POST GRADUATE DIPLOMA
IN
BAKERY SCIENCE AND TECHNOLOGY

PGDBST – 04

RHEOLOGY AND CHEMISTRY OF DOUGH

DIRECTORATE OF DISTANCE EDUCATION
GURU JAMBHESHWAR UNIVERSITY
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UNIT I: BASIC APPROACHES TO DOUGH RHEOLOGY

STRUCTURE

1.0 OBJECTIVES

This unit is designed to explain the following concepts of dough rheology:

- Basics of rheology
- Dough structure
- Oscillatory measurements
- Empirical and fundamental testing

1.1 DOUGH STRUCTURE

Dough refers to a wet mass developed after mixing of wheat flour, water and other ingredients. Physico-chemical properties of dough play important role in the bakery, pasta and ready-to-eat cereals processing industry. Dough is developed due to complex interactions among wheat constituents during mixing operation. The process of dough development begins with addition of water and commencement of mixing operation. Initially all ingredients are hydrated and appear like a sticky paste. On further mixing, the viscosity increases, sticky characteristics of dough disappear and a non-sticky mass is developed at peak consistency of dough. At this stage the dough behaves like a viscoelastic mass with both elastic and extensible characteristics.

The role of energy during mixing is crucial in the development of dough. In the process of developing dough particularly bread dough the aim is to bring about changes in the physical properties of the dough to improve its ability to retain the carbon dioxide gas produced during yeast fermentation. This improvement in gas retention ability is particularly important when the dough pieces reach the baking oven. In the early stages of baking the yeast activity is at its greatest and large volume of carbon dioxide gas is generated and released from solution in the aqueous phase of the dough. The dough pieces expand enormously at this time and well-developed dough or gluten structure is essential to withstand the internal pressure of the expanding dough.

The physical properties of dough of great concern in breadmaking process include resistance to deformation, extensibility, elasticity and stickiness. An example of a rubber band may be used to understand the first three of these properties. When the rubber band is stretched between our fingers a degree of force is required to change its shape as it resists deformation. If a modest force is applied and one end of the band is released, then it returns to its original position. This reflects the elastic properties. If the rubber band is stretched beyond a limit it will eventually reach a point of extension and ultimately breaks, which is taken as a measure of its extensibility. The fourth physical property, stickiness, is self-explanatory i.e. anything that stick to a surface has stickiness. Therefore, dough development is viewed as the modification of some very important physical properties of bread dough, which make major contributions to the character of the final product. This modification of gluten structure can be achieved by a number of different physical and chemical processes, and various combinations of these form the basis of the different groups of bread-making processes that are in common use.

Most of the desirable changes resulting from 'optimum' dough development are related to the ability of the dough to retain gas bubbles (air) and permit the uniform expansion of the dough piece under the influence of carbon dioxide gas from yeast fermentation during proof and baking. The dough with a more extensible character is especially important for improved gas retention, while reductions in dough resistance and elasticity play a major role in the modification of bubble structures during processing. It is important to distinguish between gas production and gas retention in fermented dough. Gas production refers to the generation of carbon dioxide gas as a result of yeast fermentation. If the yeast cells in the dough remain viable (alive) and sufficient food for the yeast is available, then gas production will continue, but expansion of the dough can only occur if that carbon dioxide gas is retained in the dough. Not all of the gas generated during the processing, proof and baking will be retained within the dough before it finally sets in the oven. The proportion that will be retained depends on the development of a suitable gluten matrix within which the expanding gas can be held. Gas retention in dough is therefore closely linked with the degree of dough development that occurs, and as such will be affected by a large, number of ingredients and processing parameters.

1.2 BASICS OF RHEOLOGY

Rheolgy is the study of deformation and flow of matter. Deformation relates to solids and flow to liquids. In all rheological measurements, material of interest is deformed and the force exerted and the deformation achieved is measured. The magnitude of the force that has to be applied to the material to deform it depends on the area over which it is applied. Instead of the force, it is more relevant to use the force per unit area which is called stress and which is calculated as:

$$\tau = F/A \qquad (1)$$

Where τ = stress, F = force acting upon the sample and A = area over which the force acts. Stress is measured in Pascals or N/m^2. The unit ‘Pascal’ has replaced the former unit, dyne/cm^2, which had previously been used for stress. 1Pa $\cong$ 10 dyne/cm^2.

There are two types of stresses, those that act in a direction parallel to the material surfaces they deform, called shear stresses, and those that act in a direction perpendicular to the surfaces of material they deform, called normal stresses or tensile stresses as illustrated in **Figures 1.1a and 1.1b**. The tensile stress is normally denoted by σ and the shear stress by τ.

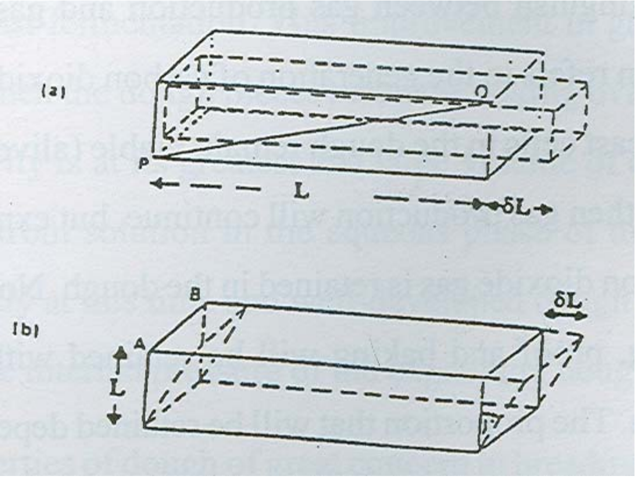

Figure 1.1 Illustration of tensile stress (a) and shear stress (b).

A stressed material often undergoes deformation (change from original dimension) and the rheological term associated with deformation is strain, a measure of relative displacement between the particles of a material. Strain is the ratio of two quantities with units of length. Therefore, it is dimensionless. **Figure 1.1b** shows the shear deformation of a rectangular test sample of height L. Its lower surface remains stationary while the upper surface is linearly displaced a distance δL.

$$\text{Strain } (\gamma) = \delta L/L, \text{ when } \gamma \text{ is small} \qquad (2)$$

In the simplest case, the rheological property of interest in a solid is its elasticity, and in liquids it is viscosity. Elasticity is the property of a material by virtue of which, after deformation and upon removal of stress, it tends to recover part or all of its original dimensions. The elasticity of a material is described by shear modulus, which is denoted by G. Mathematically this can be stated as:

$$G = \tau/\gamma \qquad (3)$$

This is equivalent to Hooke’s law, and a solid, which has a constant modulus of elasticity, is called Hookean or an ideal solid. The energy of deformation, in an ideal solid, is fully recovered when the stresses are withdrawn. Ideal fluids such as liquids and gases deform irreversibly, in other words, they flow. The energy of deformation is dissipated in fluids in the form of heat, and it cannot be recovered just by releasing stresses. An ideal fluid obeys Newton’s law, where stress is directly proportional to the rate of the resultant strain:

$$\tau = \eta\, d\gamma/dt \qquad (4)$$

Where η is the coefficient of viscosity of a fluid and $d\gamma/dt$ is the rate of strain. Deformation in a liquid is called flow and, since flow is a rate process, it is best expressed as a rate of strain. An ideal fluid with constant viscosity is also called Newtonian.

1.3 CREEP AND RECOVERY, VISCOMETRY AND STRESS RELAXATION

The food material having viscous and elastic properties is subjected to shear stress conditions during handling and processing. Depending upon the magnitude of elasticity and viscosity, the material will regain some part of its original dimensions after stress is removed. This response of a material is referred to as creep recovery. If recovery is negligible, then the material is said to be viscous. If recovery is quite remarkable, then material is said to be elastic. However, majority of materials has both the viscous and elastic parts and such material are called viscoelastic such as wheat dough and gluten.

Viscosity is a liquid property that relates to magnitude of the resistance due to shear forces within liquid. In viscometry the aim is to establish relationship between the rate of shear and shear stress while studying a liquid behaviour. When stress is proportional to the rate of shear, the material is called a Newtonian liquid such as milk, fruit juices and wine. For non-Newtonian fluids such as wheat dough, the ratio of shear stress to shear rate is known as apparent viscosity. The rheological behaviour of non-Newtonian fluid is determined by co-axial cylinder viscometer, such as Brookfield viscometers.

In stress relaxation measurements, a material is deformed to certain extent, after that the deformation is kept constant, and the stress, which is built up during deformation gradually, relaxes. This type of measurement is called stress relaxation. In creep experiment, the stress is held constant and the deformation is measured. Dough having slow stress relaxation is associated with good baking quality.

1.4 OSCILLATORY MEASUREMENTS

Foods, in general, cannot be categorized as ideal solids or ideal liquids. They are neither perfectly viscous nor perfectly elastic but are viscoelastic. Hydrated wheat gluten and wheat flour is described as viscoelastic materials, i.e. materials that exhibit both liquid-like and solid-like characteristics.

To study a viscoelastic material, small-deformation rheometry often uses parallel plate geometry, the material being placed between the plates (**Figure1.2**). The upper plate is subjected to forced oscillation of known amplitude and frequency and the lower plate is attached to a torque transducer.

When such material is subjected to sinusoidally oscillating stress, as in a controlled stress rheometer, the measured strain signal is neither exactly in phase with the stress (as it would be for a perfectly elastic solid) nor 90° out of phase (as it would be for a perfectly viscous liquid) but is somewhere in between 0° and 90° as illustrated in **Figure 1.3**. In such material, some of the energy input is stored and recovered in each cycle, and some is dissipated as heat. Material possessing such characteristics is called viscoelastic.

The sinusoidally varying stress and strain can be resolved mathematically:

$$\gamma = \gamma_o \sin \omega t \qquad (5)$$

$$\tau = \tau_0 \sin (\omega t + \delta) = \tau_0 \cos \delta \sin \omega t + \tau_0 \sin \delta \cos \omega t \quad (6)$$

Where γ_0 and τ_0 denote the maximum strain and the maximum stress or the strain amplitude and stress amplitude, respectively; ω = angular frequency; t = time and δ= the phase angle difference between stress and strain. The first of the two components of equation (6) can be interpreted as the part of the stress which is in phase with the strain, i.e. the elastic response and the second component can be interpreted as the part of the stress which is out of phase with the strain, i.e. the viscous response. Equation (6) can be rewritten by introducing G′ and G′′.

$$\tau = G' \gamma_o \sin \omega t + G'' \gamma_o \cos \omega t \qquad (7)$$

Where $G' = \dfrac{\tau_0 \cos \delta}{\gamma_0}$ and $G'' = \dfrac{\tau_0 \sin \delta}{\gamma_o}$

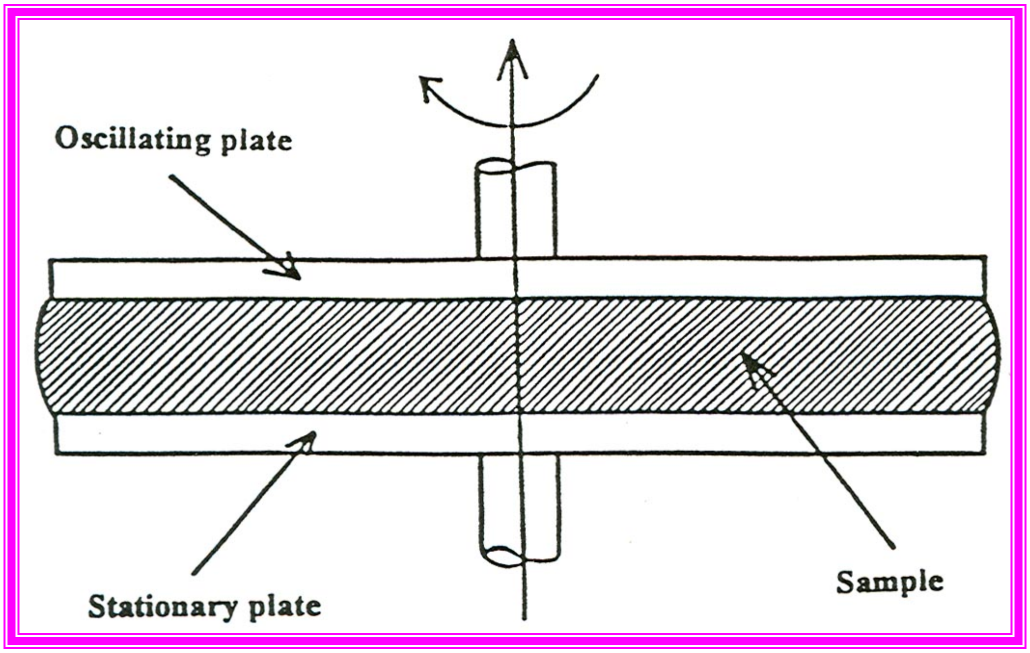

Figure 1.2 Shear deformation between parallel plates.

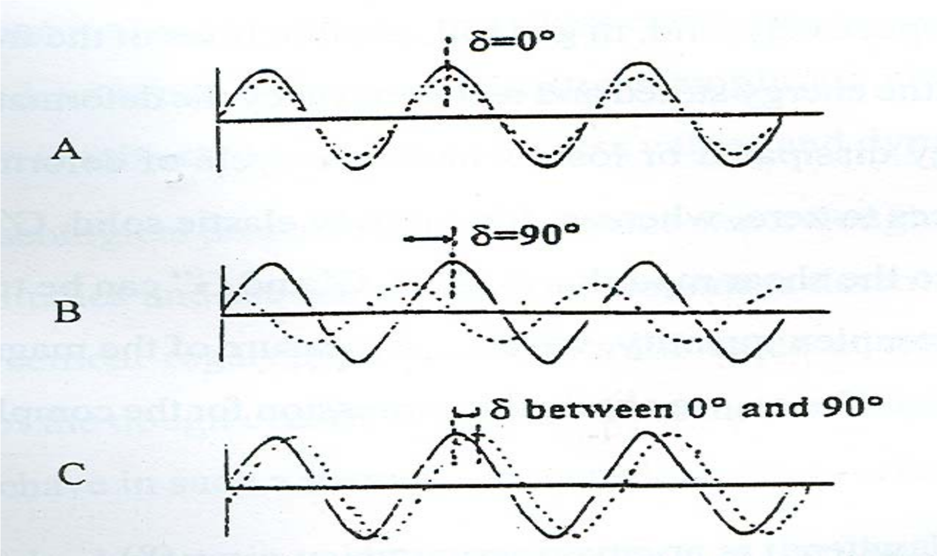

Figure 1.3 The response of an elastic solid (A), a viscous liquid (B) and a viscoelastic material (C) in a dynamic experiment. Solid lines represent stress and broken lines represent strain signal.

G′ and G″ are called the storage modulus G′ (elastic character) and the loss modulus G″ (viscous character), respectively, and, in general, are functions of the frequency (ω). G′ is taken as a measure of the energy stored and recovered in cyclic deformation, whereas G″ is related to the energy dissipated or lost as heat in a cycle of deformation. For a Newtonian fluid, G′ reduces to zero, whereas, for a purely elastic solid, G″ = 0 and the storage modulus is equal to the shear modulus G. Both G′ and G″ can be treated as real and imaginary parts of a complex quantity, which is a measure of the magnitude of the total response of the material. Hence, we obtain the expression for the complex modulus, G*:

$$G^* = G' + iG'', \text{ where i is an imaginary unit.} \qquad (8)$$

The magnitude of G* corresponds to the ratio between the maximum stress (τ_o) and maximum strain (γ_o).

$$|G^*| = \sqrt{G'^2 + G''^2} = \sqrt{\left[\left(\frac{\tau_o \cos\delta}{\gamma_o}\right)^2 + \left(\frac{\tau_o \sin\delta}{\gamma_o}\right)^2\right]} = \frac{\tau_o}{\gamma_o} \qquad (9)$$

The viscoelastic behaviour of a material is completely characterized when we know the frequency dependence and amplitude dependence of the dynamic moduli (G′, G″) and the ratio of G″ to G′, known as the loss tangent, tan δ. Tan δ indicates the relative contributions of the viscous (G″) and elastic (G′) characteristics of the material. When the material behaves more like a solid, i.e. when the deformation is essentially elastic and recoverable, the elastic character, G′, exceeds the viscous character, G″, and tan δ <1. Conversely, when the material behaves more like a liquid or viscous system, then the viscous character, G″, dominates and tan δ >1.

1.4.1 LINEAR VISCOELASTIC BEHAVIOUR

For dynamic oscillatory measurements to be of real value, they should be performed in the linear viscoelastic region. This implies that the dynamic moduli (G′, G″) and loss tangent (tan δ) should be independent of the applied stress or strain. Also, the stress-strain relationship should be linear. In a stress controlled rheometer, the region of linearity is normally determined by performing stress amplitude sweep, i.e. the sample under investigation is subjected to a range of stress values and dynamic moduli are measured.

The rheological properties of wheat flour-water dough have been investigated in a number of studies and the linearity of the responses determined. Although there is no general agreement regarding the exact strain value at which the linear viscoelastic behaviour of the dough ceases, it appears from these reports that the flour-water dough ceases to behave in such a manner at a very low strain value in the order of 0.0022.

At such a low strain value, large variation in the dynamic measurements occurs if the dough is prepared at optimum conditions of water absorption and mixing time. Such variation in experimental data complicates the interpretation of flour-water dough results in relation to the bread making performance. The large variation in the dynamic moduli disappears at higher strain values but then the theory of linear viscoelasticity is not obeyed strictly. Gluten dough behaves linearly up to much higher strains, i.e. 0.10-0.15.

For ‘synthetic’ gluten-starch doughs, it has been reported that with an increase in overall protein content (i.e. less starch), the stress amplitude dependence of dynamic measurements (G′, G″ and tan δ) decreases and essentially vanishes for wet gluten. The independent nature of the moduli for wet gluten clearly suggests that starch is responsible for the non-linear behaviour of flour-water dough. However, the factors that govern the linear viscoelastic behaviour of gluten, and those that limit it, remains unexplored.

1.5 EMPIRICAL AND FUNDAMENTAL TESTING

Rheological properties are important in determining the behaviour of wheat flour doughs during mechanical handling in addition to their influence on the quality of the finished product. Knowledge of rheological behaviour and dough properties is becoming more important as the baking industry becomes more automated. Rheological tests as applied in cereal research and industry have been classified as empirical or fundamental.

Fundamental tests provide information on the basic rheological properties of the material, such as viscosity (the ease of deformation) and elasticity (the ease of recovery). Wheat flour dough exhibits a combination of these properties and, therefore, is classed as a viscoelastic material. Empirical tests, normally used for dough quality analysis, such as the Mixograph, Farinograph and Extensigraph, fail to measure the basic rheological properties owing to their irregular sample geometry and the non-uniform deformations and deformation rates. Advantages and disadvantages of empirical and fundamental tests are listed in **Table 1.1.**

Considering the points in **Table 1.1**, it seems that with empirical tests we do not know what we are doing, but it works; with fundamental tests we know what we are doing, but it does not. This view is frustrating for those who are involved in cereal research and processing. The highly complex nature of dough is held responsible for the failure of fundamental rheological tests to predict its baking performance. Wheat dough is also a dynamic system. Simply doing nothing, allowing the dough to rest, will result in changes in its rheological properties. Dough systems also vary widely among cultivars in terms of their composition (i.e. protein, starch, lipids, enzymes, etc.), water absorptions and mixing requirements.

Table 1.1 Comparison of empirical and small-deformation fundamental tests.

Type of tests	**Advantages**	**Disadvantages**
Fundamental	*Well-defined physical properties *Useful for structural information *Non-destructive *Provide continuous measurements as a function of stress, strain, time and temperature	*Poor correlations with actual results *Expensive and slow
Empirical	*Applicable for variety of materials *Parameters correlate well with actual results *Inexpensive and fast	*Rheological parameters are defined in arbitrary units *Destructive so not useful for structural studies *Perform single point measurements in a discontinuous way *Results depend on sample size/shape *Results remain unique to the

		instrument rather than to the material *Effective for only limited number of foods
Ideal	All of the above	None of the above

The rheological properties of dough are analogous to the properties of gluten proteins. The deformations of dough experienced in empirical tests and in actual baking process are quite large relative to the magnitude of deformations applied by fundamental tests. At large deformation, the protein phase is thought to dominate the rheological behaviour of bread flour dough and the interference and/or contribution of starch-starch interaction is considered to be negligible. This is the reason why the results from empirical tests correlate well with the actual baking results.

However, starch-starch interaction dominates over protein-protein interaction under conditions of fundamental rheological tests. Therefore, the influence of protein quantity and quality, which largely control rheological properties and bread making performance, is suppressed by the starch dominance, which plays no significant role in bread making quality.

In addition, for most fundamental studies, flour-water doughs from different cultivars are mixed in different mixers at fixed mixing time and water absorption values. In fact, optimum values for water absorption and mixing times are different for different flours. This is often ignored in fundamental studies of doughs. It is these factors which make the interpretation of the dynamic rheological measurements of the flour-water doughs difficult in relation to the bread making quality.

In order to overcome these problems and to make fundamental tests more meaningful, dynamic measurements usually have to be conducted directly on gluten. The rheological properties of dough depend on the properties and composition of the gluten proteins and their tendency to interact with each other during the baking process. It is, therefore, important to understand the basic rheological properties of gluten proteins, their relative importance and their interactions that influence the rheological properties of the gluten.

1.6 SUMMARY

Dough refers to a wet mass developed after mixing of wheat flour, water and other ingredients. The process of dough development begins with addition of water and commencement of mixing operation. Initially all ingredients are hydrated and appear like a sticky paste. On further mixing, the viscosity increases, sticky characteristics of dough disappear and a non-sticky mass is developed at peak consistency of dough. At this stage the dough behaves like a viscoelastic mass with both elastic and extensible characteristics. Knowledge of rheological behaviour and dough properties is becoming more important as the baking industry becomes more automated. Rheological tests as applied in cereal research and industry have been classified as empirical or fundamental. Fundamental tests provide information on the basic rheological properties of the material, such as viscosity (the ease of deformation) and elasticity (the ease of recovery). Wheat flour dough exhibits a combination of these properties and, therefore, is classed as a viscoelastic material.

1.7 KEY WORDS

Dough: It refers to a wet mass developed after mixing of wheat flour, water and other ingredients.

Rheolgy: It is the study of deformation and flow of matter.

Extensibility: Ease of deformation or extension.

Elasticity: When a material is stretched it resists deformation. If a modest force is applied and released, then it returns to its original position. This reflects the elastic properties.

Viscoelasticity: A combination of viscous and elastic properties. If a material deforms on application of force and it regains it original dimension on withdrawal of force, then it is said that the material is viscoelastic.

Linear viscoelastic region: This implies that the dynamic moduli (G', G'') and loss tangent ($\tan \delta$) should be independent of the applied stress or strain.

1.8 SELF ASSESSMENT QUESTIONS

1. Discuss physical properties of wheat dough important to baking quality.

2. Explain the terms- (a) Rheology, (b) Shear stress & strain (c) Hooke’s law and (d) Newton’s law.

3. Explain creep recovery, viscometry and stress relaxation.

4. What is oscillatory measurement? Which are the oscillatory parameters? Explain importance of these parameters.

5. What do you understand by ‘Empirical testing’? How empirical testing is different from fundamental testing of dough?

1.9 SUGGESTED READINGS

1. Hammer RJ, Hosney RC (1998). Interactions: the key to cereal quality. AACC, St Paul, MN
2. Pomeranz, Y. (1989) Wheat is Unique. AACC Inc. St. Paul MN. USA
3. Hoseney, R.C. (1986) Principles of Cereal Science and Technology, Am. Assoc. Cereal Chemists, St. Paul, MN, USA.
4. Bushuk W, Rasper V (1994) Wheat: Production, Composition and Utilization. Blackie Acad and Professional, Glasgow
5. Pomeranz, Y. (1976) Advances in Cereal Science and Technology, Am. Assoc. Cereal Chemists, St. Paul, MN, USA
6. Samuel, A.M. (1996) The Chemistry and Technology of Cereal as Food and Feed, CBS Publishers & Distribution, New Delhi.
7. Heyne EG (1987). Wheat and wheat improvement. American Society of Agronomy. Haworth Press Inc, Canada
8. Dobraszczyk BJ, Dendy DAV (2001). Cereal and Cereal Products: Chemistry and Technology. Aspen Publisher, Inc Maryland

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UNIT II: RHEOLOGY OF DOUGH AND GLUTEN

STRUCTURE

2.0 OBJECTIVES

Thorough study of this unit will enable the reader to understand:

- Rheological behaviour of dough and gluten
- The basis of gluten viscoelasticity
- Importance of dough and gluten viscoelasticity in gas retention and bread making

2.1 INTRODUCTION

Importance of dough rheology is well recognized in predicting and controlling the quality of baked products. Variation in the elastic and viscous behaviour of different wheat flour doughs is considered as key quality factors in bakery applications. The primary aim of rheological measurements remains to differentiate between wheat varieties according to their baking performance without actually performing the baking test. Rheological tests that can correctly predict the baking performance of any wheat variety would save time, material and labour.

Now it is known, empirically by Farinograph, Extensogrpah and Mixograph that the mechanical properties of wheat flour doughs play a significant role in the handling properties of dough during processing and in the quality attributes of finished products. A relationship exists between dough strength and end use quality of wheat flour. However, these instruments fail to measure the basic rheological properties owing to their irregular sample geometry and the non-uniform deformations and deformation rates. On the contrary, fundamental tests provide information on the basic rheological properties of the material, such as viscosity (the ease of deformation) and elasticity (the ease of recovery). However, fundamental rheological tests such as oscillatory measurements on wheat flour dough have not shown relationships with baking results. During small-amplitude oscillatory measurements of dough systems, the rheological properties of the starch phase probably predominate and the influence of the protein phase, which largely controls the bread making performance of wheat flour, is suppressed by the dominance of the starch phase. Accordingly, small-amplitude rheological results obtained with dough systems often fail to correlate with baking results.

2.2 RHEOLOGICAL BEHAVIOUR OF DOUGH AND GLUTEN

The ‘dough strength’ of wheat flour can be judged from the Mixograph on the basis of the mixing time (MT), peak dough resistance (PDR) and work input (WI) requirement, which is a function of MT and PDR, as well as the general shape of the Mixograph curve. Doughs having longer mixing time (4 to 6 min), medium to high peak dough resistance (40 to 80 Mixograph Unit) and higher work input requirement (180 to 220) are characterized as ‘extra strong’. Weak doughs develop quickly with little work input (≤80) requirements. Wheat gluten samples in Mixograph require higher work input (energy) than those of the corresponding flour doughs. Gluten samples in general also take longer time to mix to peak than the corresponding flour samples. Strength of dough or gluten relates to the composition of glutenin proteins. Glutenin subunits 5+10, 17+18, 7+8, 1 and 2* have positive effects on mixing time and dough ‘strength’. On the other hand, subunits 6+8, 2+12, 3+12 and 20 are positively related with short mixing time and poor dough weakness.

Gliadin proteins tend to decrease overall dough strength and stability. Individual gliadin subgroups, i.e. α-, β-, γ- and ω-gliadins decreases dough strength parameters, such as mixing time (MT) and peak dough resistance (PDR) in accordance with the size and/or charge of the gliadin proteins (Table 2.1 & Figure 2.1). The decreasing order of these parameters for different gliadins is: ω- >, γ-, > β-, > α-gliadins. Direct relationships between mixing time and molecular size of glutenin proteins have also been shown using gel filtration chromatography. However, glutenin polymers are orders of magnitude larger than gliadins, and relationships of gliadin molecular size with functional effects have not been observed previously.

Although the molecular size of gliadin proteins shows associations with dough strength parameters, bread-making quality appears not to be related to the size of these proteins. The baking results (Table 2.1) reveal that ω-gliadin (i.e. the highest molecular weight gliadin protein) is the least effective on bread loaf volume. Considering these observations, it seems conceivable that the interactive behaviour of gliadins with other gluten proteins through covalent and non-covalent bonding may be important in determining bread making quality. It has been postulated that α- and β-gliadins associate with other proteins through a disulphide interchange mechanism, and through hydrophobic and hydrogen bonding. Recently, α-type gliadins have been reported to contain odd numbers of cysteine residues (e.g., clone A735 with seven cysteine residues. The seventh residue is envisaged to form an intermolecular S-S bond with other gluten polypeptides. Such association appears to favour extensive gluten film network formation, which, in turn, might improve gas retention and loaf volume. On the other hand, ω-gliadins are distinct from other gliadins in lacking the sulphur containing amino acid cysteine. Therefore, ω-gliadins interact with other proteins only non-covalently; these are probably less effective in influencing viscoelastic properties and bread making quality. This view is supported by the fact that ω-gliadin is less effective than α-, β- and γ-gliadins in improving the Mixograph parameter PDR and the baking parameter loaf volume.

Figure 2.1 Effects of gliadin subgroups on mixing parameters of flour.

Table 2.1 Effects of addition of purified gliadins on the Mixpograph parameters and loaf volume data of a base flour.

Gliadin added	MT (min)	PDR (MU)	LV (ml)	% increase in LV
Control	3.40 ± 0.11	44.9 ± 1.67	69.8 ± 1.40	-
α-gliadin	2.66	49.6	79.5	13.9
β-gliadin	2.80	49.8	79.2	13.5
γ-gliadin	3.08	49.3	79.3	13.6
ω -gliadin	3.20	45.7	77.5	11.0

MT = Mixing time; PDR = Peak dough resistance; LV = Loaf volume

2.3 RHEOLOGICAL PROPERTIES OF DOUGH FROM HIGH EXTRACTION, WHOLE WHEAT AND COMPOSITE FLOURS

2.4 THE BASIS OF GLUTEN VISCOELASTICITY

Wheat flour dough is largely composed of starch, proteins, lipids, and water and air cells. If the gluten proteins are removed from the flour, then the property of forming a viscoelastic dough is lost. It is generally agreed, therefore, that the gluten proteins form the framework of the dough structure. When flour is wetted, the formation of gluten is mainly caused by a complex interaction between the endosperm storage proteins, viz. gliadin and glutenin.

Usually the elastic properties of gluten are ascribed to the glutenin fraction, whereas the viscous properties come from the gliadin fraction. It is understood that the gluten of wheat owes its unique viscoelastic behaviour to an appropriate balance in the amounts of gliadin and glutenin proteins, but variation in the composition and elastic properties of the glutenin proteins appear to be largely responsible for the differences in the gluten viscoelasticity among wheat cultivars. For this reason, it is widely believed that the viscoelasticity of gluten is controlled by the glutenin proteins.

The ‘linear glutenin hypothesis’ has received wide acceptance in explaining the viscoelasticity of gluten and flour doughs. This hypothesis has passed through different stages of sophistication. According to this theory the glutenin polypeptide chains form long linear ‘concatenations’ with two S-S bonds connecting each chain in a head-to-tail fashion to the next chain. The ‘concatenations’ of glutenin molecules are assumed to participate in the formation of a three-dimensional entangled network structure.

The entanglement may be purely physical and/or at the point of entanglement, known as nodes, non-covalent interactions might occur to form cross-links (branching). The branching of glutenin polymers by S-S bonds is also not ruled out. The effectiveness of entanglement and cross-linking will depend on the length of the glutenin ‘concatenations’, which in turn depends on the number and distribution of covalent bonds and non-covalent interactions.

Under stress conditions, the entangled and non-covalently cross-linked structure in glutenin offers resistance to deformation, which is manifested in increased elasticity (elastic modulus, G′) during controlled stress rheometry. It also enables glutenin polymers to recoil after stress conditions are withdrawn. Viscous flow depends predominantly on molecular slippage at nodes and the labile nature of weak secondary forces acting between the glutenin polymers. Sulphydryl-disulphide bonds interchange and mechanical scission of S-S bonds may also contribute to viscous flow. Mechanical scission of S-S bonds probably occurs when the rate of deformation exceeds the rate at which molecular slippage or SH/SS interchange can occur resulting in glutenin polymers being subjected to stress values more than their elastic limit. The viscous nature of gliadins may be attributable to the absence of effective entanglements owing to their low M_rs. The gliadin polypeptides help molecular slip acting analogously to ball bearings.

A spiral structure hypothesis also explains the elasticity of glutenin. This hypothesis is based on the structural analogy of high M_r subunits of glutenin to the mammalian connective tissue protein, elastin, in which the elasticity is attributed to the presence of β-Spiral structure. Circular dichroism spectroscopy and structural prediction studies have indicated that the central repetitive domain of high M_r glutenin subunits is rich in β-turns. The β-turns are hypothesised to occur so frequently and regularly that they have been suggested to form a β-spiral structure, as in elastin (**Figure 2.2**). The β-spiral structure is assumed to be intrinsically elastic.

It has been suggested that under stress conditions, the β-spirals undergo deformation and on release of stress, the β-spiral structures resume their original energetically favourable conformation (**Figure 2.3**). Experimental evidence for the β-spiral conformation of the high M_r glutenin subunits has been obtained using scanning tunnelling microscopy of a purified high M_r glutenin subunit (1Bx 20) from durum wheat. There is no direct evidence as yet for the elastic nature of β-spiral, however.

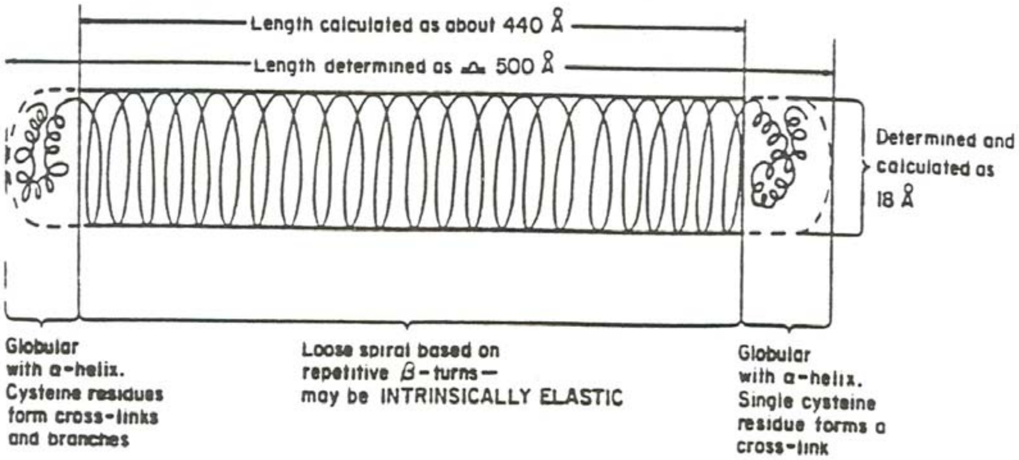


Figure 2.2 A hypothetical structural model for the high M_r subunits of glutenin.

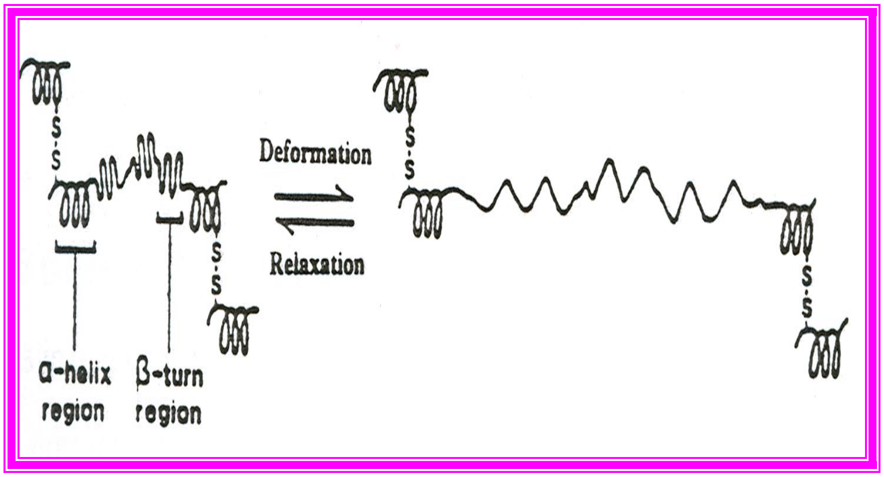


Figure 2.3 Schematic illustration of how linear glutenin molecules confer elasticity to gluten and flour water doughs. The glutenin polypeptides are joined head-to-tail via S-S bonds in a linear chain. The glutenin polypeptides polymerise into a linear chain by intermolecular S-S bonds between the cysteine residues located in the α-helical regions near N- and C- terminal ends of high M_r glutenin subunits. The central domain is thought to be rich in repetitive β-turns which form stable β-spiral structures. Under stress conditions, the β-spiral structures undergo deformation and on release of stress, the β-spirals resume the energetically more favorable original conformation. The presence of cysteine residues at either end of glutenin molecules, allows deformation/reformation to occur in the central spiral region.

2.5 IMPORTANCE OF DOUGH AND GLUTEN VISCOELASTICITY IN GAS RETENTION AND BREAD MAKING

The technological significance of wheat flour is related to the viscoelastic nature of its flour-water dough, which retains gas produced during fermentation and in the early stages of baking. The ability of a viscoelastic dough to retain gas results in a light porous crumb textured bread. Wheat gluten proteins are believed to be primarily responsible for the viscoelastic behaviour of dough and hence for the uniqueness of wheat flour. Proteins of other cereals such as corn, rice, rye, etc. do not have the ability to produce such viscoelastic dough. Flours from other cereals, therefore, fail to retain gas and give very dense and small loaves.

The bread making process is accomplished through three basic operations: mixing, fermentation and baking. Mixing transforms the flour and water into cohesive viscoelastic dough. Another key function of the mixing operation is the incorporation of air. The air is essential as it introduces the gas cells into which the CO_2 produced by the yeast fermentation diffuses. The importance of these gas cells emerges from the fact that yeast cannot produce new gas cells. Therefore, if no air cells were present, the crumb grain of the final bread would be very coarse with only a few large cells.

Dough is developed as a result of mixing to high work input levels and at high speed in mechanical dough development systems, such as the Chorleywood Process, or by mixing to low work inputs at low speeds plus long fermentation in bulk in ‘traditional’ bread making systems. Such developed dough is capable of retaining the CO_2 produced by the yeast during fermentation and in the early stages of baking. Baking rheologically transforms expanded viscoelastic dough foam into an elastic bread sponge.

Flour-water dough retains gas owing to its discontinuous discrete cellular foam structure, whereas baked bread is a continuous open-celled sponge that is permeable to gases.

Understanding the structure of the gluten proteins, and how they interact with themselves and other flour constituents to convert a wheat flour into a viscoelastic system, still largely remains a challenging problem. Also, much remains to be learned about how a viscoelastic dough retains gas and how the expanded dough is transformed into bread. However, some progress has been made in this area of research, and in the discussion that follows the role of gluten proteins in gas retention is explained. The discussion below, although based on available evidence, may be somewhat speculative.

From a colloidal point of view, in mixed flour-water dough the hydrated gluten proteins form the continuous phase with starch and air cells as the discontinuous phase embedded in it and the yeast cells are dispersed throughout the aqueous dough phase. The ‘free’ water in the dough represents the aqueous dough phase, which dissolves the water-solubles and, acts as the medium for chemical reactions and for dissolving CO_2 up to its saturation point.

Yeast ferments sugars and continuously produces CO_2 in the aqueous dough phase. When the aqueous dough phase is saturated with CO_2, most of the CO_2 diffuses into the air cells that are formed in the dough during mixing. This is attributed to the fact that the rate of diffusion of CO_2 in the dough and hence its ultimate evaporation into the surrounding atmosphere is slow. This is due to the presence of continuous gluten proteins film, pentosans and lipids.

The diffusion of CO_2 into gas cells increases the pressure within gas cells that provides the driving forces for dough expansion. The viscous flow properties of dough owing to its monomeric proteins (mainly gliadins) allow the gas cells to expand. The expansion of gas cells releases the pressure within gas cells, however, a little pressure does exist in the dough system during fermentation. The pressure in gas cells has been reported to be slightly greater than the atmospheric pressure, i.e. about 1.01. This small over-pressure results from the surface tension at the gas dough interface and the resistance of dough to deformation, i.e. expansion.

During baking, the temperature increases, water evaporates from the liquid dough phase into the gas cells, CO_2 and ethanol produced by the yeast and dissolved in the liquid dough phase also diffuse into the gas cells, which together result in an overall increase in the pressure within the gas cells. The viscous components, i.e. monomeric proteins (mainly gliadins) allow gas cells to expand to equalise the internal gas cell pressure, whereas the elastic components, i.e. polymeric proteins (mainly glutenins) provide strength to prevent the gas cells from over expanding, and thus preventing the rupture of the gluten film network enveloping the gas cells.

In flour-water dough containing insufficient amounts of good quality polymeric proteins, the gluten network would be too extensible, allowing uncontrolled expansion of gas cells, which would ultimately rupture the continuous gluten film network and, thus continuity between gas cells would be established. The continuity between gas cells or the discontinuity in the gluten film network is seen as pinholes at the dough surface. This results in the rapid loss of CO_2 even at very low temperature during baking and very early end of the oven spring. Consequently, bread of low loaf volume and dense open crumb is produced. On the other hand, good quality flour-water dough with enough strength retains CO_2 until more advanced stages of baking, i.e. ~70°C. This produces a good bread loaf volume and even crumbs texture on completion of baking.

Differences in the loss of CO_2 between poor and good quality flour doughs are not related to changes in the starch or to changes in the gluten proteins but appear to reside in the inherent differences in the gluten proteins. The ratio of monomeric to polymeric proteins and composition as well as properties of glutenin subunits in flours appears crucial to the gas retention and dough expansion.

The rapid loss of CO_2 at ~70°C is assumed to be the result of the increased elastic character of the dough due to starch gelatinisation and polymerisation of the glutenin proteins via disulphide cross-linking. This leads to a sharp increase in the tensile stress in the dough system, thus causing rupture of the gluten film network at the gluten-starch interface and subsequently loss of gas retention. More recently, rupture of the liquid film surrounding the gas cells has been considered to contribute to the rapid loss of gas during baking. The liquid film may have an additive effect with the gluten film network in gas retention.

2.6 SUMMARY

The ‘dough strength’ of wheat flour can be judged from the Mixograph on the basis of the mixing time (MT), peak dough resistance (PDR) and work input (WI) requirement, which is a function of MT and PDR, as well as the general shape of the Mixograph curve. Gluten samples in general also take longer time to mix to peak than the corresponding flour samples. Strength of dough or gluten relates to the composition of glutenin proteins. Glutenin subunits 5+10, 17+18, 7+8, 1 and 2* have positive effects on mixing time and dough ‘strength’. On the other hand, subunits 6+8, 2+12, 3+12 and 20 are positively related with short mixing time and poor dough weakness. Gliadin proteins tend to decrease overall dough strength and stability. Individual gliadin subgroups, i.e. α-, β-, γ- and ω-gliadins decreases dough strength parameters, such as mixing time (MT) and peak dough resistance (PDR) in accordance with the size and/or charge of the gliadin proteins. The decreasing order of these parameters for different gliadins is: ω->, γ-, > β-, > α-gliadins.

2.7 KEY WORDS

Dough strength: Dough strength relates to mixing time, peak dough resistance and work input parameters of mixograph instrument. Higher values of thee parameters means that the dough is stronger and vice-versa.

Gliadins: Alcohol soluble gluten proteins which are extensible in nature and impart extensibility to the dough.

Glutenins: Alcohol insoluble but dilute acid partly soluble gluten proteins which impart strength and elasticity to the dough.

Linear glutenin: Wheat glutenin proteins linked by S-S linkages in head to tail fashion resulting in a straight multi-chain of proteins are called linear glutenin.

Peak dough resistance (PDR): Resistance of dough at peak consistency is called peak dough resistance.

2.8 SELF ASSESSMENT QUESTIONS

1. How dough strength is assessed using Mixograph?
2. Explain the effects of gliadin and glutenin subunits on mixing characteristics of dough.

3. What is the fundamental basis of wheat gluten viscoelasticity?
4. Discuss in detail the importance of wheat gluten viscoelasticity in gas retention and bread making.
5. Explain linear glutenin hypothesis.

2.9 SUGGESTED READINGS

1. Rasper VF, Preston KR (1991). The Extensograph Handbook. AACC, St Paul MN

2. Bushuk W, Rasper V (1994) Wheat: Production, Composition and Utilization. Blackie Acad and Professional, Glasgow

3. Pomeranz Y (1990) Advances in Cereal Science and Technology, AACC, St Paul, MN

4. Eliasson, A.C. and Larsson, K. (1993) Cereals in Breadmaking, Marcel Dekker, Inc. New York.

5. Hoseney, R.C. (1986) Principles of Cereal Science and Technology, Am. Assoc. Cereal Chemists, St. Paul, MN, USA.

6. Sivasankar, B. (2002) Food Processing and Preservation, Prentice Hall of India Pvt.Ltd, New Delhi.

7. Samuel, A.M. (1996) The Chemistry and Technology of Cereal as Food and Feed, CBS Publishers & Distribution, New Delhi.

PGDBST- 04 **B.S.Khatkar**

UNIT III: BAKERY INGREDIENTS AND DOUGH RHEOLOGY

STRUCTURE

3.0 OBJECTIVES

This unit is designed to explain the effects of formula ingredients such as water, yeast, redox agents, sugars and emulsifiers on dough rheological properties.

3.1 INTRODUCTION

Ingredients influence rheological behaviour of dough. Ingredients are included in the formulation with specific function in mind. Water, sugar, yeast, oxidizing and reducing agents, sugar and emulsifiers are the important ingredients added in bakery products for improving dough handling characteristics, eating quality and shelf life. The additions of these additives change rheological behaviour of dough and such changes are discussed in the following paragraphs.

3.2 EFFECTS OF WATER ON THE RHEOLOGICAL BEHAVIOR OF DOUGH

The rheological properties of wheat flour dough largely depend upon its water content. The amounts of damaged starch, protein and pentosan have a strong influence on water absorption capacity of wheat flour. The water content provides vital aqueous phase to the dough. The aqueous phase will affect the behavior of the dough because of the amount and type of soluble substances, such as salts, minerals and organic material. These soluble substances have substantial influence on the pH of the dough. During dough mixing the proteins affect pH through dissociation of charged amino acid side chains. The initial pH of dough is about 5.5. Fermentation reduces the pH owing to the saturation of carbon dioxide in the water phase and production of organic acids. The sourdough has the lowest pH values.

The pH of the dough directly affects the physical properties of the gluten and the lipid-water phases. The gluten proteins range widely in their isoelectric pint (IP). Gliadin proteins have IP values > 6.5 pH, whereas the glutenin proteins exhibit IP values below 6.5. Swelling of the gluten protein increases from the IPs of proteins, and the mechanical strength of these proteins is reduced. Lowering the pH during dough fermentation leads to the strongest effect on gliadin proteins.

Salts are present in the aqueous phase of the dough. The salt contents of water affect the dough characteristics. Water of medium hardness is preferred for dough making. Extremely soft water causes the dough to be very soft and sticky, whereas extremely hard water retards the fermentation. The level of water addition also affects dough mixing characteristics. Increase in the water level in dough increases the mixing time required to achieve optimum dough consistency.

3.3 EFFECT OF YEAST ON DOUGH RHEOLOGY

The yeast is used in the dough is to leaven it so that the dough rise in volume and product develops porous structure. This is achieved by carbon dioxide produced by yeast during fermentation and early stages of baking. The yeast ferments sugar, producing carbon dioxide and ethanol. *Saccharomyces cerevisiae* strain of yeast is regarded as the most common leavening agent in bread. This is known as baker’s yeast. It is considered as necessary in bread making as flour and water. Yeast contributes to texture of the dough, bread volume, flavor, taste and the nutritional value of the bread. Due to its phytase activity the yeast improves mineral uptake in the intestines. The yeast requires sugars to produce CO_2. Yeast converts 1g of glucose into about 0.5g of CO_2, which is equal to 275 ml volume of CO_2 at atmospheric pressure and 30°C temperatures.

Without yeast the bread will have flat and compact volume. The taste and bite characteristics of bread will also be inferior without yeast in the bread formulation. Usually 3-5 per cent yeast is required to produce acceptable bread, which will have double the volume as compared to bread produced without yeast. The CO_2 gas producing by yeast is affected by temperature, pH, alcohol concentration, osmotic pressure and amount of yeast used. Yeast has reasonable tolerance to pH range of 3.5 to 8.0. However, maximum volume of CO_2 gas is production by the yeast at 5.5 pH. Yeast produces $CO_{2,}$ ethanol and organic acids during fermentation, which influences the dough structure. Yeast also contains compounds such as glutathione which causes slackening effect on the dough due to its effect on gluten proteins.

3.4 EFFECT OF OXIDATION AND REDUCTION ON DOUGH RHEOLOGY

Oxidizing/reducing (redox) agents such as potassium bromate ($KBrO_3$) and ascorbic acid have long been used as additives for improving baking quality of wheat flour. The amount of redox agents depends up on the types of flour. The amount of oxidant is used at a level of 25 mg/kg flour in case of slow mixing, whereas intense mechanical dough development requires around 100 mg/kg. The flours with higher protein contents generally have higher oxidation requirements. The requirements of redox agents are higher for varieties with short mixing times. Redox agents affect bakery products as well as the mixing behaviour of flours.

It has been observed that sometime newly flour performs poorly but will improve with storage. The thiol content (SH group) of a newly milled flour decreases by 20-30% over a few hours in air. The flour matures more quickly with the addition of oxidizing agents such as ascorbic acid or $KBrO_3$.

This demonstrates that the effect of maturing of newly milled flour is due to oxidative changes. Oxidation processes can also cause bleaching of wheat flour. However, the most common oxidizing agents e.g. $KBrO_3$ and ascorbic acid do not bleach the flour.

Oxidizing agents such as $KBrO_3$ and ascorbic acid make the dough stronger, stiffer and more elastic, whereas reducing agents like L-cysteine hydrochloride make the dough weaker, softer and more extensible. Oxidation reaction causes cross-linking of protein molecules and thus increased stiffness and elastic character of the dough. Reduction causes breakage of the disulfide bonds (S-S bonds) and thus a reduction in molecular size, making the dough weaker, softer and extensible.

L-cysteine (reducing agent) reduces the mixing time by breaking a portion of the cross-linking disulfide bonds and creating free sulfhydryl (SH) groups. It causes decrease in the elastic strength and increase in extensibility of the gluten network in the dough system. On the other hand, additions of either ascorbic acid or potassium bromate increases mixing time of flour.

The ascorbic acid and potassium bromate are slow acting oxidants, whereas, potassium iodate (KIO_3) and azodicarbonamide (ADA) are fast acting oxidants. The optimum level of oxidant addition in flour differs. Oxidants perform well when used in combination. For example for flour of medium to short mixing time and/or high protein content, 80 ppm of ascorbic acid and 10 ppm of $KBrO_3$ gives the best result. The action and importance of each redox agent is described below.

Potassium bromate ($KbrO_3$)

The fact that bromate is slow acting led to the description of a two-stage process. Bromate is converted into its corresponding halide in the finished loaf. This has raised questions about the toxicity of halogenate-based improvers. The major effect of bromate on thiol groups occurs during the baking stage just as the dough is heated. It is suggested that a minimum temperature of 40°C is necessary for oxidation to occur. Rheological tests on short time, mechanically developed doughs generally show little measurable effect of bromate alone, unless the temperature is increased to accelerate the reaction. The rate of the bromate reaction in unleavened dough is a linear function of the bromate concentration within the range from 0 to 30 ppm.

$$\underset{\text{Bromate}}{BrO_3^-} \quad + \quad \underset{\text{Protein thiol}}{2RSH} \xrightarrow{\text{Slow}} \underset{\text{Bromite}}{BrO_2^-} \quad + \quad \underset{\text{Protein disulfide}}{RSSR} \quad + \quad H_2O$$

$$\underset{\text{Bromite}}{BrO_2^-} \quad + \quad \underset{\text{Protein thiol}}{4RSH} \xrightarrow{\text{Fast}} \underset{\text{Bromide}}{Br^-} \quad + \quad \underset{\text{Protein disulfide}}{2RSSR} \quad + \quad H_2O$$

Ascorbic acid

L-Ascorbic acid should be oxidized to L-dehydroascorbic acid (DHAA), which is the active compound. Addition of DHAA has the same influence on the rheological behaviour of the dough as the addition of ascorbic acid. Dehydroascorbic acid will then take part in other reactions involving glutathione. The improving effect of ascorbic acid is obtained only with L-ascorbic acid as indicated below.

$$\text{L-ascorbic acid (LAA)} \xrightarrow[\text{LAA Oxidase}]{½O_2} \text{Dehydro-L-AA (DHLAA)} + H_2O$$

$$\text{DHLAA} + 2RSH \xrightarrow{\text{DHLAA reductase}} \text{LAA} + \text{RSSR} + H_2O$$

L-Cysteine Hydrochloride

The amino acid *L*-cysteine acts as a reducing agent in dough. The disulphide bonds between gluten proteins are reduced and free to undergo thiol-disulphide interchange. As a result of its action the dough becomes extensible and weaker. The so-called chemical dough development is an alternative to high-speed mechanical dough development. Improvers based on *L*-Cysteine are usually designed to replace the requirement for much of the mechanical work that would otherwise be used to encourage disulphide interchange. Although mixing energy is only a very small proportion of the total energy required to make bread, the oven energy consumption being the greatest, chemical dough development avoids the need for special capital equipment for high-power mixing.

$$\text{L-cysteine hydrochloride-SH} + \text{RSSR} \longrightarrow \text{RSH} + \text{L-cysteine hydrochloride-SSR}$$

Azodicarbonamide (ADA)

ADA is found effective at oxidising thiol groups to disulphides and that this improver does not react with dry flour or lose its activity when stored mixed with flour. Doughs containing ADA are cohesive and dry. They can tolerate high water absorption and still bake into loaves with high volumes and with good textures. Unlike some other improvers, ADA is not a bleach, it does not destroy vitamins in the flour, it acts extremely quickly in converting thiol groups into disulphide bonds, and it leaves a harmless and perfectly acceptable residue, biurea by following reactions.

$$\text{ADA} + 2\text{RSH} \longrightarrow \text{Biurea} + \text{RSSR}$$

3.5 EFFECT OF THIOL–DISULFIDE INTERCHANGE REACTIONS

Thiol-disulfide reaction refers to exchange of SH (thiol) and S-S (disulfide) groups of the protein in dough system during processing. Thiol group in dough increases extensibility or weakness/stickiness, whereas S-S group in dough imparts elasticity or strength. One function of an oxidizing agent may be to remove the thiol groups from the system. Exchange reactions involving S–S and SH groups have been suggested, and the reactions might involve a thiol-containing molecule of low molecular weight such as glutathione (GSH). If thiol-blocking agents are added to dough, the effect will be the same as for oxidation- stiffer dough– although the number of disulfide bonds does not change. It has been reported that there is on an average about 0.1–1.5 µ mol of SH groups per gram of flour. No correlation has been reported between the amount of thiol groups and baking performance of flour. Neither there is any correlation between the S-S content and baking performance of flour.

All thiol and disulfide groups present in the dough do not take part in exchange reactions. The groups those take part are described as chemically active. Also, interchange reactions between thiol and disulfide groups may or may not influence the viscoelastic behaviour of the dough, and thus only groups those affect viscoeasltic nature of dough are described as rheologically active SH and S-S groups.

Glutathione is a known SH group containing small molecules that occurs in wheat flour. The removal of thiol groups from dough is considered beneficial for the dough handling properties as stickiness has been found to correlate with the thiol group content of the protein. The number of thiol groups decreases during mixing. Nearly half of the initial amount of thiol groups is lost during the first minute of mixing. If the dough is allowed to rest the decrease in SH groups continue, and the level is becomes zero after about 10 min. The number of SH groups decreases if the dough is mixed in air in the presence of an oxidant such as potassium iodate or bromate. The result of ascorbic acid used as an improver in the Chorleywood process depends on the mixing atmosphere. The best result of ascorbic acid is obtained in an oxygen rich atmosphere, whereas no such influence of mixing atmosphere is observed for $KBrO_3$.

Addition of cysteine (containing the thiol group) in dough makes it softer. Similarly, addition of glutathione to dough will also have a softening or weakening effect. The softening effect is attributable to reaction of the disulfide bonds. Application of a reducing agent such as L-cysteine hydrochloride would be beneficial in case the flour is too strong. Such flour does not develop properly during mixing. The addition of cysteine reduces mixing time of such flour and proper dough development can be achieved without much of energy. Thus, the energy requirements in mechanical dough development can be reduced if a reducing agent is used.

3.6 EFFECT OF SUGAR ON RHEOLOGICAL PROPERTIES

The addition of sugar particularly sucrose has some beneficial effects in baking. It serves as yeast food, although it’s the amount be in excess that cause an osmotic effect on yeast activity. Sugar contributes brown colour to the crust, through the Maillard reaction and through caramelization. Sucrose also adds sweetness to the product.

At higher sugar/flour ratio, it can also have an influence on the structure and behaviour of doughs as well as that of the products. At a level of 5g sugar/100 g flour or higher the sugar affects the water contents of the dough. Sucrose is known to change the viscosity of starch or flour water suspensions both before and after heating. Wheat starch and water mixed in equal ratio yields dry powder. However, when flour, water and sugar are mixed in equal ration, then a free-flowing liquid is obtained.

The addition of sugar raises the gelatinization temperature of starch. All sugars do not have the same effect, disaccharide sugars are more effective than monosaccharides and of the disaccharide sucrose is the most effective.

3.7 EFFECT OF EMULSIFIERS ON RHEOLOGICAL PROPERTIES

Small quantity of fat is often added to flour in order to improve the crumb structure and volume of bread. The bread with fat will have more uniform grains with thinner walls, which gives an improved softness and bite characteristics.

Fat exerts most pronounced effect on bread volume when the fat crystals do not melt below the starch gelatinization temperature (fully hydrogenated oils). The mechanical stabilization of the structure during oven spring seems to be the obvious explanation. Emulsifiers such as mixtures of mono-and diglycerides have been used in bread making for long time. These are made by adding glycerol to triglyceride oil to attain reesterification.

Emulsifiers are also known as bread softeners. Emulsifires belong to polar lipid class. Some of them such as mono-and diglycerides, occur naturally in very small amounts among the wheat lipids. Others are synthetic analogues of polar lipids. The emulsifiers interact with water to give aqueous phases similar to those of wheat lipids. Furthermore, they mix with the naturally present wheat lipids and influence their aqueous phase properties. Such molecular mixing always takes place when oils or liquid crystalline lipid phases are exposed to one another.

The emulsifiers available in market are distilled monoglycerides. They are mainly added to flour as crumb softener and as aerating agents in cookies and cakes. However, the diacetly tartaric esters of monoglycerides (DATEM) are used as dough strengtheners. Their effect in baking is to improve mixing tolerance and uniformity of grain structure and also to increase the bread volume. Sodium or calcium stearoyl lactylates act similar to DATEM in bread making. All emulsifiers provide the crumb softening and anti-staling effect.

3.8 SUMMARY

Formula ingredients such as water, sugar, yeast, oxidizing and reducing agents, sugar and emulsifiers are the important in bakery products for improving dough handling characteristics, eating quality and shelf life. The reheological properties of wheat flour dough largely depend upon its water content. The water content provides vital aqueous phase to the dough. The aqueous phase will affect the behavior of the dough because of the amount and type of soluble substances, such as salts, minerals and organic material. Yeast contributes to texture of the dough, bread volume, flavor, taste and the nutritional value of the bread. Oxidizing/reducing (redox) agents such as potassium bromate ($KBrO_3$) and ascorbic acid have long been used as additives for improving dough handling and baking quality of wheat flour. Thiol-disulfide reaction refers to exchange of SH (thiol) and S-S (disulfide) groups of the protein in dough system during processing. Thiol group in dough increases extensibility or weakness/stickiness, whereas S-S group in dough imparts elasticity or strength.

3.9 KEY WORDS

Baker's yeast: The yeast ferments sugar, producing carbon dioxide and ethanol. *Saccharomyces cerevisiae* strain of yeast is regarded as the most common leavening agent in bread. This is known as baker's yeast.

Rheological properties: Rheology refers to flow and deformation of matter. Wheat dough (well mixed flour with water and ingredients) under stress undergoes flow and elastic recovery. These flow and elastic behavior of dough during processing are refereed to as rheological properties.

Redox agents: These are oxidizing and reducing agents such as potassium bromate ($KBrO_3$) and ascorbic acid have long been used as additives for improving baking quality of wheat flour. These agents together are called redox agents.

Reducing agents: Reduces the mixing time by breaking a portion of the cross-linking disulfide bonds and creating free sulfhydryl (SH) groups. They cause decrease in the elastic strength and increase in extensibility of the gluten network in the dough system.

Oxidizing agents: These are the chemicals which when added to wheat dough increase mixing time of flour and thus increase strength and elasticity of dough.

Emulsifiers: They are also known as bread softeners. Emulsifires belong to polar lipid class. Some of them such as mono-and diglycerides, occur naturally in very small amounts among the wheat lipids. Others are synthetic analogues of polar lipids. The emulsifiers interact with water to give aqueous phases in dough and improve the handling of dough and shelf life of bread.

3.10. SELF ASSESSMENT QUESTIONS

1. Explain effect of water on rheology of dough.
2. How yeast fermentation influences the rheological properties of dough?
3. What are redox agents? How they affect rheology of dough?
4. Discuss the importance of thiol group containing compounds in dough rheology
5. Give a brief account of importance of sugar and emulsifiers in dough rheology.

3.11. SUGGESTED READINGS

1. Rasper VF, Preston KR (1991). The Extensograph Handbook. AACC, St Paul MN
2. Bushuk W, Rasper V (1994) Wheat: Production, Composition and Utilization. Blackie Acad and Professional, Glasgow
3. Pomeranz Y (1990) Advances in Cereal Science and Technology, AACC, St Paul, MN
4. Pomeranz, Y. (1998) Wheat: Chemistry and Technology, Vol. I, 3rd Ed., Am. Assoc. Cereal Chemists, St. Paul, MN, USA.
5. Pomeranz, Y. (1989) Wheat is Unique. AACC Inc. St. Paul MN. USA
6. Hoseney, R.C. (1986) Principles of Cereal Science and Technology, Am. Assoc. Cereal Chemists, St. Paul, MN, USA.
7. Bushuk W, Rasper V (1994) Wheat: Production, Composition and Utilization. Blackie Acad and Professional, Glasgow

PGDBST- 04 **B.S.Khatkar**

UNIT IV: FLOUR CONSTITUENTS, PROCESSING PARAMETERS AND DOUGH RHEOLOGY

STRUCTURE

4.0 OBJECTIVES

Thorough study of this unit will enable the reader to understand:

- Influence of proteins, gluten and starch on dough rheology
- Effect of enzymes on rheological properties of dough
- Effects of mechanical work, mixing time and temperature on dough rheology

4.1 INFLUENCE OF PROTEINS, GLUTEN AND STARCH ON DOUGH RHEOLOGY

4.1.1 MIXING CHARACTERISTICS

The mixing characteristics of a wheat dough are attributed largely to its proteins particularly gluten proteins. Bread making quality increases linearly with increasing protein content within a variety, but, for a given protein content, bread making quality differences among wheat varieties are largely a function of the qualitative nature of the gluten proteins, which affects their rheological properties. Particular attention has been focused upon the glutenin fraction of gluten since it is qualitative variation in this fraction that accounts for a substantial proportion of the variation in dough and bread making quality that occurs amongst wheat varieties.

Quality testing is carried out routinely in order to evaluate the dough strength and bread making potential of a wheat variety. Some form of baking test is the most widely adopted procedure for assessment of the baking quality of either wheat flour or isolated gluten, but they require high levels of skill, are labour intensive and time consuming, and they often require relatively large sample sizes. Simpler, rapid indirect tests, such as the SDS-sedimentation test, have been devised and widely adopted, but they do not always differentiate effectively between wheats of different quality, especially strong and ‘extra strong’ varieties. To overcome the latter problem, measurements of gel protein or glutenin macropolymer (GMP) breakdown during dough mixing and of dynamic rheological properties of gel protein have been adopted in the UK. As with baking tests, however, these gel protein tests are intensive of highly skilled labour and time consuming, and they require the use of expensive equipment usually found only in specialized research laboratories.

The Mixograph technique has been used extensively to try to predict the dough mixing properties of wheat varieties. Mixograph is rheological instrument. This technique has also been used for optimization and/or to study the effect of various additives, such as oxidants, reductants, dough conditioners and enzymes, *etc.* commonly used in baking. The recent development of a 2g direct drive Mixograph interfaced to a personal computer for automated recording and interpretation of the results has transformed the Mixograph technique, and is especially valuable when sample size is limited. Farinograph and alveograph instruments can also be used for measurements of rheological properties of dough. The Mixograph studies suggest that the differences in the mixing characteristics among weak and ‘extra strong’ doughs are due mainly to differences in gluten protein quality with protein content playing only a minor role. However, mixing characteristics of strong dough are significantly influenced by protein content. The 2g Mixograph is a simple, rapid and effective instrument for evaluating dough and gluten protein quality. Its small sample size requirement provides an opportunity to investigate the direct effects of individual protein fractions on dough and gluten functional properties, and may allow plant breeders to assess protein quality more effectively at an early stage in the breeding process.

4.1.2 WATER ABSORPTION

The water absorption value of flour largely depends upon its protein content as evidenced from a strong positive linear relationship (R^2=0.65) between water absorption values and protein contents of flours as evidenced from Figure 4.1. The protein contents of wheat varieties also have positive linear relationship with bread making performance measured as loaf volume.

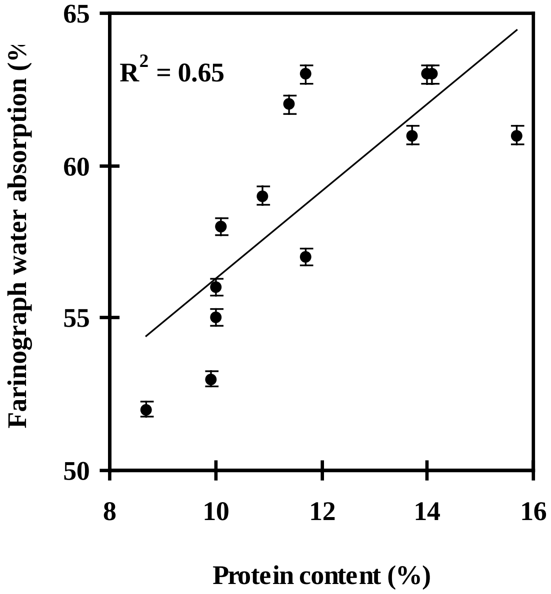


Figure 4.1 Relationships between protein content and water absorption values of flour

4.1.3 DYNAMIC RHEOLOGICAL STUDY

Recently, small-amplitude oscillatory measurements in shear have been used as a means of carrying out fundamental rheological characterisation of flour doughs. This technique offers the opportunity of studying the material structural properties under a relatively extended range of conditions. It simultaneously measures the viscous and elastic characters of a material and can also assess the amplitude-dependent and frequency-dependent behaviour of the material being analyzed.

The protein content of wheat flours exhibits a weak inverse relationship with dynamic oscillatory measurements, G′ and G″ up to about 14% protein level, but at higher protein contents the dynamic moduli are not affected (Figure 4.2). This indicates that during small-amplitude oscillatory measurements of dough systems, the starch phase has a dominating influence and masks the effect of the protein phase in dough with higher proportions of starch (i.e. less protein).

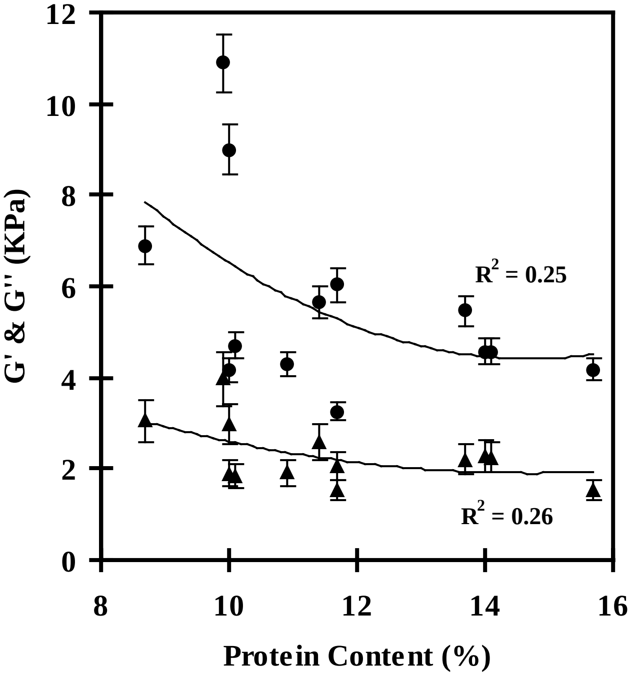


Figure 4.2 Relationship of protein content of flour with dynamic measurements

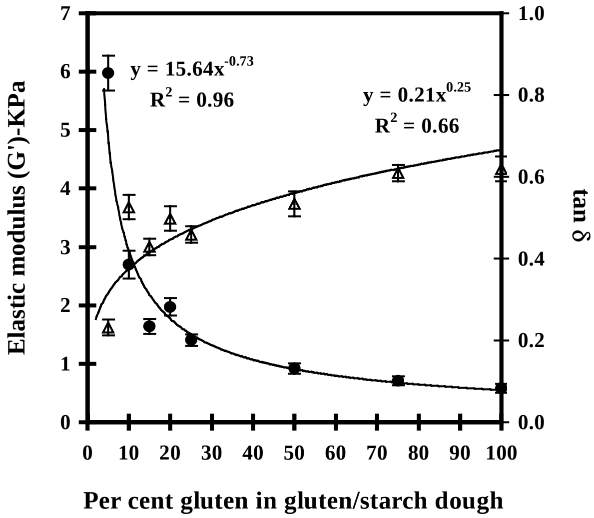


Figure 4.3 The influence of gluten concentration on the rheological behaviour of the gluten-starch dough. Frequency, 1 Hz; Stress amplitude (τ_o), 25 Pa; G′, λ; tan δ, Δ.

There is a good deal of discrepancy in the literature covering the influence of gluten protein level on the rheological properties of gluten-starch blends. Earlier research showed positive relationships between the gluten content of gluten-starch blends and both dynamic moduli. Later it was indicated that G′ varies inversely up to gluten content of 40% in a gluten-starch blend. Increasing the gluten content of the blend above 40% does have no further effect on G′. The apparent discrepancy in the results may be explained on the basis of the variable water content used to prepare the gluten-starch doughs in these studies. As a matter of fact, gluten absorbs more water than starch, and therefore, an artifact could be obtained in the results if adjustments in dough water content are not made to account for varying levels of gluten.

In studies where gluten-starch doughs are prepared using accurate water absorption values for gluten (100%) and starch (60%), the dynamic measurements (G′ and tan δ) follows a power-law dependence on increasing gluten concentration in the gluten-starch blends. The transition point occurs at around the protein content of bread wheat flours. The elastic character (G′) decreases drastically as the gluten content is increased prior to this transition, but, afterwards, a much more gradual decrease is observed. A similar, but opposite, trend can be seen for tan δ (Figure 4.3). The decrease in the elastic character of the gluten-starch doughs with increasing gluten concentration is favored by an overall decrease in the starch phase. This is because the starch particles are stiffer than the gluten polypeptides when they form a continuous matrix in the gluten-starch blend.

4.2 EFFECT OF ENZYMES ON RHEOLOGICAL PROPERTIES OF DOUGH

Enzymes play important role in the rheological properties and functionality of dough. Amylases and proteases are the main enzymes used in the dough to improve its functionality.

4.2.1 AMYLASES

Alpha-Amylase is the most important of the amylases. It is an endoenzyme that splits α (1 → 4) bonds and produces maltose, dextrins and glucose. Free water phase is needed for enzymatic hydrolysis. The alpha-amylase activity of flour is an important quality factor in breadmaking. Fermentation rate by yeast is affected badly in case α-amylase level is too low. Therefore it becomes necessary to assess level of α - amylase in flour and if required it should be supplemented with malt flour. A disadvantage of malt flour is its dark color. Flour also contains β-amylase (which can hydrolyze α (1 – 4) linkages to produce maltose and its natural level in flour is normally adequate. The amylases affect dough handling properties and quality of final products. If amylase activity in flour is low, the dough fermentation rate remains low and the dough ripening and extensibility is affected due to poor activity of yeast. As yeast acts on sugars produced by action of amylases on damaged starch. The CO_2 produced by yeast fermentation does affect the dough ripening and its extensibility. On the contrary, excess of amylase activity is also not desirable for dough to perform satisfactory on processing floor. Excess of amylase enzymes will produce large mass of sugars from starch. The dough will become sticky and its handling will be difficult and there will be more of production losses. The yeast will produce excess volume of CO_2 and as result the dough may either collapse or its structure may break open leading to inferior product.

4.2.2 PROTEASES

Protelytic enzymes are used particularly when stronger flour with higher protein content is to be utilized for biscuit production. The proteolytic enzymes weaken dough strength by breaking S-S linkages of gluten proteins in dough structure. When a very weak gluten phase is desired, as in the production of cookies and crackers, proteolytic enzymes can be used, sometimes in combination with cysteine to reduce S-S bonds. The action of these enzymes makes the dough softer and extensible. The more extensible dough performs well in biscuit and cookie production as softer dough can give more spread in oven as compared to stronger dough.

4.3 EFFECTS OF MECHANICAL WORK, MIXING TIME AND TEMPERATURE ON DOUGH RHEOLOGY

The rheological behaviour of dough changes due to the different steps involved in dough processing. Obviously, mixing or development of dough is considered the most critical operation in dough processing, since under mixing or over mixing has profound effects on final product quality. When it is optimally mixed, dough is non-sticky, is easy to handle and possesses appropriate viscoelastic properties for producing products of good quality after baking. The Farinograph and the Mixograph have been used extensively to obtain empirical information during mixing. In these mixers, the resistance of dough to the mixing blades is recorded. The appearance of the dough changes during mixing and the resulting mixing curve provides information, such as mixing time (dough development time), maximum dough resistance and dough stability. Such information has been found useful for practical bakery operations.

Wheat flours milled from different varieties differ in their mixing requirements. Flour with medium to medium-long mixing time is recommended for bread making, while flour having lesser mixing time is found more suitable for biscuit and cookie production. The mixing requirements of different flours are related to the composition of the gluten proteins. Gliadin imparts extensibility to the dough, whereas glutenin imparts strength and elasticity. If gliadin is more, the shorter will be the mixing time. Reverse is true for glutenin. Glaidin/glutenin ratio of flour is also important determinant for mixing time.

Dough mixing affects the appearance and rheological behaviour of the dough. In the beginning of mixing, protein interacts with each other and aggregate. In the under mixed dough there is a coarse three-dimensional network of these partly aggregated protein units. At optimum mixing, these units form thin films when extended. Further mixing causes the films to be perforated and eventually completely disrupted.

The Mixograph is used to differentiate wheat flours on the basis of their dough strengths as shown in Figure 4.4. The ‘strength’ of variety could be judged from the Mixogram (mixing curve) on the basis of the mixing time (MT) and work input (WI) requirement, which is a function of MT and peak dough resistance (PDR), as well as the general shape of the Mixograph curve. Work Input (WI) values are calculated by integrating the area under the mid-line of the curve from time zero to the PDR, and are expressed in arbitrary units (% torque·min).

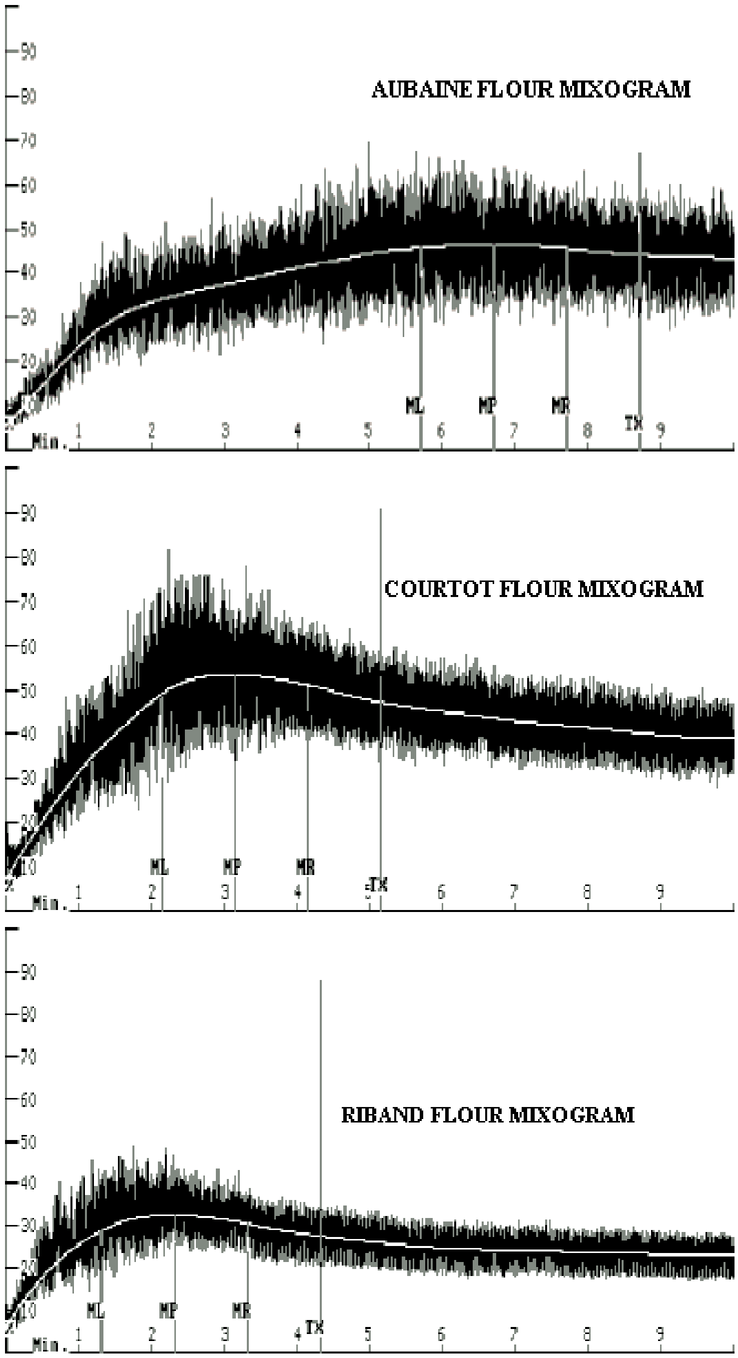
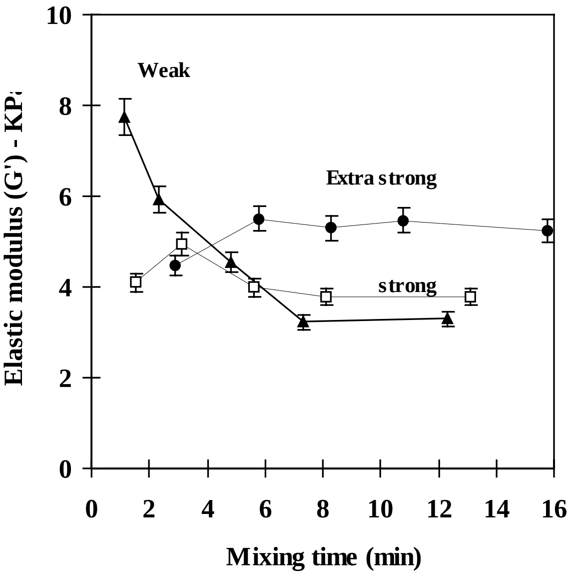


Figure 4.4. Mixing curves of weak, strong and ‘extra strong’ wheat varieties.

The Mixograph curves shown above clearly indicate that relationships exist between the mixing characteristics and dough strengths of the flours. It is of interest to see whether controlled stress rheometry could provide a possibility for relating dynamic measurements to mixing characteristics of dough. Dynamic rheological measurements on dough are performed to enable us to detect subtle differences that otherwise might be neglected, and to obtain information that might ultimately be related to structure at the molecular level.

The dynamic rheological properties of dough of different wheats behave differently during mixing as evidenced from Figure 4.5 and 4.6. The elastic modulus (G′) and the viscous modulus (G″) of weak dough decreases as the mixing time is increased. On the other hand, the ‘extra strong’ and strong doughs give lower G′ values when under mixed, which increase to a maximum at their optimum mixing times (as determined by the Mixograph), then decrease slightly, and afterwards, remain constant with further mixing. Similar trends can be seen in the G″ profiles of these doughs.

It is interesting to note that the values of G′ and G″ for under mixed weak dough are higher than those for under mixed ‘extra strong’ and strong doughs. This trend is reversed, when the doughs are mixed at or beyond their optimum mixing times (Figure 4.5 & 4.6). A likely explanation for the higher G′ and G″ values of under mixed weak dough is that the weak dough have lower water absorption, which result in drier dough when under mixed. The opposite is the case for the ‘extra strong’ and strong doughs, for which the water absorption values are significantly higher that result in wet dough when it is under mixed.



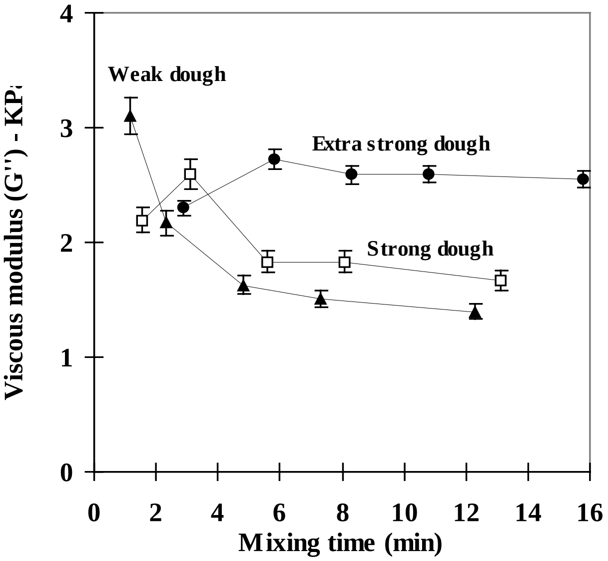


Figure 4.5 & 4.6 Changes in the elastic modulus (G′ above) and viscous modulus (G″ below) profiles of wheat flour doughs as a function of mixing time.

It evident from Fig. 4.5 and 4.6 that the G′ and G′′ values for extra strong dough remained stable for a considerable length of time and shows very little decrease in these parameters even at advanced stages of mixing. This observation is fully consistent with the Mixograph curve (Fig. 4.4**)** for extra strong wheat, which has exceptional dough stability. Another important point is that, for all varieties, the values of G′ are significantly higher than those of G′′ during the entire process of mixing. This observation clearly suggest that doughs are not ‘broken down’ structurally by the mixing action even at advanced stages of mixing, as is generally considered in the case for the Mixograph and the Farinograph. It appears, therefore, that mixing dough beyond its so-called optimum development reduces the ability of the dough to resist the destructive mixing force in the empirical recording dough mixers without actually significantly altering its basic structure. This implies that the two types of machine (recording dough mixer and dynamic rheometer) are measuring properties at different levels of structure.

The temperature affects rheological properties of dough. If temperature is increased beyond 50C, the viscosity of dough increases enormously. This is due largely to gelatinisation of starch and to some extent due to polymerization of gluten proteins. Increase in temperature also makes biochemical reaction faster such as activity of enzyme and yeast. The speed of biochemical reactions affects dough rheological properties.

4.4 SUMMARY

Flour constituents and processing parameters affect the rheological properties and baking quality of wheat dough. The rheological properties of dough include its mixing characteristics, dough handling dough strength and extensibility. The mixing characteristics of a wheat dough are attributed largely to its proteins particularly gluten proteins. Bread making quality increases linearly with increasing protein content within a variety, but, for a given protein content, bread making quality differences among wheat varieties are largely a function of the qualitative nature of the gluten proteins, which affects their rheological properties. The Mixograph technique has been used extensively to try to predict the dough mixing properties of wheat varieties. Mixograph is rheological instrument. The Mixograph studies suggest that the differences in the mixing characteristics among weak and ‘extra strong’ doughs are due mainly to differences in gluten protein quality with protein content playing only a minor role. However, mixing characteristics of strong dough are significantly influenced by protein content.

Recently, small-amplitude oscillatory measurements in shear have been used as a means of carrying out fundamental rheological characterization of flour doughs. This technique offers the opportunity of studying the material structural properties under a relatively extended range of conditions. It simultaneously measures the viscous and elastic characters of a material and can also assess the amplitude-dependent and frequency-dependent behavior of the material being analyzed.

4.5 KEY WORDS

Mixograph: It is a rheological instrument that is used to assess mixing behavior of wheat flour.

Water absorption value of flour: It is the amount water needed by wheat flour to prepare dough for suitable handling and processing. It is measured by Farinograph instrument.

Farinograph: It is a rheological instrument that is used to assess the water absorption capacity, dough strength, mixing time and dough stability.

Dynamic rheology: It refers to rheological technique for fundamental rheological characterization of flour doughs or gluten. This technique gives separate measurement of viscosity or extensibility and elasticity of dough.

Dynamic moduli: These are dymanic rheological parameters such as G' (elastic modulus) and G'' (viscous modulus).

4.6 SELF ASSESSMENT QUESTIONS

1. Explain the role of proteins in mixing requirement of wheat flour.
2. How proteins affect water absorption and dynamic rheological properties of flour?
3. Discuss the influence of gluten concentration on the rheological behaviour of the gluten-starch dough.
4. How amylases and proteases enzymes affect rheological properties of dough?
5. Explain the role of mixing time and temperature on dough rheology.

4.7 SUGGESTED READINGS

1. Pomeranz, Y. (1998) Wheat: Chemistry and Technology, Vol. I, 3rd Ed., Am. Assoc. Cereal Chemists, St. Paul, MN, USA.
2. Pomeranz, Y. (1989) Wheat is Unique. AACC Inc. St. Paul MN. USA
3. RD Phillips and JW Finley (1989). Protein Quality and the effects of processing, Marcel Dekker, New York
4. Samuel, A.M. (1996) The Chemistry and Technology of Cereal as Food and Feed, CBS Publishers & Distribution, New Delhi.
5. Sivasankar, B. (2002) Food Processing and Preservation, Prentice Hall of India Pvt.Ltd, New Delhi.
6. Salunkhe, D. and Despande, S.S. (2001) Foods of Plant origin: Production, Technology & Human Nutrition, An AVI Publications, New York.

7. D’ Appolonia BL, Kunerth WH 1984. The Farinograph Handbook, AACC, St Paul, MN, USA
8. Dobraszczyk BJ, Dendy DAV (2001). Cereal and Cereal Products: Chemistry and Technology. Aspen Publisher, Inc Maryland