assessed using some form of puncture test. The shape of the probe used for such tests is either in the form of a needle or a small diameter cylinder.

Migration of moisture from the crumb to the crust over a period of time can result in loss of crust hardness. The greater the difference in the moisture contents of the crust and the crumb the faster the migration will be. The common method for measuring sample moisture content is by a form of oven drying method (Cauvain and Young, 2008). In general, the higher the moisture content of a baked product the lower will be its hardness value (i.e. it will be softer).

Changes in taste can only be assessed using trained human panels. This also applies for loss in aroma, although here there have been instrumental techniques developed, e.g. the electronic nose. Table 22.1 lists examples of standard instrumentation and test methods.

22.3.3 Measuring crumb structure

Until the recent advances in camera and imaging technology crumb structure within the baked loaf was assessed using trained personnel. A 'score' was often given to a slice of bread according to the desirability or not of the features seen, e.g. open cell structure, streaks, brightness, etc. In spite of the training the measurements are and often become more 'subjective' in nature and there may be some drift over time in the scores given. Development of the C-Cell instrument (Calibre Control International, Ltd., Warrington, UK) has enabled the objective

Table 22.1 Examples of standard instrumentation and test methods (where appropriate)

Parameter	Examples of instruments used	Examples of test method/equipment
Hardness/softness	Stable Micro Systems TA. XTplus, TA.HDplus Bread V Squeeze rig	AACC Bread firmness method (AACC 74-09)
Springiness, rate of recovery, resilience, staling (shelf-life)	Stable Micro Systems TA. XTplus, TA.HDplus	Probes/attachments on Stable Micro Systems TA.XT instruments
Adhesiveness and cohesiveness	Stable Micro Systems TA. XTplus, TA.HDplus	Probes/attachments on Stable Micro Systems TA.XT instruments
Fracturability	Stable Micro Systems TA. XTplus, TA.HDplus	
Moisture	Brabender® Moisture Tester MT-C	ICC Recommendation 201 ICC Method 109

measurement of the characteristics of a loaf slice. An image of a slice of bread is captured and analysed (Fig. 22.13).

Measurements such as cell wall thickness, average cell size, distribution of cell sizes, cell orientation, degree of indentation on the sides of the loaf, etc., are all objectively measured and recorded. Direct comparisons can be made between loaves using the data measured. The effect of different ingredients and processing

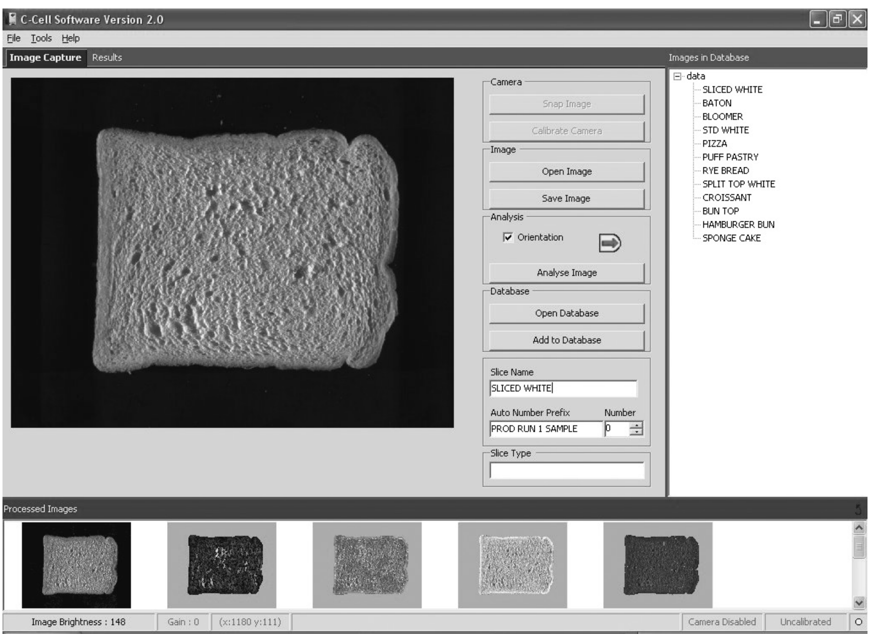


Fig. 22.13 C-Cell screen (reproduced with permission from Calibre Control).

methods on crumb structure can be quantified. When developing new equipment (e.g. dividers and moulders) for the baking industry C-Cell can be used to assess the effect that equipment has on product quality. If required a scoring system can be developed by choosing the parameters that contribute to the quality of structure sought, giving them weightings to reach an agreed unitary score. This score can be aligned to the human score, as given by a panel of trained expert assessors, and eventually replacing the latter with the machine/software generated one. This can result in more consistent and effective quality control monitoring of the bread products. A note of caution, however: it is important that the sample slice positions with respect to the loaf dimensions are consistent and sufficient sample slices taken so that any underlying variability can be taken into account when analysing any results from the data generated (Cauvain and Young, 2006).

22.3.4 Other measurements

Whilst the sensory textural properties and their measurement are described above, other physical properties have an effect on texture, e.g. loaf volume, loaf height, crumb density, etc., and a short description of techniques or instruments used would be useful in this chapter. Loaf volume can be assessed by 'seed displacement' (Cauvain, 2007) or by using electronic volume measuring equipment such as the Volscan Profiler (Stable Micro Systems) where an eye-safe laser device scans the product as it rotates while held in the instrument. The weight of the product along with its volume is recorded automatically and the density/specific volume can be calculated. For example if the results indicate a high specific volume then this may indicate that the loaf has an open texture or vice versa.

The density of breadcrumb itself can be measured by cutting a core of fixed dimensions out of the slice, weighing it and then calculating the density of the sample (Cauvain, 1992). This measurement can give an indication of how the product might 'eat' compared with one of different density or how 'light and airy' it might be. The moisture content of the core may also be determined which together with the density measurement provides the opportunity to separate out the roles of structure and moisture. Care should be taken however that the core is taken from the same position in the loaf, as the density can vary both across and along the loaf. This variation can occur for a number of reasons. One is that there is always a tendency for the centre crumb of bread, especially those baked in a pan to be lower than areas nearer to the crust. This uneven expansion occurs because dough is a poor conductor of heat and it takes a while for the centre of a dough piece when it enters the oven to stop expanding (Wiggins and Cauvain, 2007). Variations in crumb density can also occur as the result of the physical re-orientation of dough pieces before they are placed in the pan. This is the case with the technique known as four-piecing, which causes a systematic variation in cell structure and crumb density, with some areas of structure being described as being dominated by rounded cells and other by elongated cells (Cauvain and Young, 2006). The colour of both the external crust and internal crumb can also be measured and forms another sensory/textural attribute for the bread product.

22.4 Future trends

The importance of production of consistent quality breads will not diminish. The one criterion that consumers use when repeat-purchasing baked products is that the loaf should be the same as previously bought. Using texture analysis to identify the important characteristics of the product and then to maintain and measure those characteristics can be reassuring to a well-run quality department. Such measurements provide the yardstick by which they can improve the products or compare them with those of a competitor. The development of new instruments or attachments to measure textural aspects hitherto not measured for the intermediate product on the commercial plant will be beneficial in product development and improvement, for example by measuring the degree of stickiness of dough during the processing steps, and can lead to both better predictive and actual performance. Linking objective textural measurements with subjective sensory panel scores will alleviate the need for expensive panels once the characteristics describing the product are defined. Such objective textural measurements will obviate the 'drifting' that is seen when a product is assessed by different people and over an extended time period.

For the intermediate dough the interpretation of the results and graphs generated by laboratory-scale instruments is still the domain of the expert, and development of links from these data to both the performance of the dough and its effect on the final product characteristics would be useful in assisting the commercial production of many bread products. Knowledge and rule sets about the dough and the textural qualities of the final product have been created in the past (Young, 2007), but the potential of such computing techniques for optimising bread quality has yet to be realised.

22.5 Sources of further information and advice

- *Cereal Foods World*, AACC International Inc St Paul, USA.
- F2m baking + biscuit, f2m Food Multimedia GmbH, Hamburg, Germany.
- *ICC Handbook of Cereals, Flour, Dough and Product Testing* (Cauvain and Young, eds, 2009c).

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