This is to certify that the

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PHYSICOCHEMICAL PROPERTIES OF NON-DEVELOPED, PARTIALLY DEVELOPED, AND DEVELOPED WHEAT DOUGHS

presented by

LING LEE

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Food Science

Major professor

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PHYSICOCHEMICAL PROPERTIES OF NON-DEVELOPED, PARTIALLY DEVELOPED, AND DEVELOPED WHEAT DOUGHS

VOLUME I

By

LING LEE

A DISSERTATION

Submitted to
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Department of Food Science and Human Nutrition

2000

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ABSTRACT

PHYSICOCHEMICAL PROPERTIES OF NON-DEVELOPED, PARTIALLY DEVELOPED, AND DEVELOPED WHEAT DOUGHS

By

LING LEE

The rheological properties of non-developed (by the ice powder procedure), partially developed (by rheometer with shear or extensional deformation), and developed doughs (by farinograph) have been investigated and these four doughs represent different levels of dough development. To understand the relationship between gluten proteins and dough rheology, this study used (1) a rheometer and laser scanning confocal microscope (LSCM) to study the relationships between rheological properties and ultrastructural characteristics of these four types of doughs; (2) disulfide-sulfhydryl analyses, gel filtration chromatography, sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE), acid polyacrylamide gel electrophoresis (A-PAGE), and densitometry to investigate proteins in the four types of doughs mentioned and relate protein properties to dough rheology; and (3) two one-stage fermentation procedures (ice powder ingredients without the use of a mixer or normal ingredients with the use of a mixer) to make crackers and compare quality attributes of these crackers.

Rheological data revealed that developed dough had the highest G* (most elastic), followed by doughs partially developed with extensional deformation and then shear deformation, and finally by non-developed dough. The LSCM z-sectioning (scanning of different layers of the sample) and the analysis of amount of protein matrix showed that

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developed dough had the most protein matrix, and non-developed dough had the least. It also showed the higher the G*, the more the protein network.

Free sulfhydryl content was the lowest in native flour and non-developed dough, and the highest in partially developed doughs, while a reverse trend was observed for disulfide content. The protein elution profiles from gel filtration chromatography among same flour samples shifted with levels of dough development. With respect to the smallest sized protein molecules, native flour had the most, followed by non-developed, partially developed, and then developed doughs. SDS-PAGE and A-PAGE exhibited similar protein patterns among the same protein fractions of each native flour and its different doughs. Densitometric data showed that the amount of high molecular weight (HMW) glutenins increased and the amounts of low molecular weight glutenins, gliadins, and albumins/globulins decreased with progressive levels of dough development. Results also indicated that the increase in both size and amount of HMW glutenins is related to the strength of dough and the amount of protein matrix present in the dough.

Based on the one-stage fermentation procedures to make crackers, it was found that the overall qualities (i.e., weight, moisture, length, width, thickness, volume, and peak breaking force) of baked normal and ice powder crackers could distinguish among all flour samples. The overall qualities of baked normal and ice powder crackers made from the same flour showed similar trends. Baked ice powder crackers had higher weight, moisture, and peak breaking force than normal crackers, whereas they had less shrinkage and were lower in thickness and volume. As demonstrated by this study, the ice powder technique has the potential for producing acceptable crackers.

DEDICATION

To my parents, sisters, and husband

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Finally, I want to express my sincere appreciation to my parents, sisters, and husband. Their love, encouragement, and help enable my going through Graduate School.

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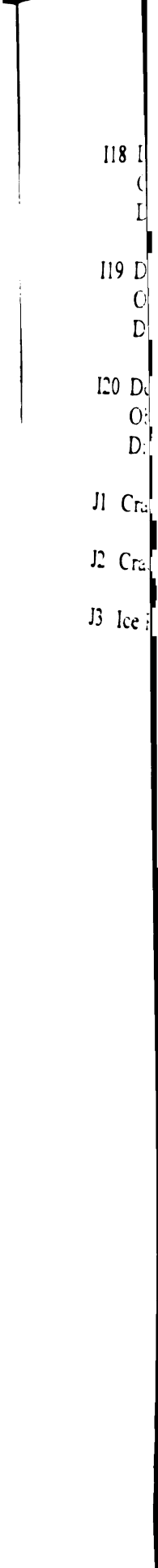
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CHAPTER 1

INTRODUCTION

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INTRODUCTION

Wheat is one of the most important foods in the world, because it provides about one-fifth of all calories consumed by humans and accounts for about 30% of grain production in the world (Pomeranz 1987). Based on the texture of the kernel, wheat can be divided into soft and hard wheats (Yamazaki et al 1981). In general, soft wheat has weaker protein strength and lower protein content than hard wheat (Pomeranz 1987). Each is commonly associated with different products: soft wheat is usually used to produce cakes, cookies, crackers, pretzels, pies, and wafers, while hard wheat is used to produce leavened bread (Loving and Brenneis 1981; Pomeranz 1987).

In the baking industry, many instruments have been developed for testing wheat flour and dough samples and further predicting final products, e.g., alveograph, amylograph, extensigraph, farinograph, and mixograph (Berland and Launay 1995; Janssen et al 1996a). The two major and traditional instruments used to test physical properties of dough samples are the farinograph and the mixograph, which mix flour and water with the involvement of energy (a combination of shear and extensional deformations) to form a dough (Hoseney 1985; Campos et al 1996; Janssen et al 1996a; Schluentz et al 2000). Due to energy addition, water penetrates into flour particles, causing hydration and protein swelling, and forming a continuous protein matrix, which gives wheat flour dough its viscoelastic property. The dough obtained from the farinograph and the mixograph has been referred to as "developed" dough (Campos et al 1996; Schluentz et al 2000). However, farinography and mixography can not separate

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hydration and energy input during dough development. As a result, it is still difficult to delineate how dough is developed.

In order to understand dough development, Campos et al (1996) produced a "non-developed" dough by combining flour and water without the addition of energy. In this study, they prepared powdered ice to mix with flour at below -8 °C. The mixture was then thawed at room temperature. Water distribution in "developed" and "non-developed" doughs was not significantly different. Continuing on with Campos et al (1996) work, Schluentz et al (2000) produced "partially developed" doughs by controlling certain levels of shear strain with a rheometer, i.e., separating shear and extensional deformations. Campos et al (1997) and Schluentz et al (2000) also investigated the rheological properties of these doughs, and observed that developed dough is the most elastic (or strong), followed by partially developed dough and then non-developed dough.

Fundamental rheological properties of dough are strongly related to the gluten proteins – glutenins and gliadins (Bushuk 1985; Janssen et al 1996b). Glutenins consist of polypeptide chains crosslinked with disulfide bonds. They are responsible for the elastic behavior of dough. Gliadins are comprised of single chain molecules and contain intra-molecular disulfide bonds, which contribute to the viscous behavior of dough (Bushuk 1985; Bloksma 1990; Janssen et al 1996b). It has been found that the mixing method can change the quantity of glutenins and the distribution of molecular size of proteins in dough (Wang et al 1992). Thus, the type and amount of glutenins and gliadins in a dough sample may not reflect the actual type and amount in its flour sample. The type and quantity of glutenins and the ratio of glutenins to gliadins in flour are also

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Campos et al (1996 and 1997) and Schluentz et al (2000) produced non-developed and partially developed doughs. They chose 50% of water absorption for all their dough samples. This water absorption may not reflect the optimal water requirements in baking for their tested flour samples. Additionally, they did not report physicochemical properties of these doughs. Nonetheless, non-developed and partially developed doughs can represent different levels of dough development, and they may provide more accurate pictures about the distribution of glutenins and gliadins involved in dough development. Therefore, the objectives of this study were as follows:

1. To study the rheological behavior of non-developed, partially developed, and farinograph-developed doughs according to the optimal water absorption of each wheat sample, and to relate it to the ultrastructural characteristics and physicochemical properties of dough samples and baking quality via cracker making.
2. To observe the ultrastructural characteristics of dough samples.
3. To study and to compare the physicochemical properties of dough samples.
4. To compare the quality of crackers made from non-developed and developed doughs, and relate those qualities to physicochemical properties of dough samples.

These studies could eventually be helpful in the development of new rheological equipment, be applicable to the baking industry for production of unique low fat and frozen dough products, and be useful for wheat breeders in the selection for and production of new varieties.

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This dissertation has been written in paper format and includes: (1) Literature review, (2) Relationships between rheological properties and ultrastructural characteristics of non-developed, partially developed, and developed doughs, (3) Biochemical studies of proteins in non-developed, partially developed, and developed doughs, and (4) Quality comparisons between normal (flour and water) and novel (flour and ice powder) ingredients to make crackers.

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CHAPTER 2

LITERATURE REVIEW

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2.1 DOUGH RHEOLOGY

2.1.1 Rheological Principles

Rheology is defined as the behavior of a material or deformation of matter under a force (Szczesniak 1983; Bushuk 1985), which is governed by stress, strain, and time. Stress is the intensity of force components acting on a body and is expressed in units of force per unit area. There are three common types of stresses: compressive (directed toward the material), tensile (directed away from the material), and shearing (directed tangentially to the material). Strain is the change in size or shape of a body in response to the applied force. There are also three types of strains: compressive, tensile, and shear (Szczesniak 1983; Bushuk 1985).

Rheologically measured materials can be divided into two types: liquids and solids (Szczesniak 1983). Each category can be further categorized into ideal and non-ideal. Viscosity of a fluid is the property which determines the resistance to motion when a shearing force is applied on a fluid (Bushuk 1985). Liquid usually flows in a viscous way represented by two viscous systems (Szczesniak 1983). One is an ideal viscous system, in which the stress is directly proportional to the rate of deformation and is termed Newtonian fluid. The other is a non-ideal viscous system, also referred to as non-Newtonian fluid. These fluids are classified into time-independent and time-dependent behavior categories. The time-independent non-Newtonian behavior includes fluids that undergo thinning (decrease in viscosity) with increasing rates of shear (pseudoplastic), and thickening (increase in viscosity) with increasing rates of shear (dilatant). The time-dependent non-Newtonian behavior includes those materials for which viscosity decreases with time at constant rate of shear (thixotropic) and those

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materials for which viscosity increases with time at constant rate of shear (rheopectic) (Bushuk 1985). Another type of rheologically measured material is the ideal elastic solid, also called Hookean solid. The ideal elastic solid is directly proportional to stress and disappears instantly and completely when stress is removed (Szczesniak 1983; Steffe 1996).

Most foods, including wheat flour doughs, exhibit both solid and liquid properties, termed "viscoelastic" (Bushuk 1985; Faubion and Hoseney 1990). Wheat flour doughs are difficult to analyze because they are not a function of applied strain or strain rate but a combination of both. In addition, the viscoelastic behavior of dough is nonlinear. Wheat flour doughs exhibit shear thinning and thixotropy (Weipert 1990).

The rheology of wheat dough has been an interesting topic for cereal chemists for several decades. In particular, information on the flow and deformation behavior of doughs has been applied to produce bakery products (e.g., bread, cakes, and cookies) in the baking industry (Bloksma and Bushuk 1988). However, the physical properties that control flow and deformation of dough still need more research as wheat flour is one of the most complex composite biological materials (Baird 1983; Bloksma and Bushuk 1988). Therefore, if the structure, chemistry and process of the formation of the dough can be understood, this information can be used to explain the behavior of dough.

2.1.2 Structural and Chemical Effects on Wheat Flour Dough

The rheological properties of a dough have been shown to be strongly related to the gluten protein and non-protein constituents interacting with gluten (Bushuk 1985; Janssen et al 1996a). Gluten includes two main protein groups: gliadins and glutenins.

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Gliadins comprise single chain molecules with molecular weights from 30,000 to 80,000 daltons (D) (Bushuk 1985). When gliadins mix with water, they form a highly viscous mass, which is assumed to contribute the property of viscosity to gluten (Bushuk 1985; Janssen et al 1996a). Glutenins contain polypeptide chains crosslinked with disulfide bonds with molecular weights from 100,000 to several millions (Bushuk 1985; Hoseney 1994). When glutenins are hydrated, they form a highly elastic mass, which is presumed to contribute the elastic property to gluten (Bushuk 1985; Janssen et al 1996a). The sulfhydryl (-SH) and disulfide (S-S) groups in gluten proteins play important roles in a wheat dough. Increasing -SH group content is related to an increase in the mobile behavior of wheat dough. On the other hand, when more S-S groups are present, a stronger dough structure results (Bushuk 1985).

2.1.3 Measurements of Wheat Flour Dough

Controlled rheological measurements on wheat flour doughs are difficult to perform and time consuming (Menjivar 1990). For example, the rheology of a dough can change due to the process of loading the dough into a rheometer. And for rotary rheometers, only rheological properties at low shear rates can be measured because highly viscous doughs come out of the bowl gap at high shear rates. Furthermore, at temperatures above 25 °C, the free edge of the sample tends to dry, leaving a hard crust that also affects measurements (Baird 1983). Consequently, it is difficult to obtain accurate and reproducible results for doughs.

The two most popular and traditional instruments for physical testing of wheat flour doughs are the farinograph and the mixograph. The farinograph and the mixograph

record the torque generated during dough mixing, which includes shear and extensional deformation (Campos et al 1996; Janssen et al 1996b). The information (e.g., optimal water absorption, optimal mixing time, stability, and consistency) can be obtained from the farinograph and the mixograph curves. The type or shape of the farinograph and the mixograph curves vary according to wheat variety, environmental growing conditions, type of flour produced during the milling, flour protein content and quality, amount of starch damage, and amount of water present (Bushuk 1985).

To measure shear deformation, a rheometer is used which involves two parallel plates with a fluid sample placed between them. The lower plate is fixed and the upper plate moves at a constant velocity. A force per unit area on the upper plate is required for motion, resulting in a shear stress (Steffe 1996).

There are three types of extensional deformation: uniaxial, planar, and biaxial. Uniaxial deformation is the stretching in one direction of a material, with a concomitant reduction in size of the material in the other two directions. Planar deformation implies that the material is being stretched on one side (becoming longer), resulting in a decrease in thickness, but no change in width of the material. Biaxial deformation is essentially the squeezing of the material, which then expands radially, decreasing in thickness and increasing in diameter (Steffe 1996).

Other instruments for physical testing of wheat flour doughs are the alveograph and the extensigraph (Berland and Launay 1995). In the alveograph, doughs are subjected to biaxial deformation. In the extensigraph, doughs are subjected to a combination of shear and uniaxial deformation (Janssen et al 1996b). These instruments have all been used for industrial applications and in research on wheat flour doughs.

However, their disadvantages are that data obtained cannot be translated into physical quantity and the instruments exert large deformational forces (Janssen et al 1996b). Therefore, more fundamental rheological techniques are needed to understand dough systems (Berland and Launay 1995).

The fundamental rheological tests most commonly used for viscoelastic materials are dynamic (oscillatory) tests at small deformation and uniaxial compression tests at large deformation (Faubion and Hoseney 1990). Dynamic measurements are particularly useful for measuring short time or high rate rheological behavior, and behavior at very low deformation and strains (Faubion et al 1985). In other words, a sample is subjected to harmonically varying small amplitude deformation in a simple shear field (Steffe 1996). In dynamic tests, the storage modulus (G'), loss modulus (G''), and complex modulus ($G^*=[(G')^2+(G'')^2]^{1/2}$) are common functions to describe viscoelastic materials. An increase in G' means that a material has a more elastic (solid-like) behavior. An increase in G'' means that a material has a liquid-like behavior.

By using dynamic tests, a number of scientists (Hibberd and Parker 1975; Navickis et al 1982; Abdelrahman and Spies 1986; Dreese et al 1988a; Berland and Launay 1995) have found that water content is critical in determining viscoelastic properties of wheat flour dough. It has been well established that both the storage (G') and loss (G'') moduli decrease as water content of a dough is increased. The effects of major dough components on the rheological properties of wheat flour dough have also been examined (Hibberd 1970; Navickis et al 1982; Dreese et al 1988b; Attenburrow et al 1990; Dreese and Hoseney 1990; He and Hoseney 1991; Petrofsky and Hoseney 1995; Janssen et al 1996c). For example, Hibberd (1970), Navickis et al (1982), and Petrofsky

and Hoseney (1995) found that an increase in the protein to starch ratio at constant water level improves the linear response of the dough systems and decreases G'. Janssen et al (1996c) used a rheometer with a constant stress to measure G' and G'' of hydrated gluten in order to compare the rheological behavior of glutens from the Dutch winter wheat cv. Obelisk and the Canadian western red spring wheat cv. Katepwa. They found that Katepwa gluten had higher G' and G'' values than Obelisk. At the same time, G' was larger than G'' for Katepwa. This meant that Katepwa gluten exhibited higher resistance, or was more elastic (solid-like), at a small deformation. However, the effect of protein and starch on the viscoelasticity of a dough has not been clearly established.

Janssen et al (1996c) demonstrated that uniaxial compression experiments were very useful in providing information about rheological properties of hydrated gluten at large deformation. They showed that gluten had a high degree of extensibility, which implied that gluten proteins were responsible for the expansion of the gas cells during the bread baking process. Moreover, Janssen et al (1996a) found that a higher glutenin content in the same wheat flour dough resulted in increased resistance to deformation, using uniaxial compression tests. Similar results were also obtained by Ram and Nigam (1981 and 1983) using a texturometer.

2.1.4 Non-Developed, Partially Developed, and Developed Doughs from Wheat Flour

"Non-developed" dough is a combination of flour and water with virtually no energy input. Olcott and Mecham (1947) and Davies et al (1969) produced non-developed doughs. According to their procedures, they used a mortar and pestle to

prepare powdered ice which was then mixed with flour. The whole process was performed in liquid nitrogen and kept at -20 °C for 24 hr. Before testing, the mixture was thawed to room temperature. However, their procedures were not recorded in detail and do not provide more insight.

Recently, Campos et al (1996) successfully produced a "non-developed" dough and clearly indicated the method for preparing the powdered ice and the mixing procedure. In this study, ice particles were sieved in order to match the particle size of the flour they were to be mixed with. The distribution of water in "developed" and "non-developed" doughs was compared, and no significant differences were found.

Partially developed dough can be produced from non-developed dough by controlling certain levels of shear strain with a rheometer (Campos et al 1997; Schluentz et al 2000). Campos et al (1997) and Schluentz et al (2000) used a Haake RS100 Controlled Stress Rheometer to analyze the rheological behavior of developed, partially developed, and non-developed doughs, and reported that developed dough has the greatest complex modulus, followed by partially developed doughs with extensional (biaxial) deformation and shear deformation, and finally by non-developed dough with the smallest complex modulus.

As described earlier (2.1.3), the farinograph and the mixograph curves can provide information on optimal water absorption and mixing time for a flour dough. When a wheat flour is mixed with its optimal amount of water for the optimal mixing time as determined by farinograph or mixograph, a developed dough is formed. The making of this developed dough in the farinograph or the mixograph involves energy, and a combination of shear and extensional deformations (Hoseney 1985; Schluentz et al

2000). Due to energy addition, water penetrates into materials, resulting in hydration, and allows proteins to swell and form a continuous protein matrix, which gives wheat flour dough its viscoelastic property (Campos et al 1996).

Although "non-developed" and "partially developed" doughs have been produced (Olcott and Mecham 1947; Davies et al 1969; Campos et al 1996; Schluentz et al 2000), information on the physicochemical properties of these doughs has not been pursued. Once the physicochemical properties of these doughs are well understood, the knowledge could be applicable to the baking industry (e.g., bread, cookies, and crackers) for the production of unique low fat and frozen dough products, and could be helpful in the development of new rheological equipment.

2.2 PHYSICOCHEMICAL PROPERTIES OF WHEAT FLOUR AND PROTEINS

2.2.1 Determination of Quality and Characteristics of Wheat Flour

There are three important wheat species for food: *Triticum aestivum* (common wheat), *T. durum* (durum wheat), and *T. compactum* (club wheat) (Yamazaki et al 1981). Common wheat is also divided into soft wheat and hard wheat based on kernel texture. In soft wheat, the adhesion of protein and starch is not very strong, and wheat endosperms fracture through cell contents rather than along cell walls under stress. Therefore, with milling, soft wheat usually yields flour with fine granules. By contrast, the adhesion of protein and starch in hard wheat is strong; thus, fracture of endosperms occurs along cell walls rather than through cell contents, and coarse granules are produced upon milling (Pomeranz 1987). In general, soft wheat has weaker protein strength and lower protein content than hard wheat.

Chemical and physical tests are usually employed to determine the quality and characteristics of wheat flour (Pomeranz 1987). These chemical tests include the determination of moisture, ash, protein, fat, and damaged starch contents, viscosity, pH, and particle size. The most commonly applied chemical analyses for flour are moisture, ash, and protein contents.

For the physical tests, physical dough testing devices are widely used. The two most common types are the farinograph and the mixograph which provide information regarding water absorption, mixing time, and mixing tolerance of a flour dough at a constant temperature. Other physical instruments include the alveograph and the extensigraph, both indicators of flour strength (Hoseney 1994). Falling number is another

physical test used to determine the quality of flour. The more sprouted the wheat, the higher the α-amylase activity, which affects the viscosity of a flour/water paste, and the lower the falling number (Pomeranz 1987; Hoseney 1994).

Recently, a new instrument -- Rapid Visco Analyser (RVA, Newport Scientific Pty. Ltd., Australia) -- has been developed. It was initially developed to measure sprouted wheat and then to measure the pasting viscosity of flour or starch. Later, it provided information with respect to predicting end-product quality (Hoseney 1994). For instance, it has been used to predict eating quality of noodles through peak paste viscosity (Panozzo and McCormick 1993; Collado and Corke 1996). The main advantages of the RVA include: small amount of sample required, disposable containers and paddles, quick measurements and simple operation (Walker et al 1988; Bernetti et al 1990; Panozzo and McCormick 1993).

2.2.2 Proteins and Protein Structure

Proteins are complex macromolecules made up of different amino acids (Cheftel et al 1985). The native protein most commonly has four levels of structure - primary, secondary, tertiary, and quaternary structures. The primary structure is composed of the linear sequence of amino acids linked by peptide bonds. The secondary structure occurs when the different regions of the primary protein structure combine together to form 3-dimensional structure, e.g., α- helix, β-pleated sheets, and β-turns. This type of protein structure mainly involves covalent bonds and hydrogen bonds. The tertiary structure is the 3-dimensional organization of the polypeptide chains, including their secondary structure, and involves hydrogen bonds, hydrophobic interactions, electrostatic forces,

and disulfide bonds. The quaternary structure is the assembly of individual protein molecules to form a functional protein aggregate (Rodwell 1988; Tatham et al 1990). Hydrogen bonds, hydrophobic interactions, electrostatic forces and disulfide bonds also stabilize the quaternary structure.

The interactions within proteins can be broken by different means. For example, heating and urea solutions break hydrogen bonds; reducing agents, e.g., mercaptoethanol (ME), disrupt disulfide bonds; salt solutions and varying the pH destroy electrostatic interactions (Cheftel et al 1985).

2.2.3 Wheat Proteins

Osborne (1907) was one of the first researchers to fractionate wheat flour proteins based on their solubilities in various solvents. The wheat proteins can be divided into four classes: albumins (soluble in water), globulins (soluble in salt solution), gliadins (soluble in ethanol), and glutenins (soluble in dilute acids or bases) (Osborne 1907). Albumins and globulins are concentrated in the germ, bran, and aleurone cells of wheat, but are present in lower concentrations in the endosperm. Gliadins and glutenins are the two main groups of storage proteins, also known as gluten proteins, in wheat. Gluten plays an important role in flour dough because it not only contributes to the viscoelastic structure of wheat flour dough but also has the ability to retain gas during fermentation (Hoseney 1994).

The gliadins are monomers associated with non-covalent interactions with average molecular weights of 40,000 D (Tatham et al 1984; Wrigley and Bietz 1988) and are responsible for a dough's cohesiveness. They can be further divided into four groups,

α-, β-, γ-, and ω-gliadins, based on their mobilities upon low pH electrophoresis (Woychick et al 1961). The α-, β-, and γ-gliadins have more cysteine/cystine, methionine, and phenylamine amino acid residues, but are lower in glutamine and glutamic acid. In contrast, ω-gliadins are high in glutamine, glutamic acid, proline, and phenylalanine contents, but contain almost no sulfur-containing amino acids (e.g., methionine and cysteine/cystine) (Wrigley and Bietz 1988).

The glutenins have molecular weights from 100,000 to several million (Tatham et al 1987). They are stabilized by interpolypeptide and disulfide bonds, and form multichains. After reduction of disulfide bonds, the resulting glutenin subunits can be separated into two groups based on molecular weight. One group, with molecular weights above 60,000 D, is designated high-molecular-weight (HMW) subunits of glutenin (Tatham et al 1987). The HMW subunits of glutenins are higher in glycine and lower in glutamine/glutamic acid and proline than gliadin proteins. The other group is termed low-molecular-weight (LMW) subunits of glutenin. The amino acid compositions of LMW subunits of glutenin are similar to α-, β-, and γ-gliadins, but the LMW subunits have higher molecular weights and are associated with disulfide bonds (Tatham et al 1987). Payne et al (1984) reported that wheat gluten proteins are comprised of approximately 50% gliadins, 10% HMW glutenins, and 40% LMW glutenins.

The molecular bonding in both gliadins and glutenins include hydrophobic interactions through phenylalanine, leucine and isoleucine; ionic bonding through lysine, histidine, and arginine residues; intramolecular bonding through disulfide linkage (cysteine) in gliadins; intermolecular bonding through disulfide interactions in glutenins, and other types of interactions through aggregation behavior of gliadins. All these

molecular bonds contribute significantly to the rheological properties of dough (Wrigley and Bietz 1988).

2.2.4 Wheat Starch

Starch is found in plants in the form of granules. Wheat starch granules are of two types and sizes: large (25-40 μm) lenticular and small (5-10 μm) spherical granules. The chemical compositions of the two types of granules are essentially the same (Hoseney 1994).

Starch granules are basically polymers of α-D-glucose. There are two types of polymers: amylose and amylopectin. Amylose is a linear polymer of α-D-glucose with α-1,4 linkage. Amylopectin is also composed of α-D-glucose with α-1,4 linkage, but it is additionally highly branched due to α-1,6 linkage. When starch granules are viewed in polarized light, they show birefringence due to high degree of molecular order (Whistler and Daniel 1985; Hoseney 1994). When starch is heated in water, starch takes up water and swells, and the viscosity increases. After starch gelatinization, there is loss of birefringence. With continued heating time, the viscosity of the starch system decreases due to soluble starch molecules orienting themselves. Once cooled down, the viscosity increases again, which reflects a decrease of energy in the system that allows more hydrogen bonding among starch chains (Hoseney 1994).

2.2.5 Gel Filtration Chromatography and Its Application in Wheat Proteins

Gel filtration chromatography is usually used to separate molecules based on their size (Cooper 1977). In the chromatographic column, there are two different phases:

mobile and stationary. When sample molecules pass through the column bed, separation occurs. This separation depends on the different abilities of the various sample molecules to enter the stationary phase. If the sample has very large molecules, they will not enter the stationary phase, but will stay in the mobile phase and come out of the column first. On the other hand, if the sample has smaller molecules, these molecules can enter the stationary phase and move slowly through the column. Therefore, molecules are eluted in order of decreasing molecular size (Cooper 1977; Pomeranz and Meloan 1987).

In order to obtain good separation, several factors need to be considered. The first one is the type of medium used as the stationary phase. Each type of medium has its own chemical and physical properties, which allow certain sizes of molecules to enter. Each medium also allows certain solvents to be used and a certain range of temperatures and pressures to be applied. The second factor to consider is the types of samples and the sample size. For example, increasing viscosity of a sample can result in lower resolution. The third factor is the type and size of the column. The longer the column, the better the separation, but this requires a longer running time. The last factor is flow rate. The lower the flow rate, the better the separation (Cooper 1977).

Gel filtration chromatography has been widely used to fractionate wheat proteins (Khan and Bushuk 1979; Hamanzu et al 1979; Rao and Nigam 1987; Huebner and Wall 1980; Weegels et al 1994). Khan and Bushuk (1979) extracted glutenins from hard red spring wheat with a reducing agent and then separated glutenins by gel filtration chromatography and further by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). They found that the first peak from gel filtration chromatography contained the smaller molecular weight subunits upon SDS-PAGE.

They suggested that some smaller molecules were held together as large molecules and came out first in groups. Similar results were also obtained by Gao and Bushuk (1993). Additionally, Weegels et al (1994) studied the effects of heating on gluten at different moisture levels. They noted that amounts of protein in the different fractions from gel filtration chromatography were changed after heating.

2.2.6. Electrophoresis and Its Application on Wheat Proteins

Successful electrophoresis requires placing the sample molecule into a stable medium which does not react with the sample. Polyacrylamide gel is commonly used since the materials do not react with proteins (Pomeranz and Meloan 1987). SDS-PAGE is a method used to separate dissolved protein molecules in a polyacrylamide gel according to their molecular size (Ng et al 1988). The principle of SDS-PAGE is that protein is extracted with an extraction solution containing SDS and reduced with ME to break disulfide bonds. The SDS gives an overall negative charge to the proteins, which causes them to unfold. Once on the SDS polyacrylamide gels, these negatively charged proteins migrate towards the anode based on their molecular weights. For instance, smaller proteins migrate further than large ones during the same time period. Protein bands in the gel are developed with a staining dye solution when the run is complete (Cooper 1977; Pomeranz and Meloan 1987; Ng et al 1988).

SDS-PAGE has been widely used for determination of molecular weights of wheat proteins (Ng and Bushuk 1987; Lookhart and Albers 1988; Ng and Bushuk 1989; Magnus and Khan 1992; Werner et al 1992; Tamás et al 1998) and for predicting the quality of flour and end products (Branlard and Dardevet 1985; Lawrence et al 1987; Ng

and Bushuk 1988). Gao et al (1992) studied the molecular structure of glutenin in relation to its functionality in doughs during breadmaking by SDS-PAGE. They found the farinograph properties of the dough were markedly affected at a low concentration of dithiothreitol (DTT), but no high molecular weight (HMW) subunits were liberated, as indicated by results of SDS-PAGE without reduction. At higher concentrations of DTT, several types of glutenin subunits were gradually liberated with increasing DTT concentration. Recently, Bean and Lookhart (1998) and Sapirstein and Fu (1998) used different extraction procedures for wheat proteins and analyzed their resultant fractions with SDS-PAGE. Furthermore, a new SDS-PAGE system incorporating a neutral pH buffer was developed (Kasarda et al 1998) in order to obtain better protein resolution and limit exposure to the toxic acrylamide monomer.

Acid polyacrylamide gel electrophoresis (A-PAGE) is another method used to separate protein molecules on a polyacrylamide gel based on their molecular size and electric charge (Ng et al 1988). In general, native protein molecules have overall positive charges. Therefore, on the A-PAGE gels, the proteins migrate from anode to cathode. Proteins with more positive charges migrate further than those with fewer positive charges. Among proteins with the same degree of charge, those with smaller molecular weights will migrate faster than those with higher molecular weights.

A-PAGE has been used for identification of wheat proteins and/or for predicting end-product quality (Khan et al 1983; Clements 1987; Lookhart and Albers 1988; Pomeranz et al 1989; Hou et al 1996). For example, Hou et al (1996) studied the relationship between the quantity of gliadin subgroups of soft wheat flours and rheological and baking properties. They noted that the quantities of certain gliadin

subgroups and total gliadins are associated with flour rheological properties and end-product quality (e.g., sugar-snap cookies and Japanese-type sponge cakes).

Two dimensional electrophoresis and multistacking SDS-PAGE are also applied to separate wheat proteins. Holt et al (1981) used two-dimensional electrophoresis (isoelectric focusing for the first dimension and SDS-PAGE for the second dimension) to identify the HMW subunits of wheat glutenins. Khan and Huckle (1992) characterized glutenin proteins based on their sizes and mobilities on a multistacking gel; and Huang and Khan (1997) investigated the compositions of native glutenin proteins by multistacking SDS-PAGE.

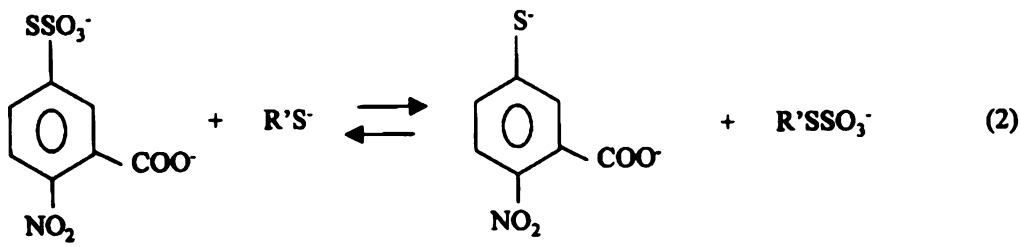
2.2.7 Determination of Disulfide and Sulfhydryl Contents on Wheat Proteins

Disulfide bonds are major contributors to the stability of the native conformations of proteins. Many methods for the determining the presence of disulfide bonds have been proposed, but none of these methods is suitable as an assay procedure because they are either insensitive or non-quantitative (Thannhauser et al 1984). Another method involving the use of the reagent 2-nitro-5-thiosulfobenzoate (NTSB) has been introduced, which is both sensitive and quantitative (Thannhauser et al 1987).

The NTSB assay is composed of two continous reactions. The first one is the cleavage of a disulfide bond with sodium sulfite at a pH above 9.

$$RSSR' + SO_3^{2-} \longrightarrow RSSO_3^- + R'S^- \qquad (1)$$

The second reaction involves the nucleophilic attack of the thiolate produced in reaction (1) on NTSB to yield 1 mole each of a thiosulfonate and 2-nitro-5-thiobenzoate (NTB).



NTSB NTB

The concentration of disulfide bonds can then be calculated from the absorbance measured at 412 nm and the extinction coefficient of NTB (13600 $M^{-1}cm^{-1}$) (Thannhauser et al 1984; Damodaran 1985; Thannhauser et al 1987). However, this method measure not only disulfide group content but also free sulfhydryl group content.

Recently, Chan and Wasserman (1993) described a solid-phase assay for cereal proteins. The principle of this method is to suspend the entire protein sample in urea and to react it with Ellman's reagent. Ellman's reagent, 5, 5'-dithiobis (2-nitrobenzoic acid) (DTNB), reacts specifically with only free sulfhydryl groups and NTSB reacts with both disulfide groups and free sulfhydryl groups. Therefore, the total disulfide groups can be calculated.

The accuracy of SH group determination depends on the possibility of stearic effects that may block the test reagent (Synowiecki and Shahidi 1991). Sulfhydryl groups occur either in exposed form, which can readily react with DTNB reagent, or in the masked form, which can not be detected unmasked. Thus, denaturants such as SDS, and

urea are commonly used to liberate the SH groups by denaturing the protein molecules (Synowiecki and Shahidi 1991).

2.3 ULTRASTRUCTURE OF FOODS BY LASER SCANNING CONFOCAL MICROSCOPY (LSCM)

2.3.1 Advantages with Using LSCM

Light and electron microscopies have been well developed and widely used in studying the microstructure and composition of foods in relation to their physical properties and processing behaviors (Vaughan 1979). In light microscopy, good quality and high resolution images of the internal structure of foods can only be obtained from thin sections of the sample because the image formation of the sample depends on transmitting light through the specimen. If slide preparative procedures apply shear and compressive forces, they may destroy or damage the structure of the sample. Moreover, sectioning is time-consuming and involves chemical processing steps (Brooker 1995). Electron microscopy yields high resolution (~ 1 nm), but is laborious and requires elaborate sample preparation. The thickness requirement is less than 1 μm. In addition, the samples need to be observed under high vacuum and at high radiation doses (Heertje et al 1987). On the other hand, laser scanning confocal microscopy overcomes all of these problems (Brooker 1995).

Laser scanning confocal microscopy has given us the capability of visualizing biological specimens within a watery environment. It allows thickly sectioned material, 5-10 μm (or even more) to be visualized and gives disturbance-free observation of the three-dimensional internal structure. It can perform optical sectioning (scanning different layers of the sample) without damaging a sample, and offers new possibilities in microstructural studies of food systems, such as mayonnaise, cheese, and rising dough (van der Voort et al 1985; Heertje et al 1987). With all of these advantages, LSCM may

be satisfactorily applied to the observation of ultrastructures of non-developed, partially developed, and developed doughs.

2.3.2 Principles of LSCM

The basic principle behind LSCM is that the total light from the objective's focal plane (the region where the sample can be examined and appears sharp and distinct in front of the objective) is focused on a point at a pinhole, passes through the pinhole, and then reaches the detector (Whallon 1993; Wilson 1985). If the light from the objective's focal plane is not entirely focused on a point at the pinhole, a bad image can be obtained (Heertje et al 1987). There are three types of laser scan operation modes: reflected, fluorescent, and transmitted modes (Whallon 1993). In reflection microscopy, the light hits the specimen and is reflected. Only the reflected light which passes through the objective can be detected by the detector. Therefore, the light source and the detector are both on the same side of the specimen, and the wavelength of light does not change after the light is reflected. In fluorescence microscopy, after the light hits the specimen, the electrons in the specimen are brought into an excited state, and then electrons are emitted as a longer wavelength, namely fluorescent light. Only the fluorescent light which passes through the objective contributes to the image. The light path in fluorescence microscopy is the same as that in reflection microscopy. In transmission microscopy, however, the light passes through the specimen and reaches a detector on the other side at the microscope base. In essence, only reflected and fluorescent images are confocal because of the pinhole in front of the detector. Due to the different light path in transmission microscopy, there is no pinhole in front of the transmission detector (Whallon 1993).

In order to get good images, choosing the right light sources and filters are important. There are several light sources for lasers. These include: argon ion laser emitting at 488 nm and 514 nm, helium-neon laser emitting at 543 nm and 633 nm, krypton-argon laser emitting at 488 nm, 568 nm, and 647 nm, and ultraviolet (UV) lasers (van der Voort et al 1985; Whallon 1993). The choice of laser wavelength depends on various factors, such as desired resolution, absorption characteristics of the specimen, and excitation requirements of the specimen dye used (van der Voort et al 1985). The purity of the excitation laser wavelength depends on the use of a selective filter. For example, barrier filters are used to eliminate unwanted (excitation) illumination from the fluorescent image. They are inserted between the specimen and the detector to remove all wavelengths which are shorter than those of the induced fluorescence (Fulcher 1982; Whallon 1993).

2.3.3 Application of Fluorescence Laser Scanning Confocal Microscopy to Foods

Most commercially available LSCM instruments are used as fluorescence LSCM. During fluorescence LSCM, images of various chemical components, such as proteins, carbohydrates, lipids, and ions, are produced by using laser light to excite a selective fluorescent dye that has already been introduced or allowed to diffuse into the food system (Brooker 1995). In order to produce the best images, the choice of dye is important. Either a powdered dye or a solution of dye can be directly applied. However, using a dye solution may affect the integrity or structure of the specimen (Brooker 1991; Blonk and van Aalst 1993).

Many fluorescent dyes are available for studying the distribution of proteins in foods, such as dairy products, emulsions, batters, doughs, and confectionery products. These include fluorescein isothiocyanate (FITC) and acridine orange which excite at about 490 nm, rhodamine 123 and Texas Red which excite at about 560 nm, or Cy 5 and the phycocyanins which excite in the region of 630 nm (Brooker 1995).

Of the above dyes, the most commonly used label for proteins is FITC (Heertje et al 1987; Strasburg and Ludescher 1995). In alkaline solution (pH 9-10), FITC combines covalently with proteins, reacting principally with the ε-amino group of amino acids, such as lysine, asparagine and glutamine. The reactive group is isothiocyanate (Kiernan 1981; Strasburg and Ludescher 1995). After FITC conjugates proteins, the optimum wavelength for FITC excitation is 490 nm (blue). The emission occurs at around 525 nm (green-yellow). Exciting light of 320 nm ultraviolet may also be used, but the emission will be less intense (Kiernan 1981).

When an oil phase is present in a food, it can be imaged using Nile Red, an oil-soluble dye that fluoresces strongly in hydrophobic environments and weakly in hydrophilic conditions (Greenspan et al 1985). When the oil phase is continuous (e.g., butter), Nile Red is always the preferred dye and can be applied directly to the surface of the specimen (Brundrett et al 1991). For solid foods, the dye must diffuse into the matrix for several hours before being examined. However, if the sample is liquid, the dye can be completely dissolved and the sample can be examined immediately (Brooker 1995).

Several reports have indicated that the fluorescence microscope is one of the most sensitive instruments for cereal grains. This microscope has been used to examine phytin, aromatic amines, niacin, and storage lipids in cereals and also applied to the main

structural elements in cereal products such as starch granules, fat, and water-soluble and water-insoluble proteins (Hargin et al 1980; Fulcher et al 1981; Fulcher 1982). Yiu (1993) observed starch grains using Nile Blue and FITC-labelled concanavilin A. Heertje and co-workers (1987) examined the gluten network and protein associated with the surface of starch grains by using FITC solution. As previously documented, the observation of fat can be accomplished using Nile Red (Greenspan et al 1985; Heertje et al 1987; Brundrett et al 1991; Brooker 1995) or Nile Blue A (Fulcher 1982). Beckett et al (1994) indicated that the continuous matrix of confectionery wafers produced from complex batters and cooked at high temperature for a short time is auto-fluorescent, exciting at 488 nm. Therefore, the structure can be viewed by fluorescence LSCM without adding fluorochromes. Heertje et al (1987) studied the structural changes in rising dough using fluorescence LSCM. They found carbon dioxide produced by yeast diffused to the air cells in the rising stage, causing expansion of the dough. Bread structure was also revealed by LSCM (Vodovotz et al 1996). In order to see starch, gluten, and air pockets in a bread sample, each component must fluoresce at a different wavelength.

Aside from cereal products, fluorescence LSCM is widely used in other food systems. Heertje et al (1990) successfully used fluorescence LSCM to observe the liquid-liquid interface between oil and water. Brooker (1993), Heertje (1993), and Blonk and van Aalst (1993) used fluorescence LSCM to observe emulsive systems. Other applications of fluorescence LSCM were extended to dairy products (e.g., cheese, yogurt, and ice cream) and meat products (Kim et al 1993; Brooker 1995). For example, Kim et

al (1993) investigated the induction of low temperature cross-linking and gelation of beef actomyosin through addition of transglutaminase by LSCM.

2.4 CRACKERS

2.4.1 Production of Saltine Crackers

The snack cracker permeates the marketplace in a broad range from semisweet, machine-cut, chemically leavened cookie-like crackers to nonsweet, fermented, and laminated crackers. The total annual sales of these products reached $3.3 billion in 1993 (Lajoie and Thomas 1994). The largest portion of all cracker production consists of the fermented crackers, such as soda, saltines, and oyster crackers (Pyler 1988; Lajoie and Thomas 1994).

For fermented crackers, two stages of fermentation--sponge and dough--are involved which require a total of 22-26 hours to enable the unique flavor and texture of these products to develop (Fields et al 1982; Doescher and Hoseney 1985; Pyler 1988; Wu and Hoseney 1989; Lajoie and Thomas 1994). During the fermented sponge stage (the first stage), 60-70% of the total flour, the yeast, and the water are allowed to mix 1 to 4 min. Then the sponge is fermented for about 16 to 18 hr at 25-30 °C and 70-90% relative humidity (Faridi and Johnson 1978; Pyler 1988; Ranhotra and Gelroth 1988; Rogers and Hoseney 1989a; Lajoie and Thomas 1994). The dough stage (the second stage) involves the fermented sponge, the remaining flour and the other ingredients (e.g., shortening, salt, and sodium and ammonium bicarbonates) which are mixed together for 3 to 7 min, and allowed to ferment for another 6 hr (Pyler 1988; Creighton and Hoseney 1990a; Creighton and Hoseney 1990b; Lajoie and Thomas 1994). After the fermented dough is obtained, it is passed through a laminating machine that transforms it into a continuous sheet by a series of rolls that reduce its thickness to about 6.4 mm. The reduced dough sheet is then folded into five to seven layers and again reduced in

thickness by passage through a set of rollers. The final rolling is set down to a 3 - 4 mm gap in order to produce the desired final thickness of the finished cracker. Then, the laminated sheet is cut, docked, stamped, and put into the oven. Baking temperature is held at 300 °C (570 °F) for 2.5 to 3.5 min. After baking, the crackers are permitted to cool. They are then broken across sheets into rows and lengthwise, and stacked and packaged in moistureproof bags (Pyler 1988).

Although cracker products are very popular around the world, a cracker formula has not been established for an official test because of the numerous formulas for crackers and amount ranges for each ingredient. In addition, the setting conditions (e.g., temperature, humidity, mixing time, and sheeting number) for making crackers vary within the cracker industry (Faridi and Johnson 1978; Doescher and Hoseney 1985; Pyler 1988; Lajoie and Thomas 1994). A laboratory procedure of a cracker production method is necessary for distinguishing quality of wheat flours for cracker production. In addition, such a procedure could enable inter-laboratory comparison of wheat cultivars for cracker-making quality if the procedure were used in each of the laboratories.

2.4.2 The Roles of Ingredients

Cracker doughs generally contain low levels of water of 20-30% (Hoseney 1994). The amount of water is determined by the properties of the flour and the consistency of the dough. The water in crackers acts as a plasticizer and enhances sponge fermentation (Rogers and Hoseney, 1987).

Yeast is usually added with the flour and water. It produces CO_2 during fermentation, which causes the decrease of pH of the dough from 6.0 to 4.0 (Wolfmeyer

and Hellman 1960). The rheological changes due to decreasing sponge pH include increasing cohesiveness of the dough and evenness of puffing (Rogers and Hoseney 1994). Proteases from fungal sources can improve the machinability of the dough, enhance the uniformity of the shape, and increase the tenderness of the cracker (Reed and Thorn 1957; Rogers and Hoseney 1989a).

Salt in the dough process retards fermentation, has a toughening effect on gluten, and provides a salty taste (Heppner 1959; Hoseney 1986). The functions of shortening or fat include uniform dispersion of ingredients in the dough, lubrication of the dough, increase in oven spring, improvement in product tenderness, and enhancement of flavor. For better dispersion of shortening, it is added in the sponge stage. If better sponge fermentation is desired, it should be added in the dough stage (Heppner 1959).

The roles of sodium bicarbonate or baking soda are to neutralize the acid generated during sponge fermentation (Lajoie and Thomas 1994) and bring the dough pH to about pH 7.0. This neutralization enhances flavor, texture, and color in the final product (Rogers and Hoseney 1994).

2.4.3 Rheological Properties of Cracker Doughs

The rheological properties of cracker doughs are complex and only partially understood (Menjivar and Faridi 1994). During the fermentation process, the consistency of cracker doughs changes a great deal. According to Faridi (1975), Doescher and Hoseney (1985), and Wu and Hoseney (1989), the resistance to extension, extensibility, and cohesiveness decreased with fermentation time. There are several methods available to measure the rheological properties of cracker doughs, including the alveograph and the

extensigraph for resistance and extensibility, the farinograph for mixing time and mixing tolerance, and the tube rheometer for shear viscosity function (Menjivar and Faridi 1994). Recently, Campos et al (1997) used a Haake RS100 Controlled Stress Rheometer to study the rheological behavior of cracker dough sheets. They found that water content, fat content, and number of folds affected the rheological behavior of cracker dough sheets. The more water, fat, or folds, the more liquid-like the behavior.

2.4.4 Determination of Cracker and Quality by Texture Analyser

The quality of a cracker is determined by the ingredients, fermentation time (total sponge and dough fermentation time), pH, and starter. Rogers and Hoseney (1989b) have reported that longer sponge fermentation time decreased both stack height and stack weight of the crackers, but increased the evenness of puffing and cracker strength. Increasing the dough fermentation time increased the elasticity of the sheeted dough and the evenness of cracker puffing. Crackers without starter showed non-uniform appearance, separation of external layers, poor lamination, poor cell structure, and very soft texture. According to the preference of consumers, the desired crackers should have a certain brittleness in the dough layers and a "snappy" bite without gumminess when the cracker is chewed (Stauffer 1994); these attributes can be achieved by allowing gluten proteolysis in the sponge or by adding fungal proteases (Rogers and Hoseney 1989b).

The General Foods Texture Profile Analysis (GF-TPA) uses the GF Texturometer to obtain force-time curves during the compression of bite-sized, uniform food samples. The TPA force-time curve uses two compressions ("two bites") of a sample, to imitate the initial chewing motion of the human mouth (Friedman et al 1963; Szczesniak 1963;

Breene 1975). Bourne (1968) applied the Instron Universal Testing Machine to measure food samples and compared results obtained from GF-TPA. They reported that the Instron is a better tool than the GF Texturometer for determining TPA parameters because speed of the Instron compression is constant at all times during the downstroke. This and the immediate reversal of the compression stroke at the end of the "first bite" resulted in sharper peaks on the Instron. However, with the use of plotters, the response speed of the pen and the pen travel time generate other factors that can limit the recording of the instrument's output (Voisey and Kloek 1975).

Recent texture research has used Texture Profile Analysis (TPA) to evaluate food quality (e.g., bread, red bean paste, and noodles) (Baik et al 1994; Lee et al 1998). Parameter definitions are based on a classification of textural characteristics developed by Friedman et al (1963), Szczesniak (1963 and 1975) and Bourne et al (1978). From the force-time curve of TPA, the hardness (height of the peak) and the springiness (recovered height after first compression) were determined. Adhesive force was the negative force between the first and the second peak. Cohesiveness is the ratio between the area under the second peak and the area under the first peak; gumminess is the product of hardness and cohesiveness; and chewiness is the product of gumminess and springiness (Bourne 1968; Peleg 1976).

Currently, the TA.XT2 Texture Analyzer is becoming more popular for evaluating food quality (e.g., cookies, chips, pretzels, biscuits, and doughs). It is quick, more accurate, and more suitable for different foods (Moreira et al 1995; Jackson et al 1996; Olinger and Velasco 1996; Hix et al 1997; Smewing 1997). It may be applied to determine cracker quality.

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CHAPTER 3

RELATIONSHIPS BETWEEN RHEOLOGICAL PROPERTIES AND ULTRASTRUCTURAL CHARACTERISTICS OF NON-DEVELOPED, PARTIALLY DEVELOPED, AND DEVELOPED DOUGHS

3.1 ABSTRACT

Farinography and mixography are two commonly used procedures for evaluating dough properties. These procedures, however, can not separate hydration and energy inputs during dough development – both critically important for understanding fundamental rheological properties of dough. A rheometer and laser scanning confocal microscope (LSCM) were used to study the relationships between rheological properties and ultrastructural characteristics of developed (by farinograph), of partially developed (by rheometer with shear or extensional deformation) and of non-developed (no deformation) dough samples of wheat flours. Rheological data revealed that developed dough had the highest G* (most elastic or strong), followed by doughs partially developed with extensional deformation and then shear deformation, and finally by non-developed dough. The LSCM z-sectioning (scanning of different layers of the sample) and the analysis of amount of protein matrix showed that developed dough had the most protein matrix, and non-developed dough had the least protein matrix. It also showed that the higher the G*, the more the protein network. Moreover, the type of deformation appeared to contribute to the development of protein matrix and further increase the dough strength. In this study, a combination of shear and extensional deformations by farinograph produced the most protein matrix and the strongest dough, followed by extensional deformation, shear deformation, and then no deformation.

3.2 INTRODUCTION

Wheat flour doughs exhibit both solid and liquid properties, termed "viscoelastic". The viscoelastic property of a dough is strongly related to the gluten proteins (Faubion and Hoseney 1990; Janssen et al 1996a). In the baking industry, many instruments have been developed for testing dough and further predicting final products, e.g., the alveograph, amylograph, extensigraph, farinograph, and mixograph (Berland and Launay 1995; Janssen et al 1996a). The two traditional instruments for testing of wheat doughs are the farinograph and the mixograph, which mix flour and water using energy (a combination of shear and extensional deformations) and form a dough, which can be referred to as developed dough (Campos et al 1996; Campos et al 1997; Schluentz et al 2000). However, the farinograph and the mixograph methods cannot separate hydration and energy input during dough development -- each critically important for understanding fundamental rheological properties of dough.

Recently, Campos et al (1996) successfully produced a "non-developed" dough, a combination of flour and water (in the form of ice powder) with minimal energy input. They found the distribution of water in "developed" dough and "non-developed" dough was not significantly different. Schluentz et al (2000) produced partially developed doughs (using well defined shear and extensional deformations) from non-developed dough and further studied the rheological properties of these doughs. The results indicated that developed dough has the greatest elasticity (strength), followed by doughs partially developed with extensional deformation, and then with shear deformation, and finally by non-developed dough.

Schluentz et al (2000) also examined the ultrastructure of developed, partially developed, and non-developed doughs by using the scanning electron microscope (SEM), and found that developed dough had the most protein matrix and non-developed dough the least. However, dough samples needed to be mounted and coated with gold particles, risking alteration of their structures. The laser scanning confocal microscope (LSCM) has several advantages that overcome this problem. For example, it is able to scan thickly sectioned material (5-10 μm, or even more) and it can also perform z-sectioning (scanning the different layers of a sample) without damaging the sample (van der Voort et al 1985; Heertje et al 1987; Whallon 1993).

Campos et al (1996 and 1997) and Schluentz et al (2000) produced non-developed and partially developed doughs using 50% of water absorption. This water absorption level may not reflect the optimal water requirements for baking of the tested flour samples. Therefore, the objective of this study was to use a rheometer and LSCM to examine the rheological properties and ultrastructural characteristics of non-developed, partially developed and developed doughs based on the optimal water absorption from farinograph of each tested wheat flour.

3.3 MATERIALS AND METHODS

3.3.1 Wheat Samples

Five wheat flours were used in this study. Two were commercial flours: cracker flour from Mennel Milling Co. (Fostoria, OH) in 1997 and a blend (1:1) of hard and soft wheat flours, both from King Milling Co. (Lowell, MI) in 1996. Three additional wheat cultivars used were one soft white (Frankenmuth from Michigan) and two soft red (Caldwell and Freedom from Ohio). These wheats were tempered to 15% moisture overnight, and then milled on a Bühler experimental mill (Bühler Ltd., Uzwil, Switzerland) to 70% flour extraction.

3.3.2 Physicochemical Analyses of Wheat Flour Samples

3.3.2.1 Chemical Analyses

Moisture, ash, protein and damaged starch contents of each flour sample were determined according to approved methods 44-15A, 08-01, 46-13, and 76-30A of AACC (1995), respectively. Table 3.1 summarizes the results of the analyses.

3.3.2.2 Physical Analyses

Farinograph and Falling Number tests were conducted for each flour sample following the approved AACC (1995) Methods 56-81B and 54-21, respectively. Table 3.2 reports Farinograph optimal water absorption, development time, mixing tolerance, and Falling Number results for each flour sample.

3.3.3 Preparation of Dough Samples for Rheological Properties

3.3.3.1 Non-Developed Doughs

Non-developed doughs were prepared using the method of Campos et al (1996) described in Appendix I-Figure A with some modifications. In this study, the amount of water (in the form of ice powder) combined with flour was based on the farinograph optimal water absorption for each flour sample (Table 3.2). To obtain uniform water distribution in the dough, the ice powder was sieved. Only particles smaller than 250 μm were used for mixing with flour in a -8 °C walk-in freezer. Before determination of the rheological properties of the dough, the powder mixture was transferred to a small petri dish (6 cm diameter x 1 cm height), wrapped with parafilm and thawed at room temperature for 24 hr; this was termed non-developed dough. For LSCM examination, non-developed doughs were then placed in a freezer (<-8 °C), and examined within one week. The samples were frozen to minimize undesirable deformation of doughs when being hand-cut with a razor blade and transferred to a slide.

3.3.3.2 Partially Developed Doughs With Shear Deformation and Extensional (Biaxial) Deformation

Doughs partially developed with shear and extensional deformations were prepared according to the method of Schluentz et al (2000) with some modifications (see Appendix I-B). The maximum shear strain obtained from partially developed dough with shear deformation was 1570%. Because different types of flours were used in this study, some doughs partially developed with extensional deformation were unable to attain the

80.5% extensional strain mentioned in the procedure of Schluentz et al (2000). Therefore, the extensional strain was kept at 71.4 % (where height=0.6 mm) to be consistent for all samples throughout the study.

Partially developed samples designated for observation by LSCM were rapidly frozen by pouring crushed dry ice particles over the parallel plates. This prevented dough from sticking to the plates causing undesirable deformation during plate separation. After the bottom plate was lowered, the dough sample was removed, placed in a container with an airtight cover, and placed in a freezer (<-8 °C) immediately, where it was kept until LSCM was carried out within one week.

3.3.3.3 Developed Doughs

Developed doughs were prepared according to the approved AACC Method 54-21 (1995) using the farinograph. After developed dough was produced, it was placed in a container and covered with wet cheese cloths to avoid sample drying. Then, the rheological properties of the developed dough were measured within 5 min. Samples for LSCM examination were placed in a container with an airtight cover and frozen in a freezer (<-8 °C) immediately. Similarly, all frozen samples were observed under LSCM within one week.

3.3.4 Oscillatory Test on Dough Samples

The rheological properties of doughs were determined from an oscillatory test on the Haake Model RS100 RheoStress (Haake, Paramus, NJ), following the procedures of Campos et al (1996) and Schluentz et al (2000). All measurements connected to a load

cell with a 5 N-cm torque capacity. The rheometer was interfaced with a computer for measurement control and data acquisition, using software developed by Haake. Following shear and extensional deformations, the complex modulus G* (Pa) was measured through a frequency range of 6.28 to 628.32 rad/s at a constant shear stress of 50 Pa at 25 °C. Only measurements made in the linear range (6.28 – 157.71 rad/s) of viscoelastic behavior were used in this study.

3.3.5 Preparation of Dough Samples for LSCM

Each type of frozen dough was cut into tiny pieces with a razor blade and transferred to a slide with forceps in a walk-in-freezer (<-8 °C). The dough samples used for LSCM were cut from the center part of the dough [non-developed dough: 0.4 cm distance from the top and 3 cm distance from the edge; partially developed dough with shear deformation: 0.1 cm distance from the top and 0.4 cm distance from the edge (where shear strain was 942%); partially developed dough with extensional deformation: 0.4 cm distance from the edge and no cut from the top because sample too thin (only 0.6 mm); developed dough: 1.5 cm from the top and edge]. All the materials (e.g., blades, forceps, and slides) were pre-frozen for at least overnight prior to use. Next, the tiny dough sample on the slide was thawed at room temperature for 20 min, stained with fluorescein isothiocyanate (FITC) solution (0.05% w/v FITC in 0.0005 M NaOH solution, pH 8.0), and allowed to dry at room temperature in a dark environment (due to light sensitivity of FITC).

3.3.6 Examination of Dough Samples by LSCM

A Zeiss 210 Laser confocal microscope (Carl Zeiss, Inc., Thornwood, NY) was used to observe ultrastructure of dough samples. Before examining each dough sample, one drop of oil was added on the top of the sample. A cover slip was placed on top and another drop of oil was added on the top of the cover slip in order to achieve higher resolution (Yiu 1993). However, the weight of the cover slip exerted enough force to deform the dough sample about 3%, which was measured from the depth of the sample before and after placing the cover slip. The additional extensional strain produced due to the weight of the cover slip on different dough samples was 1.52 %. The ultrastructure of each dough sample was viewed using a 40x oil objective lens. The identity of starch granules (as distinct from air bubbles or lipids) was determined by simple polarized light, without rotation of the stage. To examine the protein matrix of the dough samples, both confocal fluorescence and non-confocal transmitted (i.e., polarized light) images were collected from the same area of each dough sample: (1) starch granules, (2) fluorescence, (3) the overlay of (1) and (2), (4) a z series consisting of nine optical sections, and (5) the extended focus image formed by overlay of the nine images in each series. The overlaid images in this dissertation are presented in color. The z interval was 2000 nm. For both transmitted and fluorescence images, the 488 line of a dual-line argon ion laser was employed. A band pass 520-560 barrier filter was used for detection of FITC. In this study, only three middle layers (4^{th}, 5^{th}, and 6^{th}) of each dough sample are presented.. The amount of protein matrix was measured as a percent of total area from each of the three middle images of each z series using the "Measure" function of the 210's software, and was possible because the gray scale value of the protein areas was much higher than that

of the rest of the image. A least four replications were made for each dough sample.

3.3.7 Statistics

All experiments were conducted at least two times. Data were analyzed by the one-way analysis of variance (ANOVA) procedure using the Statistical Analysis System version 6.12 (SAS Institute, Cary, NC). Significance was defined at the 5% level.

3.4 RESULTS AND DISCUSSION

3.4.1 Rheological Properties

All flour samples showed similar trends: developed dough had the highest G* through all frequencies, followed by dough partially developed with extensional deformation, then dough partially developed with shear deformation, and finally non-developed dough with the lowest G*. As an example, Figure 3.1 shows results from the cracker flour dough samples. The higher the G*, the stronger the dough. These trends are in general agreement with Campos et al (1997) and Schluentz et al (2000).

Dough exhibits viscoelastic properties, related to the gluten proteins -- gliadins and glutenins (Faubion and Hoseney 1990; Janssen et al 1996b). Gliadins are responsible for the viscous behavior. Gliadins contain intra-molecular disulfide bonds, breaking of which causes unfolding of the protein molecules. Glutenins are responsible for the elastic behavior and consist of polypeptide subunits. These subunits are linked together by disulfide bonds, which are inter-molecular (Bloksma 1990).

Meredith (1964) suggested two models for dough development. One model was that dough development can be explained by the formation of a continuous network with covalent disulfide cross-links among separate protein molecules by thiol-disulfide interchange reactions. The other was that the continuity of the protein network depends on non-covalent cross-links, such as hydrogen bonds and hydrophobic interactions. Thiol-disulfide interchange reactions during mixing can change the molecular mass distribution. In this study, a combination of these two models may explain the rheological properties of non-developed, partially developed, and developed doughs. Among all these doughs, non-developed dough was the most liquid-like in behavior.

This may suggest that the protein network inside the non-developed dough was formed mainly with non-covalent cross-links and intra-chain disulfide bonds. During the mixing process, such as by shear and extensional deformations, these non-covalent cross-links and intra-chain disulfide bonds may be broken. The protein molecules would become more unfolded and could form new cross-links at new positions, including inter-chain disulfide bonds. In this way, a much bigger protein network may be produced, giving the developed dough the most elasticity. Data supporting this hypothesis can be found in the companion manuscript (Chapter 4).

The rheological behavior of doughs is affected by the mixing process (e.g., type of mixing apparatus, energy input, mixing time, and mixing speed) (Hoseney 1985; Nagao 1986; Janssen et al 1996b). Though the quantity of energy input by the farinograph was not measured in the current study, the energy addition and the type of deformation appeared to contribute to dough strength. With energy input, a weaker dough (i.e., non-developed dough) was changed into a stronger dough (i.e., developed dough). A dough without any deformation (i.e., non-developed dough) had the lowest G*, a dough subjected to only shear deformation had the second lowest, a dough subjected to only extensional deformation had the third lowest, and a dough with a combination of shear and extensional deformations had the highest G*. Based on the results of Janssen et al (1996b), gluten mixed for less than the optimal mixing time had a lower G* compared to that with the optimal mixing time. Their findings were in agreement with ours, namely, that developed doughs had the highest G* among the different doughs of the same flour.

3.4.2 Ultrastructural Characteristics

There are two types of starch granules: large lenticular granules (20-40 μm) and small spherical granules (2-10 μm) (Yiu 1993; Hoseney 1994). Both types of starch granules were observed in developed cracker flour dough (Figure 3.2A). Because of the birefringence property of starch granules under polarized light, it could be assured that the round shapes were starch granules and not air bubbles or lipids. Figure 3.2B shows the protein matrix (bright area) around the starch granules in Figure 3.2A. The protein matrix can be visualized because of the fluorescein in FITC. Fluorescein isothiocyanate conjugates with ε-amino groups of amino acids and this conjugated compound absorbs a certain wavelength (488 nm) and emits it as a longer wavelength (525 nm) (Kiernan 1981; Strasburg and Ludescher 1995). Similar technique using LSCM was also applied to observe protein matrix of bread dough with FITC (Heertje et al 1987) and of pasta with fuchsin acid (Fardet et al 1998). Figure 3.2C shows the overlaid images of Figures 3.2A and B; the areas of red color with crosses inside are starch granules and the green color is the protein matrix.

Figures 3.3A, B, and C display the different layers of protein matrix (the bright area) from the middle part of the developed cracker flour dough by using a z-sectioning function. These images were obtained from the same sample but from directly underneath the location seen in Figures 3.2A, B, and C. When a razor blade is used to cut a sample, it might destroy the protein network on the sample's cut surface. One of the advantages of z-sectioning is that it avoids damaging the structure of a sample since the laser light has the capability of scanning deeper layers of the sample without actually cutting it (Whallon 1993). These images clearly show that the distribution of protein

matrix in each layer was slightly different. Figure 3.3D is the overlaid images of Figures 3.3A, B, and C. It can be seen that the protein matrix was distributed around and across the starch granules surrounding them.

Figure 3.4 shows the protein matrices (bright regions) of different cracker flour doughs. The first row (A) is non-developed dough. The second (B) and third (C) rows are doughs partially developed with shear and extensional deformations, respectively. The bottom row is developed dough. It is obvious that the amount of protein matrix was minimal in non-developed dough as compared with the amounts present in partially developed doughs and developed dough. Similar trends were obtained using Frankenmuth, Caldwell, Freedom, and blend flour dough samples (pictures not shown). These findings were in general agreement with Schluentz et al (2000) who used SEM to examine the protein development of non-developed, partially developed, and developed doughs from soft and hard wheat flours.

In the current study, the brightness and the contrast used for images of different dough samples were different in order to obtain the highest resolution and the most observable information from each dough sample (Figure 3.4). However, the brightness and the contrast of images are two factors that influence the amount of protein matrix detected in a dough. To confirm that there was a similar trend for the amount of protein matrix appearing among different dough samples, all dough samples were also examined under the same brightness and contrast. Results showed the least amount of protein matrix in non-developed dough, and the greatest amount in developed dough (images not shown).

During dough development, water penetrates into flour particles resulting in hydration and swelling of starch and proteins. In the early stage, the swollen proteins just start to become interconnected. As dough is progressively developed with energy addition, the protein masses are stretched into a continuous network and surround most of the starch granules (Bloksma 1990). This was also observed in the present study: the amount of the protein matrix present was increased from the non-developed dough (without energy input) to the developed dough (with energy input). Between the two types of deformations, extension appeared to contribute to the amount of protein matrix formation in dough more than did shear.

Table 3.3 shows the total amount of protein matrix of different dough samples, as measured by the percent of pixels with high gray scale values in each image. The results indicate that the amount of protein matrix was significantly different among non-developed, partially developed with shear and extensional deformations, and developed doughs. The data confirm that non-developed doughs in this study had the lowest quantity of protein matrix (10.95% - 19.70%) and developed doughs had the highest amount (26.98% - 39.63%). This is also in general agreement with Schluentz et al (2000) who reported a difference in protein development, measured by numerical digital image analysis, between non-developed and developed dough samples.

3.4.3 Relationships between Rheological Properties and Ultrastructural Characteristics

Results from rheological and microscopic studies indicated that the weakest dough (i.e., non-developed dough) had the least protein matrix and the strongest dough

(i.e., developed dough) had the most protein matrix. This suggests that the dough strength relates directly to the amount of protein matrix present. Kasarda (1999) also pointed out that the greater the degree of protein matrix formation, the greater the overlap of the proteins surrounding the starch granules in dough. The degree of overlap determines the elasticity of a dough.

As described in Section 3.4.2, the energy addition and the type of deformation result in the formation of protein matrix in dough. Addition of energy increases the amount of protein matrix formation from non-developed dough to developed dough. Exertion of extensional deformation creates more protein matrix than does shear deformation. Thus, the increase in quantity of developed protein matrix due to energy addition and various types of deformations, changes a weaker dough into a stronger dough. These findings are also in agreement with Campos et al (1996) and Schluentz et al (2000).

3.5 Summary

Rheological data obtained in this study indicated that developed dough was the most elastic (strong) dough, followed by dough partially developed with extensional deformation, then dough partially developed with shear deformation, and finally by non-developed dough. The LSCM z-sectioning showed that developed dough had the most protein matrix and non-developed dough had the least protein matrix. This is in agreement with the evaluation of the protein matrix by z-sectioning. The formation and amount of protein matrix in a dough is an important factor to determining the strength of a dough. The more protein matrix present, the stronger the dough.

The energy input and the type of deformation are both significant with respect to development of protein matrix and further enhancement of dough strength. In this study, the energy addition changed the limited protein matrix of soft dough (i.e., non-developed dough) into the more developed protein matrix of stronger dough (i.e., developed dough). Since extensional deformation resulted in more protein matrix than shear deformation did, the effect of extension on dough strength was more significant than the effect of shear. Among different dough samples, a combination of extensional and shear deformations (by farinograph) generated the strongest dough with the formation of the most protein matrix. Using a rheometer to prepare dough samples enabled the application of precise energy input (types and quantity) for studies in fundamental dough rheology. Additionally, the LSCM has proven to be a great asset for examining dough development in relation to dough protein chemistry.

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Table 3.1 Chemical Properties of Wheat Flours[1]

Samples	Moisture (%)	Ash (%, db)	Protein (%,db)	Damaged Starch (%,db)
Frankenmuth	11.88c±0.05	0.50a±0.01	6.38d±0.23	6.40c±0.07
Caldwell	11.75c±0.01	0.33c±0.02	7.58b±0.07	7.63b±0.04
Freedom	11.88c±0.04	0.40b±0.03	7.20c±0.11	7.38b±0.01
Cracker	13.44a±0.06	0.25c±0.01	7.60b±0.06	6.03d±0.00
Blend[2]	12.36b±0.07	0.50a±0.02	10.59a±0.11	8.12a±0.01

[1]Values in the table are: means ± standard deviation. Different letters within the same column designate significant differences among the samples at α=0.05.

[2]Blend: soft wheat flour: hard wheat flour = 1:1.

Table 3.2 Physical Properties of Wheat Flours

Samples	Optimal Water Absorption[1] (%)	Development Time[1] (min)	Mixing Tolerance[1] (BU)	Falling Number (sec)
Frankenmuth	53.1	1.0	120	377
Caldwell	56.0	1.0	110	380
Freedom	56.6	1.2	105	376
Cracker	51.9	1.1	75	357
Blend[2]	59.6	1.5	40	317

[1]Obtained from farinograph tests.

[2]Blend: soft wheat flour: hard wheat flour = 1:1.

Table 3.3 Percentage of Amount of Protein Matrix in the Different Dough Samples[1]

Samples	Non-Developed Dough	Dough Partially Developed with Shear Deformation	Dough Partially Developed with Extensional Deformation	Developed Dough
Frankenmuth	19.70d±0.58	27.08c±1.14	30.72b±0.53	35.50a±0.72
Caldwell	15.40d±0.76	21.04c±0.91	30.22b±0.73	39.63a±1.12
Freedom	10.95d±0.61	13.31c±0.55	29.31b±1.04	34.99a±0.77
Cracker	12.01d±0.39	18.46c±0.62	21.96b±0.63	31.50a±1.07
Blend[2]	12.52d±0.62	14.48c±0.65	20.84b±1.13	26.98a±1.31

[1]Values in the table are: means ± standard deviation. Different letters within the same row designate significant differences among the samples at α=0.05.

[2]Blend: soft wheat flour: hard wheat flour = 1:1

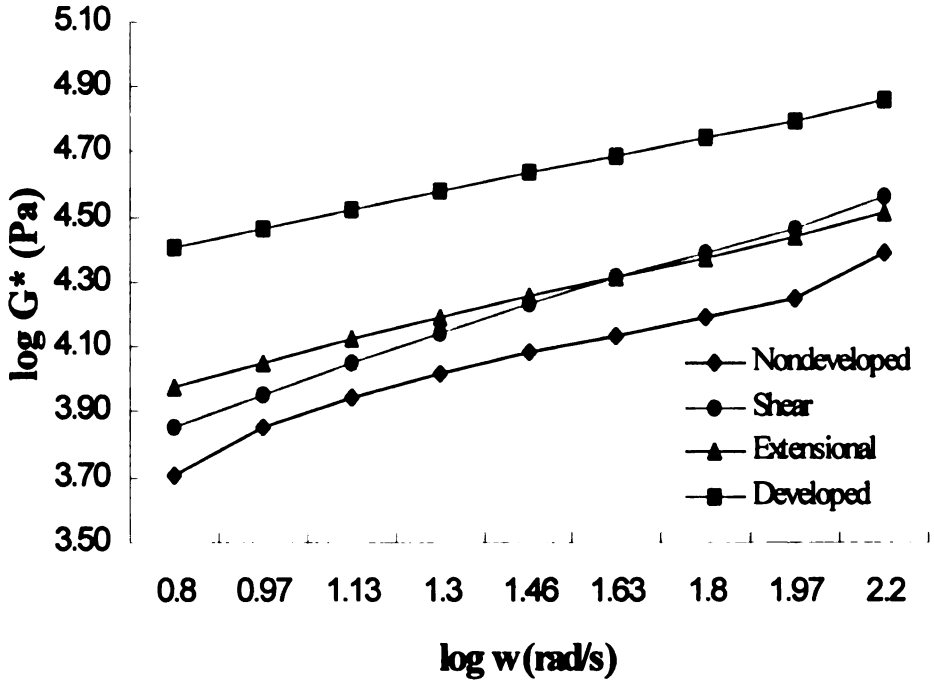
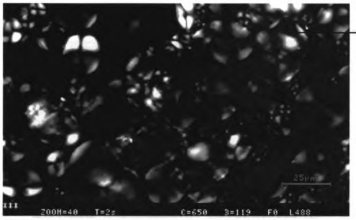
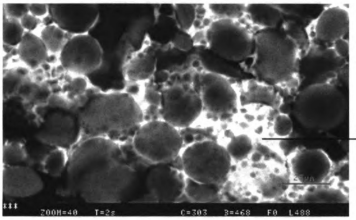


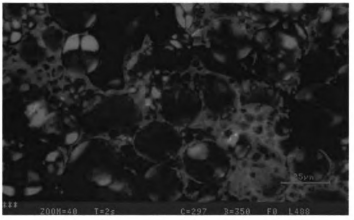
Figure 3.1 Rheological Properties of Cracker Flour Doughs.



A



B



C

Figure 3.2 Ultrastructure of Developed Dough Made from Cracker Flour.

A: Starch Granules under Polarized Light; B: Protein Matrix under Laser Light (488 nm);
C: Overlaid images of A and B
S: Starch Granules; P: Protein Matrix

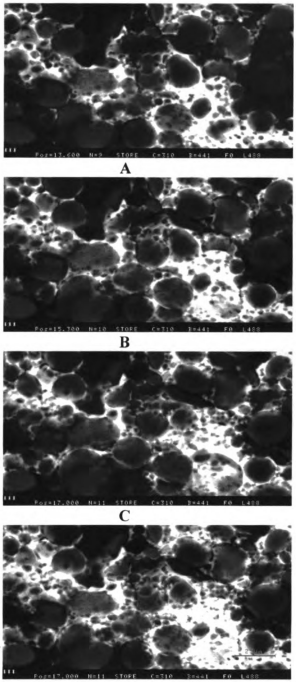


Figure 3.3 Protein Matrix of Developed Dough Made from Cracker Flour Using Z-Sectioning under Laser Scanning Microscope.

A: 4th Layer; B: 5th Layer; C:6th Layer; D: Overlay of A, B, and C Images

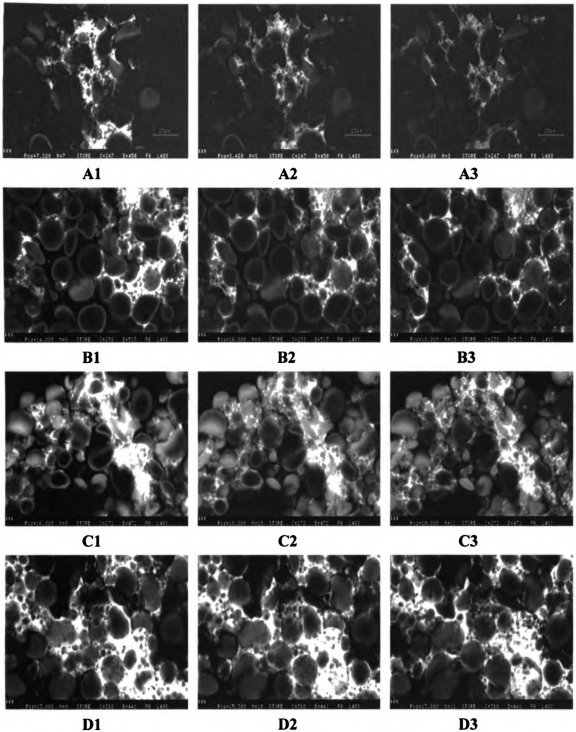


Figure 3.4 Protein Matrix from Different Cracker Flour Doughs in Z-Sectioning of Laser Scanning Microscope.

A: Non-Developed Dough: B: Dough Partially Developed with Shear Deformation: C: Dough Partially Developed with Extensional Deformation: D: Developed Dough; 1: 4th Layer: 2: 5th Layer: 3: 6th Layer

CHAPTER 4

BIOCHEMICAL STUDIES OF PROTEINS IN NON-DEVELOPED, PARTIALLY DEVELOPED, AND DEVELOPED DOUGHS

4.1 ABSTRACT

Non-developed, partially developed with shear and extensional deformations, and developed doughs represent different levels of dough development. To understand the relationship between gluten proteins and dough rheology, this study used disulfide-sulfhydryl analyses, gel filtration chromatography, sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE), acid polyacrylamide gel electrophoresis (A-PAGE), and densitometry to examine proteins in the four types of doughs mentioned. Free sulfhydryl content was the lowest in native flour and non-developed dough, and the highest in partially developed doughs, while a reverse trend was observed for disulfide content. The protein elution profiles from gel filtration chromatography among same flour samples shifted with levels of dough development. With respect to the smallest sized molecules, native flour had the most, followed by non-developed, partially developed, and then developed doughs. SDS-PAGE and A-PAGE exhibited similar protein patterns among the same protein fractions of each native flour and its different doughs. Densitometric data showed that the amount of high molecular weight (HMW) glutenins increased and the amounts of low molecular weight (LMW) glutenins, gliadins, and albumins/globulins decreased with progressive levels of dough development. Results indicate that the increase in the size and the amount of HMW glutenins is related to the strength of dough and the amount of protein matrix present in the dough.

4.2 INTRODUCTION

Fundamental rheological properties of dough are strongly related to the gluten proteins -- glutenins and gliadins (Bushuk 1985; Janssen et al 1996). Glutenins consist of polypeptide chains crosslinked with disulfide bonds. They are responsible for the elastic behavior of dough. On the other hand, gliadins are comprised of single chain molecules and contain intra-molecular disulfide bonds, which contribute to the viscous behavior of dough (Bushuk 1985; Bloksma 1990; Janssen et al 1996). It has been found that the mixing method can change the amount of glutenins and the distribution of molecular size (Wang et al 1992). Hence, the type and amount of glutenins and gliadins in a dough sample may not reflect the type and amount present in its flour sample. The type and quantity of glutenins and the ratio of glutenins to gliadins in flour are also correlated to the quality of the final products (Payne et al 1984; Ng and Bushuk 1988; Hou et al 1994).

Recently, Campos et al (1996) produced a "non-developed" dough, a combination of flour and water with minimal energy input (no type of deformation was involved), and Schluentz et al (2000) produced partially developed doughs (either shear or extensional deformation was applied). These dough samples represent different levels of dough development, and examining them for the distribution of glutenins and gliadins and some chemical reactions (intra- and inter-molecular bonds) related to dough development is warranted to gain a better understanding of the relationship between proteins and dough rheology. Therefore, the objectives of this study were: (1) to characterize and quantify glutenins and gliadins from non-developed, partially developed, and developed doughs, and (2) to relate the information to rheological and ultrastructural characteristics.

4.3 MATERIALS AND METHODS

4.3.1 Materials

Five wheat flour samples were used as described in Chapter 3 (section 3.3.1).

4.3.2 Physicochemical Analyses of Wheat Flour Samples

Chemical and physical analyses were described in Chapter 3 (section 3.3.2.1 and 3.3.2.2).

4.3.3 Preparation of Dough Samples

Dough samples (non-developed, partially developed and developed) were prepared as indicated in Chapter 3 (section 3.3.3.1, 3.3.3.2 and 3.3.3.3).

4.3.4 Dough Flour Samples

Dough samples were frozen and lyophilized. The lyophilized samples were ground by mortar and pestle and then sieved through a screen with 250 μm openings to obtain uniformly sized particles. These uniform particles were used throughout the biochemical studies.

4.3.5 Disulfide-Sulfhydryl Analyses

Free sulfhydryl (-SH) and disulfide (S-S) contents of the different dough samples were determined according to the methods of Chan and Wasserman (1993) (also see Appendix I-C). Each sample was analyzed three times.

4.3.6 Gel Filtration Chromatography

4.3.6.1 Extraction of Total Proteins

Each native flour and its dough samples (1.25 g) was suspended in 25 ml of 0.05 M sodium phosphate buffer (pH 6.8) containing 2% SDS and 0.104% sodium azide (Huang and Khan 1997). The sample was stirred with a magnetic stirrer overnight at room temperature and then centrifuged at 15,000x g at room temperature for 20 min. An aliquot (20 ml) of supernatant was loaded onto the gel filtration column.

4.3.6.2 Fractionation of Proteins Using Gel Filtration Chromatography

Chromatography of total proteins of each sample was accomplished on a Sephadex G200 (2.5 cm x 87 cm) column. The eluting solvent was 0.05 M sodium phosphate buffer (pH 6.8) with 0.1% SDS and 0.104% sodium azide. Sodium azide was included to prevent microbial growth. The column was operated with downward flow at a flow rate of 0.6 ml/min. Proteins in the column effluent were monitored at 280 nm. Preliminary runs showed that total proteins could be fractionated into three peaks. The first peak (I) was mainly glutenins, the second peak (II) was gliadins, and the third peak (III) was albumins and globulins based on SDS-PAGE results (Figure 4.1). Since this study was focussed on glutenins and gliadins, Peak I was further separated into 2 parts (I-A and I-B). Peak I-A was collected from the first one-third of Peak I, and Peak I-B was the rest of Peak I. All of Peaks I-A, I-B, and II were used for further electrophoretic analyses. After all fractions were collected from the gel filtration column, they were

frozen and then lyophilized. Protein content of each fraction sample was determined (AACC Method 46-13,1995).

4.3.7 Electrophoresis

4.3.7.1 Total Protein and Glutenin Extraction for Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis (SDS-PAGE)

Fifty milligrams of each protein peak fraction were used to extract total non-reduced and reduced proteins, and reduced glutenin proteins according to Pogna et al (1990) (Appendix I-D). The total proteins of each native flour were used as standards. For non-reduced total proteins, extraction buffer did not contain 2-mercaptoethanol. The loading volumes for each sample for SDS-PAGE are given in Table 4.1.

4.3.7.2 Ethanol-Soluble Protein Extraction for Acid Polyacrylamide Gel Electrophoresis (A-PAGE)

Ethanol-soluble proteins from each peak fraction sample and from native flour (50 mg) were extracted based on the method of Pogna et al (1990) (Appendix I-D). The loading volume for A-PAGE was 5 μl.

4.3.7.3 SDS-PAGE and A-PAGE

SDS-PAGE and A-PAGE were according to Pogna et al (1990) (Appendix I-E and F). Electrophoresis was run in gels 1.5 mm thick (18 cm wide, 16 cm long) with a vertical electrophoresis apparatus (Hoefer Scientific Instruments, San Francisco, CA).

4.3.8 Quantification of Proteins by Densitometry

Quantification (%) of each protein band from each lane of the gels was performed by a reflectance scanning densitometer (GS 300, Hoefer Scientific Instruments, San Francisco, CA) with GS 365W Software. Using these quantities (measurements), the total areas (%) for each group of proteins (i.e., HMW glutenins, LMW glutenins/gliadins, and albumins/globulins on SDS-PAGE, and α-, β-, γ-, and ω-gliadins on A-PAGE) were calculated for each run.

4.3.9 Statistics

Data were collected from at least three replicates and analyzed by the one-way analysis of variance (ANOVA) procedure using the Statistical Analysis System version 6.12 (SAS Institute, Cary, NC). Significance was defined at the 5% level.

4.4 RESULTS AND DISCUSSION

4.4.1 Sulfhydryl (-SH) and Disulfide (S-S) Analyses

Cystine is composed of two cysteine groups that have formed a S-S bond either within the same polypeptide chain or between two different chains. These intrachain and interchain bonds, respectively, through disulfide linkage contribute to the rheological properties of dough (Wrigley and Bietz 1988). Table 4.2 summarizes the free -SH, S-S, and total cysteine contents of all flour samples and their respective doughs. There were significant differences in free -SH content among different doughs of the same flour. Results also showed that the total free -SH group contents were lower in native flour, non-developed and developed doughs, and higher in partially developed doughs, whereas the opposite was true for the S-S contents (even though the findings were not statistically significant). This may suggest that when either shear or extensional deformation was applied, S-S bonds were broken, exposing more free -SH groups. Similar results were obtained for doughs using different mechanical methods (Tanaka and Bushuk 1973 and MacRitchie 1975) and energy levels (Singh 1990).

When the developed dough was formed, the S-S content increased slightly compared to the two partially developed doughs, implying the formation of larger molecular size proteins via interchain S-S bonds (Kasarda 1999). However, the S-S content in developed dough was not higher than that in non-developed dough, perhaps due to a decrease in the rate of interchain S-S bond formation as large polymers form (Kasarda 1999).

Based on statistical analyses, S-S contents were not significantly different among each flour and its different doughs. This could be due to an inherent limitation: only

about 2% of S-S bonds in gluten can be broken by exchange with free -SH groups of protein molecules (Mauritzen 1967). It was not surprising, therefore, that we could not significantly differentiate ($p<0.05$) the S-S contents among different doughs of the same flour samples. It was also expected that different doughs made from the same flour should have similar total cysteine content, and this was confirmed in the present study.

4.4.2 Gel Filtration Chromatography

All flour samples used in this study exhibited similar trends in gel filtration, electrophoretic, and densitometric results, therefore, the cracker flour sample was chosen as a representative example for discussion purposes for this paper and thereafter. Figure 4.2 shows the protein elution profiles from gel filtration chromatography of native cracker flour and its different doughs. It can be seen that protein extracts were fractionated into three main peaks of decreasing molecular weight range, representing mainly the glutenins, gliadins, and albumins/globulins. (the first two peaks are characterized in detail in the latter part of this paper). Singh (1990) obtained similar peak results using size-exclusion high performance liquid chromatography. In Singh' s study, the molecular weight distributions of glutenins, gliadins, and albumins/globulins were estimated as >100, 80-25, and 25-5 kD, respectively. However, there was some overlap in sizes between the types of proteins. Arakawa and Yonezawa (1975) also used gel filtration to separate flour proteins. They suggested that the proteins from the first peak were mostly high molecular weight proteins (aggregative polypeptides).

Among dough samples, the protein elution profiles shifted from the right to the left (i.e., later to earlier) with increasing levels of dough development (Figure 4.2). This

indicated that native flour contained the highest amount of small molecules, followed by non-developed, partially developed with shear deformation, partially developed with extensional deformation, and finally developed doughs. In addition, the two partially developed doughs each had a sharper peak I than did native flour, non-developed and developed doughs. Another experiment was designed to investigate why partially developed doughs had a sharper peak (see Appendix I-G). It was found that both folded and unfolded types of proteins affected the absorbance (data not shown). Unfolded proteins had a higher absorbance, resulting in a higher peak. This trend appeared in all other doughs from each of the flour samples examined.

Some speculations could be made based on these findings. When the 280 nm wavelength is used to detect proteins, it mainly detects three amino acids --- tyrosine, tryptophan, and phenylalanine (Cheftel et al 1985). Without any deformation of a dough sample, there could be more folded native proteins, primarily involving intrachain disulfide bonds (Kasarda 1999). These folded proteins could bury the three amino acids inside the macromolecules, and consequently, native flour and its non-developed dough would have lower absorbance. With shear or extensional deformation, some bonds (e.g., S-S bonds, hydrogen bonds, and hydrophobic interactions) may break and be reformed at essentially the same time (Mecham et al 1965; Wrigley and Békés 1999). The bonds broken probably outnumber the new bonds formed in partially developed doughs.

Murthy and Dahle (1969) reported that cleavage of S-S bonds corresponded to the unfolding of the molecules. In the current study, there was higher free -SH content in the partially developed doughs (Table 4.2), and it is speculated that the proteins were more unfolded and therefore more of the three detectable amino acids (above) were exposed on

their outside surfaces. Thus, partially developed doughs demonstrated higher absorbance. When both shear and extensional deformations by farinograph were applied to make developed doughs, unfolded proteins gradually re-configured to form different inter and intra chain bonds (e.g., disulfide bonds). This was evident from the increase in S-S contents from partially developed to developed doughs (Table 4.2). As these new S-S bonds form, protein molecules fold (aggregate) again, which re-buries the amino acid residues inside the protein, thereby decreasing the absorbance of the developed doughs.

4.4.3 Electrophoresis

4.4.3.1 SDS-PAGE

Electrophoretic patterns of cracker flour and its dough samples under non-reduced condition are presented in Figure 4.3. There were no visible protein bands detected in fraction I-A. However, streaking was observed in the HMW glutenin region, indicating a wide range of proteins throughout this region. In addition, some larger proteins remained on the top of the gel due to the fact that they were too large to enter into the running gel under non-reduced conditions (Singh et al 1990).

Both HMW and LMW glutenins and gliadins were in fraction I-B but albumins and globulins were not present. Gliadins in this fraction were probably present due to the indistinct boundary between fractions I-B and II. In addition, some gliadins possibly interacted with glutenins and eluted out in peak I-B, which is in agreement with Arakawa and Yonezawa (1975) that proteins in the first peak (I) from gel filtration were mostly aggregative proteins. The aggregation behavior of these proteins was attributed to the

differences in gluten proteins or differences in the polypeptide compositions of gluten. Some protein bands of LMW-glutenins, gliadins, albumins, and globulins could be seen in the electrophoretic patterns of fraction II (Figure 4.3). The presence of LMW glutenins, albumins, and globulins in this fraction may be due not only to contamination but also to protein aggregation (Singh 1990).

Figure 4.4 shows the SDS-PAGE patterns of different protein fractions under reduced conditions from cracker flour and its different doughs. More protein bands, as expected, could be observed in all samples due to the de-polymerization of larger molecules under reduced conditions. In all flour and dough samples, fraction I-A had HMW and LMW glutenins; fraction I-B consisted of mostly HMW and LMW glutenins, gliadins, and a small amount of albumins/globulins; and fraction II contained LMW glutenins, gliadins, and albumins/globulins. This suggested that some high molecular weight proteins were composed of small molecules (Bean and Lookhart 1998).

The protein patterns of reduced glutenins were similar to those of total reduced proteins (gels not shown). Fraction I-A showed bands only in the HMW and LMW glutenin regions; fraction I-B exhibited bands mostly in the HMW glutenin and LMW glutenin/gliadin regions and only few in the albumin/globulin region; and fraction II demonstrated bands in the LMW glutenin/gliadin and albumin/globulin regions.

During the procedure of glutenin extraction, the ethanol soluble proteins (e.g., gliadins) were removed by ethanol. However, some gliadins still appeared on the SDS-PAGE gels under reduced conditions. This could confirm that these gliadins chemically reacted with glutenins (e.g., S-S bonds) and formed some of the larger high

molecular weight proteins, and were thus not accessible for extraction by ethanol. Bean and Lookhart (1998) also reported similar findings.

4.4.3.2 A-PAGE

For each sample, gliadins fractionated by A-PAGE were divided into 4 subgroups: α-, β-, γ-, and ω-gliadins according to Bushuk and Sapirstein (1991). No gliadins were detected in fraction I-A of the various flours and their different dough samples (see Figure 4.5 for cracker flour results). This indicated that proteins in fraction I-A on SDS-PAGE were mostly HMW and LMW glutenins. Most of the gliadins in fraction I-B were β-, γ-, and ω-gliadins. It appeared that β-, γ-, and ω-gliadins were chemically involved with glutenin proteins, as revealed during SDS-PAGE (see above). Fraction II contained all four types of gliadins, i.e., α-, β-, γ-, and ω-gliadins.

4.4.4 Quantification of Proteins by Densitometry

4.4.4.1 Proteins Fractionated by SDS-PAGE under Non-Reduced Conditions

In SDS-PAGE, any streaks that occur are mainly due to the presence of multiple proteins of various molecular sizes (Singh et al 1990). Therefore, in this study, all streaking parts of each sample run were accounted for as proteins when quantifying proteins. As described earlier, non-reduced proteins of fractions I-A for all flour and dough samples on SDS-PAGE gels were in the HMW glutenin region; thus, any changes in the amounts of HMW glutenins at different levels of dough development were not observable from densitometric results (Table 4.3). However, data from fractions I-B and

II clearly showed changes in the amounts of HMW glutenins at different levels of dough development; the amount of total HMW glutenins increased, while those of total LMW glutenins and gliadins decreased. The amount of albumins and globulins in fraction II also diminished, suggesting that albumins and globulins might be involved in the formation of larger molecules. These phenomena may be explained by the reports of Bietz and Wall (1973 and 1980) that glutenins can interact with low molecular weight gliadins, albumins, and globulins in three ways: 1) disulfide interchange may promote more stable configurations, while simultaneously incorporating other polypeptides; 2) covalent interactions may occur between bonding sites; and 3) proteins may associate noncovalently through hydrophobic interactions or hydrogen bonds.

4.4.4.2 Proteins Fractionated by SDS-PAGE under Reduced Conditions

Densitometric data on SDS-PAGE gels of reduced proteins from different chromatography fractions of cracker flour and dough samples are listed in Table 4.4. Data indicated that the quantity of HMW glutenins progressively increased and the quantity of smaller molecules (e.g., LMW glutenins, gliadins, albumins, and globulins) gradually decreased in each of the corresponding fractions from samples with different levels of deformations, with the exception of the total LMW glutenins and gliadins in fraction II. It appears that the decrease in proportion of small molecules was associated with the increase in HMW glutenins. This provided further evidence that LMW glutenins, gliadins, albumins, and globulins could be involved in the formation of larger molecules during dough development, which is also in agreement with Tsen (1967) and Singh et al (1990). They stated that with energy input (a combination of shear and

extensional deformations), protein molecules become involved in chemical interactions with each other, e.g., -SH and S-S interactions, hydrogen bonds, and hydrophobic interactions, causing an increase in the concentration of larger molecules and a decrease in the concentration of smaller molecules. Nevertheless, the increase in and the elongation of developing high molecular weight proteins are limited because only one cysteine residue is likely to participate in intermolecular S-S bonds in some of the glutenin subunits with an odd number of cysteine residues (Lafiandra and Masci 1999).

4.4.4.3 Gliadin Proteins Fractionated by A-PAGE

Table 4.5 lists quantities of gliadins present in different dough samples as determined by densitometer from A-PAGE gels of their chromotographic fractions. There were no gliadins detected in any I-A fractions. This indicated that non-reduced and reduced proteins in fraction I-A on SDS-PAGE gels were only HMW and LMW glutenins (Figures 4.3 and 4.4).

During different dough stages, the amounts of α-, β-, and ω-gliadins in fraction I-B increased, but γ-gliadins decreased. The possible reason for this finding is the way α-, β-, γ- and ω-gliadins were linked to glutenins during dough development. It has been reported that gliadins may have interactions with themselves or glutenins via non-covalent interactions and/or S-S bonds (Branlard and Dardevet 1985; Wrigley and Bietz 1988; Tamás et al 1998). It has also been found that, using mechanical methods, the extractability of proteins could increase with the increase in protein molecular size due to the breakage of some bonds, such as S-S bonds and hydrophobic interactions (Singh et al 1990). In this study, gliadins were extracted occasionally by a vortex,

however, the energy from a vortex is not high enough to break S-S bonds. It may affect only non-covalent interactions (e.g., hydrophobic interactions, hydrogen bonds, and electrostatic interactions). This may imply that with progressive levels of dough development, there is an increase in the amounts of α-, β-, and ω-gliadins involved with large HMW proteins via non-covalent interactions. Consequently, native flour and non-developed dough, which had the fewest larger molecules and non-covalent interactions, also had the lowest amounts of α-, β-, and ω-gliadins; and developed dough, with the most larger molecules and non-covalent interactions, had the highest amounts of α-, β-, and ω-gliadins. On the other hand, the amount of γ-gliadins decreased with levels of dough development, possibly due to an increase in chemical interactions between HMW glutenins and γ-gliadins via S-S bonds; thus fewer γ-gliadins were extracted using a vortex in fraction I-B.

Another reason for finding high amounts of ω-gliadins in fraction I-B is because of their size; ω-gliadins are larger in molecular size than α-, β-, and γ-gliadins (Bietz and Wall 1980) and therefore elute earlier during gel filtration than the other gliadins. This contributed to the proportionately more ω-gliadins appearing in fraction I-B. The distribution of α-, β-, γ-, and ω-gliadins in fraction II also varied with progressive levels of dough development: while the levels of α- and ω-gliadins decreased, those of β- and γ-gliadins increased. These changes in distributions of gliadins among fractions and among dough levels within a fraction were probably due to inter-gliadin and gliadin-glutenin interactions, including hydrophobic interactions, hydrogen bonding, and S-S linkage (Bietz and Wall 1980; Tamás et al 1998).

4.4.5 Relationships among Chemical, Rheological, and Ultrastructural Properties of Different Dough Samples

This study found that the protein molecular size and the quantity of HMW glutenins were related to dough strength and protein matrix. Based on the results of disulfide-sulfhydryl analyses, gel filtration chromatography, and densitometry, non-developed dough had the most small molecular size proteins with the fewest interchain S-S bonds, and developed dough had the most large molecular size proteins containing the most interchain S-S bonds. Results from rheological data and from LSCM images (in Chapter 3) showed that non-developed doughs were the weakest doughs and contained the least amount of protein matrix, respectively, and that developed doughs were the strongest and had the most protein matrix. Thus, the increase in the quantity of large molecular size proteins via interchain S-S bonds appeared to contribute to both the dough strength and the formation of protein matrix.

From the current study, it was revealed that the presence of larger glutenin polymers in higher amounts correlated with stronger doughs. This finding seems to be supported by Sapirstein and Fu (1998) and Kasarda (1999). Kasarda (1999) explained that the HMW glutenins have three domains --- small N-terminal and C-terminal domains, and a large central domain. All the cysteine residues, forming intra- and intermolecular S-S bonds, are in or close to the N- and C-terminal domains. The central domain is rich in glutamine residues that are able to build strong hydrogen bonds with other gluten proteins. All these bonds determine the size and the quantity of the HMW glutenins and further contribute to the dough strength. For example, with smaller molecules and a low degree of interchain S-S bonds, the elasticity of dough is low and it

behaves in a more fluid-like manner. With large molecules and a high degree of interchain S-S bonds, dough becomes more solid-like in behavior (Shewry et al 1992). It would follow, then, that non-developed dough with the lowest amount of HMW glutenins was the softest dough and developed dough with the highest amount of HMW glutenins was the strongest, as seen in this study and the Chapter 3.

It was also found that the amount of protein matrix increased with the increases in glutenin size and the amount of HMW glutenins during dough development such that non-developed dough had the least protein matrix, partially developed doughs had an intermediate amount, and developed dough had the most. Perhaps the greater the size of the glutenin polymers, the more they could overlap and interact to form a continuous matrix surrounding the starch granules in dough. The overlapping could be responsible for maintaining the stability and elasticity of the protein matrix (Kasarda 1999).

4.5 SUMMARY

Disulfide-sulfhydryl analyses revealed that the free -SH content was lower in native flour, non-developed and developed doughs, and higher in partially developed doughs, with reverse trends for disulfide content. According to gel filtration chromatography analyses, native flour had the most small molecular size proteins, followed by non-developed, partially developed, and then developed doughs. The two partially developed doughs had sharper peak I′ s (the largest molecular size proteins eluted) than native flour, non-developed, and developed doughs. The results implied that the larger molecular size proteins were formed via S-S bonds.

SDS-PAGE and A-PAGE exhibited similar protein patterns among the same protein fractions of each native flour and its different doughs. More protein bands appeared under reduced conditions due to the de-polymerization of larger molecules. Densitometric data suggested that the total HMW glutenins increased during dough development. In contrast, the amounts of LMW glutenins, gliadins, and albumins/globulins decreased. Similar trends were observed under both non-reduced and reduced conditions. These findings could imply that the increase in HMW glutenins may involve interactions of glutenins with smaller molecules, such as LMW glutenins, gliadins, and albumins/globulins via S-S bonds, hydrogen bonds, and hydrophobic interactions. Additionally, it was found that non-developed dough was the weakest dough and had the least protein matrix, and that developed dough was the strongest dough and had the most protein matrix. Thus, the increases in both size and amount of HMW glutenins during dough development contributed to the formation of protein network and further enhanced dough strength.

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TABLE 4.1 Sample Loading Volume (μl) for Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis

Sample	Total Proteins		Glutenins
	Non-Reduced	Reduced	Reduced
Native Flour	25	20	25
Protein Fractions			
I-A[1]	25	30	35
I-B[1]	20	15	25
II[1]	10	15	30

[1]I-A, I-B, and II are the protein fractions eluted in order during Gel Filtration Chromatography.

TABLE 4.2 Effect of Different Dough Preparations on Free Sulfhydryl (-SH), Disulfide (S-S) and Total Cysteine Contents (nM/mg of protein)[1]

Flour Sample[2]	Free -SH	S-S	Total Cysteine
Frankenmuth			
F	6.81d±0.03	68.54a±0.07	143.89a±0.14
N	6.53d±0.07	68.89a±0.11	144.30a±0.26
S	9.94bc±0.24	66.67b±0.20	143.28a±0.20
E	11.20ab±0.17	67.54ab±0.16	146.26a±0.10
D	8.67c±0.08	67.96ab±0.23	144.60a±0.34
Cracker			
F	8.73c±0.06	66.45a±0.13	141.63a±0.21
N	8.51c±0.07	66.90a±0.17	142.29a±0.23
S	13.61b±0.07	63.73a±0.10	141.07a±0.14
E	15.82ab±0.07	63.54a±0.13	142.90a±0.20
D	8.77c±0.09	66.34a±0.17	141.44a±0.26
Caldwell			
F	7.36d±0.06	67.39a±0.06	142.14a±0.08
N	7.07d±0.18	68.41a±0.41	143.38a±0.91
S	9.92b±0.09	65.46a±0.25	140.84a±0.50
E	14.55a±0.10	65.16a±0.42	144.86a±0.81
D	8.08c±0.05	68.03a±0.28	144.13a±0.50
Freedom			
F	6.02b±0.04	56.88a±0.02	119.78a±0.03
N	6.01b±0.06	57.13a±0.14	120.26a±0.36
S	6.99b±0.11	55.42a±0.28	117.82a±0.54
E	9.62a±0.10	54.49a±0.47	118.59a±0.81
D	7.40b±0.07	56.04a±0.29	119.49a±0.50
Blend			
F	3.30d±0.03	58.32a±0.18	119.94a±0.23
N	3.06d±0.05	58.40a±0.32	119.85a±0.72
S	4.98b±0.06	56.38a±0.16	117.74a±0.30
E	6.01a±0.04	55.83a±0.23	117.66a±0.43
D	4.00c±0.10	57.26a±0.22	118.52a±0.42

[1]Values in the table are: means ± standard deviation. Different letters within the same flour sample and same column denote significant differences among native flour and its different doughs (α=0.05).

[2]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

TABLE 4.3 Quantification (%) of Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Cracker Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Cracker	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	100	67.9	3.3	100	68.2	3.3	100	69.4	3.7	100	71.6	4.8	100	73.5	5.8
LMW[1]+ Gliadins	0	32.1	85.9	0	31.8	86.0	0	30.6	86.1	0	28.4	85.8	0	26.5	84.8
Albumins+ Globulins	0	0	10.8	0	0	10.7	0	0	10.2	0	0	9.4	0	0	9.4

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 4.4 Quantification (%) of Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Cracker Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Cracker	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	24.1	12.6	5.1	25.1	12.9	5.3	28.5	13.3	5.4	35.6	14.0	6.0	48.6	14.2	6.5
LMW[1]+ Gliadins	72.4	72.4	72.5	71.5	72.2	72.2	68.3	72.1	72.7	61.6	72.1	74.9	48.9	72.0	74.9
Albumins+ Globulins	3.5	15.0	22.4	3.4	14.9	22.5	3.2	14.6	21.9	2.8	13.9	19.1	2.5	13.8	18.6

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 4.5 Quantification (%) of Ethanol Soluble Proteins (Gliadins) from Each Protein Fraction Obtained from Gel Filtration Chromatography of Cracker Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Cracker	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
α-Gliadins	0	1.5	21.3	0	1.5	20.8	0	1.7	19	0	2.1	18.9	0	2.3	18.5
β-Gliadins	0	1.7	32.8	0	2.4	33.2	0	2.2	34.7	0	4.2	36.5	0	7.5	36.7
γ-Gliadins	0	31.9	28.6	0	30.8	30.4	0	29.4	30.9	0	27.6	31.5	0	23.5	32.2
ω-Gliadins	0	64.9	15.3	0	65.3	15.6	0	66.7	15.4	0	66.1	13.1	0	66.7	12.6

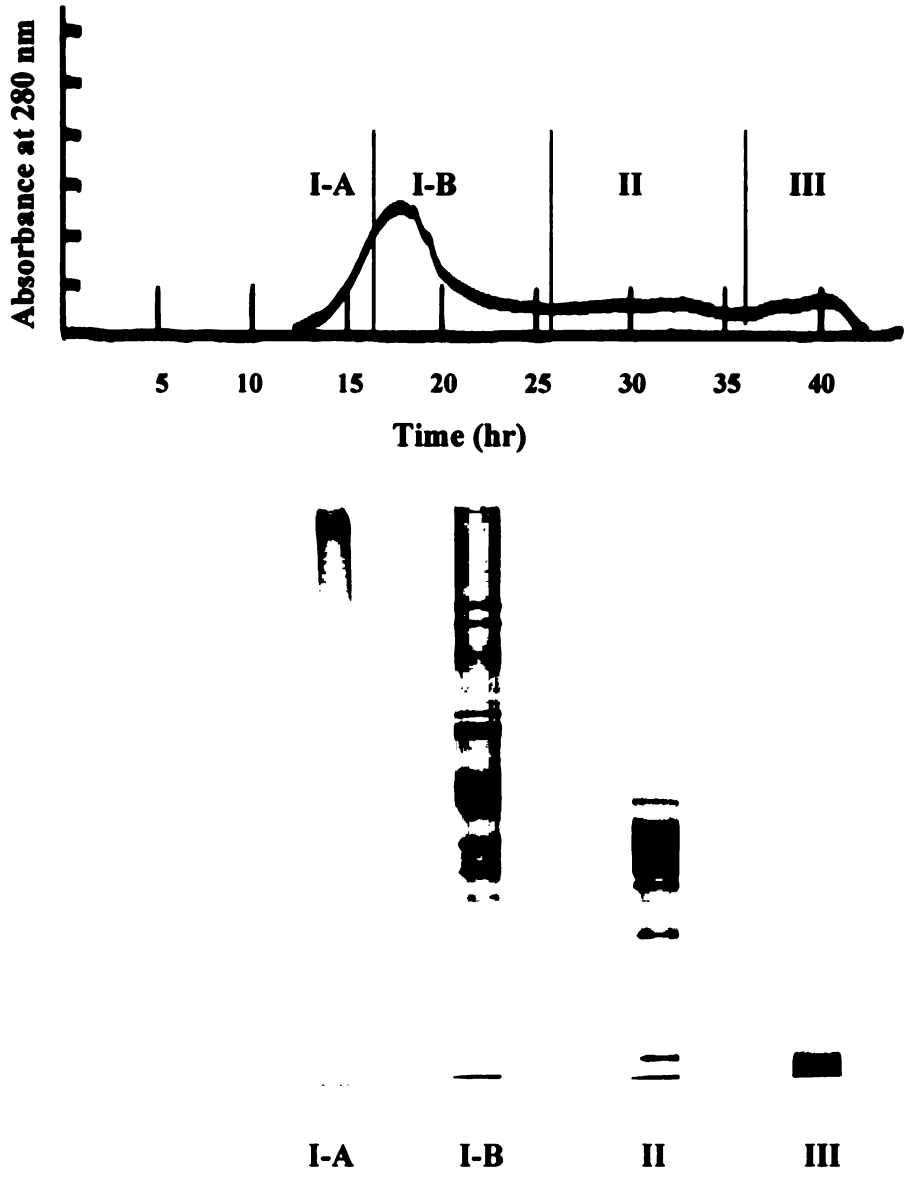

Figure 4.1 Preliminary Results of Cracker Flour Protein Fractionated by Gel Filtration Chromatography and by SDS-PAGE

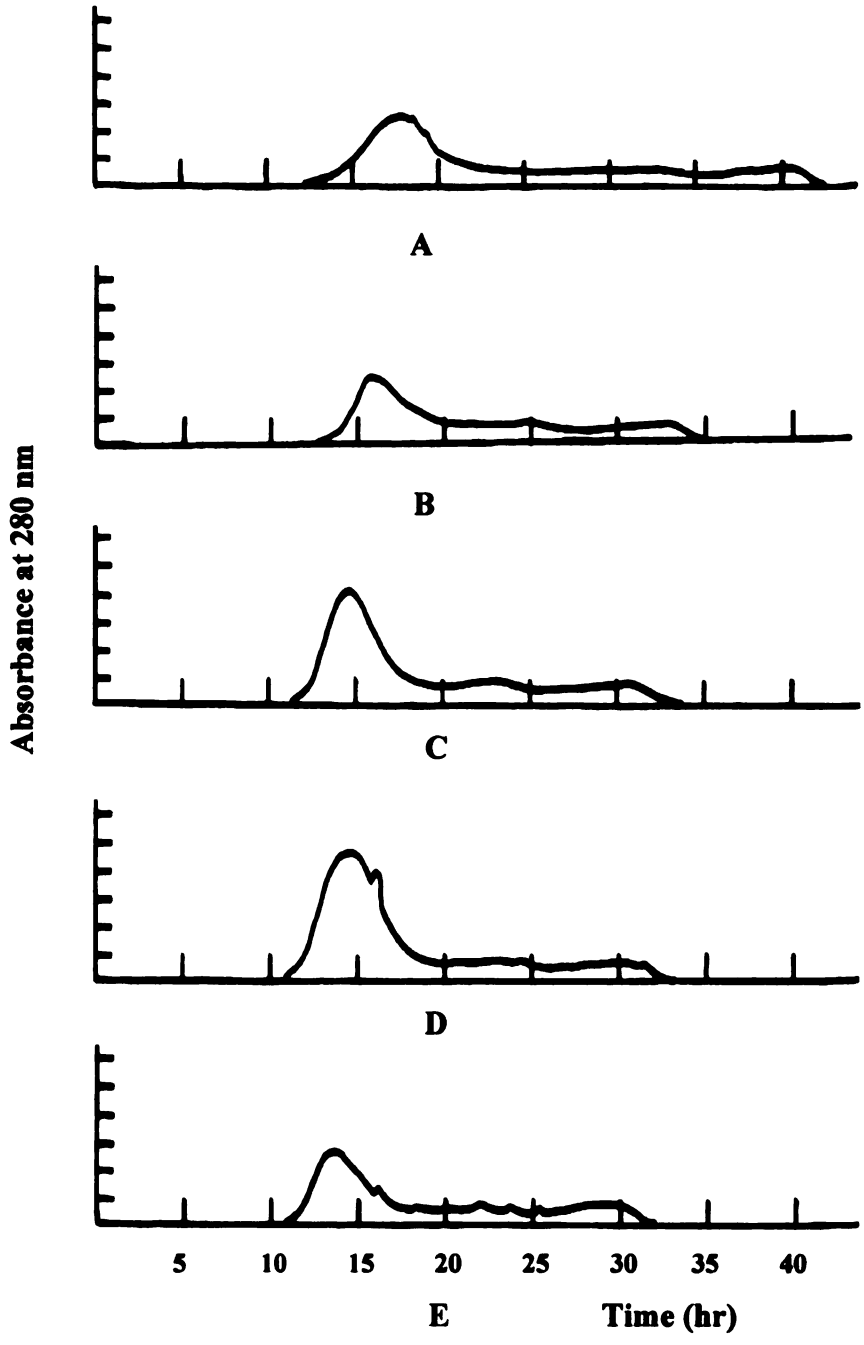

Figure 4.2 Protein Elution Profiles for Cracker Flour and Dough Samples upon Gel Filtration Chromatography

A: Native Flour; B: Non-Developed Dough; C: Dough Partially Developed with Shear Deformation; D: Dough Partially Developed with Extensional Deformation E: Developed Dough

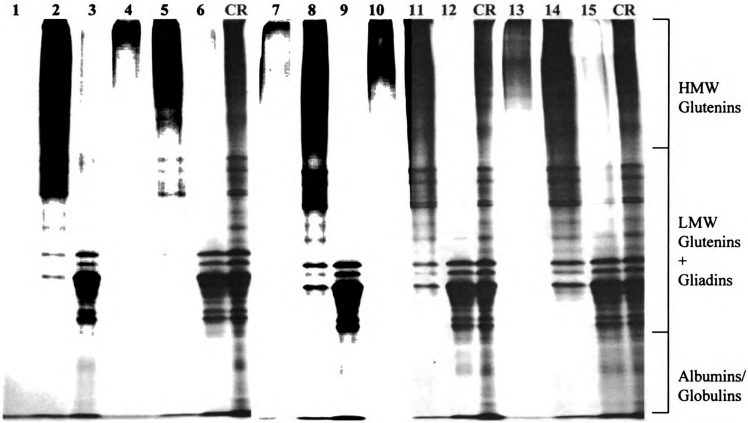

Figure 4.3 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Cracker Protein Fractions Obtained from Gel Filtration Chromatography under Non-Reduced Conditions. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; CR: Total Flour Proteins of Cracker. Regions for High Molecular Weight (HMW) Glutenins, Low Molecular Weight (LMW) Glutenins, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)

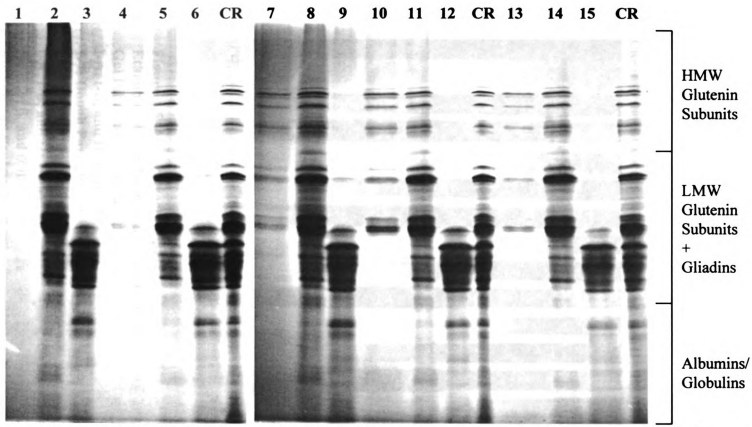

Figure 4.4 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Cracker Protein Fractions Obtained from Gel Filtration Chromatography under Reduced Conditions. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; CR: Total Flour Proteins of Cracker. Regions for High Molecular Weight (HMW) Glutenins, Low Molecular Weight (LMW) Glutenins, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)

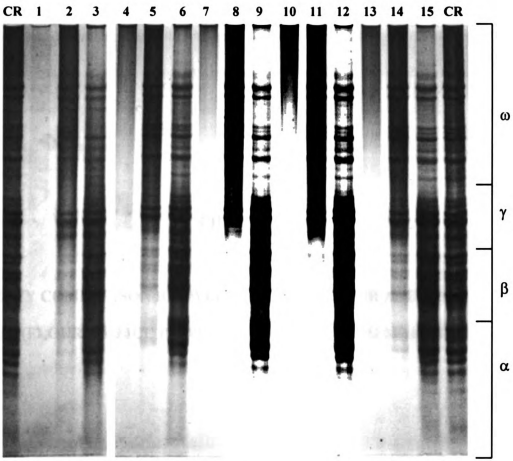

Figure 4.5 Acid Polyacrylamide Gel Electrophoretic Patterns of Ethanol-Soluble Proteins of Cracker Protein Fractions Obtained from Gel Filtration Chromatography. CR: Cracker Flour; Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II. Regions for ω, γ, β, and α indicate gliadin subgroups based on the method of Bushuk and Sapirstein (1991)

CHAPTER 5

QUALITY COMPARISON BETWEEN NORMAL (FLOUR AND WATER) AND NOVEL (FLOUR AND ICE POWDER) INGREDIENTS TO MAKE CRACKERS

5.1 ABSTRACT

Normal cracker production involves two-stages of fermentation which is time consuming. An ice powder technique to form dough revealed advantages for studying fundamental dough rheology. The present study used two one-stage fermentation procedures (ice powder ingredients without the use of a mixer or normal ingredients with the use of a mixer) to make crackers, and compared quality attributes of these crackers. Results showed that the overall qualities (e.g., weight, moisture, length, width, thickness, volume, and peak breaking force) of baked normal and ice powder crackers could distinguish among all flour samples using the one-stage fermentation procedures. For both types of crackers, the heavier the baked cracker weight, the higher the cracker moisture. The baked crackers made from stronger flours were generally thicker and bigger, with a larger degree of shrinkage (length and width) and higher peak breaking forces than those made from weaker flours. Results also indicated that the qualities between baked normal and ice powder crackers, made from same flour, were significantly ($p<0.05$) different in some parameters (e.g., weight, moisture content, thickness, and volume), but that overall similar trends in quality were observed. Baked ice powder crackers had higher weight, moisture, and peak breaking force than normal crackers, whereas they had less shrinkage and were lower in thickness and volume. As demonstrated by this study, the ice powder technique has potential for producing acceptable crackers.

5.2 INTRODUCTION

Snack crackers have become increasingly popular around the world. The largest portion of cracker production consists of the fermented crackers, such as saltine crackers (Lajoie and Thomas 1994). Traditional fermented crackers are the product of two fermentation stages: sponge and dough (Doescher and Hoseney 1985). During the fermented sponge stage, 60-70% of the total flour, yeast, and water are mixed for 1 to 4 min and then fermented for 16 to 18 hr at 25-30°C and 70-90% relative humidity (Ranhotra and Gelrogh 1988). During the fermented dough stage, the fermented sponge, the remaining flour and the other ingredients (e.g., shortening and salt) are mixed together for 3 to 7 min and allowed to ferment for another 6 hr (Creighton and Hoseney 1990). However, there is little information on using this procedure to evaluate flours for cracker-making potential. Perhaps, this is partly due to the time factor limiting the number of flour samples that can be tested per week.

Recently, Lee et al (1999) developed a one-stage fermentation procedure for evaluation of flours for cracker-making potential. Both two-stage and one-stage fermentation procedures could distinguish cracker-making quality among flour samples used, and yielded similar trends in their overall results. Moreover, the one-stage fermentation procedure was simple and had a time efficiency factor 2.5 times better than the two-stage fermentation procedure.

Campos et al (1996) used ice powder to produce non-developed dough. They found no significant differences in water distribution between non-developed and traditionally developed doughs. Later, Campos et al (1997) and Schluentz et al (2000) also investigated the rheological properties of dough samples prepared by the ice powder

procedure. As of yet, however, no baked products had been produced from doughs made with this method.

The objectives of the present study were (1) to examine the ice powder technique for making crackers based on a one-stage fermentation procedure without the use of a mixer, and (2) to compare the qualities of ice powder crackers with those of normal crackers made from a one-stage fermentation procedure with the use of a mixer.

5.3 MATERIALS AND METHODS

5.3.1 Cracker Ingredients

Nineteen wheat samples were selected for the present study. There were eight commercial flours: cake, cookie, cracker, bread, and hard red spring from Mennel Milling Co. (Fostoria, OH) in 1997; hard red winter, soft red winter, and a blend sample of the hard red winter and the soft red winter (1:1) both from King Milling Co. (Lowell, MI) in 1996; and 11 pure soft wheat cultivars harvested in 1993 from Michigan (Chelsea and Frankenmuth), Ohio (Caldwell, Clark, Dynasty, Excel, and Freedom,), and Washington (Hyak, Lewjain, Madsen, and Tres). These eleven wheat cultivars were tempered to 15% moisture overnight, and then milled on a Bühler experimental mill (Bühler Ltd., Uzwil, Switzerland) to 70% flour extraction. Other ingredients were active dry yeast (Red Star Yeast and Products, Milwaukee, WI), Crisco vegetable shortening (Procter & Gamble, Cincinnati, OH) made from partially hydrogenated vegetable oil, vegetable shortening powder (Armour Food Ingredients, Springfield, KY), iodized salt (Meijer Inc., Grand Rapids, MI), baking soda (Arm & Hammer, Princeton, NJ), and distilled water.

5.3.2 Physicochemical Analyses of Wheat Flour Samples

Chemical and physical analyses were as described in Chapter 3 (section 3.3.2.1 and 3.3.2.2).

5.3.3 Preparation of Ice Powder

Ice powder was prepared based on the procedure of Campos et al (1996, Appendix I-Figure A).

5.3.4 Cracker Formula and Preparation

Figures 5.1 and 5.2 show one-stage fermentation procedures for making crackers from normal (water) and novel (ice powder) ingredients, respectively. In the preliminary studies, the blend flour sample exhibited good potential for cracker making. Thus, the amount of water added to each tested flour was adjusted as follows based on the blend flour sample:

[29% x 100 g of tested flour x (100-14)/(100-A)] x B/C

Where A = the moisture content of the flour to be tested

B = optimal farinograph water absorption of blend flour sample

C = optimal farinograph water absorption of tested flour for making a cracker

For making ice powder crackers, ice powder and shortening powder were used instead of the water and Crisco vegetable shortening used for normal crackers. Additionally, all utensils (e.g., beakers and balance) and ingredients were stored in a walk-in freezer (<-8°C) for at least 24 hr in order to avoid melting of ice powder during dough preparation. Samples were weighed and distributed in the same environment.

5.3.5 Cracker Dough Sheeting and Baking

After fermentation (Figures 5.1 and 5.2), the dough was flattened by hand to give a uniform piece of dough (7.4 cm diameter x 2.3 cm thickness). The dough was then passed through seven different openings of the sheeter (15.91, 12.30, 9.50, 5.65, 2.88, 1.27, and 1.04 mm). The cracker dough was passed through the first four gaps three times each. After the first passages through the 2.88 and 1.27 mm gaps, the dough was

folded onto itself once and passed through the same sheeter opening; this was repeated twice for a total of three passes through each of the two gaps. The dough was sheeted three more times in the final sheeter opening without folding.

After the dough had been sheeted, it was cut with a hand-cutter-docker (21 cells of 5.08 x 5.56 cm), placed on a rectangular-shaped rack (40.01 x 21.59 cm), and then baked at 265 °C for 4 min 10 sec in a rotary oven (National MFG Co., Lincoln, NE). Baked cracker sheets were allowed to cool for 30 min and broken into individual crackers.

5.3.6 Cracker Quality Analysis

Two commercial saltine crackers (unsalted tops), Meijer Inc. (Grand Rapids, MI) and Nabisco (East Hanover, NJ), were used as references.

5.3.6.1 Physical Measurements

Weight, length, width, thickness, and volume of baked crackers were chosen as parameters for evaluating the cracker quality. Length, width, and thickness of each baked cracker were measured using a vernier caliper manufactured by Glogau & Co. (Germany). Volume was determined by putting an individual baked cracker into a known-volume container (110 cc) and using rape seeds to measure baked cracker volume by displacement.

5.3.6.2 Moisture Measurement

Individual baked crackers were crushed using a mortar and pestle and the moisture content of each crushed cracker was determined according to AACC Method 44-15A (1995).

5.3.6.3 Texture Analysis

The TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) was used to evaluate texture of baked crackers. The peak breaking force (Newtons) of the center part of each baked cracker was obtained by a 3 mm diameter Warner Bratzler probe at a speed of 2 mm/s.

5.3.7 Statistics

All experiments were conducted at least four times. Data were analyzed by the one-way analysis of variance (ANOVA) procedure using the Statistical Analysis System version 6.12 (SAS Institute, Cary, NC). Significance was defined at the 5% level.

5.4 RESULTS AND DISCUSSION

5.4.1 Physicochemical Properties of Wheat Flour Samples

Table 5.1 shows the physicochemical properties of wheat flour samples. The moisture contents ranged from 10.8 to 13.4%. The ash contents were from 0.25 to 0.51%. There was also a wide range in protein content (6.3 - 12.5%) among different flours. As expected, hard wheat flours (i.e., bread, hard red winter, and hard red spring) and blend flour with 50% hard red winter had higher protein contents than soft wheat flours (i.e., Dynasty, Clark, cracker, Madsen, soft red winter, cookie, Lewjain, Freedom, Hyak, Caldwell, cake, Chelsea, Frankenmuth, Excel, and Tres). The ranges of the falling number and water absorption among flours were 243 - 398 sec and 51.9 - 64.7%, respectively.

The mixing times varied from 1 to 7 min, and mixing tolerance index (MTI) values ranged greatly from 5 to 145 BU. Mixing time and MTI can be used as indices to differentiate the strengths of flours. Generally, stronger flours have longer mixing times and lower MTI values (Shuey 1982). This also was reflected in our results (Table 5.1), where bread, hard red winter, and hard red spring flours were the strongest flours among all flour samples; and in contrast, cv. Frankenmuth, cv. Excel, and cv. Tres flours were the weakest (Table 5.1). Thus, the 19 chosen flour samples exhibited a wide range of flour quality.

5.4.2 Quality of Normal Crackers

Among all flour samples, bread, hard red winter, hard red spring, and cv. Madsen could not be made into normal and novel crackers using either of the one-stage

fermentation procedures (Figures 5.1 and 5.2) because the resultant cracker doughs were too dry. Therefore, the following results do not include these four flour samples. Quality parameters of baked normal crackers are listed in Table 5.2. Data are ranked from the strongest to the weakest dough based on Farinograph results (Table 5.1). It appeared that the one-stage fermentation procedure (with the use of a mixer, Figure 5.1) could significantly differentiate baked normal cracker qualities (e.g., weight, moisture, length, width, thickness, volume, and peak breaking force from texture analysis) among different flour samples. Baked cracker weight varied from 3.26 g for those made from cracker flour to 4.22 g for those from cv. Chelsea flour. In general, the heavier the baked cracker, the higher the moisture content. The moisture contents of baked crackers from blend, cracker, and soft red winter flours and of commercial crackers were not significantly different (Table 5.2).

The size of each cracker was 5.56 cm long and 5.08 cm wide after cutting the dough sheet but prior to baking. However, after baking, the length and width of crackers had decreased 1.9 - 3.8% and 1.2 - 6.1%, respectively, due to contraction of the cracker dough (Pizzinatto and Hoseney 1980). Stronger flours (e.g., blend flour) resulted in greater contraction of crackers upon baking. These observations are in general agreement with previously published reports (Creighton and Hoseney 1990, Levine and Drew 1994).

The thickness of normal crackers after baking ranged from 0.40 to 0.54 cm. Crackers made from blend, cv. Dynasty and cv. Clark flour samples were the thickest, whereas those from cv. Frankenmuth sample were the thinnest. The thickness of the baked crackers appears to correlate with the dough strength of the flour. Similar findings were also obtained by Pizzinatto and Hoseney (1980) and Rogers and Hoseney (1994).

The volume of baked normal crackers varied from 16.3 to 21.3 cc. It was assumed that there would be a relationship between the thickness and volume. However, some thinner baked crackers did not exhibit smaller volumes because of a smaller degree of shrinkage and the presence of blisters on the top surface of the baked cracker. Based on the volume, cracker and cv. Frankenmuth flour samples could produce crackers most similar to commercial crackers.

The peak breaking forces measured by texture analysis were significantly different (6.2 - 11.9 N) among baked normal crackers. Crackers made from blend and cracker flour samples had the highest peak breaking forces, and those from cv. Frankenmuth and cv. Excel samples had the lowest. Results from statistical analyses revealed that the peak breaking force was related to the dough strength. Crackers made from stronger flours (e.g., blend flour) had higher peak breaking forces than those from weaker flours (e.g., cv. Frankenmuth flour). Overall, it appeared that the cracker flour sample could be used to make the best quality of crackers compared with commercial ones.

5.4.3 Quality of Ice Powder Crackers

Quality parameters of baked ice powder crackers are listed in Table 5.3. Again, data are ranked from the strongest to the weakest dough based on Farinograph results (Table 5.1). The data indicated that the ice powder technique could differentiate cracker quality among different flour samples according to the one-stage fermentation procedure (without the use of a mixer, Figure 5.2). While weight of baked normal crackers ranged

from 3.26 - 4.22 g, weights of baked ice powder crackers ranged from 3.84 - 4.83 g, which were significantly heavier ($p<0.05$).

For both normal and ice powder crackers, the baked cracker weight was related to its moisture --- the heavier the cracker, the higher the moisture content. As an example, cv. Lewjain and cv. Chelsea crackers with the heaviest weights had the highest moisture contents. During the process of making normal and ice powder crackers from each flour, the amount of water added, setting conditions, and baking temperature and time were all the same. However, the moisture contents of baked ice powder crackers were statistically higher ($p<0.05$) than those of their counterpart normal crackers. Some speculations can be made. The first concern was to examine for differences in the moisture contents of the shortenings used. It was found that the moisture contents for both regular shortening (used for normal crackers) and shortening powder (used for ice powder crackers) were very low and almost the same (data not shown). Therefore, the amount of water in these two shortenings was most likely not a factor influencing the moisture contents of these two types of baked crackers.

The next factor to be considered for the difference in moisture contents of these two types of baked crackers was the types of shortenings. Regular shortening used in normal crackers has the function of lubricating the dough during mixing and further enhancing the tenderness of the final product (Hepper 1959). On the other hand, shortening used in the ice powder crackers was in a dry powder form, which may not have lubricated dry flour particles. Thus, the ability of these two types of crackers to hold water before and after baking may be different. Another speculation was that the ability to hold free and bound water in these two types of dough was different. However,

in other analyses (data not shown), there were no significant differences in either free or bound water between normal and ice powder cracker doughs.

During the process for making normal cracker dough (Figure 5.1), a mixer was used to form the dough, which involved the addition of energy in the form of a combination of shear and extensional deformations; the normal cracker dough is termed developed dough in this study. On the other hand, no mixer was used for the process of making ice powder cracker dough (Figure 5.2). The mixture (i.e., of all powdered ingredients) was thawed and fermented at 30 °C for 24 hr, yielding a dough that was formed with almost no energy involvement, and termed non-developed dough. Nevertheless, sheeting is one type of extensional deformation (Steffe 1996). During the sheeting process, ice powder cracker dough (i.e., non-developed dough) was changed into ice powder cracker dough partially developed with extensional deformation.

In a previous study (Chapter 4), it was found that the types and the amounts of high molecular weight (HMW) glutenins were different in partially developed dough with extensional deformation and developed dough. Partially developed dough with extensional deformation had fewer HMW glutenins and interchain disulfide (S-S) bonds than did developed dough. Thus, it is possible that different types and different amounts of proteins may occur during the cracker making process (but prior to baking) in these two types of crackers and contribute to the differences in moisture contents of the final cracker products. Further investigations in this area are warranted.

The lengths and widths of baked ice powder crackers ranged from 5.44 to 5.58 cm and from 4.80 to 5.05 cm, respectively. Comparing data in Tables 5.2 and 5.3, the degree of shrinkage upon baking of ice powder crackers (0 - 2.2% in length and 2 - 5.7% in

width) was less than that for normal crackers (1.9 - 3.8% in length and 1.2 - 6.1% in width), even though these findings were not statistically significant. Pizzinatto and Hoseney (1980) and Creighton and Hoseney (1990) pointed out that cracker doughs made from weaker flours had less baking shrinkage than those made from stronger flours.

In the present study, when the operator handled normal and ice powder cracker doughs, ice powder cracker doughs were softer than normal cracker doughs, which was in agreement with the findings reported in Chapters 3 and 4. Dough partially developed with extensional deformation is more liquid-like (a weaker dough) than developed dough (a stronger dough) due to differences in sizes of proteins present and the amount of protein matrix developed. Consequently, ice powder crackers made from dough partially developed with extensional deformation (by dough sheeting) had less shrinkage than normal crackers made from developed dough (with dough mixer).

Table 5.3 shows that thickness (0.34 - 0.51 cm) and volume (15.5 - 18.6 cc) of baked ice powder crackers varied among flour samples. They were affected by the strength of the flour from which the crackers were made. These findings are in agreement with a previous publication (Rogers and Hoseney 1994) that a stronger flour can form a more elastic dough and result in a thicker and larger volume final product. As an example, of the flours studied, baked crackers made from the cv. Clark flour sample were the thickest and the closest to commercial crackers, whereas those made from the cv. Frankenmuth flour sample were the thinnest.

It was also found that the baked ice powder crackers were statistically thinner ($p<0.05$) and smaller in volume than their counterpart normal crackers (Tables 5.2 and 5.3). Cracker thickness and volume are related to dough strength (Rogers and Hoseney

1994): the stronger the dough, the thicker and larger the baked crackers. As mentioned earlier, doughs partially developed with extensional deformation were softer to handle than developed doughs; and this corresponds to the subsequent lower values of thickness and volume for baked ice powder crackers.

Peak breaking forces among baked ice powder crackers of all flour samples were significantly different ($p<0.05$) and ranged from 6.6 to 12.5 N. Blend and cracker flour samples produced ice powder and normal crackers with the highest peak forces, a characteristic that is dependent on the strength of a flour (Creighton and Hoseney 1990). The peak breaking force values of ice powder crackers were not statistically lower ($p<0.05$) than those of normal crackers, even though the ice powder cracker doughs were softer. This was probably because ice powder crackers were generally smaller in volume, thinner and more dense than their normal counterparts.

5.5 SUMMARY

This study demonstrated that the overall qualities of baked normal and ice powder crackers could distinguish among flours based on their respective one-stage fermentation procedures (ice powder ingredients without the use of a mixer or normal ingredients with the use of a mixer). The heavier the baked cracker weight, the higher the cracker moisture. The crackers made from stronger flours generally shrank more during baking, but were thicker, bigger, and harder than those made from weaker flours. Even though the qualities between two types of crackers (normal and ice powder) made from the same flour were statistically different in some parameters, such as weight, moisture content, thickness, and volume, the overall trends for cracker quality among all flour samples were similar. Ice powder crackers had higher weight, moisture, and peak breaking force than normal crackers. In contrast, they shrank less and were smaller and thinner. In general, the cracker flour sample could produce both normal and ice powder crackers that were close to the overall quality of commercial crackers. The results suggest that the ice powder technique could successfully produce crackers. Furthermore, the ice powder technique for making ice powder cracker dough requires only that the mixture (i.e., all powdered ingredients) be thawed and fermented without the use of a mixer.

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Table 5.1 Physicochemical Properties of Wheat Flours

Flour Sample[1]	Moisture (%)	Ash (%,db)	Protein Content (%,db)	Falling Number (sec)	Water Absorption[2] (%, db)	Mixing Time[2] (min)	MTI[2,3] (BU)
Bread	11.3	0.33	10.2	243	60.9	2.1	5
Hard Red Winter	12.7	0.51	11.7	301	62.5	3.0	20
Hard Red Spring	13.2	039	12.5	269	64.6	7.0	40
Blend[4]	12.4	0.50	10.6	317	59.5	1.5	40
Dynasty	12.1	0.46	7.4	363	55.7	1.3	70
Clark	11.9	0.50	8.2	392	59.1	2.0	75
Cracker	13.4	0.25	7.6	357	51.9	1.1	75
Madsen	11.2	0.43	8.7	300	64.7	2.2	85
Soft Red Winter	12.0	0.47	9.7	322	56.3	1.0	95
Cookie	11.6	0.32	7.4	316	53.7	1.3	95
Lewjain	12.4	0.36	8.2	348	58.0	1.3	100
Freedom	11.9	0.40	7.2	376	56.6	1.2	105
Hyak	12.5	0.32	6.3	309	57.8	1.3	110
Caldwell	11.8	0.33	7.6	380	56.0	1.0	110
Cake	12.1	0.31	6.8	398	53.2	1.3	110
Chelsea	10.8	0.49	7.2	354	56.6	1.3	115
Frankenmuth	11.9	0.50	6.4	377	53.1	1.0	120
Excel	11.4	0.43	7.6	345	55.6	1.4	140
Tres	11.2	0.47	8.5	395	58.6	1.3	145

[1]Samples are ranked based on the strength of the dough.
[2]From Farinograph results.
[3]MTI: Mixing tolerance index.
[4]Blend: the mixture of 50% soft red winter and 50% hard red winter wheat flours (ratio 1:1).

Table 5.2 Quality Parameters for Normal Crackers Baked from the One-Stage Fermentation Procedure [1]

Cracker Sample	Weight (g)	Moisture (%)	Length (cm)	Width (cm)	Thickness (cm)	Volume (cc)	Peak Breaking Force (N)[2]
Blend[3]	3.59ef	5.19h	5.37ef	4.77i	0.52ab	19.6d	11.9c
Dynasty	3.53fg	6.30ef	5.45a	4.97bc	0.52ab	20.2c	7.5jk
Clark	3.72cd	7.59c	5.43abcd	4.92def	0.54a	20.7b	9.3fg
Cracker	3.26j	4.80ij	5.44ab	5.02a	0.49cde	18.0g	10.4d
Soft Red Winter	3.46gh	4.58j	5.40cde	4.92cdef	0.46fg	17.0h	6.4l
Cookie	3.73c	7.21d	5.41bcd	4.97bcd	0.45g	18.5cd	9.3fg
Lewjain	4.02b	9.17a	5.43abc	4.85h	0.48cdef	20.4bc	9.0gh
Freedom	3.63e	7.35cd	5.35f	4.88fgh	0.50bc	20.7bc	7.9ij
Hyak	4.02b	7.58c	5.40de	4.79i	0.52ab	19.3d	8.8gh
Caldwell	3.63e	6.54e	5.41bcd	4.93cdef	0.52ab	18.6e	9.8ef
Cake	3.65de	6.01fg	5.35ef	4.87gh	0.41h	16.3i	10.1de
Chelsea	4.22a	8.64b	5.40cde	4.84h	0.48def	21.3a	8.4hi
Frankenmuth	3.37i	6.37e	5.44ab	4.93cde	0.40h	18.0g	6.2l
Excel	3.47gh	5.71g	5.38ef	5.01ab	0.45g	19.2d	6.8kl
Tres	3.40hi	4.16k	5.36f	4.91efg	0.47efg	18.5ef	9.1fg
Nabisco	3.01k	4.58j	5.07h	4.87gh	0.52ab	18.3efg	14.5a
Meijer	2.86l	5.10hi	5.13g	4.93cdef	0.48cdef	18.0fg	13.1b

[1]Different letters within the same column designate significant differences among the samples at $p<0.05$.
[2]From texture analyses of the crackers. N: Newtons.
[3]Blend: the mixture of 50% soft red winter and 50% hard red winter wheat flours (ratio 1:1).

Table 5.3 Quality Parameters for Ice Powder Crackers Baked from the One-Stage Fermentation Procedure [1]

Cracker Sample	Weight (g)	Moisture (%)	Length (cm)	Width (cm)	Thickness (cm)	Volume (cc)	Peak Breaking Force (N)[2]
Blend[3]	4.23ef	8.26i	5.49d	4.80g	0.48b	17.8cd	12.5bc
Dynasty	4.22efg	8.83g	5.58a	4.99b	0.48b	17.6cde	7.7ij
Clark	4.36cd	10.01c	5.54bc	4.92cde	0.51a	18.0bc	9.4efg
Cracker	3.84i	7.98j	5.55ab	4.92cde	0.48b	16.5h	11.1d
Soft Red Winter	4.09gh	7.92j	5.49de	4.92cde	0.42de	15.9ij	7.1jk
Cookie	4.34cde	9.34ef	5.53bc	4.99b	0.40ef	16.9fgh	9.3efg
Lewjain	4.55b	11.48a	5.54bc	4.87ef	0.44cd	17.7cd	8.9gh
Freedom	4.26def	9.41e	5.45f	4.89e	0.45c	17.7cd	8.1hi
Hyak	4.46bc	9.88d	5.51cd	4.83fg	0.48b	17.3def	8.8gh
Caldwell	4.28def	9.28f	5.53bc	4.96bc	0.48b	17.0fg	9.9ef
Cake	4.31def	8.65h	5.44f	4.87ef	0.38f	15.5j	10.2e
Chelsea	4.83a	10.63b	5.51cd	4.84fg	0.44cd	18.6a	8.7gh
Frankenmuth	4.01h	8.94g	5.56ab	4.98b	0.34g	16.0i	6.6k
Excel	4.18fg	8.35i	5.49d	5.05a	0.40ef	17.2ef	7.4ijk
Tres	4.04h	7.76k	5.46ef	4.90de	0.43cd	16.6gh	9.2fg
Nabisco	2.97k	4.57m	5.10h	4.83fg	0.50ab	18.3ab	14.0a
Meijer	3.11j	5.08l	5.17g	4.95bcd	0.48b	18.0bc	12.9b

[1]Different letters within the same column designate significant differences among the samples at $p<0.05$.
[2]From texture analyses of the crackers. N: Newtons.
[3]Blend: the mixture of 50% soft red winter and 50% hard red winter wheat flours (ratio 1:1).

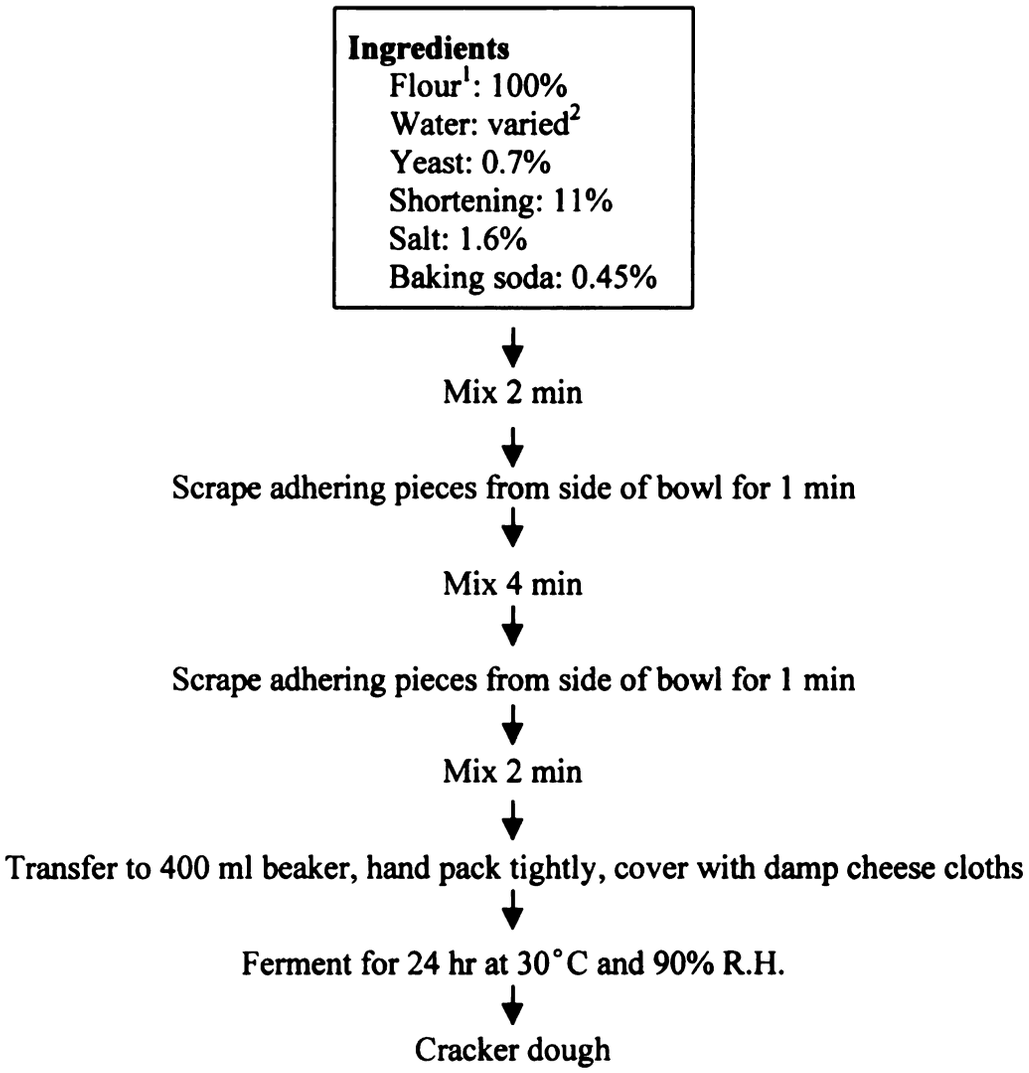

Figure 5.1 One-Stage Fermentation Procedure for Making Normal Crackers

[1]Wheat flour samples: 100g flour base with 14% moisture basis.
[2]See Materials and Methods section; amount based on farinograph absorption.

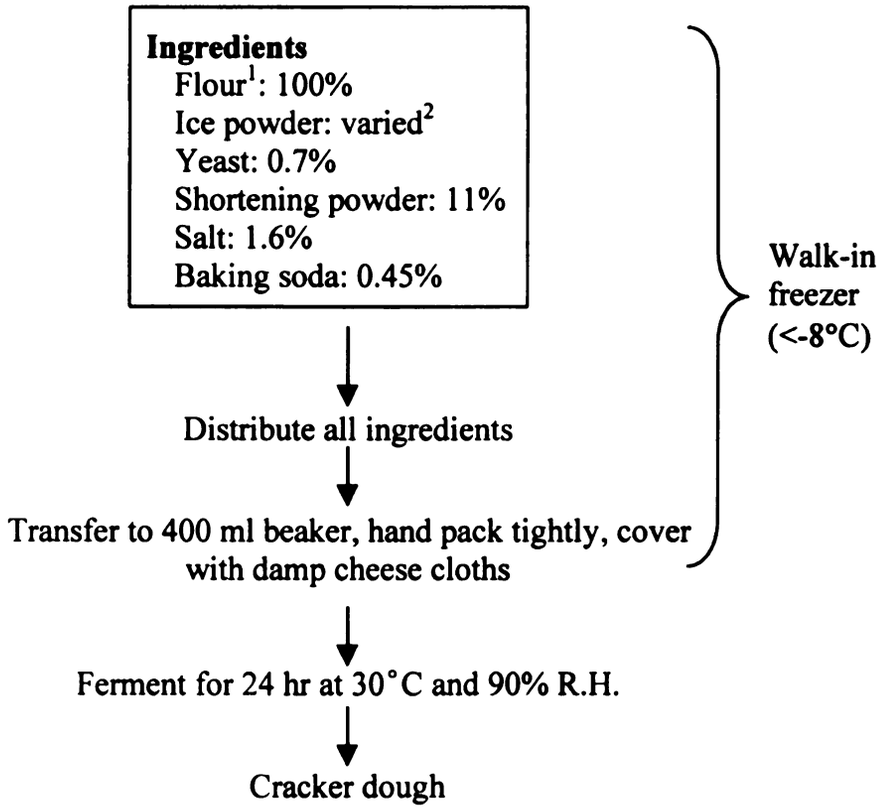

Figure 5.2 One-Stage Fermentation Procedure for Making Ice Powder Crackers

[1]Wheat flour samples: 100g flour base with 14% moisture basis.
[2]See Materials and Methods section; amount based on farinograph absorption.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Non-developed dough is produced with minimal energy input (no involvement of any deformation) and yet has a uniform distribution of water through the combining of flour and ice particles. One application for this unique dough is the addition of the distinct type of deformations (either shear or extensional deformation) with a rheometer to produce partially developed doughs. Traditional instruments (e.g., farinograph and mixograph) for making dough combine both shear and extensional deformations. Non-developed, partially developed (by rheometer with shear or extensional deformation), and developed (by farinograph) doughs represent different levels of dough development and enable the study of fundamental dough rheology.

In this study, rheological data revealed that developed dough had the highest G* (the most elastic), followed by dough partially developed with extensional deformation, and then dough partially developed with shear deformation, and finally by non-developed dough. The laser scanning confocal microscope (LSCM) z-sectioning showed that developed dough had the most protein matrix and non-developed dough the least. Disulfide-sulfhydryl analyses found that the free sulfhydryl content was lower in native flour, non-developed and developed doughs, and higher in partially developed doughs, with reverse trends for disulfide content. According to gel filtration chromatography analyses, native flour had the most proteins of small molecular size, followed by non-developed, partially developed, and then developed doughs.

Sodium dodecyl sulfate polyacrylamide gel electrophoresis and acid polyacrylamide gel electrophoresis exhibited similar protein patterns among the same protein fractions of each native flour and its different doughs. Densitometric data indicated that the amount of high molecular weight (HMW) glutenins increased with

progressive levels of dough development. In contrast, the amounts of low molecular weight (LMW) glutenins, gliadins, and albumins/globulins decreased.

Powdered ingredients were used in examine cracker-making potential of flours, and to compare quality of ice powder crackers with that of normal crackers based on their respective one-stage fermentation procedures (ice powder ingredients without the use of a mixer or normal ingredients with the use of a mixer). Results demonstrated that the overall qualities (e.g., weight, moisture, length, width, thickness, volume, and peak breaking force) between these two types of baked crackers, made from the same flour, were statistically different in some parameters, such as weight, moisture content, thickness, and volume, but they yielded similar trends. Baked ice powder crackers had higher weight, moisture, and peak breaking force, and less shrinkage than normal crackers, but were smaller in volume due to being thinner.

Based on the results of these studies, the following conclusions can be drawn:

(1) Using a rheometer to prepare dough samples enables the application of precise force input (types and quantity) for studies in fundamental dough rheology. Between the two types of deformations, the effect of extension on dough strength is more significant than the effect of shear.

(2) The LSCM is a powerful tool to examine dough development in relation to dough protein chemistry. The LSCM can not only observe the microstructure of inner layers of a dough sample but also avoid altering the structure of the dough.

(3) The amount of protein matrix present in dough is related to the energy addition and type of deformation used. The energy input contributes to the amount of protein matrix development, such as from non-developed to developed doughs. A

combination of shear and extensional deformations results in the most protein matrix formation, followed by extensional deformation, and then shear deformation, and finally by no deformation. The amount of protein matrix development in dough determines its dough strength.

(4) The type of deformation is an important key for the increases in size and amount of HMW glutenins. A combination of shear and extensional deformations contributed the most to the formation of large protein molecular size (e.g., HWM glutenins), followed by extensional deformation, shear deformation and no deformation.

(5) The increases in size and amount of HMW glutenins with progressive levels of dough development involve the small protein molecules (e.g., LMW glutenins, gliadins, albumin, and globulins) via different bonds (e.g., disulfide bonds). The larger the size and the higher the amount of HMW glutenins in dough, the more developed the protein matrix and the stronger the dough.

(6) The ice powder technique can be used for cracker-making and it requires only that the mixture (i.e., all powdered ingredients) be thawed and fermented without the use of a mixer.

CHAPTER 7

FUTURE RECOMMENDATIONS

The following are recommendations for further research:

(1) To understand more about the fundamental dough rheology, the physicochemical properties of doughs partially developed with different shear and/or extensional strains, or with different shear and/or extensional forces should be studied.

(2) To delineate further the relationship between gluten proteins and dough rheology, the size and structure of proteins in non-developed, partially developed, and developed doughs should be examined.

(3) To identify how chemical bonds are involved in the formation of high molecular weight (HWM) glutenins during dough development, some chemical reactions (e.g., hydrophobic interactions and hydrogen bonds) in different dough samples should be investigated.

(4) To understand the differences in moisture contents of baked ice powder and normal crackers, the water holding ability related to the types and amounts of high molecular weight glutenins in these two types of crackers during baking should be researched.

(5) To obtain similar quality ice powder and commercial crackers, the quality of ice powder crackers should be improved.

(6) To apply the ice powder technique further, other bakery products could be produced.

PHYSICOCHEMICAL PROPERTIES OF NON-DEVELOPED, PARTIALLY DEVELOPED, AND DEVELOPED WHEAT DOUGHS

VOLUME II

By

LING LEE

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Food Science and Human Nutrition

2000

APPENDICES

APPENDIX I

EXPERIMENTAL PROCEDURES

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Figure A. Flow

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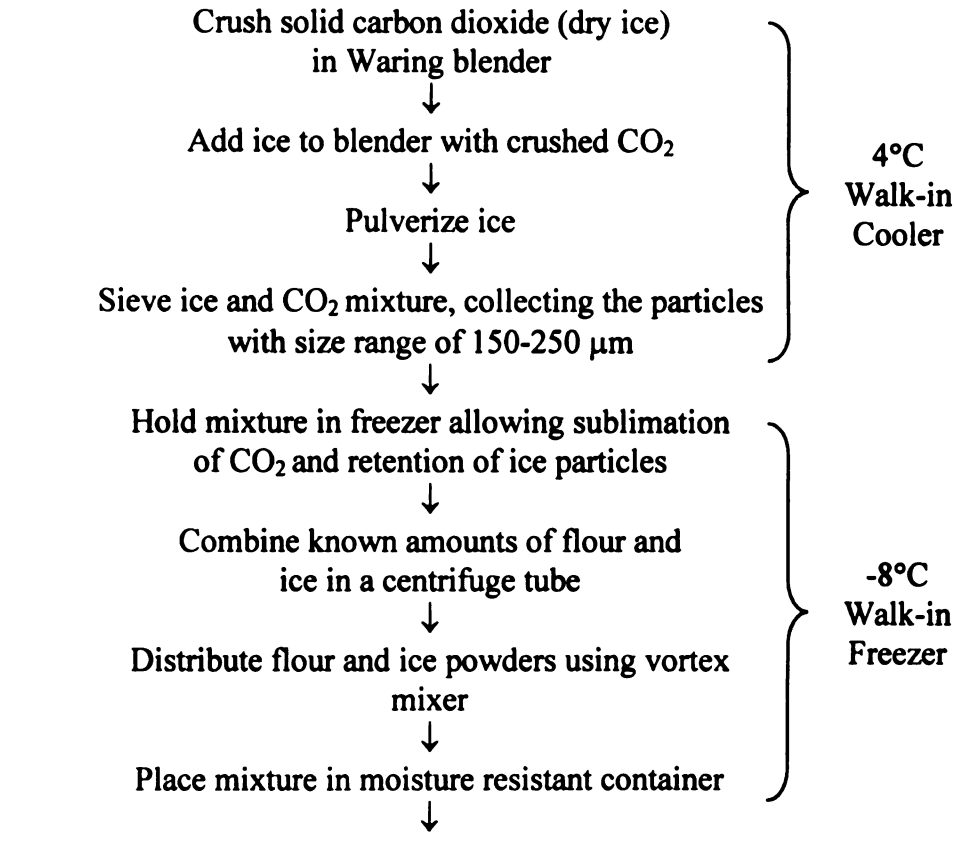

Figure A. Flow Diagram of The Powder Method for Making "Non-Developed Dough" (Campos et al., 1996).

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CAMPOS, D. T., STEFFE, J. F., and NG, P. K. W. 1996. Mixing wheat flour and ice to form " undeveloped dough ". Cereal Chem. 73: 105-107.

B. Procedures o

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B. Procedures of Doughs Partially Developed with Shear and Extensional (Biaxial) Deformations

(a) Shear Deformation (Schluentz et al 2000)

A Haake Model RS100 RheoStress (Haake, Paramus, NJ) controlled-stress rheometer was used to produce partially developed doughs. Shear deformation was created by rotating parallel plates, 20 mm in diameter, to a maximum strain in a creep test. Maximum strain at the outer rim of the plates was determined from the following equation (Steffe 1996):

$$\gamma_0 = R\psi/h \quad \text{—(1)}$$

where γ_0: Maximum strain

R: Outer radius of plate (mm)

ψ: Sweep angle in radians

h: Distance between the parallel plates (mm)

In this study, R=10 mm, $\psi=\pi$ radians, and h=2 mm. Following Eq (1), the maximum shear deformation was 1570% strain.

After non-developed dough was formed (described in 3.3.3.1), a quartered section of non-developed dough (about 4 cm x 0.2 cm) was removed from the parafilm with a spatula and placed on the stationary plate of the rheometer. To prevent dough from sticking to the parallel plates, the dough was coated with a thin layer of corn oil. Once the bottom stationary plate was moved to measurement position (2 mm gap width), a thin layer of petroleum jelly was applied around the outside of the sample to prevent drying during measurement. Then, a creep program was set to shear the dough sample at 600 Pa until a maximum strain of 1570%, equivalent to 180° rotation, was achieved. After that,

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(b) Extensional (Biaxial) Deformation (Schluentz et al 2000)

A Haake Model RS100 RheoStress (Haake, Paramus, NJ) rheometer was also used to create extensional deformation. In extensional deformation, the upper plate is fixed and the lower plate moves vertically upward. The dough sample was placed between two 20 mm diameter stainless steel plates. The extensional strain for an incompressible material with a partially full gap is (Steffe 1996)

$$\varepsilon_B = -1/2 \ln(h/h_0) \quad \text{— (2)}$$

where ε_B = Extensional strain

h = Final height

h_0 = Initial height

After non-developed dough was made, the non-developed dough with its parafilm covering was cut into quarters with scissors. The quartered dough (about 4 cm x 0.2 cm) was removed from the parafilm with a spatula and placed on the lower stationary plate of the rheometer lubricated with corn oil. The stationary plate was moved vertically upward at 2.5 mm/min until a gap width of 2.5 mm was obtained. Once the position was attained, the lower parallel plate was moved vertically upward and induced lubricated squeezing flow at 1.5 mm/min until the gap reached 0.6 mm. Based on Eq (2), the extensional strain was 71.4% (where h = 0.6 mm). After that, the dynamic rheological properties of the extensionally deformed dough sample were measured.

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STEFFE, J. F. 1996. Rheological Methods in Food Process Engineering. Freeman Press, East Lansing, MI.

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C. Procedure for Disulfide-Sulfhydryl Analyses

(a) Determination of Free Sulfhydryl Content (Chan and Wasserman 1993)

Thirty milligrams of a sample were suspended in 1.0 ml of reaction buffer (Buffer A) consisting of 8 M Urea, 3 mM ethylene-diamine tetraacetic acid (EDTA), 1% sodium dodecyl sulfate (SDS), and 0.2 M Tris (hydroxymethyl) amino methane - hydrogen chloride (Tris-HCl, pH 8.0). Samples were vortexed for 30 sec and placed on a constant agitation shaker for 1 hr. After that, 0.1 ml of Buffer B containing 10 mM 5, 5′ - dithiobis (2-nitrobenzoic acid) (DTNB) in 0.2 M Tris-HCl (pH 8.0) was added to each sample and shaking was continued for another 1 hr. Then samples were centrifuged at 13,600 x g for 10 min, and the absorbance of the supernatant was read at 412 nm against a blank consisting of 1.0 ml of buffer A and 0.1 ml of buffer B.

(b) Determination of Total Sulfhydryl (SH and Reduced SS) Content (Chan and Wasserman 1993)

Thirty milligrams of a sample were suspended in 1.0 ml of reaction buffer consisting of 50 mM glycine, 100 mM sodium sulfite, 3 mM EDTA, 0.2 M Tris-HCl, 8M Urea, 1% SDS, and 0.5 mM 2-nitro-5-thiosulfobenzoic acid (NTSB, pH 9.5). The NTSB solution was synthesized from DTNB based on Thannhauser et al (1987). Samples were then shaken in a dark room for 1 hr and centrifuged at 13,600 x g for 10 min. Supernatant (0.1 ml) was diluted with 0.9 ml of buffer A and the absorbance then read at 412 nm against a blank containing 1.0 ml of buffer A.

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Where SS: c

TS: t

SH: f

CHAN, K. Y. ar
groups an
proteins. C

THANNHAUSER
disulfide b

(c) Calculation of Free Sulfhydryl and Total Sulfhydryl Contents (Chan and Wasserman 1993)

Free sulfhydryl and total sulfhydryl contents were calculated using the following equation:

$$A = \varepsilon bc$$

where A: absorbance reading

ε: molar extinction coefficient (13,600 $M^{-1}cm^{-1}$)

b: cell thickness

c: concentration

Disulfide content was calculated as the difference between total sulfhydryl and free sulfhydryl contents, using the formula:

$$SS = (TS-SH)/2$$

Where SS: disulfide content

TS: total sulfhydryl content

SH: free sulfhydryl content

LITERATURE CITED

CHAN, K. Y. and WASSERMAN, B. P. 1993. Direct colorimetric assay of free thiol groups and disulfide bonds in suspensions of solubilized and particulate cereal proteins. Cereal Chem. 70: 22-26.

THANNHAUSER, T. W., KONISHI, Y., and SCHERAGA, H. A. 1987. Analysis for disulfide bonds in peptides and proteins. Methods Enzymol. 143: 115-119.

(a) Total Prot

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water. 5% of 2

sample solution

glycerol. and 0

used instead of

(b) Glutenin P

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0.5 ml of extra

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D. Protein Extraction Method

(a) Total Protein Extraction for SDS-PAGE (Pogna et al 1990)

Each protein fraction (50 mg) obtained from gel filtration chromatography and native flour sample (50 mg) was stirred in 0.5 ml and 1.0 ml of extraction buffer, respectively, for 2 hr at room temperature and vortexed every 20 min. Before loading, the sample was heated at 80°C for 30 min. Extraction buffer contained 63.5% of distilled water, 5% of 2-mercaptoethanol (2-ME), and 31.5% of SDS sample solution. The SDS sample solution consisted of 0.2 M Tris-HCl (pH 6.8) with 6.4% (w/v) SDS, 31.8% (v/v) glycerol, and 0.03% (w/v) Pyronin Y. For the non-reduced condition, distilled water was used instead of 2-ME.

(b) Glutenin Protein Extraction for SDS-PAGE (Pogna et al 1990)

Each fraction sample (50 mg) obtained from gel filtration chromatography was extracted with 300 μl of 60% ethanol for 2 hr at 50°C. The samples were vortexed every 20 min. The contents were centrifuged for 5 min at 14,000 x g at room temperature. The supernatant was discarded. This step was repeated one more time. The residue was placed under the fume hood for at least 30 min. Then, the residue was resuspended with 0.5 ml of extraction buffer [see D(a)] for another 2 hr at room temperature and vortexed every 20 min. The sample was then heated at 80°C for 30 min. The total proteins (25 μl) of each native flour were used as standards.

(c) **Ethanol-S**

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POGNA, N. E.
1990. C
genetics

(c) Ethanol-Soluble Proteins for A-PAGE (Pogna et al 1990)

Ethanol-soluble proteins from each fraction sample (25 mg) and native flour (50 mg) were extracted with 150 µl of 60% ethanol for 2 hr at 50°C. The samples were vortexed every 20 min. After that, the contents were centrifuged for 5 min at 14,000 x g at room temperature. An aliquot (100 µl) of supernatant was collected and cold acetone (800 µl) was added to it. The mixture was vortexed and allowed to stand for another15 min. Then the sample was centrifuged for 10 min at 14,000 x g at room temperature and the supernatant was discarded. The residue was placed under the fume hood for at least 30 min. Before loading, the residue was resuspended with 100 µl of acid sample buffer, consisting of 30% (w/v) glycerol, 36% (w/v) urea, 0.14% (v/v) acetic acid, and 0.5% (w/v) methyl green dye.

LITERATURE CITED

POGNA, N. E., AUTRAN, J. C., MELLINI, F., LAFIANDRA, D., and FEILLET, P. 1990. Chromosome 1B-encoded gliadins and glutenin subunits in durum wheat: genetics and relationship to gluten strength. J. Cereal Sci. 11: 15-34.

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Scientific Instru

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E. SDS-PAGE (Pogna et al 1990)

For gel preparation, the separating gel was 15% (T=15.1%, C=0.58%) which consisted of 15.0 ml of 30% (w/v) acrylamide, 1.74 ml of 1.5% (w/v) bis-acrylamide, 12.0 ml of 1M Tris-HCl (pH 8.4), 0.22 ml of water, 0.3 ml of 10% (w/v) SDS, 0.75 ml of 1% (w/v) ammonium persulfate (APS), and 20 µl of N, N, N', N' -tetramethylethylenediamene (TEMED). The stacking gel was 4.5% (T=4.5%, C=1.3%) and was composed of 1.58 ml of 30% (w/v) acrylamide, 0.43 ml of 1.5% (w/v) bis-acrylamide, 1.25 ml of 1 M Tris-HCl (pH 6.8), 6.14 ml of water, 0.1 ml of 10% (w/v) SDS, 0.5 ml of 1% (w/v) APS, and 10 µl of TEMED. Electrophoresis was run in gels 1.5 mm thick (18 cm wide, 16 cm long) with a vertical electrophoresis apparatus (Hoefer Scientific Instruments, San Francisco, CA) at 20°C for 20 hr at a constant current of 12.5 mA per gel.

After the run, each gel was stained overnight with a staining solution. The staining solution included 15 ml Coomassie Brilliant Blue (R-250) (4 g dissolved in 1 liter of 95% ethanol), 25 ml of 60% (w/v) trichloroacetic acid (TCA), and 210 ml of distilled water. The gel was then washed several times with distilled water for a period of 24 hr. The gel was stained with a second staining solution [2 g of Coomassie PAGE Blue G90 in 1 liter distilled water, 1 liter of 2 N sulfuric acid, 220 ml of 10 N potassium hydroxide, and 300 ml of 100% (w/v) TCA] overnight. The gel was washed several times with distilled water prior to being photographed.

POGNA, N. E
1990. (
genetic

LITERATURE CITED

POGNA, N. E., AUTRAN, J. C., MELLINI, F., LAFIANDRA, D., and FEILLET, P. 1990. Chromosome 1B-encoded gliadins and glutenin subunits in durum wheat: genetics and relationship to gluten strength. J. Cereal Sci. 11: 15-34.

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POGNA, N. E.,
1990. Ch
genetics a

F. A-PAGE (Pogna et al 1990)

For gel preparation, each gel was made from 15.5 ml of 30% (w/v) acrylamide, 10.0 ml of 1.5% (w/v) bis-acrylamide, 12.5 ml of 8 M urea, 1.6 ml of 2.5% (w/v) ascorbic acid, 0.1 ml of 0.56% (w/v) ferrous sulfate, 0.3 ml of 99+% acetic acid, and 27 µl of 0.6% hydrogen peroxide (H_2O_2). The gels were run at 16°C for 3 hr at a constant voltage of 500 V.

After the run, each gel was stained overnight with a staining solution. The staining solution consisted of 15 ml Coomassie Brilliant Blue (R-250) (4 g dissolved in 1 liter of 95% ethanol), 25 ml of 60% (w/v) TCA, and 210 ml of distilled water. The gel was then washed several times with distilled water prior to being photographed.

LITERATURE CITED

POGNA, N. E., AUTRAN, J. C., MELLINI, F., LAFIANDRA, D., and FEILLET, P. 1990. Chromosome 1B-encoded gliadins and glutenin subunits in durum wheat: genetics and relationship to gluten strength. J. Cereal Sci. 11: 15-34.

G. E

(a) Materials

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(b) Methods

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The residue was

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G. Effects of Folded and Unfolded Proteins on Absorbance (280 nm)

(a) Materials

Hard red spring wheat flour from Mennel Milling Co. (Fostoria, OH) in 1997.

(b) Methods

Total proteins of hard red spring wheat flour (5 g) were extracted with 100 ml of sodium phosphate (pH 6.8) containing 2% SDS. The sample was stirred with a magnetic stirrer overnight and centrifuged at 15,000 x g at room temperature for 20 min. The supernatant was dialyzed and then lyophilized.

Fifty mg of samples were re-suspended in 30 ml of sodium phosphate buffer (pH 6.8) without (samples A and C) and with (sample B) 2% SDS. The absorbance (280 nm) of samples A and B was read at 0, 0.5, 1, 2, 3, and 12 hr. Sample C was centrifuged at 15,000 x g at room temperature for 20 min. The supernatant was discarded and the residue was washed with water and centrifuged again. This was repeated one more time. The residue was dissolved in 30 ml of sodium phosphate containing 2% SDS with a magnetic stirrer for 30 min. The absorbance (280 nm) was read at 0, 3 and 12 hr.

(c) Results

Table 1 Ab

Samples
A
B
C

(c) Results

Table 1 Absorbance (280 nm) of Unfolded and Folded Proteins at Different Time Intervals

Samples	Time Interval (hr)					
	0	0.5	1	2	3	12
A	0.657	0.658	0.656	0.661	0.660	0.653
B	0.648	0.663	0.693	0.708	0.708	0.713
C	0.02	---	---	----	0.02	0.03

APPENDIX II

RHEOLOGICAL RESULTS

Figu

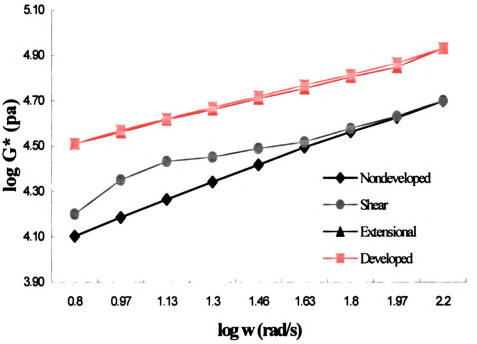

Figure 1 Rheological Properties of Frankenmuth Flour Doughs

log G* (pa)

5
4
4
4
4
3
3
3

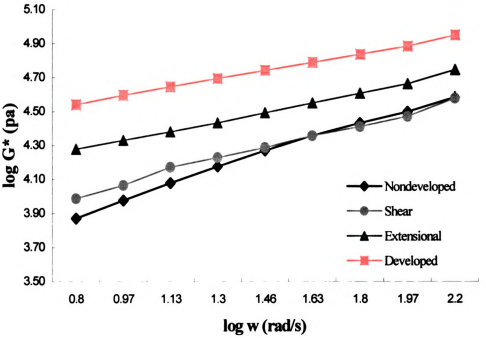

Figure 2 Rheological Properties of Caldwell Flour Doughs

log G* (pa)

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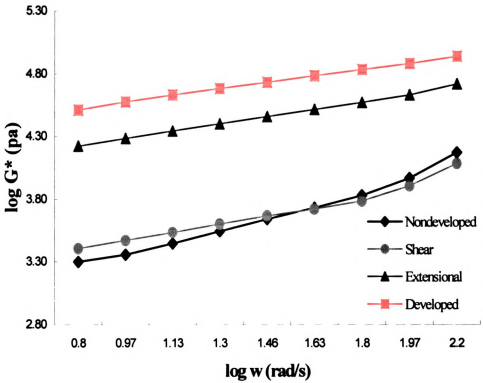

Figure 3 Rheological Properties of Freedom Flour Doughs

log G* (pa)
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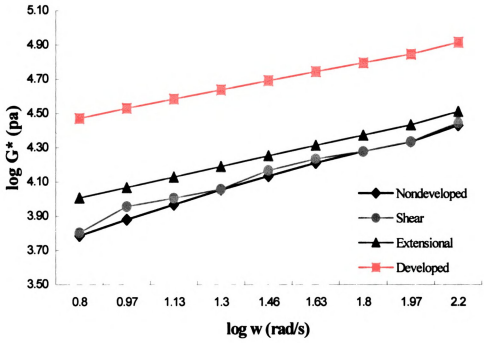

Figure 4 Rheological Properties of Blend Flour Doughs

APPENDIX III

ULTRASTRUCTURAL IMAGES

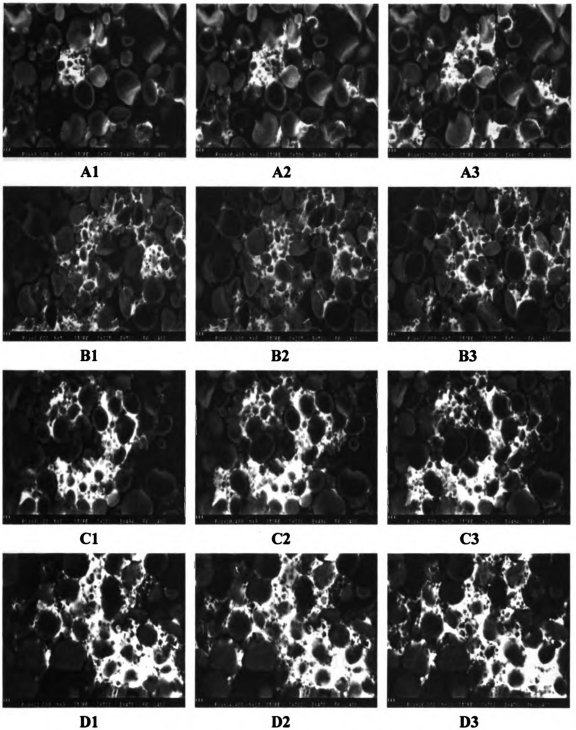

Figure 1 Protein Matrix from Different Frankenmuth Flour Doughs under Z-Sectioning of Laser Scanning Microscope

A: Non-Developed Dough; B: Dough Partially Developed with Shear Deformation; C: Dough Partially Developed with Extensional Deformation; D: Developed Dough; 1: 4th Layer; 2: 5th Layer; 3: 6th Layer

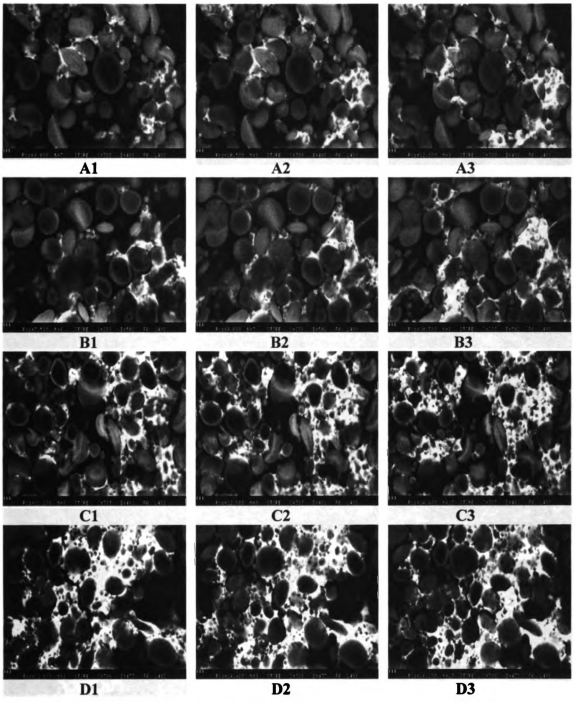

Figure 2 Protein Matrix from Different Caldwell Flour Doughs under Z-Sectioning of Laser Scanning Microscope.

A: Non-Developed Dough; B: Dough Partially Developed with Shear Deformation; C: Dough Partially Developed with Extensional Deformation; D: Developed Dough; 1: 4th Layer; 2: 5th Layer; 3: 6th Layer

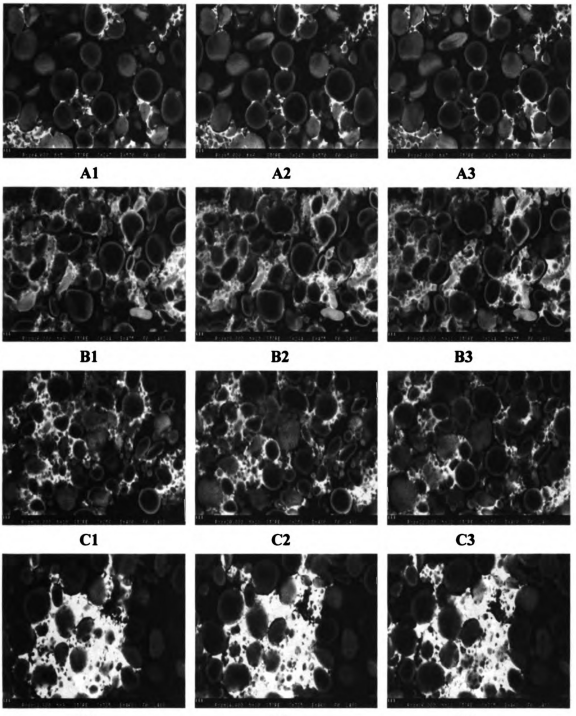

Figure 3 Protein Matrix from Different Freedom Flour Doughs under Z-Sectioning of Laser Scanning Microscope.

A: Non-Developed Dough; B: Dough Partially Developed with Shear Deformation; C: Dough Partially Developed with Extensional Deformation; D: Developed Dough; 1: 4th Layer; 2: 5th Layer; 3: 6th Layer

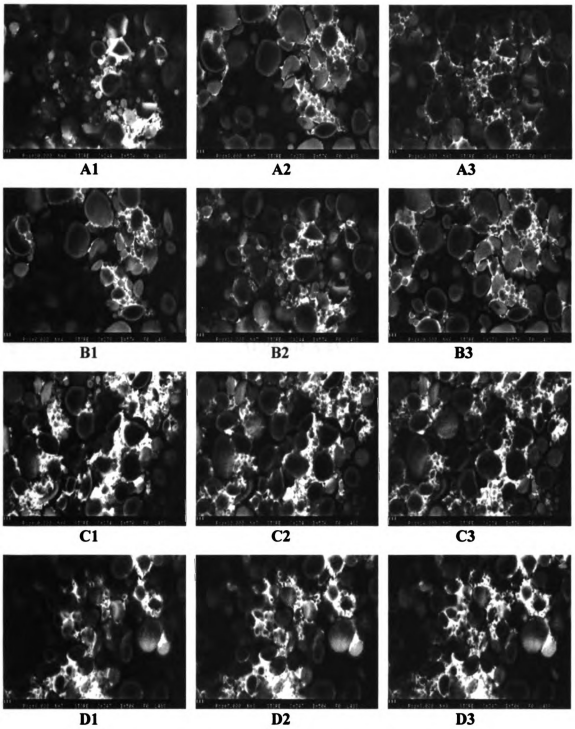

Figure 4 Protein Matrix from Different Blend Flour Doughs under Z-Sectioning of Laser Scanning Microscope.

A: Non-Developed Dough; B: Dough Partially Developed with Shear Deformation; C: Dough Partially Developed with Extensional Deformation; D: Developed Dough; 1: 4th Layer; 2: 5th Layer; 3: 6th Layer

APPENDIX IV

PROTEIN ELUTION PROFILES

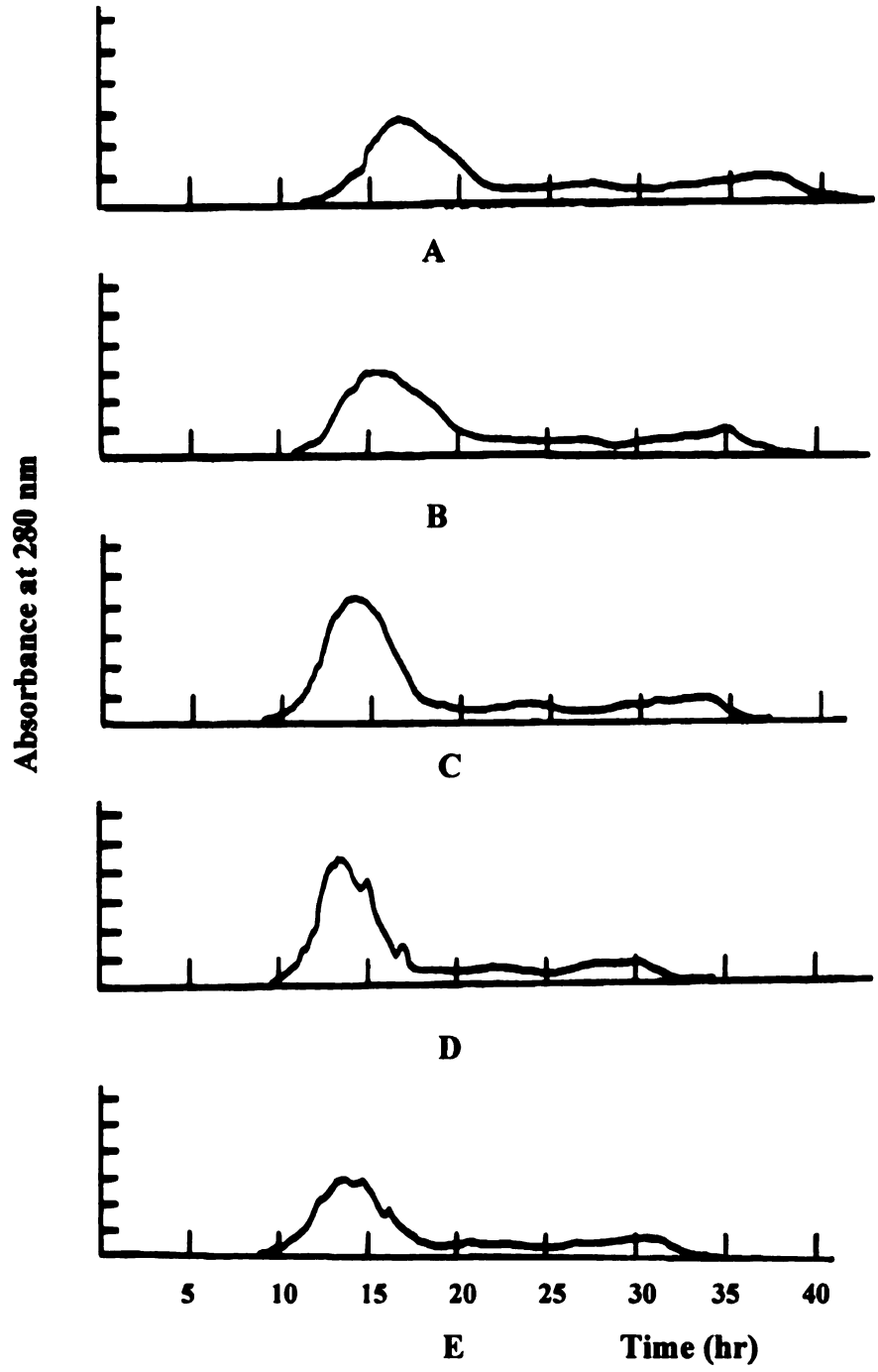

Figure 1 Protein Elution Profiles for Frankenmuth Flour and Dough Samples upon Gel Filtration Chromatography.

A: Native Flour; B: Non-Developed Dough; C: Dough Partially Developed with Shear Deformation; D: Dough Partially Developed with Extensional Deformation E: Developed Dough

Absorbance at 280 nm

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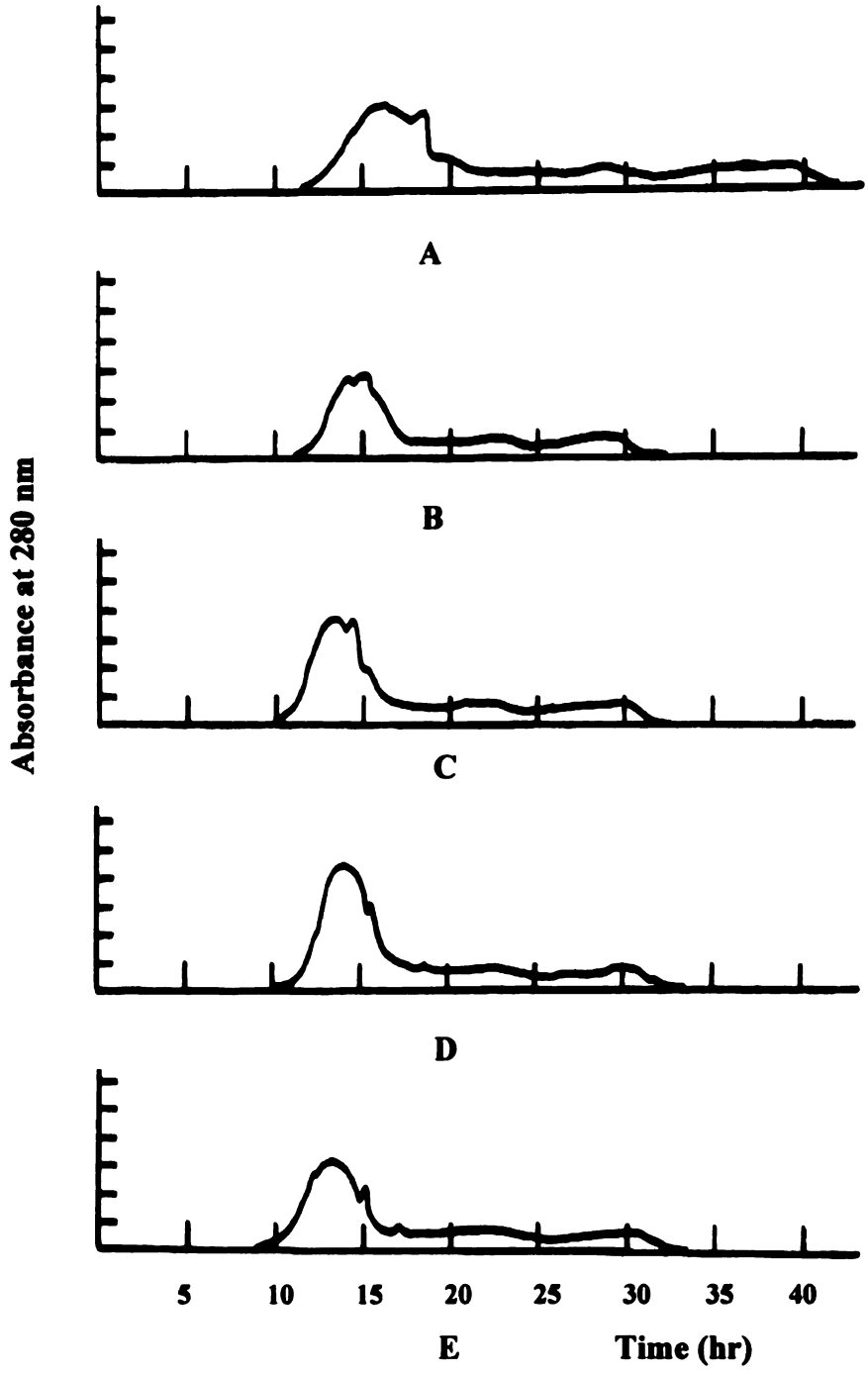

Figure 2 Protein Elution Profiles for Caldwell Flour and Dough Samples upon Gel Filtration Chromatography.

A: Native Flour; B: Non-Developed Dough; C: Dough Partially Developed with Shear Deformation; D : Dough Partially Developed with Extensional Deformation E: Developed Dough

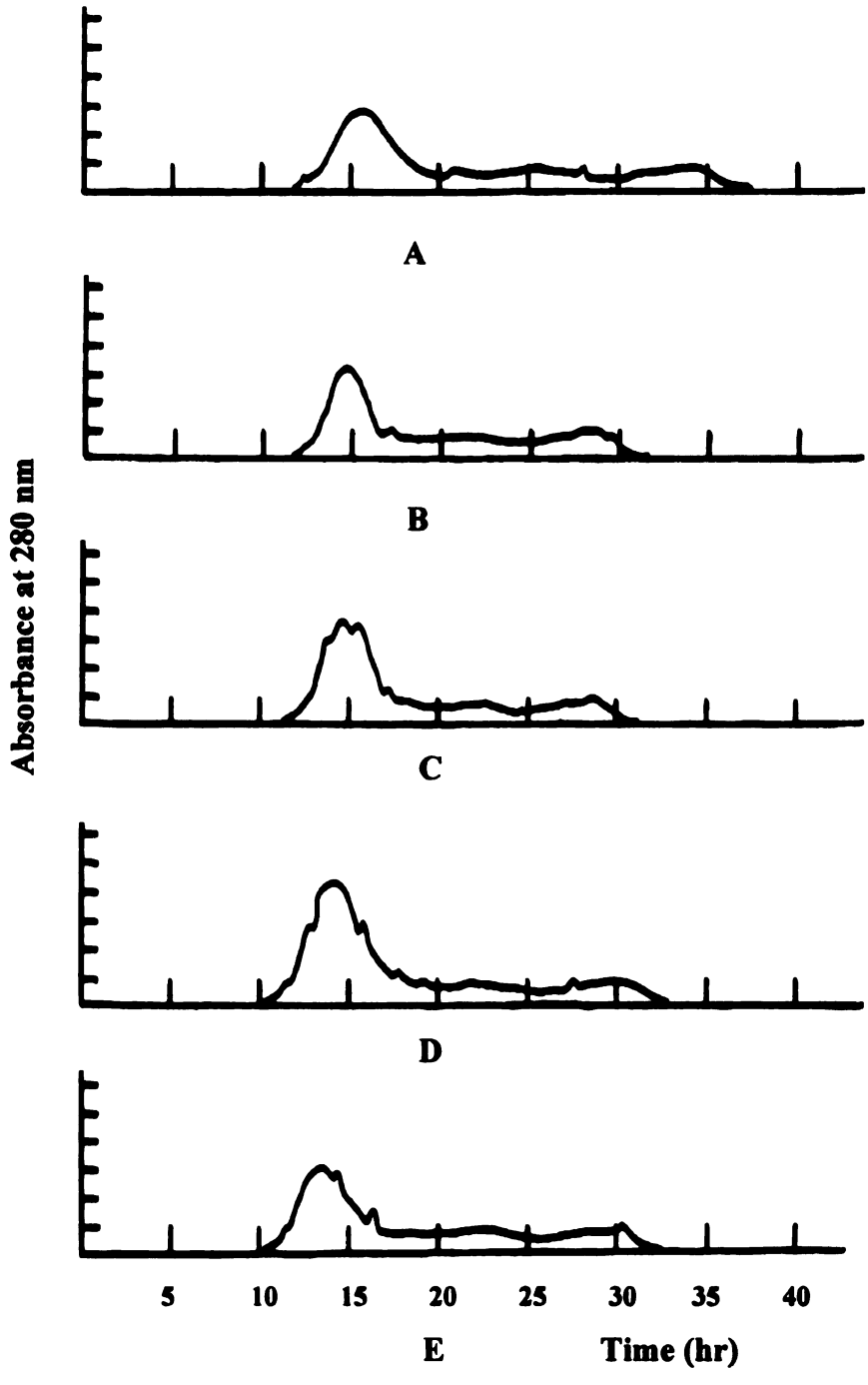

Figure 3 Protein Elution Profiles for Freedom Flour and Dough Samples upon Gel Filtration Chromatography.

A: Native Flour; B: Non-Developed Dough; C: Dough Partially Developed with Shear Deformation; D: Dough Partially Developed with Extensional Deformation E: Developed Dough

Absorbance at 280 nm

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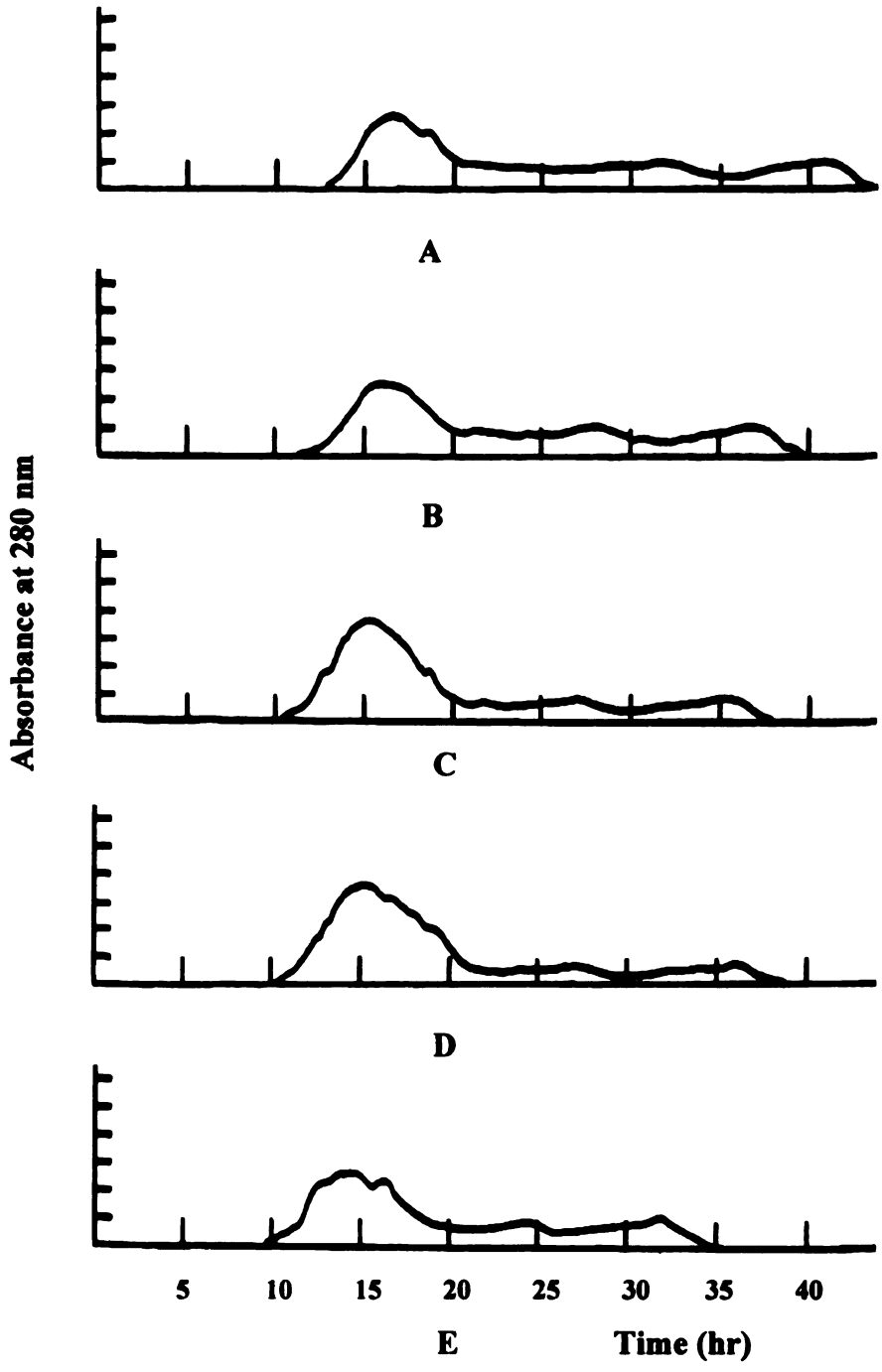


Figure 4 Protein Elution Profiles for Blend Flour and Dough Samples upon Gel Filtration Chromatography.

A: Native Flour; B: Non-Developed Dough; C: Dough Partially Developed with Shear Deformation; D: Dough Partially Developed with Extensional Deformation E: Developed Dough

APPENDIX V

ELECTROPHORETIC RESULTS

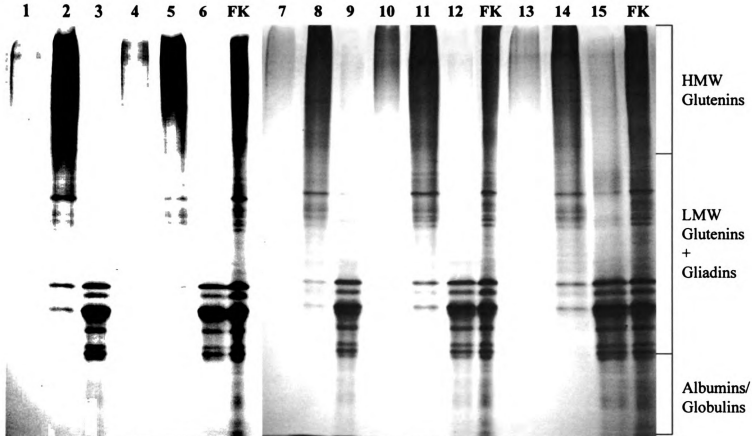


Figure 1 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Frankenmuth Protein Fractions Obtained from Gel Filtration Chromatography under Non-Reduced Conditions. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; FK: Total Proteins of Frankenmuth Flour. Regions for High Molecular Weight (HMW) Glutenins, Low Molecular Weight (LMW) Glutenins, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)

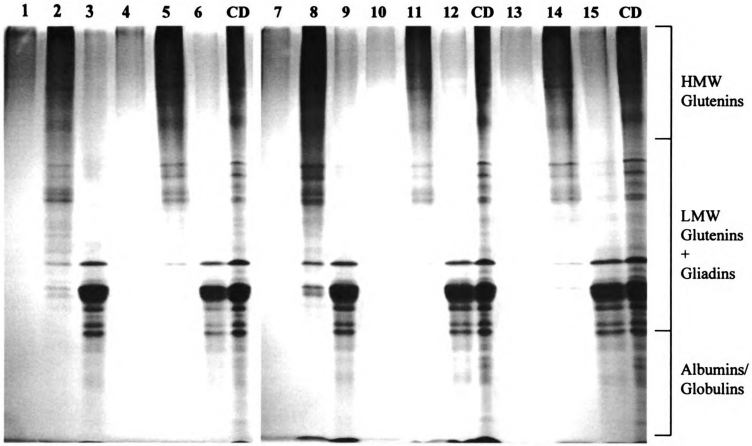
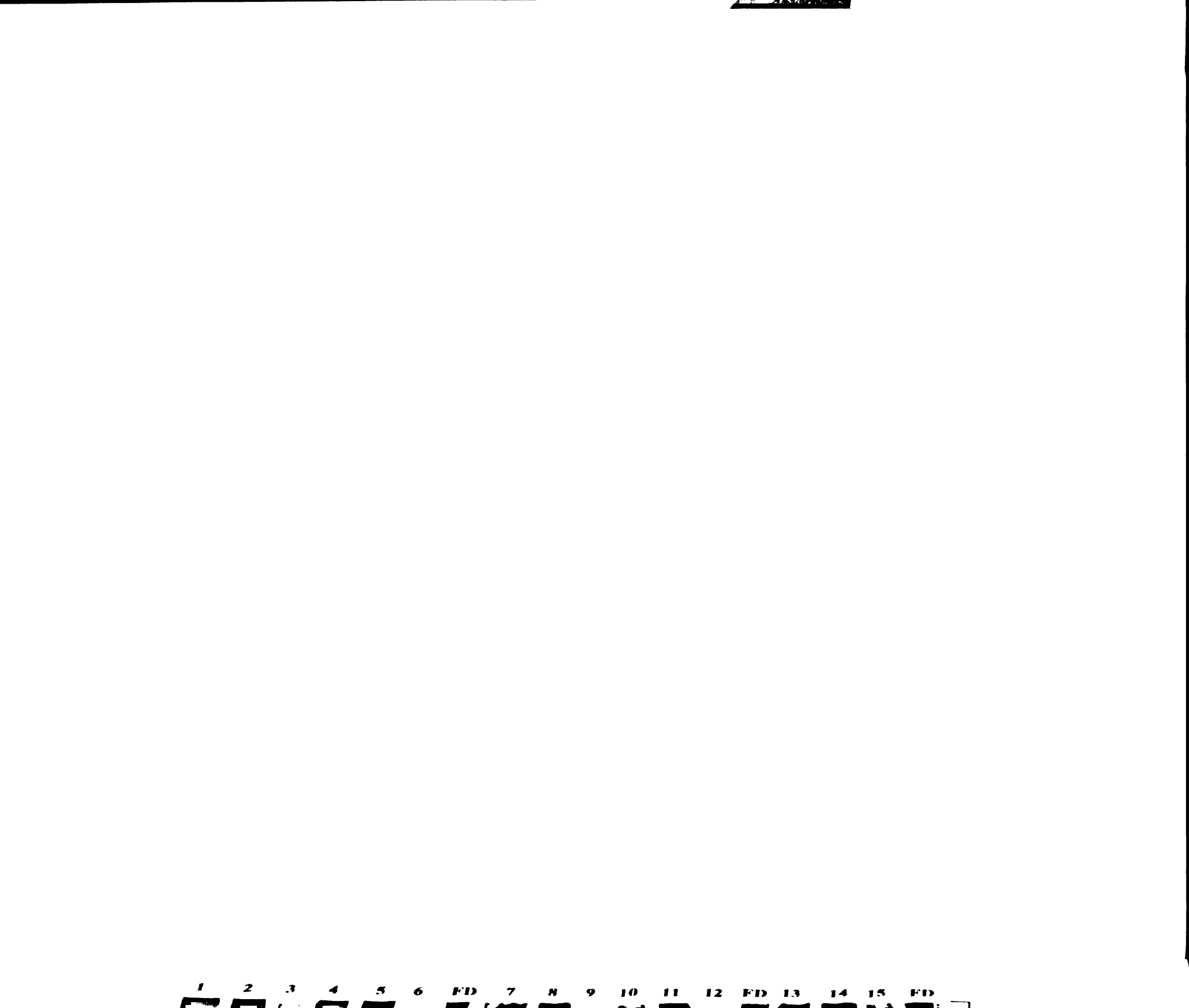


Figure 2 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Caldwell Protein Fractions Obtained from Gel Filtration Chromatography under Non-Reduced Conditions. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; CD: Total Proteins of Caldwell Flour. Regions for High Molecular Weight (HMW) Glutenins, Low Molecular Weight (LMW) Glutenins, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)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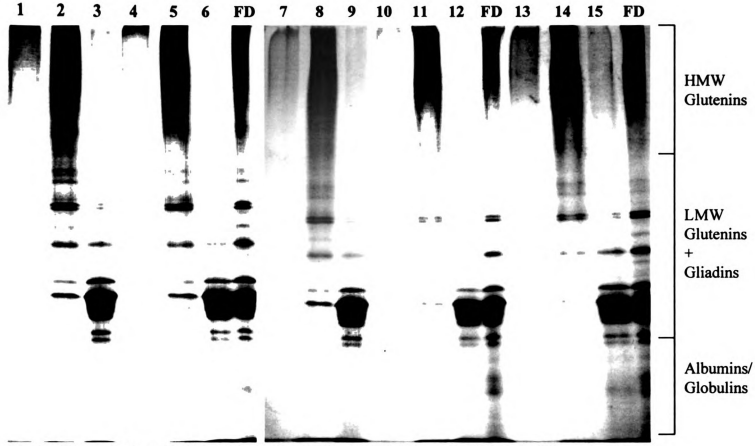


Figure 3 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Freedom Protein Fractions Obtained from Gel Filtration Chromatography under Non-Reduced Conditions. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; FD: Total Proteins of Freedom Flour. Regions for High Molecular Weight (HMW) Glutenins, Low Molecular Weight (LMW) Glutenins, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)

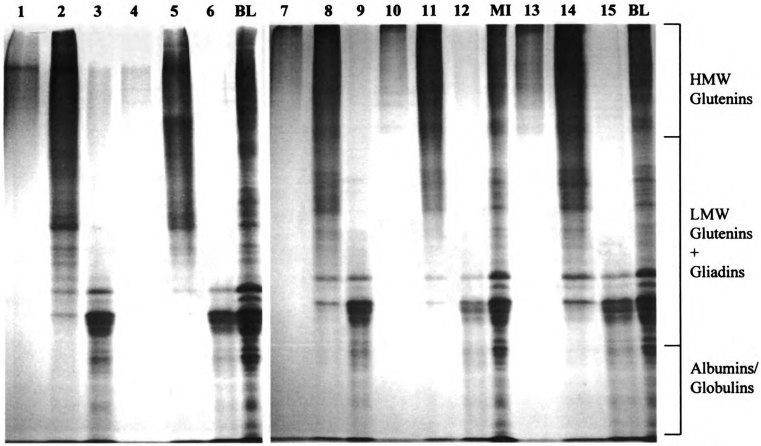
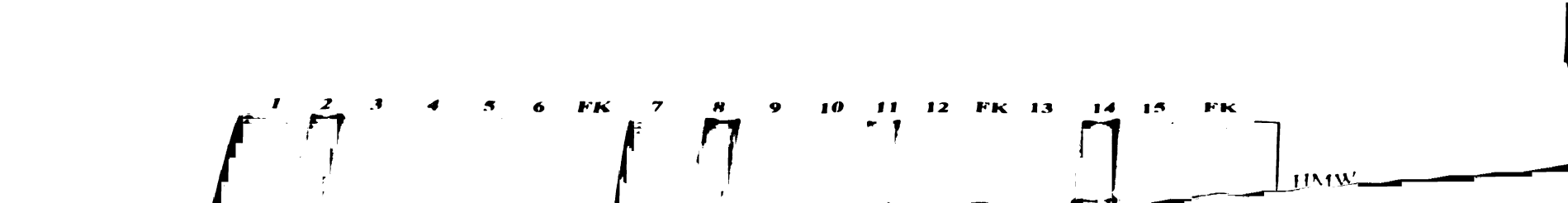


Figure 4 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Blend Protein Fractions Obtained from Gel Filtration Chromatography under Non-Reduced Conditions. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; BL: Total Proteins of Blend Flour. Regions for High Molecular Weight (HMW) Glutenins, Low Molecular Weight (LMW) Glutenins, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)


1 2 3 4 5 6 FK 7 8 9 10 11 12 FK 13 14 15 FK
HMW

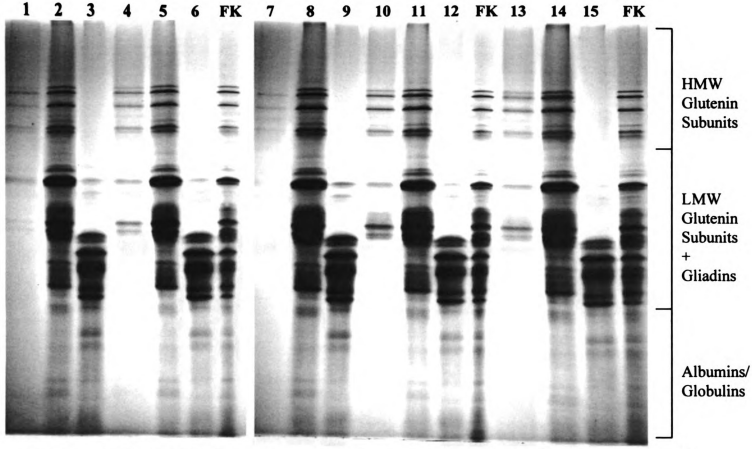
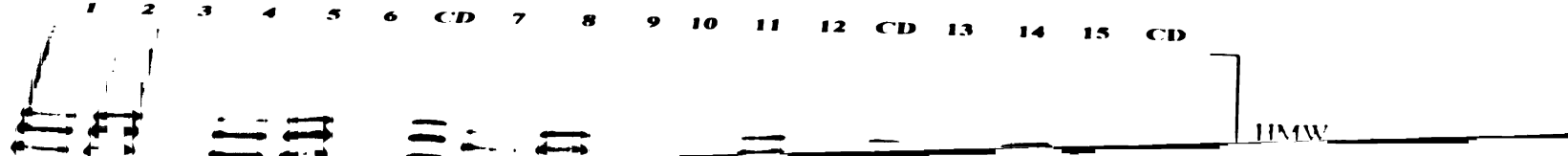


Figure 5 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Frankenmuth Protein Fractions Obtained from Gel Filtration Chromatography under Reduced Conditions. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; FK: Total Proteins of Frankenmuth Flour. Regions for High Molecular Weight (HMW) Glutenins, Low Molecular Weight (LMW) Glutenins, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)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CD
HMW

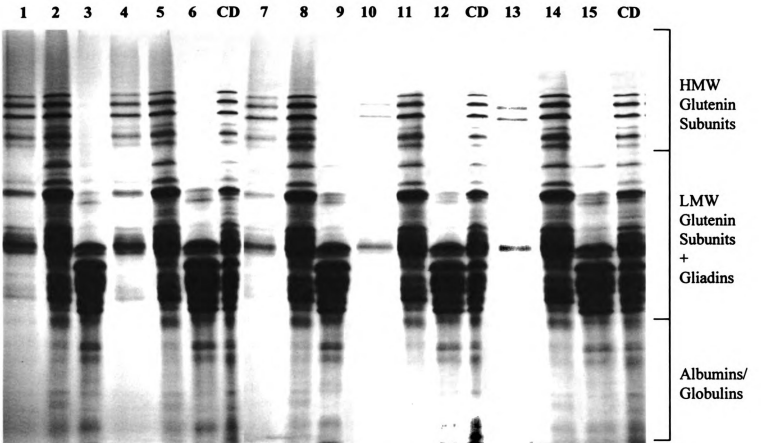
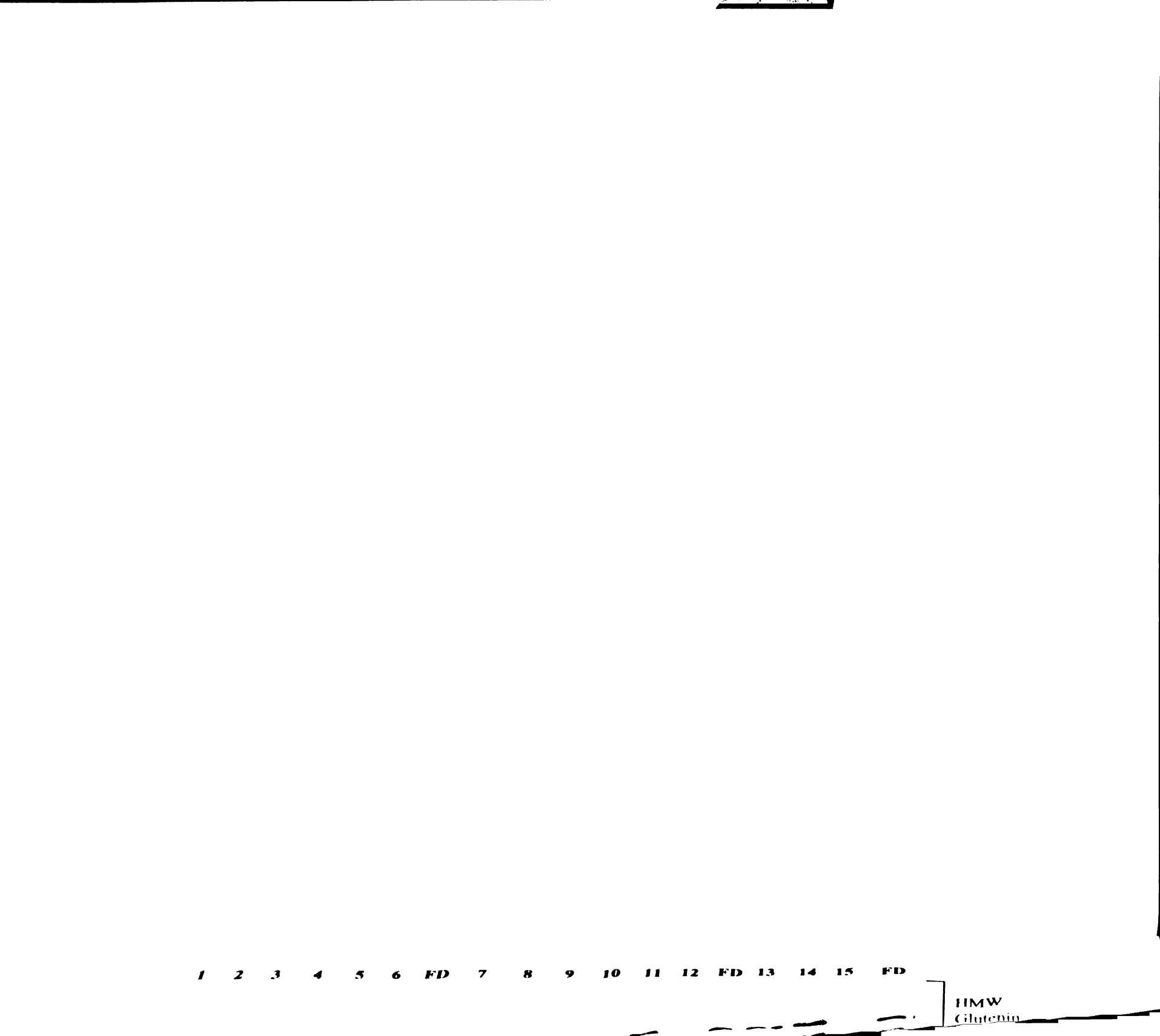


Figure 6 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Caldwell Protein Fractions Obtained from Gel Filtration Chromatography under Reduced Conditions. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; CD: Total Proteins of Caldwell Flour. Regions for High Molecular Weight (HMW) Glutenins, Low Molecular Weight (LMW) Glutenins, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)


1 2 3 4 5 6 FD 7 8 9 10 11 12 FD 13 14 15 FD
HMW
Glutenin

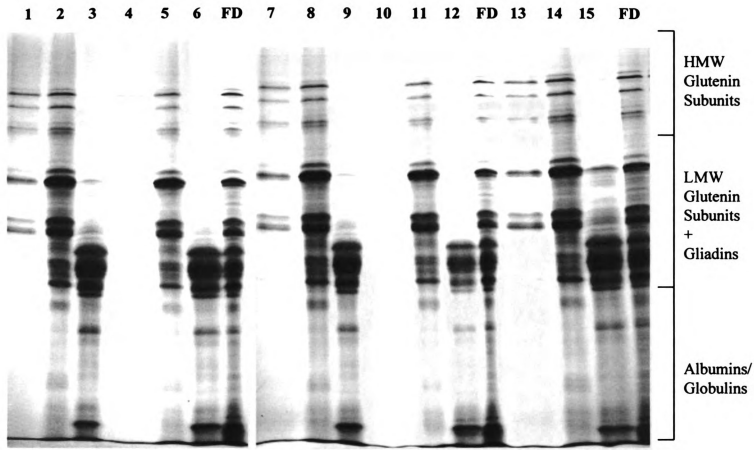


Figure 7 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Freedom Protein Fractions Obtained from Gel Filtration Chromatography under Reduced Conditions. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; FD: Total Proteins of Freedom Flour. Regions for High Molecular Weight (HMW) Glutenins, Low Molecular Weight (LMW) Glutenins, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)

1 2 3 4 5 6 BL 7 8 9 10 11 12 MI 13 14 15 BL

HMW

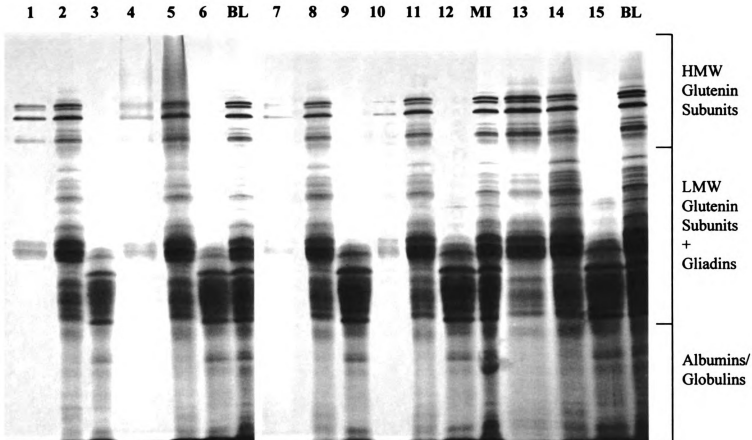


Figure 8 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Blend Protein Fractions Obtained from Gel Filtration Chromatography under Reduced Conditions. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; BL: Total Proteins of Blend Flour. Regions for High Molecular Weight (HMW) Glutenins, Low Molecular Weight (LMW) Glutenins, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)

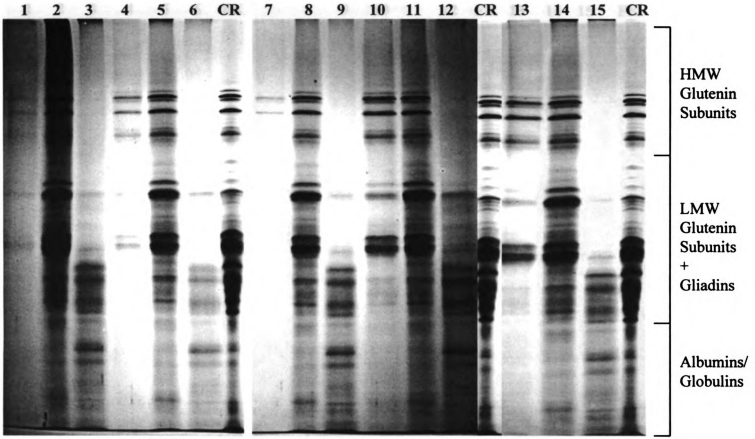


Figure 9 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Reduced Glutenins from Cracker Protein Fractions Obtained from Gel Filtration Chromatography. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; CR: Total Proteins of Cracker Flour. Regions for High Molecular Weight (HMW) Glutenin Subunits, Low Molecular Weight (LMW) Glutenin Subunits, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)

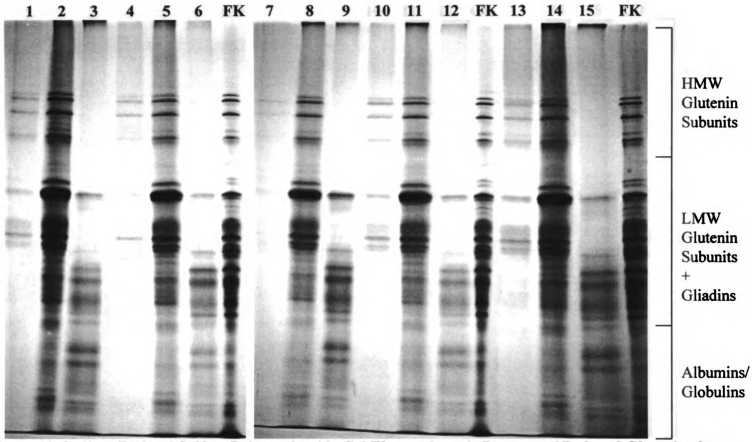
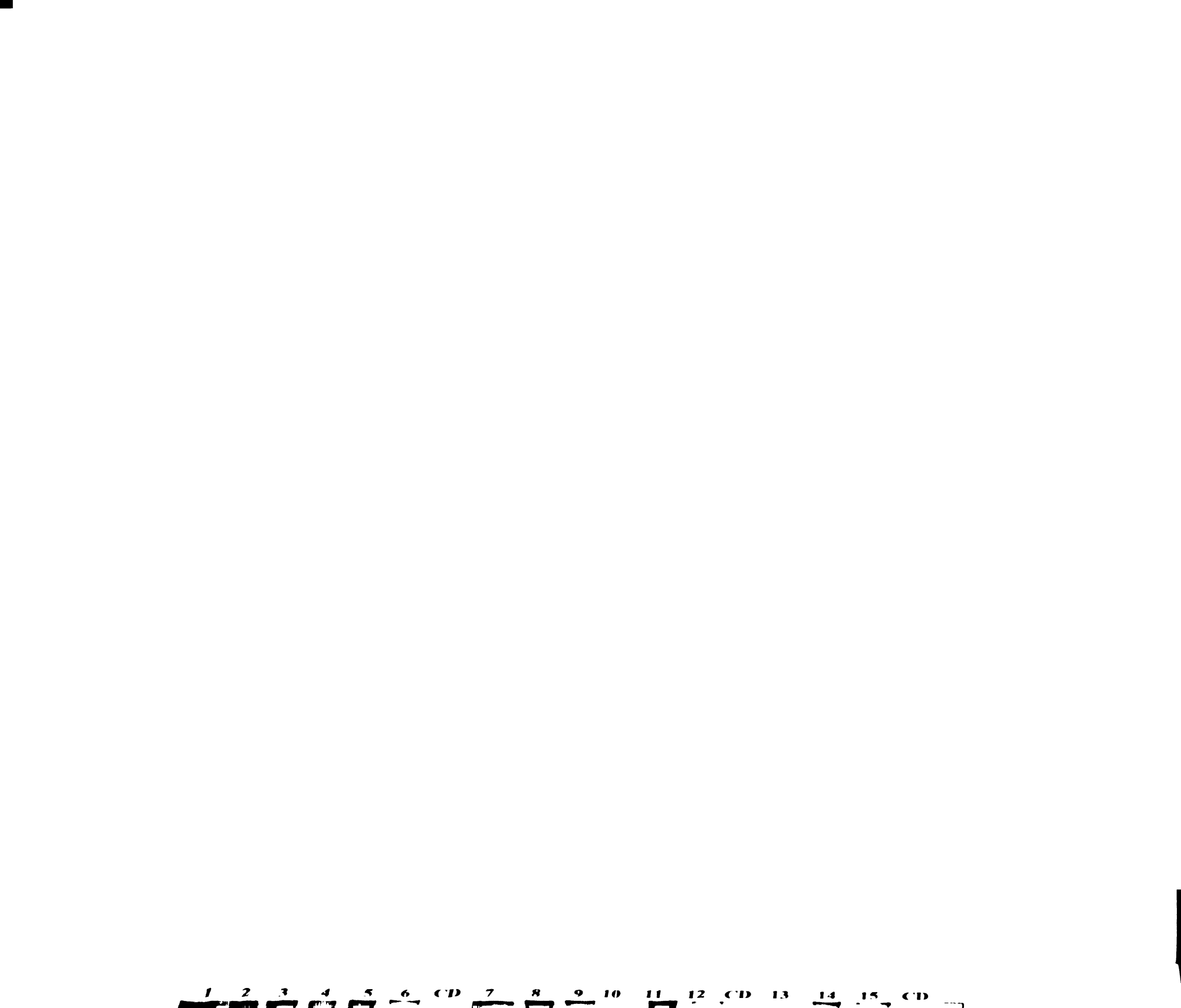


Figure 10 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Reduced Glutenins from Frankenmuth Protein Fractions Obtained from Gel Filtration Chromatography. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; FK: Total Proteins of Frankenmuth Flour. Regions for High Molecular Weight (HMW) Glutenin Subunits, Low Molecular Weight (LMW) Glutenin Subunits, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)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CD
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CD

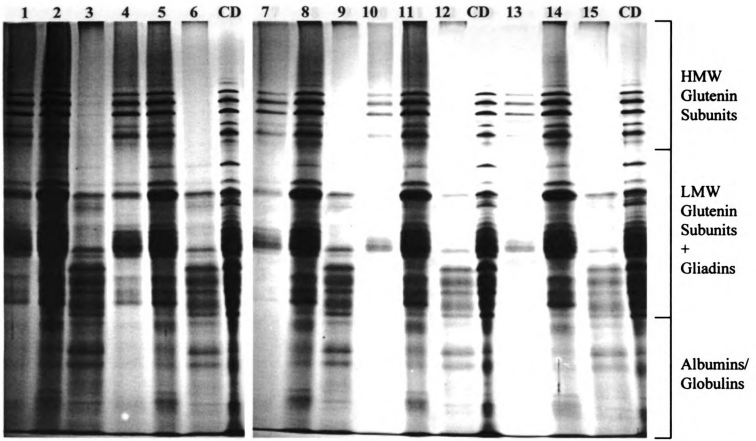
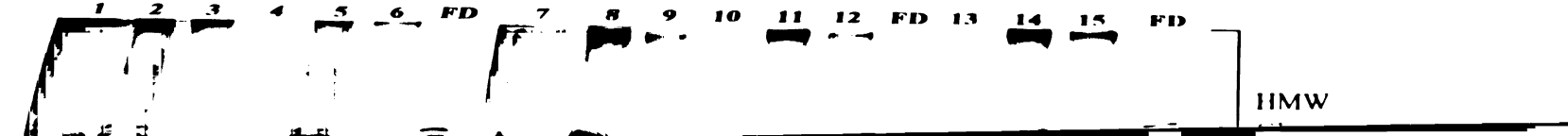


Figure 11 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Reduced Glutenins from Caldwell Protein Fractions Obtained from Gel Filtration Chromatography. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; CD: Total Proteins of Caldwell Flour. Regions for High Molecular Weight (HMW) Glutenin Subunits, Low Molecular Weight (LMW) Glutenin Subunits, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)


1
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FD
13
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FD
HMW

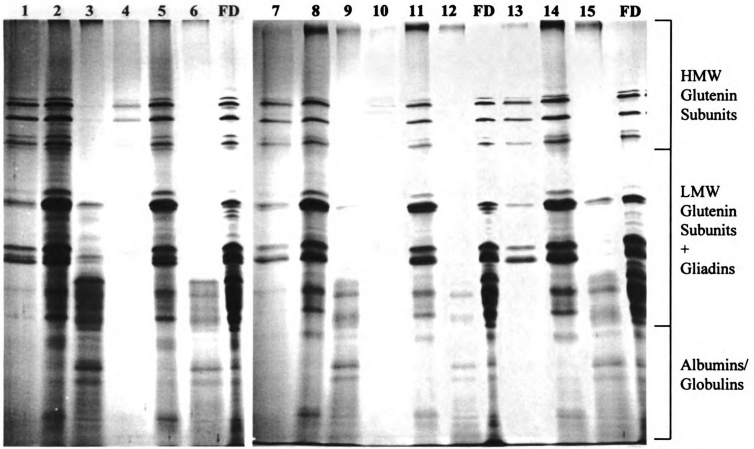
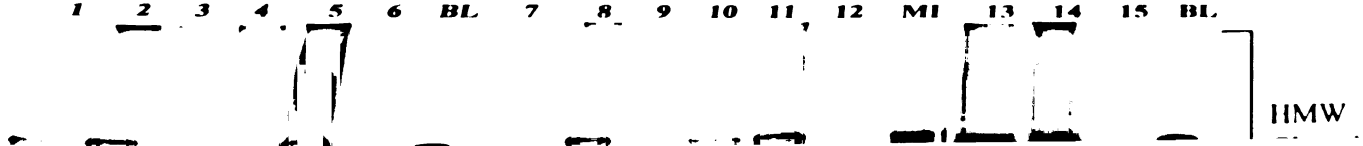


Figure 12 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Reduced Glutenins from Freedom Protein Fractions Obtained from Gel Filtration Chromatography. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; FD: Total Proteins of Freedom Flour. Regions for High Molecular Weight (HMW) Glutenin Subunits, Low Molecular Weight (LMW) Glutenin Subunits, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)


1 2 3 4 5 6 BL 7 8 9 10 11 12 MI 13 14 15 BL
HMW

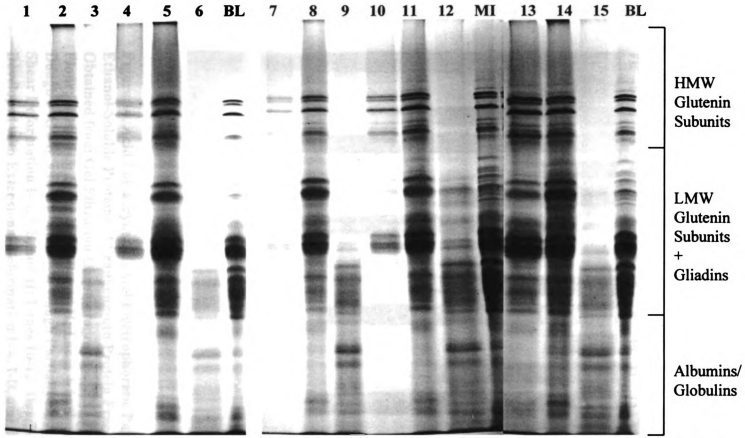


Figure 13 Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoretic Patterns of Reduced Glutenins from Blend Protein Fractions Obtained from Gel Filtration Chromatography. Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II; BL: Total Proteins of Blend Flour. Regions for High Molecular Weight (HMW) Glutenin Subunits, Low Molecular Weight (LMW) Glutenin Subunits, Gliadins, and Albumins/Globulins are identified according to Singh et al (1990)

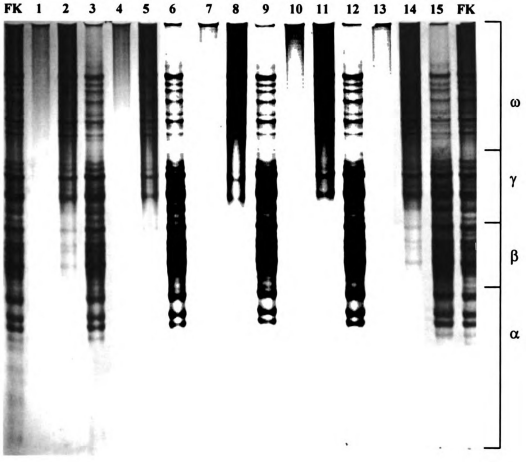


Figure 14 Acid Polyacrylamide Gel Electrophoretic Patterns of Ethanol-Soluble Proteins of Frankenmuth Protein Fractions Obtained from Gel Filtration Chromatography. FK: Frankenmuth Flour; Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II. Regions for ω, γ, β, and α indicate gliadin subgroups based on the method of Bushuk and Sapirstein (1991)

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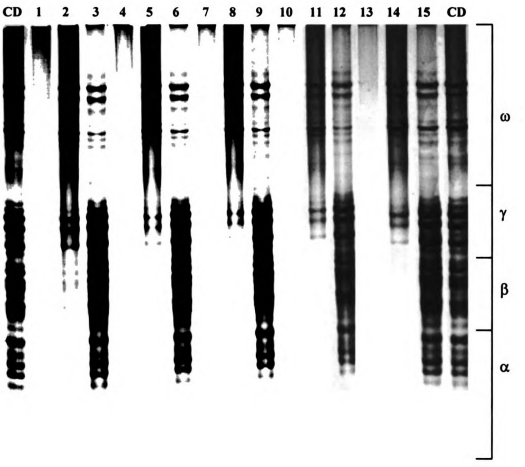

Figure 15 Acid Polyacrylamide Gel Electrophoretic Patterns of Ethanol-Soluble Proteins of Caldwell Protein Fractions Obtained from Gel Filtration Chromatography. CD: Caldwell Flour; Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II. Regions for ω, γ, β, and α indicate gliadin subgroups based on the method of Bushuk and Sapirstein (1991)

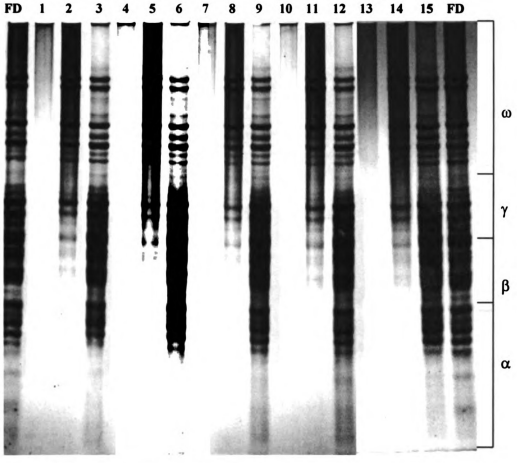

Figure 16 Acid Polyacrylamide Gel Electrophoretic Patterns of Ethanol-Soluble Proteins of Freedom Protein Fractions Obtained from Gel Filtration Chromatography. FD: Freedom Flour; Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II. Regions for ω, γ, β, and α indicate gliadin subgroups based on the method of Bushuk and Sapirstein (1991)

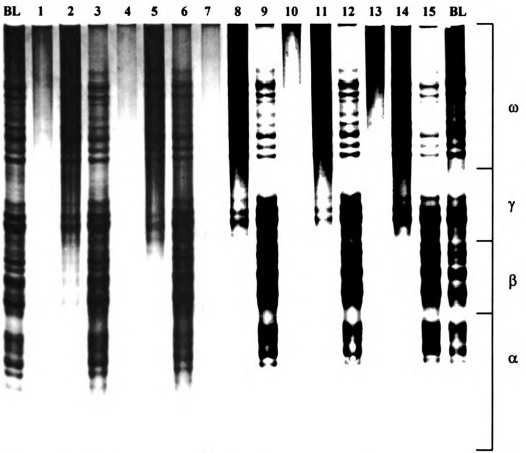

Figure 17 Acid Polyacrylamide Gel Electrophoretic Patterns of Ethanol-Soluble Proteins of Blend Protein Fractions Obtained from Gel Filtration Chromatography. BL: Blend Flour; Lanes 1-3: Flour I-A, I-B, and II; Lanes 4-6: Non-Developed Dough I-A, I-B, and II; Lanes 7-9: Dough Partially Developed with Shear Deformation I-A, I-B, and II; Lanes 10-12: Dough Partially Developed with Extensional Deformation I-A, I-B, and II; Lanes 13-15: Developed Dough I-A, I-B, and II. Regions for ω, γ, β, and α indicate gliadin subgroups based on the method of Bushuk and Sapirstein (1991)

APPENDIX VI

DENSITOMETRIC DATA

TABLE 1 Quantification (%) of Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration

TABLE 1 Quantification (%) of Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Frankenmuth Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Frankenmuth	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	100	70.5	2.8	100	70.5	2.9	100	71.7	3.5	100	73.6	3.9	100	74.8	5.6
LMW[1]+ Gliadins	0	29.5	86.7	0	29.5	86.7	0	28.3	86.1	0	26.4	85.8	0	25.2	84.3
Albumins+ Globulins	0	0	10.5	0	0	10.4	0	0	10.4	0	0	10.3	0	0	10.1

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 2 Quantification (%) of Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration

TABLE 2 Quantification (%) of Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Caldwell Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Caldwell	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	100	68.5	2.6	100	68.9	2.62	100	70.2	2.9	100	74.9	5.6	100	75.8	6.2
LMW[1]+ Gliadins	0	31.5	91.3	0	31.1	91.27	0	29.8	91.1	0	25.1	88.5	0	24.2	84.4
Albumins+ Globulins	0	0	6.1	0	0	6.11	0	0	6.0	0	0	5.9	0	0	5.4

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 3 Quantification (%) of Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration

TABLE 3 Quantification (%) of Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Freedom Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Freedom	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	100	66.7	2.1	100	66.9	2.9	100	68.2	3.1	100	72.9	3.5	100	74.6	5.5
LMW[1]+ Gliadins	0	33.3	92.5	0	33.1	91.7	0	31.8	91.6	0	27.1	91.5	0	25.4	89.5
Albumins+ Globulins	0	0	5.4	0	0	5.4	0	0	5.3	0	0	5.0	0	0	5.0

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 4 Quantification (%) of Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration

TABLE 4 Quantification (%) of Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Blend[1] Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Blend	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[2]	100	65.2	1.9	100	65.8	1.9	100	67.6	2.9	100	70.5	3.5	100	73.5	5.3
LMW[2]+ Gliadins	0	34.8	89.7	0	34.2	89.8	0	32.4	88.9	0	29.5	88.9	0	26.5	87.5
Albumins+ Globulins	0	0	8.4	0	0	8.3	0	0	8.2	0	0	7.6	0	0	7.2

[1]Blend: The mixture of 50% soft red winter and 50% hard red winter.
[2]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 5. Quantification (%) of Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration

TABLE 5 Quantification (%) of Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Frankenmuth Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Frankenmuth	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	28.3	13.1	2.5	28.8	13.5	2.7	36.5	15.7	3.4	45.0	16.5	3.5	50.7	17.0	4.20
LMW[1]+ Gliadins	68.6	75.8	77.3	69.1	76.1	77.5	61.9	74.0	77.7	53.6	73.2	78.7	48.4	72.4	78.8
Albumins+ Globulins	3.1	11.1	20.2	2.1	10.5	19.8	1.6	10.3	18.9	1.4	10.3	17.8	0.9	10.6	17.0

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 6. Quantification (%) of Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration

TABLE 6 Quantification (%) of Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Caldwell Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Caldwell	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	25.5	12.2	8.0	25.6	12.7	7.7	30.6	16.1	8.0	46.0	17.2	8.8	52.8	21.7	8.8
LMW[1]+ Gliadins	71.2	72.1	71.8	70.7	74.2	72.4	65.9	72.3	72.4	51.7	71.2	72.6	46.2	68.3	73.9
Albumins+ Globulins	3.3	15.7	20.2	3.7	13.1	19.9	3.5	11.6	19.6	2.3	11.6	18.6	1.0	10.0	17.3

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 7 Quantification (%) of Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Freedom Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Freedom	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	20.1	10.0	2.6	20.3	10.5	2.9	23.6	12.7	3.5	37.7	16.2	3.9	51.0	16.9	4.2
LMW[1]+ Gliadins	76.8	74.1	74.8	76.4	74.2	75.2	73.4	73.9	75.8	59.5	71.0	76.3	46.8	71.9	77.7
Albumins+ Globulins	3.1	15.9	22.6	3.3	15.3	21.9	3.0	13.5	20.7	2.8	12.8	19.8	2.2	11.2	18.1

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 8 Quantification (%) of Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Blend[1] Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Blend	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[2]	24.0	11.7	1.1	25.4	11.8	1.3	28.4	13.1	1.6	35.9	5.8	1.9	48.8	16.9	2.2
LMW[2]+ Gliadins	72.4	73.3	78.7	71.0	73.2	78.7	69.1	73.1	78.8	61.6	72.0	78.9	49.0	72.4	78.9
Albumins+ Globulins	3.6	15.0	20.2	3.6	15.0	20.0	2.5	13.8	19.6	2.5	12.2	19.2	2.2	10.7	18.9

[1]Blend: The mixture of 50% soft red winter and 50% hard red winter.
[2]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 8. Quantification (%) of Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration

TABLE 9 Quantification (%) of Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Cracker Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Cracker	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	40.9	21.5	2.2	41.7	23.7	2.3	44.3	26.0	3.0	47.6	28.4	3.1	52.4	30.5	3.5
LMW[1]+ Gliadins	59.1	70.7	77.6	58.3	68.8	77.9	55.7	66.8	78.0	52.4	65.2	78.5	47.6	63.4	79.1
Albumins+ Globulins	0	7.8	20.2	0	7.5	19.8	0	7.2	19.0	0	6.4	18.4	0	6.1	17.4

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 10 Quantification (%) of Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Frankenmuth Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Frankenmuth	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	45.6	26.5	0.5	46.6	26.5	0.5	49.1	28.5	0.7	51.9	30.7	1.0	54.6	31.5	1.5
LMW[1]+ Gliadins	54.4	67.8	81.0	53.4	68.0	81.1	50.9	66.3	81.3	48.1	64.8	82.1	45.4	64.3	82.3
Albumins+ Globulins	0	5.7	18.5	0	5.5	18.4	0	5.1	18.0	0	4.5	16.9	0	4.2	16.2

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 11 Quantification (%) of Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Caldwell Flour and Its Different Doughs

Sample	*Native Flour*	*Non-Developed Dough*	*Dough Partially Developed with*	*Dough Partially Developed with*	*Developed Dough*

TABLE 11 Quantification (%) of Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Caldwell Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Caldwell	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	44.9	25.9	3.9	45.0	26.3	4.1	48.5	27.9	4.6	50.3	29.9	4.7	54.9	31.5	5.8
LMW[1]+ Gliadins	55.1	66.4	77.1	55.0	66.2	77.2	51.5	65.0	76.9	49.5	63.7	78.1	45.1	62.3	77.2
Albumins+ Globulins	0	7.7	19.0	0	7.5	18.7	0	7.1	18.5	0	6.4	17.2	0	6.2	17.0

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 12 Quantification (%) of Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Freedom Flour and Its Different Doughs

Sample	*Native Flour*	*Non-Developed Dough*	Dough Partially Developed with	Dough Partially Developed with	Developed Dough

TABLE 12 Quantification (%) of Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Freedom Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Freedom	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[1]	37.4	20.6	1.0	39.2	21.8	1.1	43.9	25.7	1.7	48.4	28.5	1.8	54.6	32.1	2.1
LMW[1]+ Gliadins	62.6	70.6	78.1	60.8	69.5	79.1	56.1	66.3	79.2	51.6	64.4	79.5	45.4	61.0	80.5
Albumins+ Globulins	0	8.8	20.9	0	8.7	19.8	0	8.0	19.1	0	7.1	18.7	0	6.9	17.4

[1]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 13 Quantification (%) of Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Blend[1] Flour and Its Different Doughs

Sample	*Native Flour*	*Non-Developed Dough*	*Dough Partially Developed with*	*Dough Partially Developed with*	*Developed Dough*

TABLE 13 Quantification (%) of Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Blend[1] Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Blend	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
HMW[2]	42.1	23.6	0.3	42.5	23.9	0.5	42.9	23.9	0.9	47.6	27.8	1.9	53.4	31.6	2.2
LMW[2]+ Gliadins	57.9	68.3	74.8	57.5	68.1	74.8	57.1	68.6	74.9	52.4	65.0	77.6	46.6	61.6	80.0
Albumins+ Globulins	0	8.1	24.9	0	8.0	24.7	0	7.5	24.2	0	7.2	20.5	0	6.8	17.8

[1]Blend: The mixture of 50% soft red winter and 50% hard red winter.
[2]HMW: High molecular weight glutenin subunits; LMW: Low molecular weight glutenin subunits.

TABLE 14 Quantification (%) of Ethanol Soluble Proteins (Gliadins) from Each Protein Fraction Obtained from Gel Filtration Chromatography of Frankenmuth Flour and Its Different Doughs

Sample	*Native Flour*	*Non-Developed Dough*	*Dough Partially Developed with*	*Dough Partially Developed with*	*Developed Dough*

TABLE 14 Quantification (%) of Ethanol Soluble Proteins (Gliadins) from Each Protein Fraction Obtained from Gel Filtration Chromatography of Frankenmuth Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Frankenmuth	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
α-Gliadins	0	0	17.3	0	0	16.7	0	0.5	16.8	0	0.6	16.5	0	1.1	15.8
β-Gliadins	0	0.9	30.1	0	1.1	31.8	0	1.4	32.0	0	3.0	33.2	0	6	34.9
γ-Gliadins	0	28.4	31.7	0	21.1	30.9	0	16.7	31.1	0	14.4	32.6	0	8.7	33.3
ω-Gliadins	0	68.5	20.9	0	77.7	20.6	0	81.4	20.1	0	82.0	17.7	0	84.2	16.0

TABLE 15 Quantification (%) of Ethanol Soluble Proteins (Gliadins) from Each Protein Fraction Obtained from Gel Filtration Chromatography of Caldwell Flour and Its Different Doughs

Sample	*Native Flour*	*Non-Developed Dough*	Dough Partially Developed with	Dough Partially Developed with	Developed Dough

TABLE 15 Quantification (%) of Ethanol Soluble Proteins (Gliadins) from Each Protein Fraction Obtained from Gel Filtration Chromatography of Caldwell Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Caldwell	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
α-Gliadins	0	0.3	20.7	0	0	19.9	0	0	19.8	0	0	17.2	0	0	16.5
β-Gliadins	0	3.7	30.9	0	3.3	30.8	0	3.5	31.5	0	4.0	33.0	0	4.1	35.7
γ-Gliadins	0	29.8	32.6	0	29.6	33.5	0	26.3	33.3	0	24.9	34.5	0	20.5	34.1
ω-Gliadins	0	66.2	15.8	0	67.1	15.8	0	70.2	15.4	0	71.1	15.3	0	75.4	13.7

TABLE 16 Quantification (%) of Ethanol Soluble Proteins (Gliadins) from Each Protein Fraction Obtained from Gel Filtration Chromatography of Freedom Flour and Its Different Doughs

Sample	*Native Flour*	*Non-Developed Dough*	*Dough Partially Developed with*	*Dough Partially Developed with*	*Developed Dough*

TABLE 16 Quantification (%) of Ethanol Soluble Proteins (Gliadins) from Each Protein Fraction Obtained from Gel Filtration Chromatography of Freedom Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Freedom	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
α-Gliadins	0	0.6	18.5	0	0.5	18.4	0	0.8	18.2	0	1.0	17.2	0	1.3	16.7
β-Gliadins	0	4.3	30.1	0	4.7	30.9	0	4.7	32.7	0	5.2	34.6	0	5.6	35.9
γ-Gliadins	0	23.0	27.9	0	21.4	29.5	0	21.4	30.1	0	20.5	30.5	0	19.4	33.8
ω-Gliadins	0	72.1	23.5	0	73.4	21.2	0	73.1	19.0	0	73.3	17.7	0	73.7	13.6

TABLE 17 Quantification (%) of Ethanol Soluble Proteins (Gliadins) from Each Protein Fraction Obtained from Gel Filtration Chromatography of Blend[1] Flour and Its Different Doughs

Sample	*Native Flour*	*Non-Developed Dough*	*Dough Partially Developed with*	*Dough Partially Developed with*	*Developed Dough*

TABLE 17 Quantification (%) of Ethanol Soluble Proteins (Gliadins) from Each Protein Fraction Obtained from Gel Filtration Chromatography of Blend[1] Flour and Its Different Doughs

Sample	Native Flour			Non-Developed Dough			Dough Partially Developed with Shear Deformation			Dough Partially Developed with Extensional Deformation			Developed Dough		
Blend	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II	I-A	I-B	II
α-Gliadins	0	0	18.6	0	0	18.1	0	0	17.4	0	0	16.5	0	0	16.5
β-Gliadins	0	1.5	32.5	0	1.8	33.5	0	2.4	35.7	0	2.5	37.0	0	4.3	37.9
γ-Gliadins	0	19.8	27.5	0	19.3	27.2	0	18.8	28.4	0	17.5	28.0	0	15.2	29.0
ω-Gliadins	0	78.7	21.4	0	78.9	21.2	0	78.8	18.5	0	80	18.5	0	80.5	16.6

[1]Blend: The mixture of 50% soft red winter and 50% hard red winter.

APPENDIX VII

A MODIFIED PROCEDURE (ONE-STAGE FERMENTATION) FOR EVALUATING FLOUR CRACKER-MAKING POTENTIAL

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ABSTRACT

Cracker products are popular around the world, however there is no standard baking procedure for screening a flour' s potential for cracker-baking quality. Traditional published procedures involve two fermentation stages, making the evaluation of flour samples a time-consuming process. This study reports a modified procedure (one-stage fermentation) and compares it with the two-stage fermentation procedure for discriminating among flours for making crackers. A wide range of wheat flour samples (19) were used in this study and a set of cracker qualities identified (i.e., weight, moisture, dimension and texture). Results showed that both procedures could discriminate among flours for cracker-making quality. Though differences were found between the two procedures for some measured cracker quality parameters, similar trends among tested flour samples were observed. With one operator, about 15 flour samples could be evaluated for cracker-making potential in a 48 hr period using the modified procedure, as compared to about 6 samples using the two-stage fermentation procedure.

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INTRODUCTION

Snack crackers have become increasingly popular around the world. The largest portion of cracker production consists of the fermented crackers, such as saltine crackers (Lajoie and Thomas 1994). Traditional fermented crackers are the product of two fermentation stages: sponge and dough (Doescher and Hoseney 1985). During the fermented sponge stage, 60 - 70% of the total flour, yeast, and water are mixed for 1 to 4 min and then fermented for 16 to 18 hr at 25 - 30°C and 70 - 90% relative humidity (Ranhotra and Gelroth 1988). During the fermented dough stage, the fermented sponge, the remaining flour and the other ingredients (e.g., shortening and salt) are mixed together for 3 to 7 min and allowed to ferment for another 6 hr (Creighton and Hoseney 1990a). The fermented dough is then put through a series of rolls to be formed into a continuous sheet of five to seven layers. This laminated sheet is then cut, docked, stamped, and baked (Pyler 1988).

Although cracker products are popular around the world, a cracker making procedure has not been standardized because of the numerous setting conditions (e.g., temperature, humidity, mixing time, and sheeting number) and formulae (Doescher and Hoseney 1985; Pyler 1988). Traditional published procedures involve two fermentation stages, limiting the number of flour samples evaluable in a 48 hr period by one operator. The objectives of this study were (1) to develop a modified procedure (one-stage fermentation), (2) to compare it with a modified published two-stage procedure, and (3) to use the one-stage procedure for discriminating among flours for cracker making potential.

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MATERIALS AND METHODS

Cracker Ingredients

Nineteen wheat samples were selected for the present study. There were eight commercial flours: cake, cookie, cracker, bread, and hard red spring from Mennel Milling Co. (Fostoria, OH) in 1997; hard red winter, soft red winter, and a blend sample with the hard red winter and the soft red winter (1:1) both from King Milling Co. (Lowell, MI) in 1996; and 11 pure soft wheat cultivars harvested in 1993 from Michigan (Chelsea and Frankenmuth), Ohio (Caldwell, Clark, Dynasty, Excel, and Freedom,), and Washington (Hyak, Lewjain, Madsen, and Tres). These eleven wheat cultivars were tempered to 15% moisture overnight, and then milled on a Bühler experimental mill (Bühler Ltd., Uzwil, Switzerland) to 70% flour extraction. Other ingredients were active dry yeast (Red Star Yeast and Products, Milwaukee, WI), Crisco vegetable shortening (Procter & Gamble, Cincinnati, OH) made from partially hydrogenated vegetable oil, iodized salt (Meijer Inc., Grand Rapids, MI), baking soda (Arm & Hammer, Princeton, NJ), and distilled water.

Physicochemical Analyses of Wheat Flour Samples

Moisture, ash, protein, damaged starch contents, and optimal water absorption from farinographs of each flour sample were determined according to approved methods 44-15A, 08-01, 46-13, 76-30A, and 54-21 of AACC (1995), respectively. Table 1 summarizes the results of the analyses.

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Cracker Formula and Preparation

Figures 1 and 2 show the one-stage fermentation and the two-stage fermentation procedures for making crackers, respectively. In the preliminary studies, the blend flour sample exhibited good potential for cracker making. Thus, the amount of water added to each tested flour was adjusted as follows based on the blend flour sample:

[29% x 100 g of tested flour x (100-14)/(100-A)] x B/C

Where A = moisture content of the tested flour

B = optimal farinograph water absorption of blend flour sample

C = optimal farinograph water absorption of tested flour for making a cracker

Cracker Dough Sheeting and Baking

After fermentation (Figures 1 and 2), the dough was flattened by hand to give a uniform piece of dough (7.4 cm diameter x 2.3 cm thickness). The dough was then passed through seven different openings of the sheeter (15.91, 12.30, 9.50, 5.65, 2.88, 1.27, and 1.04 mm). The cracker dough was passed through the first four gaps three times each. After the first passage through the 2.88 and 1.27 mm gaps, the dough was folded onto itself once and passed through the same sheeter opening; this was repeated twice for a total of three passes through each of the two gaps. The dough was sheeted three more times through the final sheeter opening without folding.

After the dough had been sheeted, it was cut with a hand-cutter-docker (21 cells of 5.08 x 5.56 cm), placed on a rectangular rack (40.01 x 21.59 cm), and then baked at

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265 °C for 4 min 10 sec in a rotary oven (National MFG Co., Lincoln, NE). Baked cracker sheets were allowed to cool for 30 min and broken into individual crackers.

Cracker Quality Analysis

Two commercial saltine crackers (unsalted tops), Meijer Inc. (Grand Rapids, MI) and Nabisco (East Hanover, NJ), were used as references.

Physical Measurements

Weight, length, width, thickness, and volume of crackers were chosen as parameters for evaluating the cracker quality. Length, width, and thickness of each cracker were measured using a vernier caliper manufactured by Glogau & Co. (Germany). Volume was determined by putting an individual cracker into a known-volume container (110 cc) and using rape seeds to measure cracker volume by displacement.

Moisture Measurement

Individual crackers were crushed using a mortar and pestle and the moisture content of each crushed cracker was immediately determined according to the AACC Method 44-15A (1995).

Texture Analysis

The TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) was used to evaluate the texture of baked crackers. The peak breaking force (Newtons) of the

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center part of each cracker was obtained using a 3 mm diameter Warner Bratzler probe at a speed of 2 mm/s.

Statistics

All experiments were conducted at least four times. Data were analyzed by the one-way analysis of variance (ANOVA) procedure using the Statistical Analysis System version 6.12 (SAS Institute, Cary, NC). Significance was defined at the 5% level.

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RESULTS AND DISCUSSION

Comparison of the Two Procedures

Five commercial flours (i.e., bread, hard red spring, cracker, cookie, and cake flours) with different flour properties based on farinograph results (data not shown) were used to compare one-stage and two-stage fermentation procedures. Among these five flour samples, bread and hard red spring flours could not be made into crackers using the one-stage fermentation procedure because the resultant cracker doughs were too dry. These two flours could make crackers using the two-stage fermentation procedure, however, they baked incompletely and had higher weight, moisture content, thickness, and volume, resulting in low crispiness. Therefore, results of these two flour samples are not included in Table 2, which lists the quality parameters of baked crackers made with one-stage and two-stage fermentation procedures. It appeared that both procedures could significantly differentiate cracker qualities (e.g., weight, moisture, length, width, thickness, volume, and peak breaking force), and also exhibited similar trends in overall quality. It was obvious that crackers made with the one-stage fermentation procedure had higher values for weight, moisture content, thickness, volume and peak breaking force; however, there were no significant differences in length and width of crackers from the two different procedures made with the same flour.

When the operator handled the cracker doughs made with both types of procedures, it was found that the cracker dough made with the two-stage fermentation procedure was softer than that made with the one-stage fermentation procedure. This could be due to different amounts of CO_2 generated in these two procedures during fermentation. The amount of CO_2 can affect the density of a dough (Rogers and

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Hoseney, 1989); the more CO_2 present in a dough, the lower the density of the dough. The lower density of a cracker dough could permit faster evaporation during baking and subsequently lower cracker weight and moisture content (Pizzinatto and Hoseney 1980 and Rogers and Hoseney 1989). This was also reflected in our findings (Table 2).

The thickness, volume, and peak breaking force are related to the strength of a dough (Pizzinatto and Hoseney 1980; Rogers and Hoseney 1994). The stronger (or harder) doughs generally produced thicker, bigger, and harder crackers than the weaker (or softer) doughs. Since cracker dough made with the two-stage fermentation procedure was softer than that made with the one-stage fermentation procedure, the baked crackers made with two-stage fermentation had lower values of thickness, volume, and peak breaking force.

It should be noted that the one-stage fermentation procedure was simple and allowed 15 flour samples to be evaluated in a 48 hr period by one operator, as compared to six flour samples in the same time period when using the two-stage fermentation procedure. Because both procedures could distinguish cracker quality, and results demonstrated similar trends for the different flour samples examined, the one-stage fermentation process was selected as the choice for cracker procedure to discriminate flours for cracker making potential in the rest of this study.

Differentiation of Cracker Quality by the One-Stage Fermentation Procedure

Among 19 flour samples, bread, hard red winter, hard red spring, and cv. Madsen could not be made into crackers using the one-stage fermentation procedure because the resultant cracker doughs were too dry. Therefore, the following results do not include

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these four flour samples. Quality parameters of baked crackers are listed in Table 3. Data are ranked from the strongest to the weakest dough based on Farinograph results (data not shown). It appeared that the one-stage fermentation procedure could significantly differentiate baked cracker qualities (e.g., weight, moisture, length, width, thickness, volume, and peak breaking force) among different flour samples. Baked cracker weight varied from 3.26 g for those made from cracker flour to 4.22 g for those from cv. Chelsea flour. In general, the heavier the baked cracker, the higher the moisture content. The moisture contents of baked crackers from blend, cracker, and soft red winter flours and of commercial crackers were not significantly different (Table 3).

The size of each cracker was 5.56 cm long and 5.08 cm wide after cutting the dough sheet but prior to baking. However, after baking, the length and width of crackers had decreased 1.9 - 3.8% and 1.2 - 6.1%, respectively, due to contraction of the cracker dough (Pizzinatto and Hoseney 1980). Stronger flours (e.g., blend flour) resulted in greater contraction. These observations are in general agreement with previously published reports (Creighton and Hoseney 1990b, Levine and Drew 1994).

The thickness of crackers after baking ranged from 0.40 to 0.54 cm. Crackers made from blend, cv. Dynasty and cv. Clark flour samples were the thickest, whereas those made from cv. Frankenmuth sample were the thinnest. The thickness of the baked crackers appears to correlate with the dough strength of the flour. Similar findings were also obtained by Pizzinatto and Hoseney (1980) and Rogers and Hoseney (1994).

The volume of baked crackers varied from 16.3 to 21.3 cc. It was assumed that there would be a relationship between the thickness and volume. However, some thinner baked crackers did not exhibit smaller volumes due to their smaller degree of shrinkage

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and the presence of blisters on the top surface of the baked cracker. Based on the volume, cracker and cv. Frankenmuth flour samples could produce crackers most similar to commercial crackers.

The peak breaking forces measured by texture analysis were significantly different (6.2 - 11.9 N) among baked crackers. Baked crackers made from blend and cracker flour samples had the highest peak breaking forces, and those from cv. Frankenmuth and cv. Excel samples had the lowest. Results from statistical analyses revealed that the peak breaking force was related to the dough strength. Baked crackers made from stronger flours (e.g., blend flour) had higher peak breaking forces than those from weaker flours (e.g., cv. Frankenmuth flour). Overall, it appeared that the cracker flour sample could be used to make the best quality of crackers, as compared to commercial crackers.

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SUMMARY

This study demonstrated that both one-stage and two-stage cracker-making procedures could be used to distinguish differences among flours for cracker making potential, and yielded similar trends in their overall (i.e., weight, moisture, length, width, thickness, volume, and peak breaking force) results on cracker qualities. Crackers made from the one-stage fermentation procedure had higher values for weight, moisture content, thickness, volume, and peak breaking force, however were not significantly different in length and width when compared with crackers from the same flour made with the two-stage procedure. Using the one-stage fermentation procedure, the cracker flour sample could produce crackers most similar to the overall quality of commercial crackers. The one-stage procedure has the potential to be successfully used for screening flours for cracker-baking quality, with an operator efficiency factor of 2.5 times more than the two-stage procedure.

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Table 1 Physicochemical Properties of Wheat Flours

Flour Sample[1]	Moisture (%)	Ash (%, db)	Protein (%, db)	Damaged Starch Content (%, db)	Water Absorption (%, db)
Bread	11.3	0.33	10.2	8.7	60.9
Hard Red Winter	12.7	0.51	11.7	9.3	62.5
Hard Red Spring	13.2	0.39	12.5	9.9	64.6
Blend[2]	12.4	0.50	10.6	8.1	59.5
Dynasty	12.1	0.46	7.4	6.8	55.7
Clark	11.9	0.50	8.2	7.6	59.1
Cracker	13.4	0.25	7.6	6.0	51.9
Madsen	11.2	0.43	8.7	11.7	64.7
Soft Red Winter	12.0	0.47	9.7	7.4	56.3
Cookie	11.6	0.32	7.4	5.8	53.7
Lewjain	12.4	0.36	8.2	8.5	58.0
Freedom	11.9	0.40	7.2	7.4	56.6
Hyak	12.5	0.32	6.3	9.1	57.8
Caldwell	11.8	0.33	7.6	7.6	56.0
Cake	12.1	0.31	6.8	4.9	53.2
Chelsea	10.8	0.49	7.2	6.3	56.6
Frankenmuth	11.9	0.50	6.4	6.4	53.1
Excel	11.4	0.43	7.6	6.0	55.6
Tres	11.2	0.47	8.5	7.6	58.6

[1]Samples are ranked from the strongest to the weakest flours based on farinograph results.

[2]Blend: 50% soft red winter and 50% hard red winter.

Table 2 Cracker Quality by Comparison of Two Different Cracker-Making Procedures (One-Stage and Two-Stage) [1]

Flour Sample [2]	***Weight (g)***	***Moisture (%)***	***Length (cm)***	***Width (cm)***	**Thickness (cm)**	**Volume (cc)**	**Peak Breaking Force (N)** [3]
One Stage							

Table 2 Cracker Quality by Comparison of Two Different Cracker-Making Procedures (One-Stage and Two-Stage) [1]

Flour Sample[2]	Weight (g)	Moisture (%)	Length (cm)	Width (cm)	Thickness (cm)	Volume (cc)	Peak Breaking Force (N)[3]
One Stage							
Cracker flour	3.26b±0.12	4.80c±0.24	5.44ab±0.04	5.02a±0.04	0.49a±0.01	18.0a±0.5	10.4a±1.4
Cookie flour	3.73a±0.07	7.21a±0.37	5.41bc±0.12	4.97bc±0.07	0.45b±0.02	18.5a±0.5	9.3b±1.2
Cake flour	3.65a±0.06	6.01b±0.29	5.37cd±0.07	4.87d±0.05	0.41c±0.02	16.3b±0.5	10.1a±1.0
Two Stage							
Cracker flour	2.82c±0.13	1.81e±0.04	5.41bc±0.05	5.02a±0.03	0.37d±0.02	16.0b±0.5	8.9b±0.9
Cookie flour	2.87c±0.12	2.91d±0.07	5.40bc±0.06	5.00ab±0.04	0.33e±0.02	16.0b±0.9	6.1c±0.6
Cake flour	2.68d±0.07	1.45f±0.03	5.33d±0.06	4.87d±0.04	0.28f±0.03	14.3c±0.5	6.4c±0.5

[1]Values in the table are: means ± standard deviation. Different letters within the same column designate significant differences among the samples at α=0.05.

[2]Samples are ranked from the strongest to the weakest flours based on farinograph results.

[3]From texture analyses of the crackers. N: Newtons.

Table 3. Cracker Quality Using a One-Stage Fermentation Procedure

Table 3 Cracker Quality Using a One-Stage Fermentation Procedure [1]

Flour Sample[2]	Weight (g)	Moisture (%)	Length (cm)	Width (cm)	Thickness (cm)	Volume (cc)	Peak Breaking Force (N)[3]
Blend[4]	3.59ef±0.11	5.19h±0.23	5.37ef±0.07	4.77i±0.03	0.52ab±0.01	19.6d±0.5	11.9c±2.0
Dynasty	3.53fg±0.11	6.30ef±0.29	5.45a±0.11	4.97bc±0.04	0.52cd±0.03	20.2c±0.4	7.5jk±0.9
Clark	3.72cd±0.14	7.59c±0.32	5.43abcd±0.09	4.92def±0.03	0.54a±0.02	20.7b±0.5	9.3fg±0.8
Cracker	3.26j±0.12	4.80ij±0.24	5.44ab±0.04	5.02a±0.04	0.49cde±0.01	18.0g±0.5	10.4d±1.4
Soft Red Winter	3.46gh±0.08	4.58j±0.03	5.40cde±0.07	4.92cdef±0.06	0.46fg±0.02	17.0h±0.8	6.4l±0.6
Cookie	3.73c±0.07	7.21d±0.37	5.41bcd±0.12	4.97bcd±0.07	0.45g±0.02	18.5cd±0.5	9.3fg±1.2
Lewjain	4.02b±0.15	9.17a±0.58	5.43abc±0.07	4.85h±0.02	0.48cdef±0.03	20.4bc±0.9	9.0gh±1.0
Freedom	3.63e±0.10	7.35cd±0.36	5.35f±0.06	4.88fgh±0.04	0.50bc±0.03	20.7bc±0.5	7.9ij±0.6
Hyak	4.02b±0.18	7.58c±0.36	5.40de±0.06	4.79i±0.04	0.52ab±0.02	19.3d±0.5	8.8gh±0.9
Caldwell	3.63e±0.10	6.54e±0.28	5.41bcd±0.12	4.93cdef±0.03	0.52ab±0.03	18.6e±0.9	9.8ef±1.3
Cake	3.65de±0.06	6.01fg±0.29	5.35ef±0.07	4.87gh±0.05	0.41h±0.02	16.3i±0.5	10.1de±1.0
Chelsea	4.22a±0.14	8.64b±0.48	5.40cde±0.09	4.84h±0.02	0.48def±0.01	21.3a±1.0	8.4hi±1.1
Frankenmuth	3.37i±0.08	6.37e±0.23	5.44ab±0.07	4.93cde±0.02	0.40h±0.03	18.0g±0.9	6.2l±0.7
Excel	3.47gh±0.10	5.71g±0.33	5.38ef±0.06	5.01ab±0.03	0.45g±0.02	19.2d±0.4	6.8kl±0.8
Tres	3.40hi±0.08	4.16k±0.22	5.36f±0.09	4.91efg±0.01	0.47efg±0.02	18.5ef±0.6	9.1fg±1.1
Nabisco	3.01k±0.02	4.58j±0.14	5.07h±0.04	4.87gh±0.04	0.52ab±0.03	18.3efg±0.5	14.5a±1.6
Meijer	2.86l±0.02	5.10hi±0.16	5.13g±0.04	4.93cdef±0.04	0.48cdef±0.03	18.0fg±0.0	13.1b±2.4

[1]Values in the table are: means ± standard deviation. Different letters within the same column designate significant differences among the samples at α=0.05.

[2]Ranked according to farinograph dough strength results; Nabisco and Meijer are brand name commercial crackers used for comparison.

[3]From texture analyses of the crackers. N: Newtons.

[4]Blend: 50% soft red winter and 50% hard red winter.

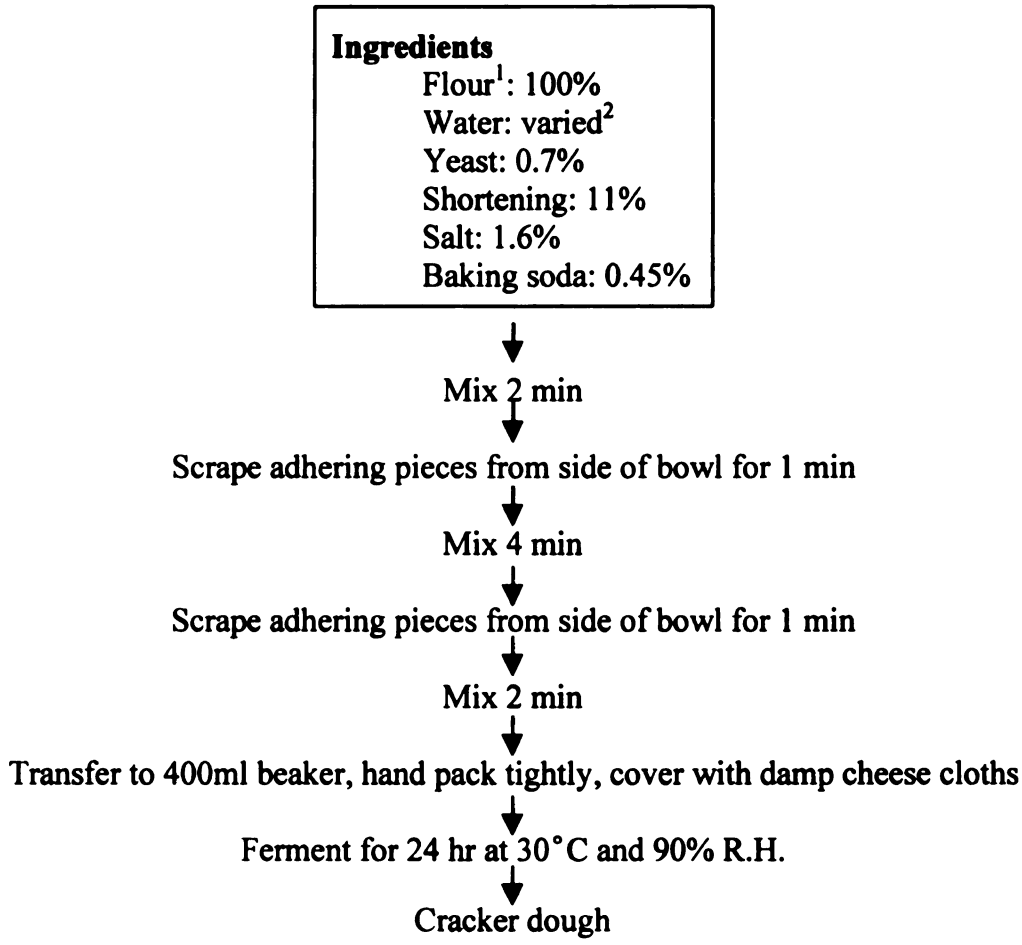

Figure 1 One-Stage Fermentation Procedure for Making Crackers

[1]Wheat flour samples: 100g flour base with 14% moisture basis.
[2]See Materials and Methods section.

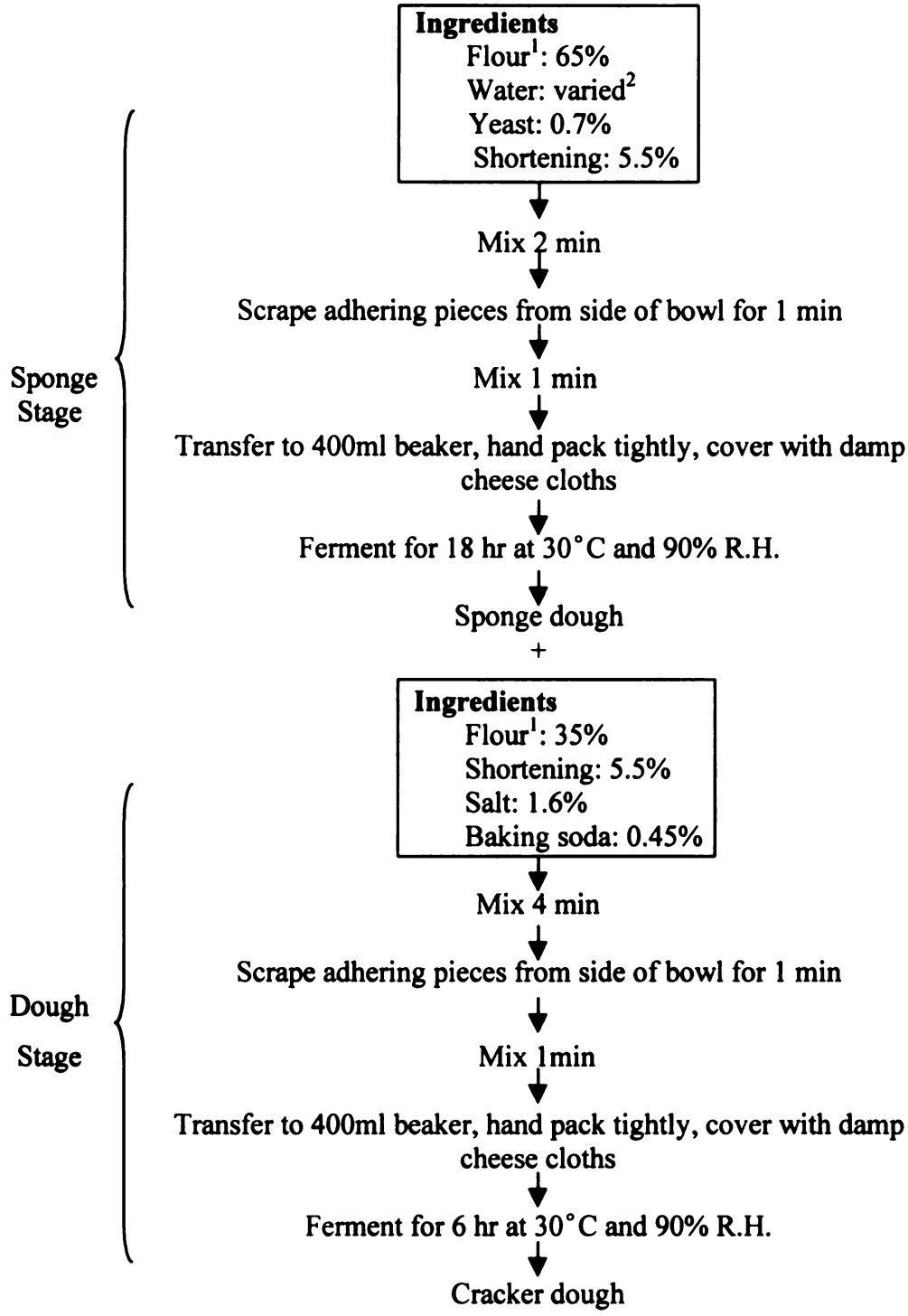

Figure 2 Two-Stage Fermentation Procedure for Making Crackers[3]

[1]Wheat flour samples: 100g flour base with 14% moisture basis.
[2]See Materials and Methods section.
[3]Based on the procedure of Faridi and Johnson (1978) and Pizzinatto and Hoseney (1980) with some modifications.

APPENDIX VIII

RAW DATA

A. Chemical Properties

Table A1 Chemical Properties of Wheat Flours

Samples	Moisture Content (%)		Ash Content (%, db)		Protein Content (%, db)		Damaged Starch Content (%, db)	
ESWW[1]								
Chelsea	10.82	10.73	0.48	0.49	7.21	7.19	6.32	6.30
Frankenmuth	11.91	11.84	0.50	0.49	6.22	6.54	6.35	6.45
WSWW[1]								
Lewjain	12.39	12.44	0.36	0.36	7.89	8.15	8.47	8.51
Madsen	11.22	11.11	0.43	0.43	8.74	8.66	12.38	11.07
Club								
Hyak	12.60	12.45	0.31	032	6.42	6.25	9.0.7	9.13
Tres	11.17	11.27	0.48	0.45	8.49	8.48	7.63	7.63
SRW[1]								
Caldwell	11.74	11.75	0.31	0.34	7.63	7.53	7.66	7.60
Clark	11.93	11.80	0.50	0.49	8.26	8.11	7.53	7.73
Dynasty	12.13	12.07	0.46	0.45	7.83	7.02	6.70	6.84
Excel	11.44	11.33	0.44	0.41	7.65	7.48	6.03	6.03
Freedom	11.85	11.90	0.42	0.38	7.28	7.12	7.38	7.38
Commercial Flours								
Cake	12.07	12.13	0.32	0.30	6.36	7.19	4.90	4.94
Cookie	11.56	11.54	0.33	0.31	7.39	7.40	5.83	5.81
Cracker	13.39	13.48	0.24	0.25	7.55	7.64	6.03	6.03
Bread	11.25	11.29	0.35	0.30	10.21	10.20	8.71	8.67
Hard red spring	13.17	13.14	0.43	0.35	12.66	12.42	9.94	9.90
Soft red winter	11.99	11.97	0.47	0.47	9.80	9.60	7.35	7.41
Hard red winter	12.71	12.75	0.52	0.50	11.54	11.78	9.31	9.31
Blend[2]	12.41	12.31	0.48	0.51	10.51	10.67	8.11	8.13

[1]ESWW: Eastern soft white winter; WSWW: Western soft white winter; SRW: Soft red winter.

[2]Blend: 50% soft red winter and 50% hard red winter.

B. Physical Properties

Table B1 Physical Properties of Wheat Flours

Samples	Arrival time (min)	Mixing time (min)	Dept. Time[1] (min)	Stab.[1] (min)	MTI[1] (BU)	Water abs.[1] (%, db)	Falling number (sec)
ESWW[2]							
Chelsea	0.75	1.33	2.50	1.75	115	56.64	354.0
Frankenmuth	0.67	1.00	2.00	1.33	120	53.07	377.0
WSWW[2]							
Lewjain	0.92	1.25	3.00	2.08	100	58.04	348.3
Madsen	1.50	2.17	3.25	1.75	85	64.66	300.3
Club							
Hyak	1.00	1.25	2.25	1.25	110	57.77	308.5
Tres	0.83	1.33	1.75	0.92	145	58.63	395.3
SRW[2]							
Caldwell	0.50	1.00	2.00	1.50	110	56.02	380.3
Clark	1.17	2.00	4.00	2.83	75	59.13	392.3
Dynasty	1.00	1.33	2.17	1.17	70	55.70	362.5
Excel	1.08	1.42	2.50	1.42	140	55.64	345.3
Freedom	0.75	1.17	3.67	2.92	105	56.56	375.5
Commercial Flours							
Cake	0.67	1.25	3.75	3.08	110	53.15	398.0
Cookie	0.83	1.25	2.25	1.42	95	53.68	316.0
Cracker	0.83	1.08	2.42	1.58	75	51.93	356.5
Bread	1.08	2.08	12.00	10.92	5	60.87	242.5
Hard red spring	3.33	7.00	13.00	9.67	40	64.62	268.5
Soft red winter	0.50	1.00	4.50	4.00	95	56.29	321.5
Hard red winter	0.80	3.00	16.00	25.20	20	62.51	301.3
Blend[3]	0.75	1.50	8.50	7.75	40	59.52	317.3

[1]Dept. time: Departure time; Stab.: Stability; MTI: Mixing tolerance index; Water abs.: Optimal water absorption.

[2]ESWW: Eastern soft white winter; WSWW: Western soft white winter; SRW: Soft red winter.

[3]Blend: The mixture of 50% soft red winter and 50% hard red winter.

C. Rheological Data

Table C1 G* (Pa) of Different Frankenmuth Dough Samples

T (min)	ω (rad/s)	Non-Developed Dough		Dough Partially Developed with Shear Deformation		Dough Partially Developed with Extensional Deformation		Developed Dough	
0.06	6.28	11470.29	13961.04	14457.68	17371.06	30366.51	34566.61	32290.22	32601.13
0.25	9.24	13978.96	16752.08	15615.1	29384.91	39276.57	33676.49	36993.33	37480.71
0.43	13.51	16901.07	20031.96	17878.57	36378.32	40517.00	42517.16	41529.59	42308.88
0.60	19.85	20308.22	23758.06	20396.99	36387.2	44609.25	47290.05	46639.57	47531.11
0.77	29.15	24221.47	28316.54	23960.97	38130.89	51578.71	51174.70	52081.00	53221.61
0.92	42.79	28799.96	33832.14	26547.63	39702.91	57152.89	57152.93	58558.5	59677.65
1.08	62.83	33736.22	39525.89	30678.59	45432.14	69526.46	58920.68	64782.9	66625.45
1.19	92.36	39038.25	45565.77	34638.93	51347.32	60769.04	80927.14	73351.64	74589.45
1.27	157.71	46238.77	54053.16	40705.95	60086.3	78592.94	93578.84	85919.24	86167.33
1.33	245.04	53500.91	70023.9	46505.67	67197.5	88475.19	98105.07	95116.04	91252.12
1.37	383.27	59690.32	49364.88	100577.13	108149.53	100394.4	104433.8	79459.8	83360.14
1.41	628.32	174422.72	1298915.5	1128478.75	1050947.38	74590.73	93948.59	895627.38	257703.97

Table C2 G* (Pa) of Different Cracker Dough Samples

T (min)	ω (rad/s)	Non-Developed Dough		Dough Partially Developed with Shear Deformation		Dough Partially Developed with Extensional Deformation		Developed Dough	
0.06	6.28	5159.29	4964.86	8337.21	6029.89	7768.88	11178.17	26723.57	24362.76
0.25	9.24	7482.19	6777.03	10724.48	7233.69	9223.04	13448.96	30553.48	28261.18
0.43	13.51	9353.13	8377.25	13818.67	8851.53	10880.47	15719.18	34321.86	32498.18
0.60	19.85	11263.77	9487.03	17426.65	10590.04	12780.25	18328.66	38402.4	37482.64
0.77	29.15	13445.01	10762.03	21479.5	12756.67	14881.16	21159.64	42872.57	43473.71
0.92	42.79	15077.48	12120.87	26178.44	15093.79	17142.92	24469.31	47723.87	50151.89
1.08	62.83	17563.96	13644.22	31617.29	17639.51	19709.58	28015.08	53380.1	57528.45
1.19	92.36	20090.19	15519.44	37621.33	20386.04	22520.82	32096.81	59612.59	65024.58
1.27	157.71	27222.94	22300.12	46325.76	27417.08	26774.69	38837.96	69357.69	76313.65
1.33	245.04	43311.75	38606.84	57008.29	31833.22	30332.7	44878.82	81201.22	81042.66
1.37	383.27	100315.51	56605.07	49672.6	78213.38	42894.35	48411.73	101717.52	141469.44
1.41	628.32	863948.38	735857.19	681730.19	754423.94	133549.95	35591.34	287403.06	631928.19

Table C3 G* (Pa) of Different Caldwell Dough Samples

T (min)	ω (rad/s)	Non-Developed Dough		Dough Partially Developed with Shear Deformation		Dough Partially Developed with Extensional Deformation		Developed Dough	
0.06	6.28	7320.49	7533.58	732106	12151.39	20170.22	17960.92	39914.98	29642.94
0.25	9.24	9416.21	9554.77	8333.19	14975.87	23100.21	19736.42	44309.68	34839.42
0.43	13.51	11996.51	12005.51	9589.67	20228.13	26217.04	22029.65	48834.63	40132.52
0.60	19.85	15246.39	14822.32	11158.51	22919.75	29425.57	25087.62	53593.46	45860.87
0.77	29.15	19040.45	18266.48	12815.57	26104.58	33909.04	28628.94	58975.6	52045.9
0.92	42.79	23675.13	22035.69	15142.21	30579.88	38169.61	33239.61	64982.41	59045.93
1.08	62.83	27967.96	26232.29	17187.12	34563.51	43246.29	38313.19	71242.28	66854.99
1.19	92.36	32373.53	30754.02	19179.24	40143.02	48883.18	43858.0	79011.79	75205.23
1.27	157.71	39499.73	37586.41	25052.42	51139.57	58674.79	53354.35	91809.21	87453.94
1.33	245.04	47603.82	56110.75	29973.0	66064.83	66931.45	62197.8	102136.42	98891.66
1.37	383.27	12275.43	88091.23	51206.14	73933.3	78168.7	70796.12	91961.16	66136.34
1.41	628.32	864607.69	1184463.3	2339624	1017565.31	665078.0	127973.07	859405.88	1064923.62

Table C4 G* (Pa) of Different Freedom Dough Samples

T (min)	ω (rad/s)	Non-Developed Dough		Dough Partially Developed with Shear Deformation		Dough Partially Developed with Extensional Deformation		Developed Dough	
0.06	6.28	2217.7	1784.69	2370.28	2723.4	17294.83	16105.1	34035.39	30799.99
0.25	9.24	2550.86	2017.31	2722.68	3199.26	19922.98	18635.77	40039.77	35429.98
0.43	13.51	3164.8	2438.03	3174.39	3673.82	22720.47	21432.57	45677.85	39896.68
0.60	19.85	4004.25	3018.11	3712.59	4304.86	25797.26	24698.24	51748.27	44891.41
0.77	29.15	5041.53	3743.54	4330.21	4987.13	29354.96	28336.76	58031.54	50202.25
0.92	42.79	6224.21	4629.92	4968.04	5590.35	33348.12	32325.98	65302.22	56612.83
1.08	62.83	7625.85	5943.62	5735.89	6448.65	37689.7	37184.05	73338.13	63257.18
1.19	92.36	10019.31	8581.55	7755.71	8417.33	43218.63	42470.43	81961.82	70968.01
1.27	157.71	16303.21	13524.6	11067.29	13291.81	52509.99	52606.69	93105.28	81391.7
1.33	245.04	23536.36	23868.78	20551.34	22104.61	60556.62	61544.57	101715.59	87660.62
1.37	383.27	51877.04	48201.83	24676.59	56474.5	73812.88	69586.79	72750.93	57705.82
1.41	628.32	926661.94	4545991.5	739273.06	690594.5	152314.33	296689.47	545664.56	1267417.88

Table C5 G* (Pa) of Different Blend[1] Dough Samples

t (min)	ω (rad/s)	Non-Developed Dough		Dough Partially Developed with Shear Deformation		Dough Partially Developed with Extensional Deformation		Developed Dough	
0.06	6.28	6523.26	5697.1	6103.07	6617.56	9837.91	10455.52	30929.54	28358.18
0.25	9.24	7888.28	7300.36	9172.07	9004.31	11288.2	12086.71	35476.84	32650.62
0.43	13.51	9389.8	9217.32	10729.95	9603.34	13023.33	13939.07	40010.94	37066.43
0.60	19.85	11162.48	11558.55	12724.55	10195.27	14995.5	16115.65	45337.74	42115.99
0.77	29.15	13252.98	14123.96	15689.62	13878.9	17287.66	18613.48	51216.74	47636.54
0.92	42.79	15540.7	17115.48	16779.56	17765.83	19955.85	21366.12	57885.36	53810.02
1.08	62.83	17888.99	20213.72	18400.16	19760.55	22854.74	24570.32	65154.02	60555.93
1.19	92.36	20218.94	23202.82	21059.0	22432.89	26415.73	28044.41	72712.59	68560.27
1.27	157.71	25666.79	28590.74	27102.82	28896.45	31795.49	33235.8	84955.99	80645.13
1.33	245.04	37476.04	42504.47	42940.71	40345.77	35481.13	37470.7	96145.38	91284.8
1.37	383.27	51390.49	45707.79	34874.99	48766.56	43378.48	43961.37	130272.55	133211.44
1.41	628.32	972155.31	299251.59	9843060	965991.38	503314.12	494733.66	339841.69	425916.34

[1]Blend: The mixture of 50% soft red winter and 50% hard red winter.

D. LSCM Images

(D1) Frankenmuth Sample

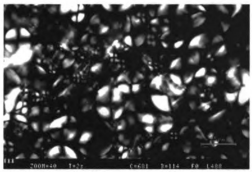

Figure D1-1-1-1 Starch Granules of Non-Developed Dough

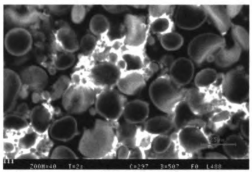

Figure D1-1-1-2 Protein Matrix of Non-Developed Dough

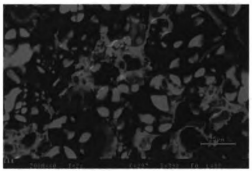

Figure D1-1-1-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

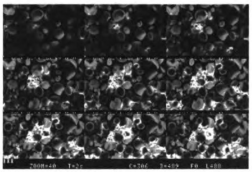

Figure D1-1-1-4 Z-Sectionings of Non-Developed Dough

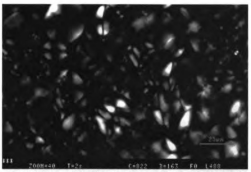

Figure D1-1-2-1 Starch Granules of Non-Developed Dough

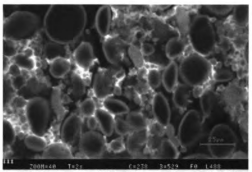

Figure D1-1-2-2 Protein Matrix of Non-Developed Dough

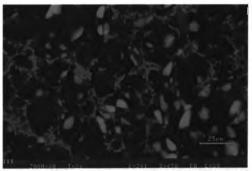

Figure D1-1-2-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

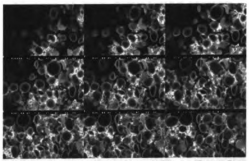

Figure D1-1-2-4 Z-Sectionings of Non-Developed Dough

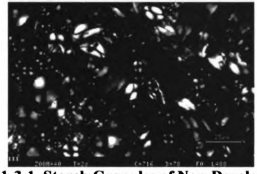

Figure D1-1-3-1 Starch Granules of Non-Developed Dough

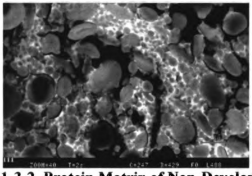

Figure D1-1-3-2 Protein Matrix of Non-Developed Dough

Figure D1-1-3-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

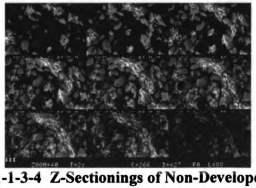

Figure D1-1-3-4 Z-Sectionings of Non-Developed Dough

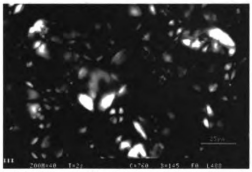

Figure D1-1-4-1 Starch Granules of Non-Developed Dough

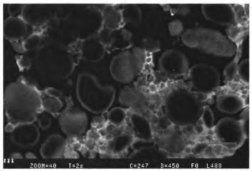

Figure D1-1-4-2 Protein Matrix of Non-Developed Dough

Figure D1-1-4-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

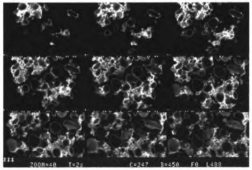

Figure D1-1-4-4 Z-Sectionings of Non-Developed Dough

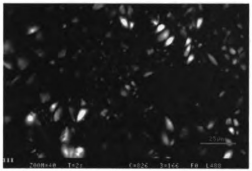

Figure D1-2-1-1 Starch Granules of Partially Developed Dough with Shear Deformation

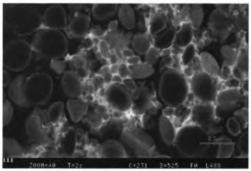

Figure D1-2-1-2 Protein Matrix of Partially Developed Dough with Shear Deformation

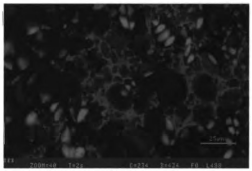

Figure D1-2-1-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

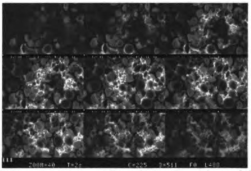

Figure D1-2-1-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

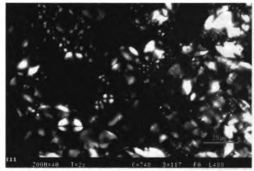

Figure D1-2-2-1 Starch Granules of Partially Developed Dough with Shear Deformation

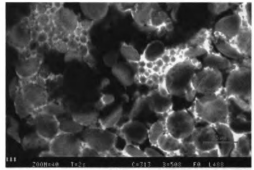

Figure D1-2-2-2 Protein Matrix of Partially Developed Dough with Shear Deformation

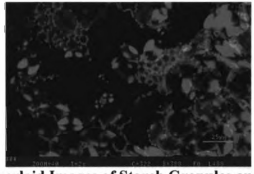

Figure D1-2-2-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

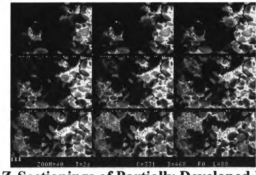

Figure D1-2-2-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

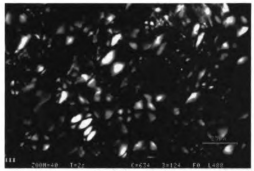

Figure D1-2-3-1 Starch Granules of Partially Developed Dough with Shear Deformation

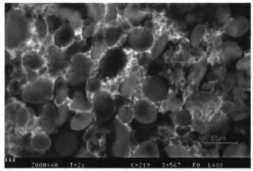

Figure D1-2-3-2 Protein Matrix of Partially Developed Dough with Shear Deformation

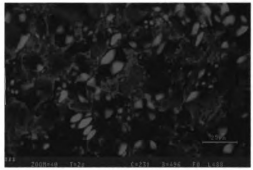

Figure D1-2-3-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

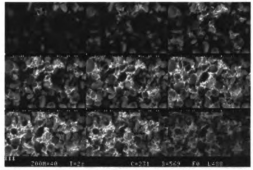

Figure D1-2-3-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

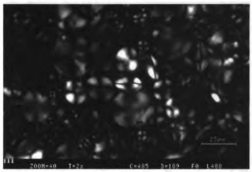

Figure D1-2-4-1 Starch Granules of Partially Developed Dough with Shear Deformation

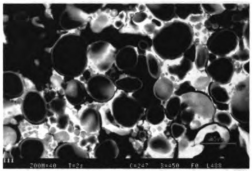

Figure D1-2-4-2 Protein Matrix of Partially Developed Dough with Shear Deformation

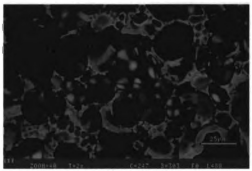

Figure D1-2-4-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

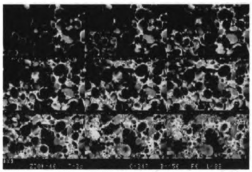

Figure D1-2-4-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

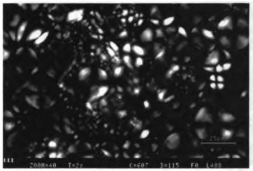

Figure D1-3-1-1 Starch Granules of Partially Developed Dough with Extensional Deformation

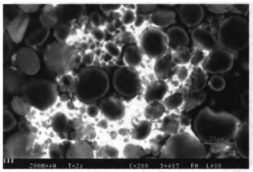

Figure D1-3-1-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

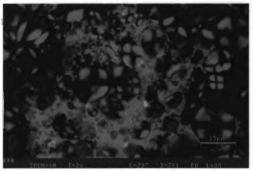

Figure D1-3-1-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

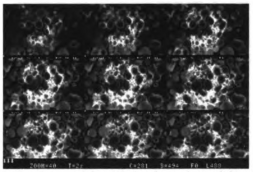

Figure D1-3-1-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

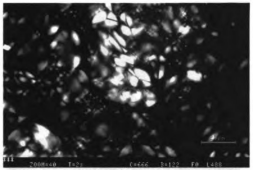

Figure D1-3-2-1 Starch Granules of Partially Developed Dough with Extensional Deformation

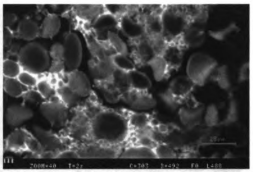

Figure D1-3-2-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

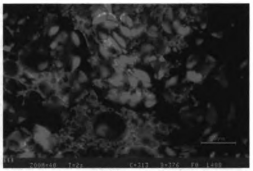

Figure D1-3-2-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

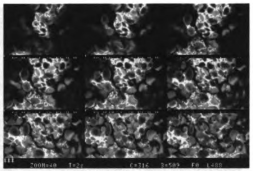

Figure D1-3-2-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

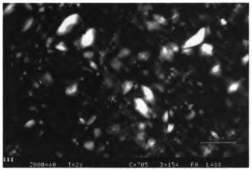

Figure D1-3-3-1 Starch Granules of Partially Developed Dough with Extensional Deformation

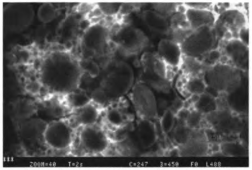

Figure D1-3-3-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

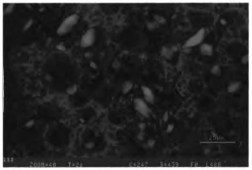

Figure D1-3-3-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

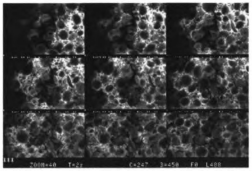

Figure D1-3-3-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

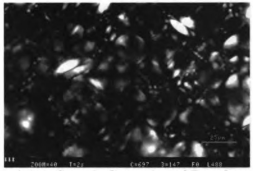

Figure D1-4-1-1 Starch Granules of Developed Dough

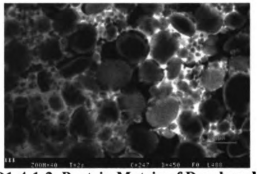

Figure D1-4-1-2 Protein Matrix of Developed Dough

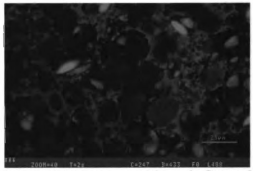

Figure D1-4-1-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

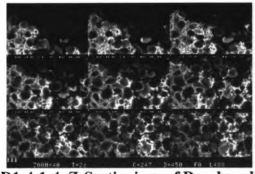

Figure D1-4-1-4 Z-Sectionings of Developed Dough

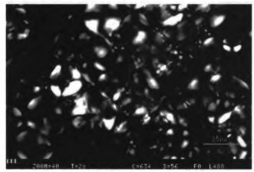

Figure D1-4-2-1 Starch Granules of Developed Dough

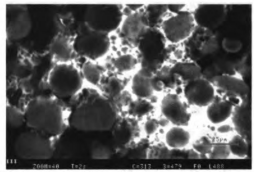

Figure D1-4-2-2 Protein Matrix of Developed Dough

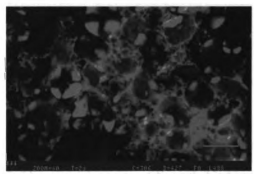

Figure D1-4-2-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

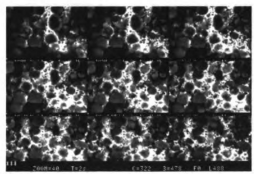

Figure D1-4-2-4 Z-Sectionings of Developed Dough

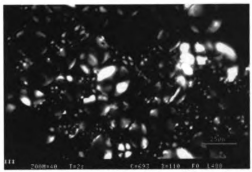

Figure D1-4-3-1 Starch Granules of Developed Dough

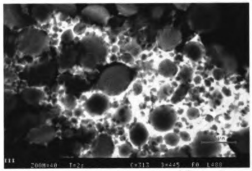

Figure D1-4-3-2 Protein Matrix of Developed Dough

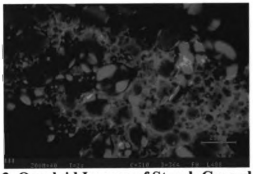

Figure D1-4-3-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

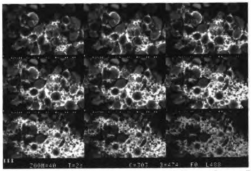

Figure D1-4-3-4 Z-Sectionings of Developed Dough

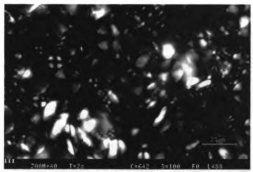

Figure D1-4-4-1 Starch Granules of Developed Dough

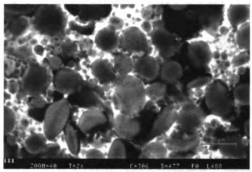

Figure D1-4-4.2 Protein Matrix of Developed Dough

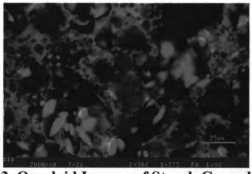

Figure D1-4-4-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

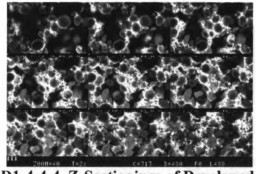

Figure D1-4-4-4 Z-Sectionings of Developed Dough

(D2) Cracker Sample

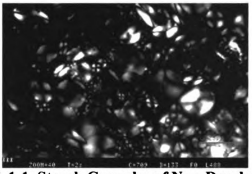

Figure D2-1-1-1 Starch Granules of Non-Developed Dough

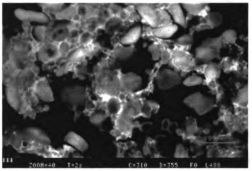

Figure D2-1-1-2 Protein Matrix of Non-Developed Dough

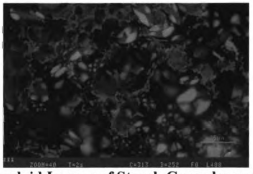

Figure D2-1-1-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

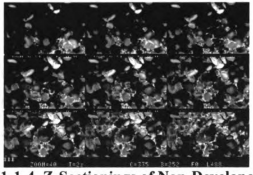

Figure D2-1-1-4 Z-Sectionings of Non-Developed Dough

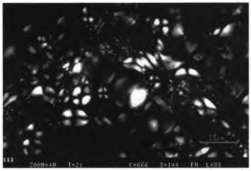

Figure D2-1-2-1 Starch Granules of Non-Developed Dough

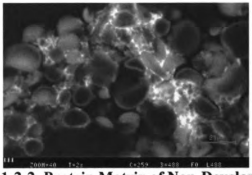

Figure D2-1-2-2 Protein Matrix of Non-Developed Dough

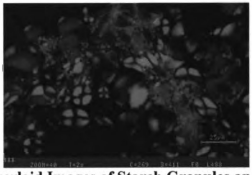

Figure D2-1-2-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

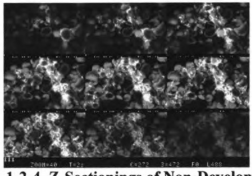

Figure D2-1-2-4 Z-Sectionings of Non-Developed Dough

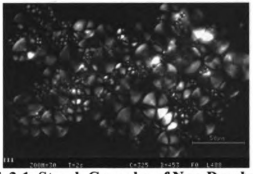

Figure D2-1-3-1 Starch Granules of Non-Developed Dough

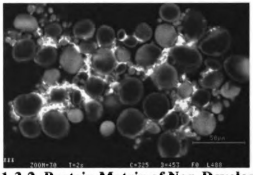

Figure D2-1-3-2 Protein Matrix of Non-Developed Dough

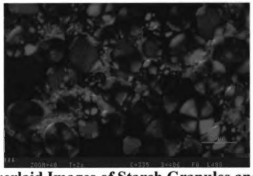

Figure D2-1-3-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

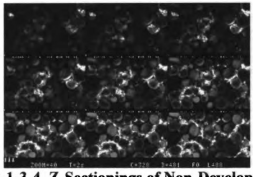

Figure D2-1-3-4 Z-Sectionings of Non-Developed Dough

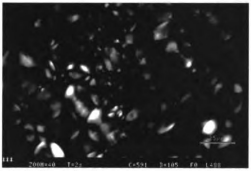

Figure D2-1-4-1 Starch Granules of Non-Developed Dough

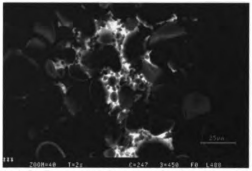

Figure D2-1-4-2 Protein Matrix of Non-Developed Dough

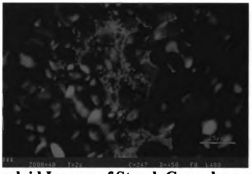

Figure D2-1-4-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

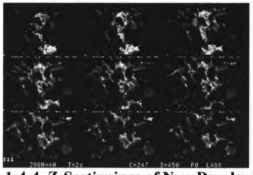

Figure D2-1-4-4 Z-Sectionings of Non-Developed Dough

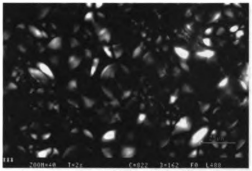

Figure D2-2-1-1 Starch Granules of Partially Developed Dough with Shear Deformation

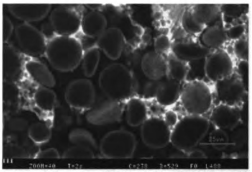

Figure D2-2-1-2 Protein Matrix of Partially Developed Dough with Shear Deformation

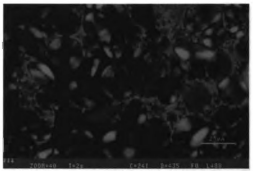

Figure D2-2-1-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

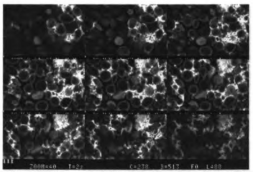

Figure D2-2-1-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

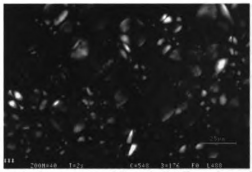

Figure D2-2-2-1 Starch Granules of Partially Developed Dough with Shear Deformation

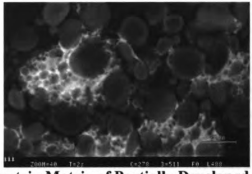

Figure D2-2-2-2 Protein Matrix of Partially Developed Dough with Shear Deformation

Figure D2-2-2-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

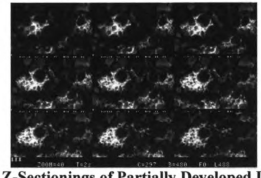

Figure D2-2-2-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

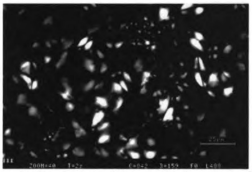

Figure D2-2-3-1 Starch Granules of Partially Developed Dough with Shear Deformation

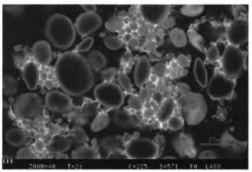

Figure D2-2-3-2 Protein Matrix of Partially Developed Dough with Shear Deformation

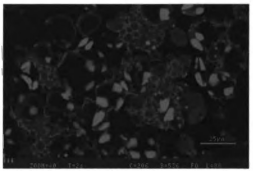

Figure D2-2-3-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

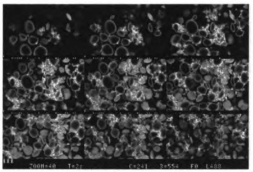

Figure D2-2-3-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

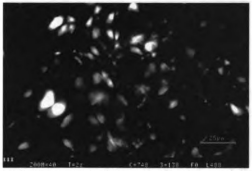

Figure D2-2-4-1 Starch Granules of Partially Developed Dough with Shear Deformation

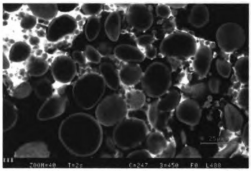

Figure D2-2-4-2 Protein Matrix of Partially Developed Dough with Shear Deformation

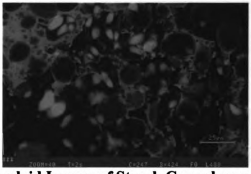

Figure D2-2-4-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

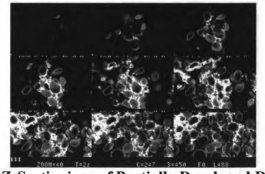

Figure D2-2-4-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

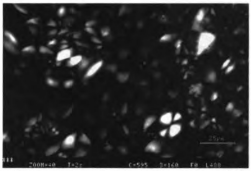

Figure D2-3-1-1 Starch Granules of Partially Developed Dough with Extensional Deformation

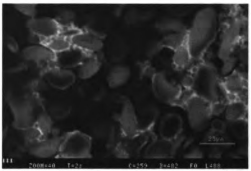

Figure D2-3-1-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

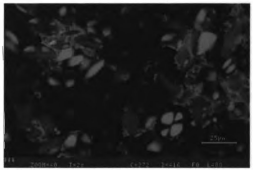

Figure D2-3-1-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

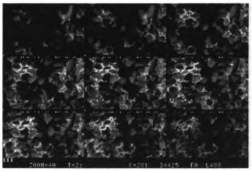

Figure D2-3-1-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

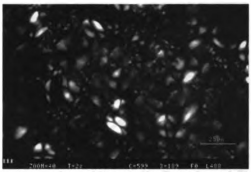

Figure D2-3-2-1 Starch Granules of Partially Developed Dough with Extensional Deformation

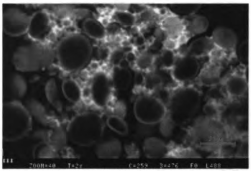

Figure D2-3-2-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

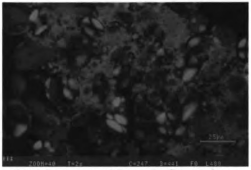

Figure D2-3-2-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

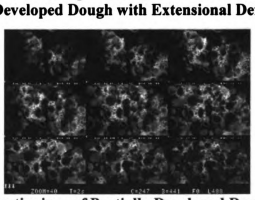

Figure D2-3-2-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

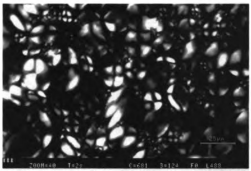

Figure D2-3-3-1 Starch Granules of Partially Developed Dough with Extensional Deformation

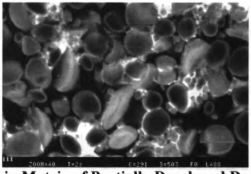

Figure D2-3-3-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

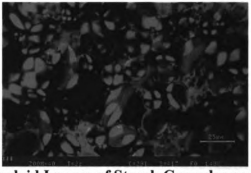

Figure D2-3-3-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

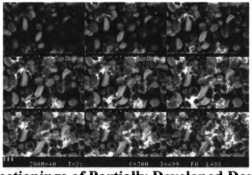

Figure D2-3-3-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

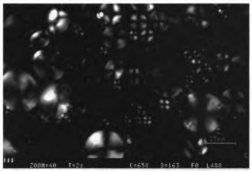

Figure D2-3-4-1 Starch Granules of Partially Developed Dough with Extensional Deformation

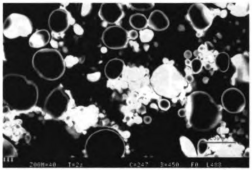

Figure D2-3-4-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

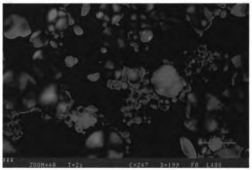

Figure D2-3-4-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

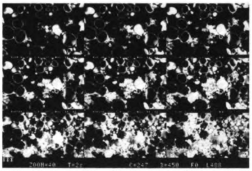

Figure D2-3-4-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

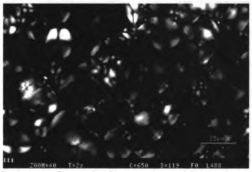

Figure D2-4-1-1 Starch Granules of Developed Dough

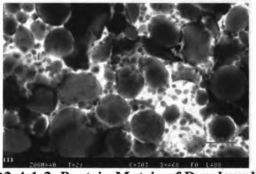

Figure D2-4-1-2 Protein Matrix of Developed Dough

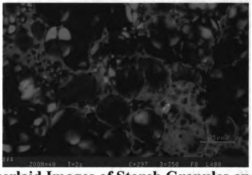

Figure D2-4-1-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

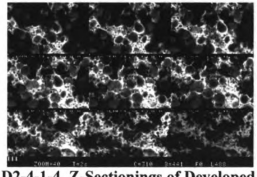

Figure D2-4-1-4 Z-Sectionings of Developed Dough

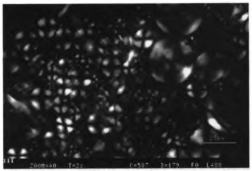

Figure D2-4-2-1 Starch Granules of Developed Dough

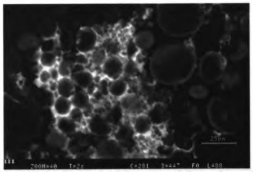

Figure D2-4-2-2 Protein Matrix of Developed Dough

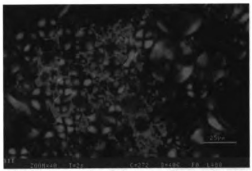

Figure D2-4-2-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

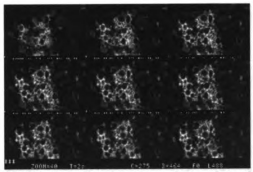

Figure D2-4-2-4 Z-Sectionings of Developed Dough

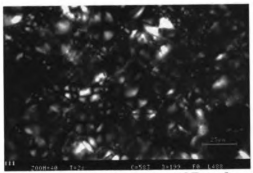

Figure D2-4-3-1 Starch Granules of Developed Dough

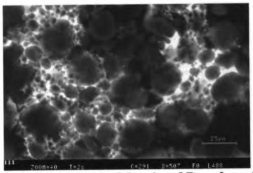

Figure D2-4-3-2 Protein Matrix of Developed Dough

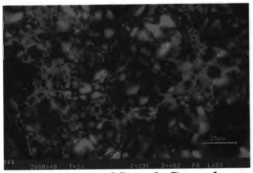

Figure D2-4-3-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

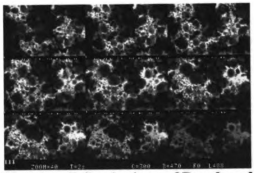

Figure D2-4-3-4 Z-Sectionings of Developed Dough

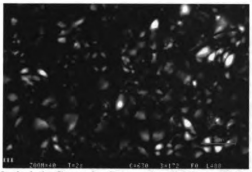

Figure D2-4-4-1 Starch Granules of Developed Dough

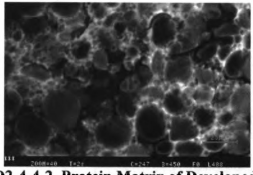

Figure D2-4-4-2 Protein Matrix of Developed Dough

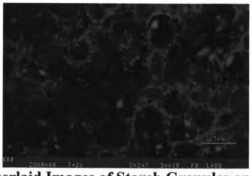

Figure D2-4-4-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

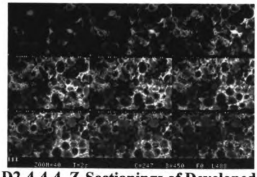

Figure D2-4-4-4 Z-Sectionings of Developed Dough

(D3) Caldwell Sample

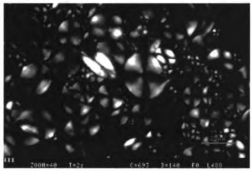

Figure D3-1-1-1 Starch Granules of Non-Developed Dough

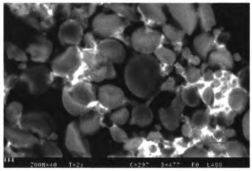

Figure D3-1-1-2 Protein Matrix of Non-Developed Dough

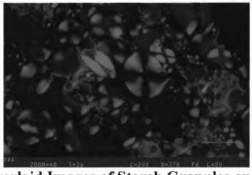

Figure D3-1-1-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

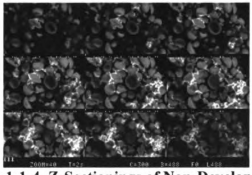

Figure D3-1-1-4 Z-Sectionings of Non-Developed Dough

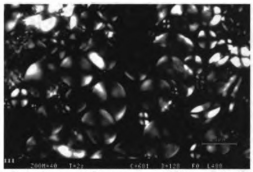

Figure D3-1-2-1 Starch Granules of Non-Developed Dough

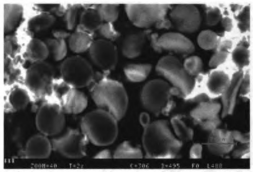

Figure D3-1-2-2 Protein Matrix of Non-Developed Dough

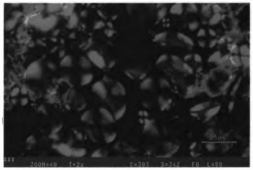

Figure D3-1-2-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

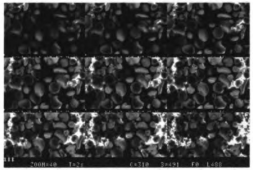

Figure D3-1-2-4 Z-Sectionings of Non-Developed Dough

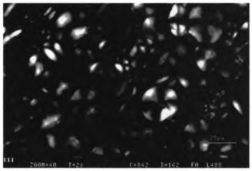

Figure D3-1-3-1 Starch Granules of Non-Developed Dough

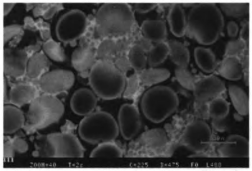

Figure D3-1-3-2 Protein Matrix of Non-Developed Dough

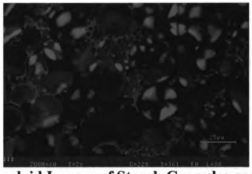

Figure D3-1-3-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

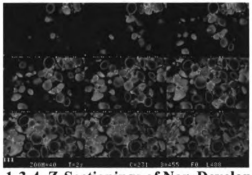

Figure D3-1-3-4 Z-Sectionings of Non-Developed Dough

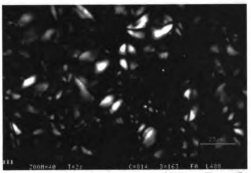

Figure D3-1-4-1 Starch Granules of Non-Developed Dough

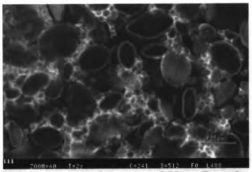

Figure D3-1-4-2 Protein Matrix of Non-Developed Dough

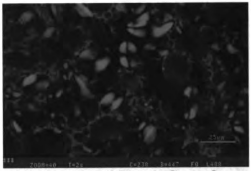

Figure D3-1-4-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

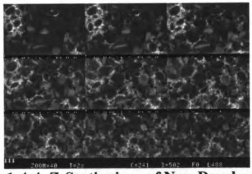

Figure D3-1-4-4 Z-Sectionings of Non-Developed Dough

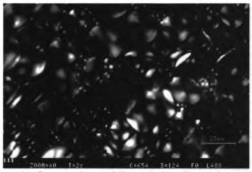

Figure D3-2-1-1 Starch Granules of Partially Developed Dough with Shear Deformation

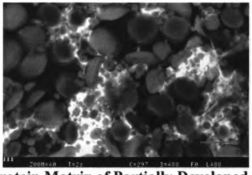

Figure D3-2-1-2 Protein Matrix of Partially Developed Dough with Shear Deformation

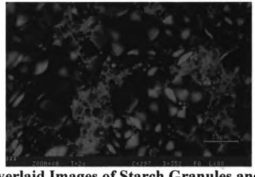

Figure D3-2-1-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

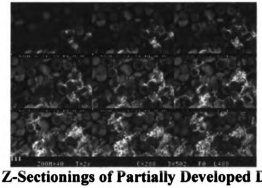

Figure D3-2-1-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

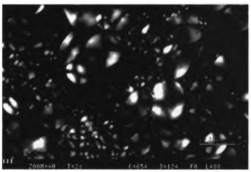

Figure D3-2-2-1 Starch Granules of Partially Developed Dough with Shear Deformation

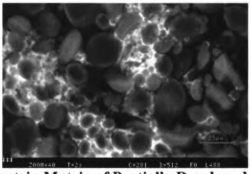

Figure D3-2-2-2 Protein Matrix of Partially Developed Dough with Shear Deformation

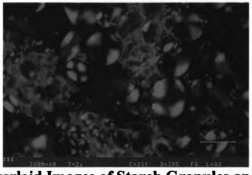

Figure D3-2-2-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

Figure D3-2-2-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

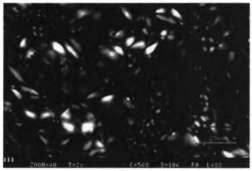

Figure D3-2-3-1 Starch Granules of Partially Developed Dough with Shear Deformation

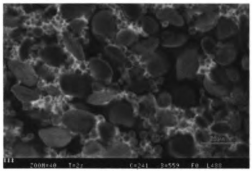

Figure D3-2-3-2 Protein Matrix of Partially Developed Dough with Shear Deformation

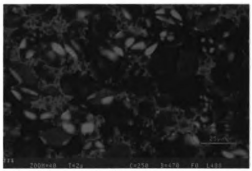

Figure D3-2-3-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

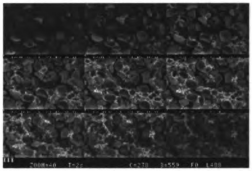

Figure D3-2-3-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

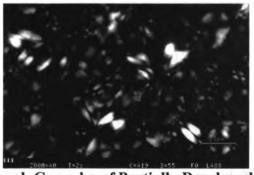

Figure D3-2-4-1 Starch Granules of Partially Developed Dough with Shear Deformation

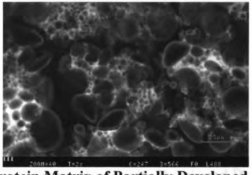

Figure D3-2-4-2 Protein Matrix of Partially Developed Dough with Shear Deformation

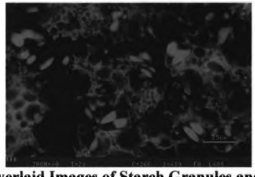

Figure D3-2-4-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

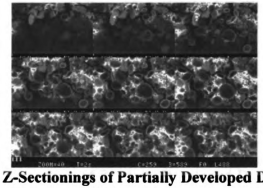

Figure D3-2-4-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

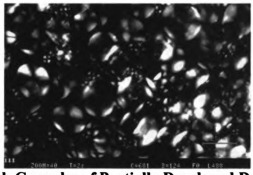

Figure D3-3-1-1 Starch Granules of Partially Developed Dough with Extensional Deformation

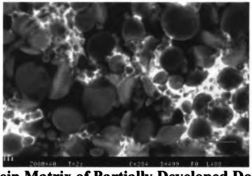

Figure D3-3-1-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

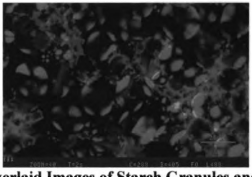

Figure D3-3-1-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

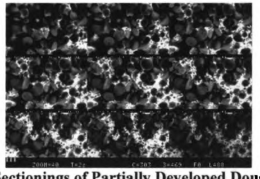

Figure D3-3-1-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

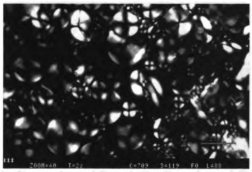

Figure D3-3-2-1 Starch Granules of Partially Developed Dough with Extensional Deformation

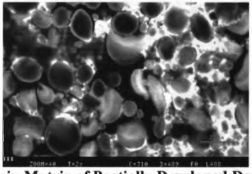

Figure D3-3-2-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

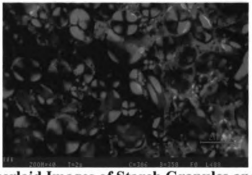

Figure D3-3-2-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

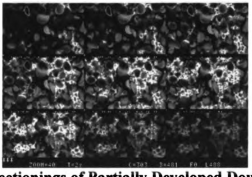

Figure D3-3-2-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

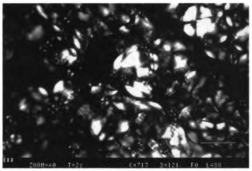

Figure D3-3-3-1 Starch Granules of Partially Developed Dough with Extensional Deformation

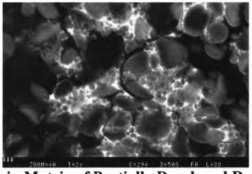

Figure D3-3-3-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

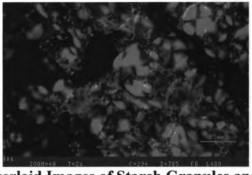

Figure D3-3-3-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

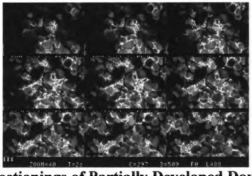

Figure D3-3-3-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

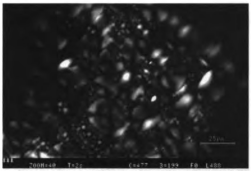

Figure D3-3-4-1 Starch Granules of Partially Developed Dough with Extensional Deformation

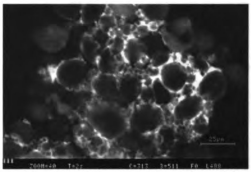

Figure D3-3-4-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

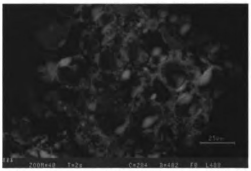

Figure D3-3-4-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

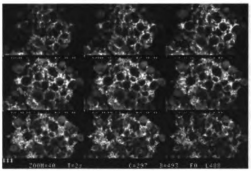

Figure D3-3-4-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

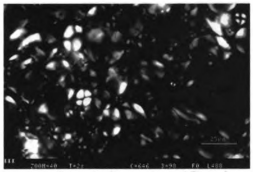

Figure D3-4-1-1 Starch Granules of Developed Dough

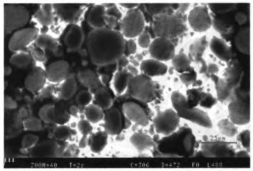

Figure D3-4-1-2 Protein Matrix of Developed Dough

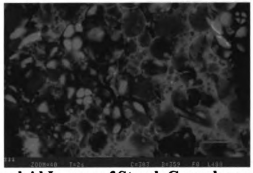

Figure D3-4-1-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

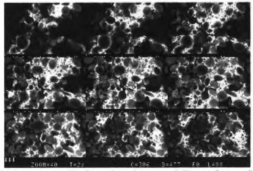

Figure D3-4-1-4 Z-Sectionings of Developed Dough

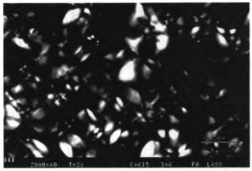

Figure D3-4-2-1 Starch Granules of Developed Dough

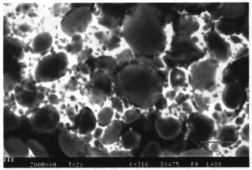

Figure D3-4-2-2 Protein Matrix of Developed Dough

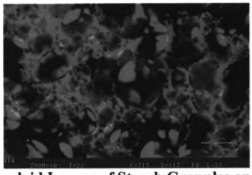

Figure D3-4-2-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

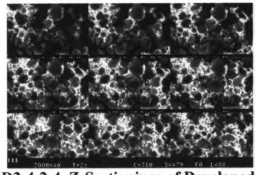

Figure D3-4-2-4 Z-Sectionings of Developed Dough

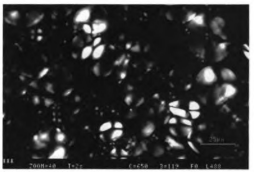

Figure D3-4-3-1 Starch Granules of Developed Dough

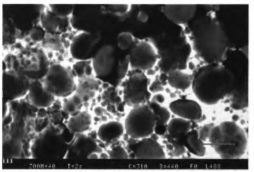

Figure D3-4-3-2 Protein Matrix of Developed Dough

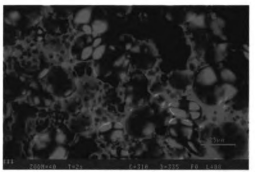

Figure D3-4-3-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

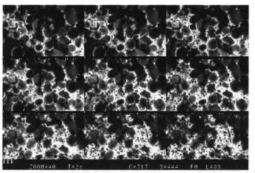

Figure D3-4-3-4 Z-Sectionings of Developed Dough

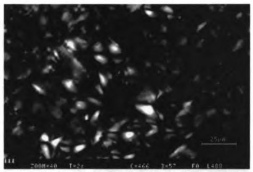

Figure D3-4-4-1 Starch Granules of Developed Dough

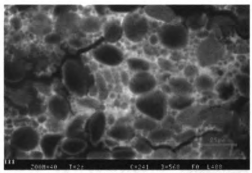

Figure D3-4-4-2 Protein Matrix of Developed Dough

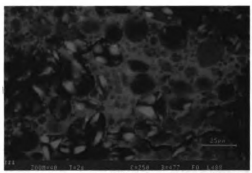

Figure D3-4-4-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

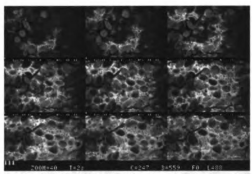

Figure D3-4-4-4 Z-Sectionings of Developed Dough

(D4) Freedom Sample

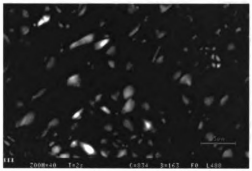

Figure D4-1-1-1 Starch Granules of Non-Developed Dough

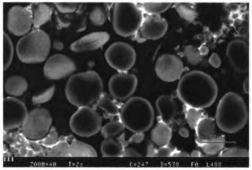

Figure D4-1-1-2 Protein Matrix of Non-Developed Dough

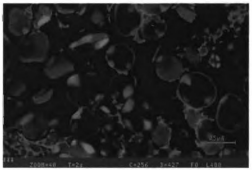

Figure D4-1-1-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

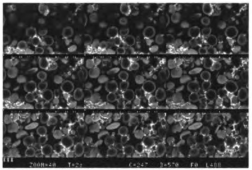

Figure D4-1-1-4 Z-Sectionings of Non-Developed Dough

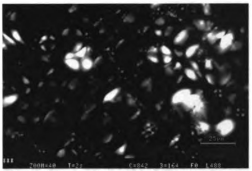

Figure D4-1-2-1 Starch Granules of Non-Developed Dough

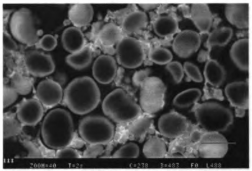

Figure D4-1-2-2 Protein Matrix of Non-Developed Dough

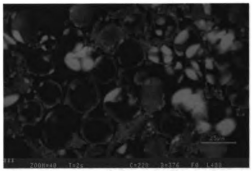

Figure D4-1-2-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

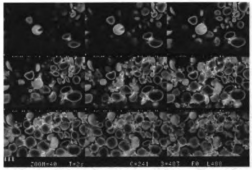

Figure D4-1-2-4 Z-Sectionings of Non-Developed Dough

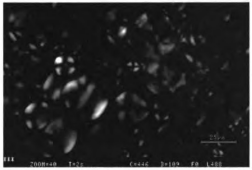

Figure D4-1-3-1 Starch Granules of Non-Developed Dough

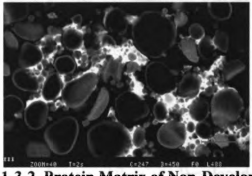

Figure D4-1-3-2 Protein Matrix of Non-Developed Dough

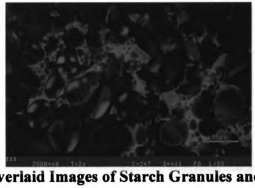

Figure D4-1-3-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

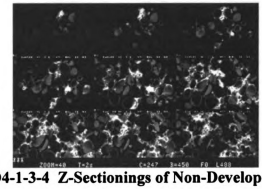

Figure D4-1-3-4 Z-Sectionings of Non-Developed Dough

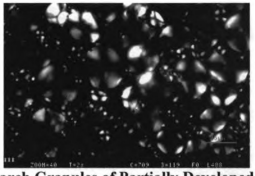

Figure D4-2-1-1 Starch Granules of Partially Developed Dough with Shear Deformation

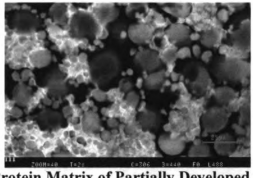

Figure D4-2-1-2 Protein Matrix of Partially Developed Dough with Shear Deformation

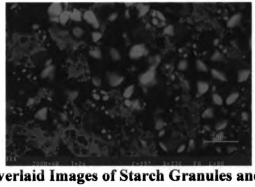

Figure D4-2-1-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

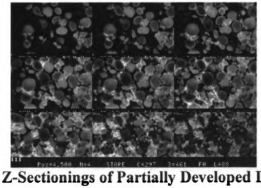

Figure D4-2-1-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

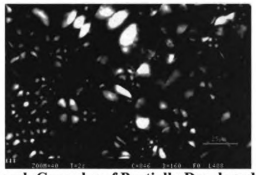

Figure D4-2-2-1 Starch Granules of Partially Developed Dough with Shear Deformation

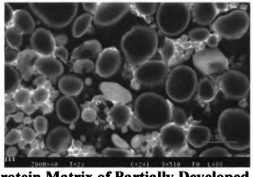

Figure D4-2-2-2 Protein Matrix of Partially Developed Dough with Shear Deformation

Figure D4-2-2-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

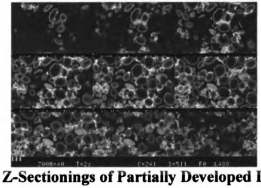

Figure D4-2-2-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

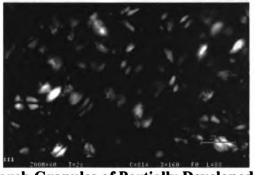

Figure D4-2-3-1 Starch Granules of Partially Developed Dough with Shear Deformation

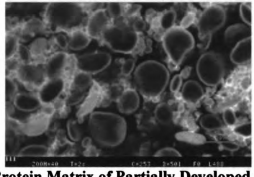

Figure D4-2-3-2 Protein Matrix of Partially Developed Dough with Shear Deformation

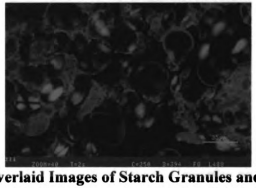

Figure D4-2-3-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

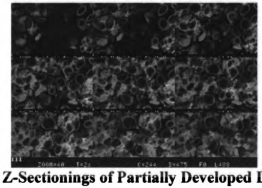

Figure D4-2-3-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

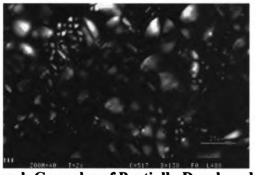

Figure D4-2-4-1 Starch Granules of Partially Developed Dough with Shear Deformation

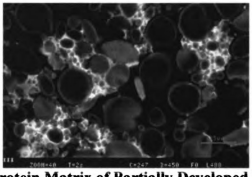

Figure D4-2-4-2 Protein Matrix of Partially Developed Dough with Shear Deformation

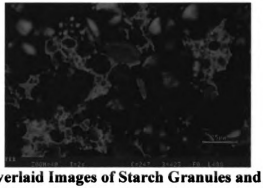

Figure D4-2-4-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

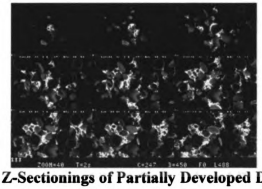

Figure D4-2-4-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

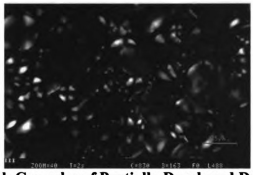

Figure D4-3-1-1 Starch Granules of Partially Developed Dough with Extensional Deformation

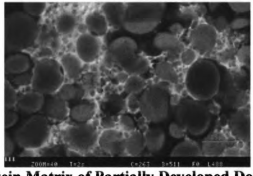

Figure D4-3-1-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

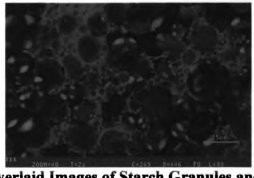

Figure D4-3-1-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

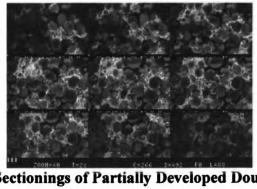

Figure D4-3-1-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

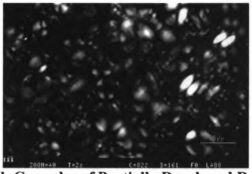

Figure D4-3-2-1 Starch Granules of Partially Developed Dough with Extensional Deformation

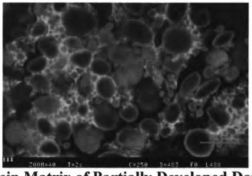

Figure D4-3-2-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

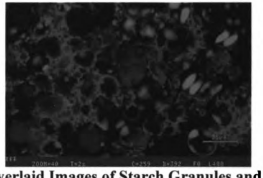

Figure D4-3-2-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

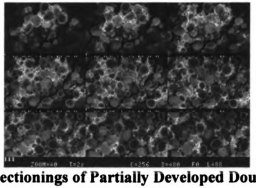

Figure D4-3-2-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

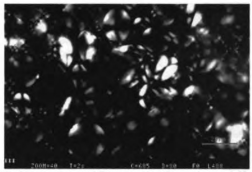

Figure D4-3-3-1 Starch Granules of Partially Developed Dough with Extensional Deformation

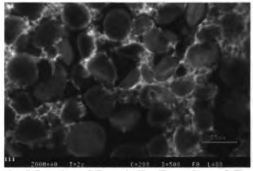

Figure D4-3-3-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

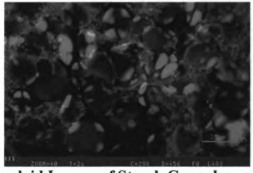

Figure D4-3-3-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

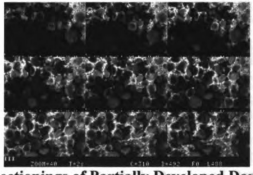

Figure D4-3-3-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

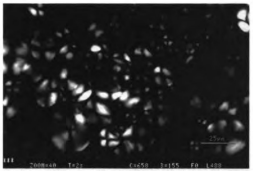

Figure D4-3-4-1 Starch Granules of Partially Developed Dough with Extensional Deformation

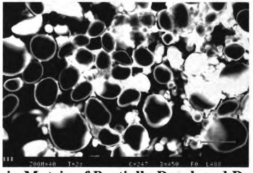

Figure D4-3-4-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

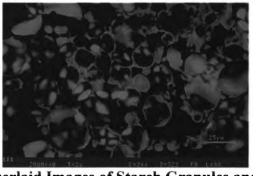

Figure D4-3-4-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

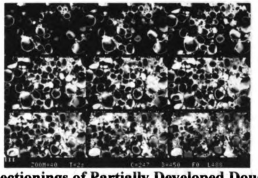

Figure D4-3-4-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

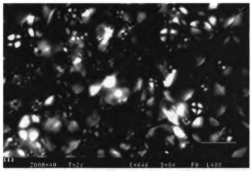

Figure D4-4-1-1 Starch Granules of Developed Dough

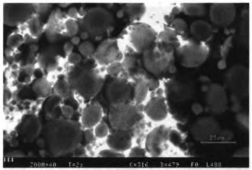

Figure D4-4-1-2 Protein Matrix of Developed Dough

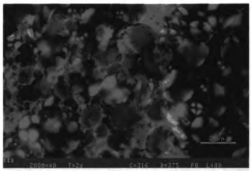

Figure D4-4-1-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

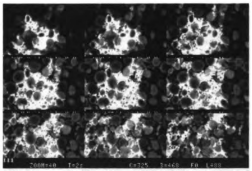

Figure D4-4-1-4 Z-Sectionings of Developed Dough

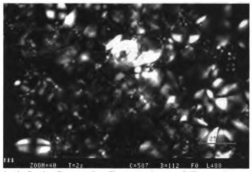

Figure D4-4-2-1 Starch Granules of Developed Dough

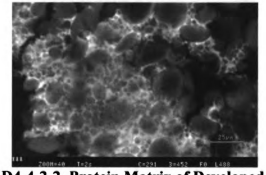

Figure D4-4-2-2 Protein Matrix of Developed Dough

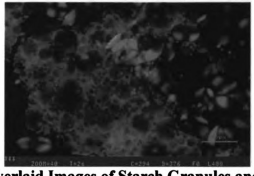

Figure D4-4-2-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

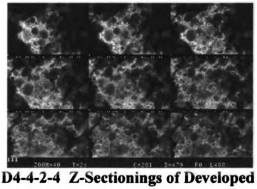

Figure D4-4-2-4 Z-Sectionings of Developed Dough

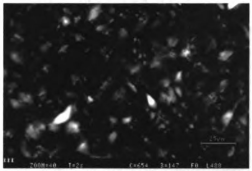

Figure D4-4-3-1 Starch Granules of Developed Dough

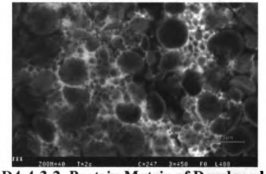

Figure D4-4-3-2 Protein Matrix of Developed Dough

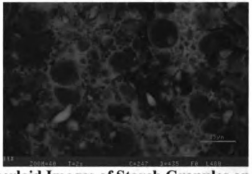

Figure D4-4-3-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

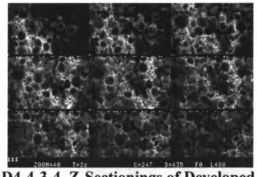

Figure D4-4-3-4 Z-Sectionings of Developed Dough

(D5) Blend (50% soft red winter and 50% hard red winter) Sample

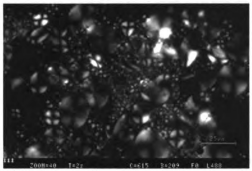

Figure D5-1-1-1 Starch Granules of Non-Developed Dough

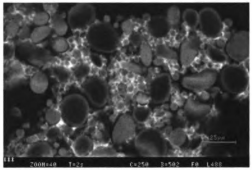

Figure D5-1-1-2 Protein Matrix of Non-Developed Dough

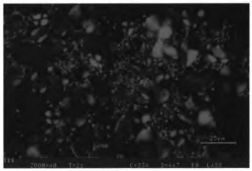

Figure D5-1-1-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

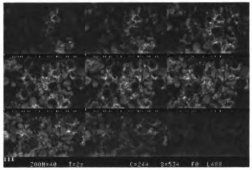

Figure D5-1-1-4 Z-Sectionings of Non-Developed Dough

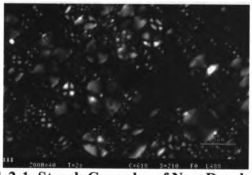

Figure D5-1-2-1 Starch Granules of Non-Developed Dough

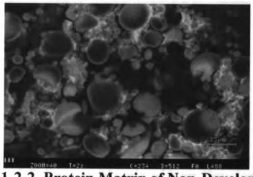

Figure D5-1-2-2 Protein Matrix of Non-Developed Dough

Figure D5-1-2-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

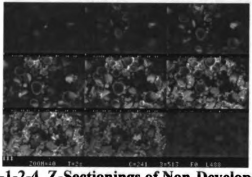

Figure D5-1-2-4 Z-Sectionings of Non-Developed Dough

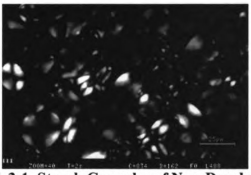

Figure D5-1-3-1 Starch Granules of Non-Developed Dough

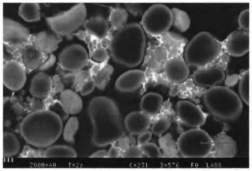

Figure D5-1-3-2 Protein Matrix of Non-Developed Dough

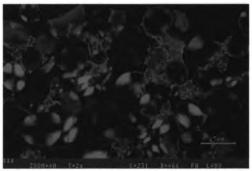

Figure D5-1-3-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

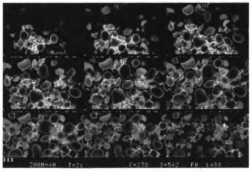

Figure D5-1-3-4 Z-Sectionings of Non-Developed Dough

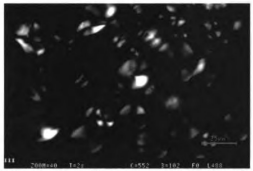

Figure D5-1-4-1 Starch Granules of Non-Developed Dough

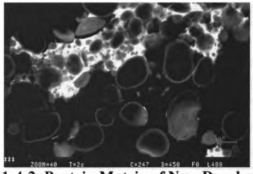

Figure D5-1-4-2 Protein Matrix of Non-Developed Dough

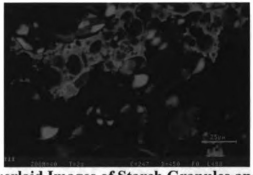

Figure D5-1-4-3 Overlaid Images of Starch Granules and Protein Matrix of Non-Developed Dough

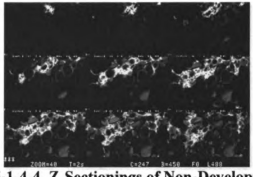

Figure D5-1-4-4 Z-Sectionings of Non-Developed Dough

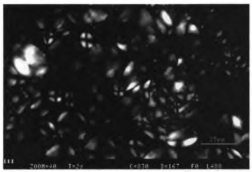

Figure D5-2-1-1 Starch Granules of Partially Developed Dough with Shear Deformation

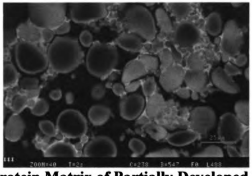

Figure D5-2-1-2 Protein Matrix of Partially Developed Dough with Shear Deformation

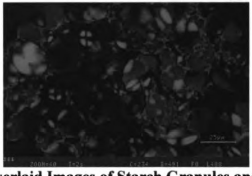

Figure D5-2-1-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

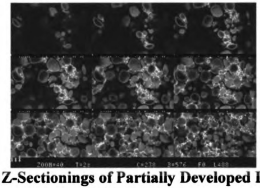

Figure D5-2-1-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

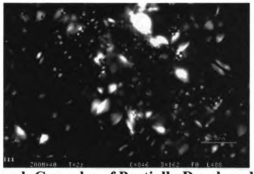

Figure D5-2-2-1 Starch Granules of Partially Developed Dough with Shear Deformation

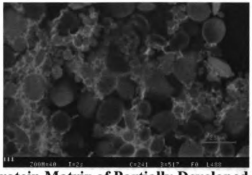

Figure D5-2-2-2 Protein Matrix of Partially Developed Dough with Shear Deformation

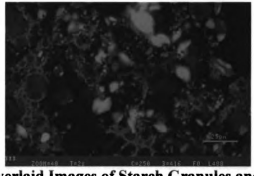

Figure D5-2-2-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

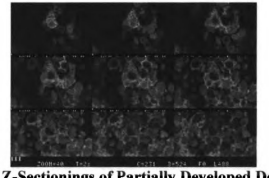

Figure D5-2-2-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

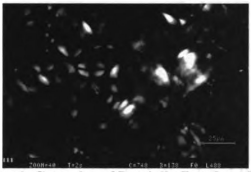

Figure D5-2-3-1 Starch Granules of Partially Developed Dough with Shear Deformation

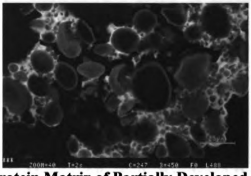

Figure D5-2-3-2 Protein Matrix of Partially Developed Dough with Shear Deformation

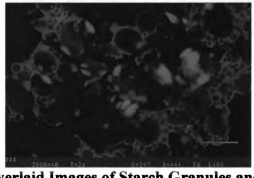

Figure D5-2-3-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Shear Deformation

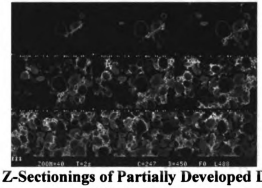

Figure D5-2-3-4 Z-Sectionings of Partially Developed Dough with Shear Deformation

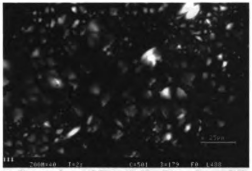

Figure D5-3-1-1 Starch Granules of Partially Developed Dough with Extensional Deformation

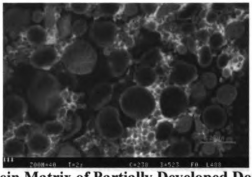

Figure D5-3-1-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

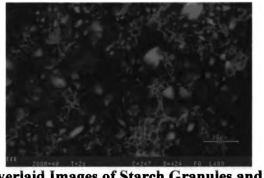

Figure D5-3-1-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

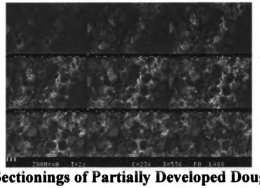

Figure D5-3-1-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

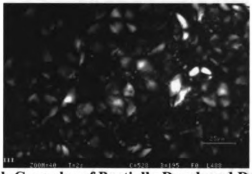

Figure D5-3-2-1 Starch Granules of Partially Developed Dough with Extensional Deformation

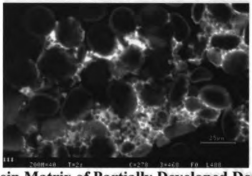

Figure D5-3-2-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

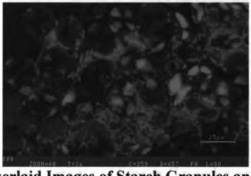

Figure D5-3-2-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

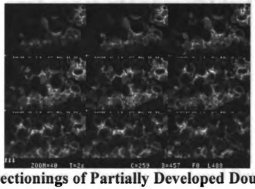

Figure D5-3-2-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

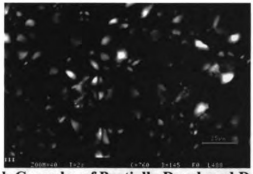

Figure D5-3-3-1 Starch Granules of Partially Developed Dough with Extensional Deformation

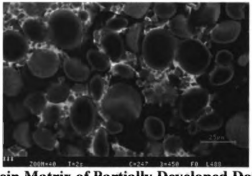

Figure D5-3-3-2 Protein Matrix of Partially Developed Dough with Extensional Deformation

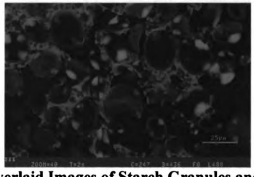

Figure D5-3-3-3 Overlaid Images of Starch Granules and Protein Matrix of Partially Developed Dough with Extensional Deformation

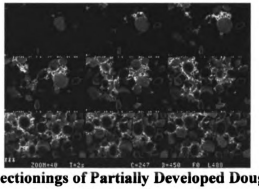

Figure D5-3-3-4 Z-Sectionings of Partially Developed Dough with Extensional Deformation

Figure D5-4-1-1 Starch Granules of Developed Dough

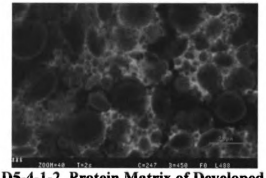

Figure D5-4-1-2 Protein Matrix of Developed Dough

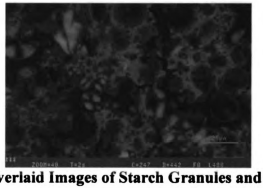

Figure D5-4-1-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

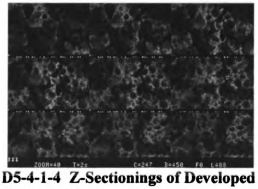

Figure D5-4-1-4 Z-Sectionings of Developed Dough

Figure D5-4-2-1 Starch Granules of Developed Dough

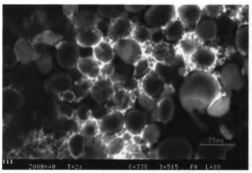

Figure D5-4-2-2 Protein Matrix of Developed Dough

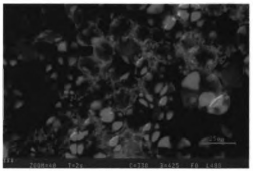

Figure D5-4-2-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

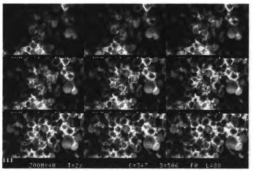

Figure D5-4-2-4 Z-Sectionings of Developed Dough

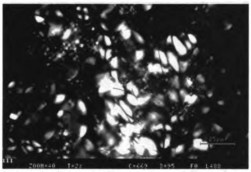

Figure D5-4-3-1 Starch Granules of Developed Dough

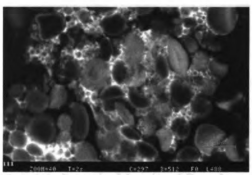

Figure D5-4-3-2 Protein Matrix of Developed Dough

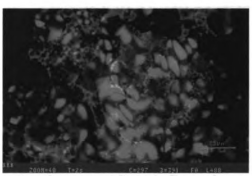

Figure D5-4-3-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

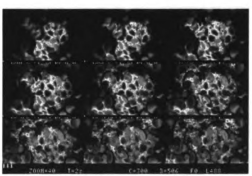

Figure D5-4-3-4 Z-Sectionings of Developed Dough

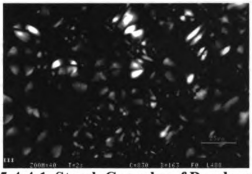

Figure D5-4-4-1 Starch Granules of Developed Dough

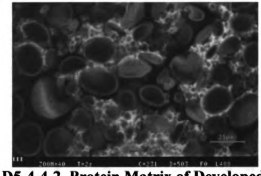

Figure D5-4-4-2 Protein Matrix of Developed Dough

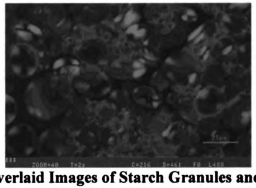

Figure D5-4-4-3 Overlaid Images of Starch Granules and Protein Matrix of Developed Dough

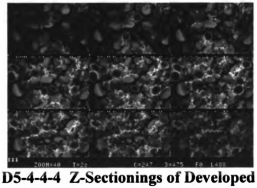

Figure D5-4-4-4 Z-Sectionings of Developed Dough

E. Amount of Protein Matrix

Table E1 Amount of Protein Matrix (%) from Z-Sectioning of LSCM

Sample[1]	Replicate[2]			
	1	2	3	4
Frankenmuth				
N	16.72\18.48\21.74	19.54\20.45\20.73	19.15\19.66\19.90	18.01\19.95\21.65
S	27.12\28.13\29.71	24.55\25.01\27.42	25.44\25.98\28.86	26.78\27.47\28.46
E	28.56\30.14\32.74	30.87\31.45\31.67	28.65\30.46\31.94	---
D	34.96\35.87\35.94	35.41\36.45\36.89	34.01\34.49\35.03	34.88\35.79\36.31
Cracker				
N	11.87\12.86\12.88	10.95\11.12\12.99	11.44\11.87\12.87	11.03\11.81\12.35
S	17.95\18.24\19.52	17.45\18.99\20.05	18.13\18.56\19.95	16.85\17.16\18.61
E	20.34\20.75\22.60	22.11\22.35\23.07	20.73\21.24\22.92	21.91\22.19\23.25
D	30.49\32.97\34.40	30.14\31.85\33.95	30.85\31.15\31.75	29.86\29.99\30.54
Caldwell				
N	13.68\15.15\17.19	13.41\14.65\15.98	14.56\14.97\15.80	15.68\16.03\17.67
S	19.22\19.87\21.53	19.81\20.24\21.84	21.28\22.56\23.12	19.06\19.97\23.91
E	29.63\30.84\31.81	28.56\29.48\30.10	28.96\30.78\32.93	28.68\29.91\30.96
D	38.62\39.29\39.96	37.83\38.09\38.71	38.75\40.73\41.42	38.90\39.87\43.36
Freedom				
N	9.74\10.94\11.87	9.61\9.95\11.64	10.62\11.97\12.23	---
S	11.93\12.82\13.68	11.56\12.97\14.11	13.01\13.24\14.76	12.79\13.55\15.33
E	28.67\30.58\32.46	28.16\29.40\29.68	27.49\27.90\28.79	27.69\29.10\31.80

Table E1 (cont' d)

D	33.49\34.75\36.22	34.05\35.99\37.45	33.48\34.51\34.97	---
Blend[3]				
N	12.03\13.75\13.86	11.56\12.07\12.82	11.48\11.95\12.16	11.98\12.38\14.25
S	14.24\14.86\15.93	12.67\13.97\14.61	14.06\14.29\15.69	---
E	20.33\21.48\23.38	18.95\19.65\20.11	20.14\21.74\21.78	---
D	26.73\28.76\30.94	25.47\26.89\28.01	25.11\25.58\26.44	25.72\25.90\28.24

[1]N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.
[2]Each replicate consists of layers 4, 5, and 6 (out of 9); top to bottom from the middle part of its dough sample.
[3]Blend: 50% soft red winter and 50% hard red winter wheat flours.

F. Moisture Contents of Different Dough Samples

Table F1 Moisture Contents (%) of Different Dough Samples

Sample[1]	1	2
Frankenmuth		
N	7.13	7.02
S	6.74	6.88
E	8.22	8.54
D	5.30	5.18
Cracker		
N	6.43	6.75
S	7.75	7.97
E	6.31	6.52
D	5.93	5.99
Caldwell		
N	6.04	6.12
S	7.01	6.75
E	8.09	7.87
D	5.33	5.11
Freedom		
N	6.84	6.94
S	7.38	7.28
E	8.12	7.81
D	6.55	6.42
Blend[2]		
N	6.31	6.60
S	8.37	8.33
E	7.29	7.15
D	6.73	6.43

[1]N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.
[2]Blend: 50% soft red winter and 50% hard red winter.

G. Free Sulfhydryl and Total Cysteine Contents

Table G1 Free Sulfhydryl and Total Cysteine Contents (nm/mg of proteins) of Different Flours and Their Dough Samples[1]

Sample	Free S-H			Total Cysteine		
Frankenmuth						
F	6.84	6.78	6.81	143.89	144.03	143.75
N	6.45	6.58	6.56	144.58	144.25	144.07
S	9.86	10.21	9.75	143.05	143.38	143.41
E	11.02	11.21	11.37	146.30	146.15	146.33
D	8.59	8.74	8.68	144.34	144.48	144.98
Cracker						
F	8.76	8.66	8.77	141.39	141.72	141.78
N	8.45	8.49	8.59	142.06	142.52	142.29
S	13.54	13.68	13.61	141.02	141.23	140.96
E	15.82	15.89	15.75	142.85	142.73	143.12
D	8.67	8.82	8.82	141.28	141.74	141.30
Caldwell						
F	7.31	7.35	7.42	142.06	142.21	142.15
N	7.24	6.89	7.08	143.54	142.4	144.20
S	9.85	9.89	10.02	140.43	140.69	141.40
E	14.59	14.62	14.44	144.00	144.96	145.62
D	8.04	8.14	8.06	144.55	144.26	143.58
Freedom						
F	5.98	6.05	6.03	119.80	119.79	119.75
N	5.94	6.05	6.04	119.86	120.56	120.36
S	6.88	6.99	7.10	117.35	118.41	117.7
E	9.54	9.59	9.73	118.86	118.45	118.46
D	7.46	7.42	7.32	119.01	119.56	119.90
Blend[2]						
F	3.26	3.32	3.32	119.82	120.20	119.80
N	3.02	3.12	3.04	119.32	119.56	120.67
S	4.92	5.03	4.99	117.45	118.04	117.73
E	6.03	6.04	5.96	117.24	117.65	118.09
D	4.12	3.95	3.93	118.06	118.87	118.63

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

[2]Blend: 50% soft red winter and 50% hard red winter.

H. Moisture and Protein Contents of Each Protein Fraction Obtained from Gel Filtration Chromatography

Table H1 Moisture and Protein Contents of Each Protein Fraction Obtained from Gel Filtration Chromatography of Different Flours and Their Dough Samples

Sample[1]	Moisture Content (%)		Protein Content (%)	
	1	2	1	2
Frankenmuth				
F				
I-A	47.80	47.86	0.53	0.54
I-B	27.92	28.02	6.4	6.8
II	24.84	24.96	3.3	3.5
N				
I-A	38.13	38.09	1.10	1.26
I-B	31.42	31.60	4.41	4.47
II	30.71	30.89	3.82	3.98
S				
I-A	45.44	45.52	0.69	0.67
I-B	17.28	17.30	5.43	5.43
II	27.22	27.38	3.80	3.86
E				
I-A	33.31	33.35	1.52	1.66
I-B	24.01	24.05	4.75	4.79
II	25.84	26.08	3.38	3.37
D				
I-A	35.01	35.55	1.43	1.43
I-B	21.13	21.27	5.00	5.12
II	28.75	28.99	3.01	3.05
Cracker				
F				
I-A	41.51	41.67	1.24	1.28
I-B	35.93	36.01	4.25	4.29
II	35.29	35.61	3.35	3.35
N				
I-A	39.54	40.46	1.68	1.72
I-B	21.70	21.90	5.45	5.47
II	24.62	23.58	4.17	4.27
S				
I-A	28.89	29.71	1.85	1.85
I-B	26.45	26.25	5.42	5.46
II	14.24	14.64	4.62	4.61
E				
I-A	35.66	37.30	1.93	1.97

Table H1 (cont' d)

I-B	23.52	24.18	5.02	5.10
II	14.20	14.86	5.31	5.29
D				
I-A	32.18	32.19	1.86	1.92
I-B	19.64	19.96	6.13	6.09
II	19.88	19.92	4.62	4.76
Caldwell				
F				
I-A	31.92	32.02	0.97	0.96
I-B	28.24	28.28	4.51	4.59
II	23.47	23.73	4.39	4.59
N				
I-A	29.22	29.50	1.25	1.31
I-B	30.04	30.44	5.00	5.14
II	23.52	22.76	4.82	4.96
S				
I-A	37.38	37.84	0.83	0.93
I-B	22.25	22.77	5.44	5.52
II	21.91	21.71	4.90	4.88
E				
I-A	20.92	21.06	1.08	1.06
I-B	26.98	27.48	4.51	4.55
II	25.86	26.58	3.88	4.00
D				
I-A	29.74	30.30	1.29	1.33
I-B	32.01	32.27	4.87	4.87
II	29.50	30.16	4.32	4.42
Freedom				
F				
I-A	28.16	29.76	1.95	1.97
I-B	29.15	29.37	4.48	4.52
II	18.25	19.67	5.10	5.20
N				
I-A	39.25	41.03	1.15	1.21
I-B	23.52	24.32	5.30	5.48
II	23.22	23.64	4.75	4.83
S				
I-A	23.85	23.99	1.51	1.52
I-B	24.08	24.16	4.85	4.91
II	17.81	18.05	4.82	4.84
E				
I-A	31.59	33.95	1.15	1.05

Table H1 (cont' d)

I-B	18.70	18.73	4.92	5.04
II	9.64	9.64	4.01	3.91
D				
I-A	19.08	19.46	1.93	1.99
I-B	6.81	6.87	6.38	6.54
II	13.34	13.35	5.01	5.11
Blend[2]				
F				
I-A	36.02	37.48	1.68	1.70
I-B	28.49	29.53	5.35	5.41
II	17.36	17.66	5.10	5.14
N				
I-A	37.23	37.69	1.83	1.84
I-B	31.31	32.11	5.93	5.99
II	29.12	29.12	4.72	5.82
S				
I-A	35.01	35.69	1.21	1.27
I-B	28.98	30.18	5.75	5.77
II	30.01	30.23	4.89	4.97
E				
I-A	59.72	60.44	1.76	1.80
I-B	36.57	39.03	5.11	5.27
II	24.25	24.21	5.42	5.43
D				
I-A	35.01	35.85	3.72	3.90
I-B	26.72	27.40	6.72	6.86
II	21.69	22.51	4.47	4.55

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

[2]Blend: 50% soft red winter and 50% hard red winter.

I. Densitometric Data

Table I1 Densitometric Data for Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Frankenmuth Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	2.6\2.7	6.0\5.2	2.5\2.5	5.1\6.0	6.7\5.8	1.0\1.1	6.3\6.3
2	2.5\2.5	3.0\2.8	1.3\1.6	5.8\6.3	4.5\4.4	0.3\0.5	3.1\3.1
3	6.0\5.8	2.8\3.8	0.5\1.2	8.8\7.2	8.6\7.6	1.3\1.4	5.7\7.2
4	3.1\3.2	1.8\1.7	0.6\0.4	7.7\7.9	2.8\3.5	0.6\0.8	3.8\4.3
5	3.8\3.6	5.5\5.0	0.2\0.3	7.8\5.8	4.6\5.9	1.7\1.4	3.3\4.3
6	3.1\3.3	2.0\2.1	0.5\0.2	6.2\6.7	2.4\2.5	1.0\0.8	2.1\2.3
7	1.9\1.7	2.5\3.0	0.9\0.5	2.9\3.4	4.4\4.9	0.8\0.7	1.8\2.6
8	1.4\1.6	1.9\1.9	0.5\0.7	5.4\4.4	1.5\1.9	0.7\0.7	2.0\2.3
9	1.1\1.1	3.7\4.5	1.2\0.8	2.6\4.7	3.3\2.5	2.9\3.6	2.2\2.9
10	1.2\1.3	2.1\1.6	1.6\2.0	2.3\2.2	3.7\2.5	0.6\0.4	1.9\1.2
11	1.2\1.5	3.1\3.4	0.8\0.3	0.8\0.8	2.3\2.3	1.6\1.4	1.5\1.2
12	2.7\2.3	1.9\1.4	1.4\1.5	2.9\3.4	1.6\1.5	1.6\1.3	1.5\1.5
13	2.3\2.1	4.2\3.4	1.3\2.5	1.2\2.8	2.4\1.9	1.2\1.2	0.8\0.6
14	1.5\1.6	2.8\3.1	1.5\1.8	2.6\2.5	1.7\1.5	0.3\0.3	1.0\1.6
15	1.0\1.1	3.1\3.9	2.3\1.5	5.8\4.8	2.4\2.6	1.1\1.6	1.8\2.3
16	6.8\7.1	3.1\2.4	3.1\2.4	2.4\1.9	3.1\3.9	1.9\2.4	1.7\1.5
17	3.2\3.4	2.1\3.0	6.2\7.8	0.8\0.3	7.7\7.5	1.6\1.3	5.6\4.2
18	2.3\1.8	1.9\1.9	5.0\5.4	3.7\3.7	1.4\0.8	2.8\2.1	2.4\3.1
19	1.9\2.3	4.4\5.6	11.9\9.9	1.7\1.9	2.0\2.3	0.9\0.5	3.8\3.6
20	4.4\4.5	4.4\4.8	12.1\10.3	2.2\2.0	1.0\1.3	1.5\1.3	4.1\4.3
21	1.8\1.3	7.9\6.3	6.0\7.5	1.1\2.2	1.9\2.3	8.1\8.7	1.8\1.8
22	7.2\7.1	4.1\4.2	6.6\7.4	1.4\0.9	5.5\5.3	6.0\6.0	1.8\2.4
23	2.1\1.8	3.8\4.6	2.9\2.4	1.2\1.1	1.2\0.9	14.4\16.5	3.6\3.2
24	3.1\3.5	3.0\2.5	1.7\1.7	1.2\0.8	2.6\2.7	7.5\6.2	4.1\3.9
25	4.4\4.9	2.6\2.2	1.1\0.4	3.8\3.7	3.7\4.8	10.9\10.0	5.0\5.4
26	4.0\4.0	3.4\3.6	5.0\4.2	2.9\3.0	3.7\4.2	3.5\3.4	4.1\3.7
27	4.6\4.5	2.5\2.5	2.0\3.5	2.0\1.6	4.3\3.2	14.2\14.4	4.8\4.1
28	2.4\2.6	3.5\3.8	4.2\4.5	2.3\2.6	1.3\1.5	2.7\2.9	2.6\2.8
29	8.7\8.5	2.5\1.5	7.7\6.0	1.9\1.9	4.0\3.6	3.8\4.6	10.0\11.4
30	7.7\7.3	4.4\4.9	7.1\8.5	3.4\3.4	3.4\3.1	3.5\2.5	5.8\4.9

Table I1 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
4.9\5.1	1.3\1.8	7.8\6.5	3.4\3.5	3.6\4.2	17.1\18.0	4.8\4.9	1.1\0.8
4.2\4.0	0.6\0.8	6.4\7.6	5.9\5.8	4.2\3.6	7.5\7.0	3.7\4.3	0.8\1.5
6.5\6.5	0.7\0.2	7.4\7.5	2.9\3.5	2.2\2.2	10.3\10.3	2.4\1.6	1.8\1.9
5.1\4.2	0.7\0.5	4.3\4.3	3.2\3.6	1.0\1.0	7.9\7.5	3.1\3.2	0.9\0.4
5.4\5.6	0.2\0.1	3.2\2.5	3.7\2.7	2.3\2.5	5.3\5.2	2.6\2.1	0.6\0.6
1.8\2.3	1.4\1.5	7.2\7.9	6.2\6.5	1.5\1.0	7.3\7.6	4.0\4.5	1.7\1.2
2.4\2.6	0.4\0.5	4.8\5.6	3.0\3.5	1.2\1.2	2.6\3.2	3.0\4.1	1.0\1.3
2.0\1.6	0.6\0.8	7.9\7.2	3.5\3.6	1.6\2.4	2.8\2.1	3.4\2.8	2.3\2.5
1.3\1.7	1.3\1.9	2.9\2.8	1.6\1.1	0.8\1.2	2.1\2.0	2.8\2.4	0.9\1.3
3.9\4.3	1.7\1.4	2.3\1.8	5.0\4.6	2.7\2.1	4.6\4.1	1.4\1.3	1.6\1.4
4.4\4.6	3.1\2.4	4.8\5.3	4.3\4.3	1.5\0.9	1.0\1.5	3.8\3.8	2.6\2.8
7.6\7.0	8.0\8.1	4.0\3.4	2.7\2.1	2.0\2.3	2.1\1.2	4.0\5.5	2.0\2.6
1.4\1.4	1.5\1.5	2.4\2.8	4.7\5.2	2.1\1.9	0.9\1.7	3.1\2.6	1.5\0.5
2.1\2.3	3.6\5.0	0.6\0.8	7.8\8.9	2.8\2.7	1.1\1.3	4.2\3.2	2.5\2.5
2.9\3.2	3.2\2.8	1.2\1.2	4.5\4.6	2.1\3.1	1.8\2.3	1.7\1.5	7.7\6.7
4.7\4.4	2.6\2.1	1.2\1.5	3.0\2.3	1.8\0.8	0.8\1.2	3.4\3.6	4.9\4.4
4.6\4.2	3.4\2.9	5.2\4.9	2.9\2.5	2.6\2.3	0.3\0.6	1.7\2.2	2.7\3.2
5.4\6.6	1.4\1.2	1.2\1.2	1.0\1.4	1.5\1.8	1.0\0.7	1.6\2.1	2.6\3.6
2.5\2.3	4.0\3.2	2.3\3.3	2.7\3.4	1.9\3.0	0.7\1.5	3.2\2.2	7.5\8.8
5.8\5.2	10.3\11.0	1.4\1.4	2.1\2.0	1.6\1.1	0.8\1.1	2.2\2.2	3.1\2.8
6.8\6.6	7.7\8.1	2.4\2.0	1.4\0.4	9.0\8.4	0.6\0.6	3.1\3.0	3.4\2.4
0.8\1.3	21.3\23.4	1.1\0.6	4.0\3.2	4.5\3.5	0.9\0.8	6.1\7.2	5.2\3.8
1.6\1.3	3.7\3.5	2.8\2.7	4.9\5.7	18.3\19.6	2.9\1.9	3.9\4.3	11.5\12.9
1.0\1.2	2.7\2.1	0.9\0.5	1.6\1.6	3.9\3.6	0.8\1.2	6.9\5.5	5.5\5.6
2.5\2.6	2.7\2.1	1.5\2.1	3.3\2.0	7.1\7.2	1.6\1.2	4.7\3.3	4.7\4.9
1.0\0.6	4.0\3.4	3.7\3.5	1.1\2.2	8.4\7.3	1.6\0.6	3.5\3.9	7.4\7.1
3.6\3.5	1.1\0.9	2.3\2.8	4.0\4.5	3.2\3.6	2.9\3.9	2.9\3.9	4.4\5.0
1.0\1.0	1.1\2.0	2.5\2.6	1.9\2.4	1.0\1.3	2.1\1.6	1.9\1.9	3.8\3.5
1.8\2.8	1.3\2.3	1.7\1.0	2.0\1.4	2.2\3.4	5.7\4.2	2.4\3.3	1.9\1.9
1.1\0.1	4.5\4.3	2.3\2.4	1.6\1.4	1.3\0.4	2.9\2.9	4.4\3.5	2.4\2.1

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I2 Densitometric Data for Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Cracker Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	1.5\1.2	0.6\0.8	4.6\4.1	13.1\14.5	7.0\8.4	1.3\1.0	5.3\4.5
2	1.0\1.6	5.3\5.1	2.6\2.4	10.3\9.9	6.1\6.5	2.4\2.8	7.7\7.2
3	0.9\1.4	2.8\2.2	2.3\2.4	7.7\6.7	4.9\5.0	3.3\3.6	3.6\3.1
4	0.9\0.8	4.8\4.1	3.5\3.7	4.0\4.5	8.4\7.0	2.7\2.4	6.4\6.3
5	3.8\3.4	3.7\4.1	10.6\11.6	7.1\6.6	8.4\9.0	7.8\8.3	4.2\4.6
6	6.0\5.6	3.5\3.1	3.8\3.5	6.3\5.6	9.1\8.5	3.0\3.3	8.2\8.0
7	5.4\5.1	6.0\5.6	5.2\6.7	3.8\3.7	4.0\4.5	4.1\4.2	3.3\2.9
8	8.3\8.5	7.9\8.6	2.8\2.0	5.6\6.3	4.5\4.0	3.6\3.3	6.3\6.4
9	8.2\8.0	10.5\9.5	3.7\3.5	3.7\3.8	5.0\4.5	6.1\6.3	8.0\8.2
10	7.0\7.3	4.3\4.6	4.1\4.6	6.6\7.1	3.4\3.8	3.3\3.0	7.2\7.7
11	4.4\4.6	2.4\2.8	2.6\2.9	4.3\4.0	2.9\2.7	2.4\2.7	4.5\5.3
12	4.5\4.1	3.1\3.5	2.0\2.8	4.5\4.0	2.2\1.9	1.9\2.5	3.3\3.0
13	1.6\1.4	4.1\3.7	1.9\2.1	2.2\2.5	1.0\0.9	2.8\2.4	3.1\2.6
14	2.5\2.7	2.2\2.8	2.9\2.6	2.7\2.9	2.0\1.6	3.3\3.4	2.1\2.3
15	2.9\2.5	4.1\4.8	2.0\2.2	3.1\2.9	1.8\2.1	2.5\1.9	3.3\3.6
16	2.1\1.6	1.3\2.3	2.4\2.6	1.2\0.8	2.1\1.8	0.9\1.2	2.2\2.2
17	3.9\3.6	2.1\1.7	2.0\1.5	0.9\0.7	2.4\2.6	3.8\4.0	2.6\3.1
18	2.0\2.2	2.3\1.3	2.4\2.3	1.1\1.4	3.8\3.4	2.4\2.5	1.7\1.8
19	2.1\2.4	3.7\3.3	1.8\1.7	0.7\0.8	0.7\0.9	5.3\4.8	1.1\0.9
20	1.6\1.0	4.1\3.4	2.1\1.9	1.1\0.9	0.8\0.9	3.2\3.3	2.3\2.1
21	1.5\2.0	3.5\4.2	3.8\3.1	0.5\0.7	2.6\2.4	4.0\4.1	1.0\0.5
22	2.6\2.1	1.0\1.0	3.5\3.8	0.7\0.9	1.6\2.0	3.3\3.2	2.2\2.2
23	2.5\2.8	2.4\2.8	3.1\3.1	0.7\0.8	1.7\1.9	4.1\4.0	1.8\1.7
24	3.8\3.5	1.0\1.6	6.7\5.2	1.4\1.1	0.9\1.0	3.4\3.3	1.6\1.0
25	2.7\2.5	4.1\3.5	2.4\2.3	1.4\1.6	2.5\2.9	6.3\6.1	0.5\0.9
26	2.5\2.9	2.0\1.5	8.8\7.8	0.8\1.2	2.7\2.9	4.2\4.1	1.0\1.6
27	4.1\4.5	2.8\2.4	3.1\3.8	1.1\1.2	1.9\1.7	2.5\2.4	0.5\1.0
28	3.4\3.8	1.5\2.0	1.5\1.8	0.7\0.5	1.0\1.6	4.0\3.8	0.9\0.5
29	1.2\1.5	1.4\1.8	0.6\0.3	1.6\1.4	2.9\2.5	1.0\1.3	0.9\1.1
30	5.1\5.4	1.4\1.0	1.5\2.0	1.2\1.1	1.6\1.0	1.2\0.9	3.1\3.6

Table I2 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
5.5\4.7	1.0\0.7	3.2\4.3	5.3\5.8	1.6\2.3	9.3\9.5	4.1\3.3	1.1\0.9
4.1\5.1	1.5\1.6	9.3\8.2	2.8\2.2	2.1\2.3	2.8\2.6	3.5\3.9	3.6\4.4
4.6\4.2	3.3\3.6	6.0\5.5	5.3\5.1	3.0\2.5	2.8\2.5	4.2\4.4	3.1\3.1
4.7\5.5	5.1\4.8	3.3\3.5	3.2\3.5	4.7\4.9	3.6\3.9	2.2\2.1	2.7\2.1
5.6\6.1	6.9\7.4	3.9\4.2	5.6\5.9	5.0\5.5	4.6\5.0	6.2\6.4	5.4\6.1
5.4\5.8	8.7\8.1	3.3\3.0	4.2\3.5	2.4\1.9	5.7\5.3	3.7\3.2	4.2\3.4
4.6\4.7	3.2\3.2	5.3\5.1	5.1\5.3	3.3\3.7	3.9\4.4	3.1\3.0	3.0\2.9
7.7\6.7	4.4\4.2	7.9\8.2	4.8\4.1	1.6\1.2	8.5\8.0	6.3\6.0	3.0\2.8
2.4\3.0	3.7\4.4	5.1\5.3	3.6\3.5	2.4\2.6	3.5\3.3	6.4\6.2	1.5\1.2
3.2\3.5	1.7\1.3	3.5\3.0	5.9\5.6	2.9\3.1	4.7\5.3	2.6\2.9	1.8\1.6
3.0\2.4	2.8\3.4	3.7\4.4	2.1\2.4	1.6\1.9	7.2\6.2	3.1\3.4	1.9\1.7
6.1\5.6	0.8\1.0	6.6\5.9	3.6\3.7	4.3\4.6	5.0\5.5	2.4\2.1	0.9\1.1
1.2\1.5	3.3\3.0	4.2\4.0	3.1\3.9	2.6\2.9	4.1\4.6	3.4\4.1	4.6\5.1
2.9\2.7	2.0\2.1	5.5\5.4	3.5\4.2	4.1\3.6	3.3\3.5	1.8\2.1	3.1\3.1
3.5\3.2	3.4\2.8	3.1\3.2	2.0\1.4	1.2\1.6	5.3\4.7	7.1\6.5	4.4\3.6
2.7\2.9	1.3\1.7	3.3\3.6	2.4\2.1	1.4\1.4	3.2\3.8	4.4\4.2	1.6\1.8
1.3\1.7	3.2\3.2	1.8\1.5	4.1\4.8	5.7\6.2	3.7\3.8	3.3\4.1	6.1\5.4
4.7\4.6	2.7\2.0	4.0\4.2	1.6\1.4	2.3\1.6	3.8\3.2	2.1\2.2	1.2\1.4
1.9\1.8	1.6\1.4	3.0\3.5	2.4\2.5	8.5\8.8	1.5\1.3	3.2\3.5	10.4\9.2
5.4\5.7	5.0\4.5	3.3\3.3	7.0\6.5	3.1\2.9	3.8\3.7	1.1\1.4	5.3\5.8
1.3\1.0	3.0\3.3	1.7\1.0	2.2\2.8	2.5\3.0	2.6\2.5	4.1\3.4	4.6\4.2
2.3\2.6	8.1\8.7	0.6\0.4	3.5\3.2	8.8\8.5	0.9\1.1	3.4\3.1	5.3\5.0
2.6\2.0	4.4\3.7	1.0\1.7	2.5\2.9	5.5\5.0	1.3\1.5	2.1\2.4	4.2\4.6
1.8\1.5	4.2\4.4	0.7\0.5	2.5\2.4	2.3\2.1	1.1\0.9	3.2\3.7	2.8\3.1
1.5\1.2	4.8\5.1	1.2\1.4	0.9\1.1	3.7\3.3	0.5\0.6	3.9\3.5	2.1\2.7
1.8\1.9	3.5\3.3	0.5\0.8	3.9\3.1	2.9\2.6	0.4\0.5	2.1\1.8	3.4\4.2
2.6\3.2	2.0\2.7	1.4\1.2	1.1\0.9	1.9\1.6	0.4\0.5	2.0\2.2	1.7\1.9
1.7\1.3	1.6\1.5	0.5\0.7	1.4\1.6	4.9\4.7	0.6\0.5	3.0\3.1	2.9\3.0
2.6\2.3	0.7\1.0	2.2\2.4	2.9\2.5	3.3\2.9	0.7\0.7	0.9\1.0	2.8\3.0
1.5\1.8	2.1\2.0	0.8\0.5	1.4\2.0	0.5\0.9	1.1\1.0	1.0\0.7	1.2\1.5

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I3 Densitometric Data for Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Caldwell Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	1.8\2.0	6.3\5.5	3.5\3.1	8.2\6.5	8.7\8..4	2.0\2.3	0.2\0.5
2	3.4\3.9	4.7\4.2	4.4\4.1	10.1\11.1	4.3\4.1	2.7\2.1	0.5\0.2
3	5.5\4.8	4.4\5.4	4.6\4.9	2.6\3.3	2.2\2.5	3.8\4.1	0.7\0.7
4	3.5\3.1	5.1\5.4	2.5\2.9	3.6\3.5	4.8\5.6	1.9\1.9	1.5\1.5
5	2.2\2.9	6.3\4.9	6.2\5.4	2.8\2.5	3.9\4.1	3.1\3.1	2.8\2.7
6	3.2\2.9	4.1\5.2	3.0\3.8	3.0\3.4	6.2\5.4	1.8\1.5	2.6\2.7
7	3.6\3.6	3.7\4.0	2.6\2.3	3.9\3.4	2.3\2.1	2.5\2.9	5.9\5.5
8	1.8\1.8	4.1\4.2	2.6\2.7	3.8\3.4	2.5\2.4	2.2\2.1	7.9\8.3
9	3.4\2.1	3.7\3.4	1.4\1.6	4.7\5.1	1.3\1.6	3.2\3.8	5.1\5.0
10	2.6\2.9	2.8\3.1	2.3\2.1	3.5\4.1	2.5\2.6	1.9\2.1	14.9\15.0
11	3.1\2.1	3.6\3.5	2.1\2.3	2.9\3.4	2.1\2.4	4.3\3.8	7.7\7.9
12	2.5\3.0	4.6\4.6	3.0\3.2	2.0\2.2	3.6\3.5	1.3\1.0	7.9\7.7
13	2.9\3.4	3.6\3.1	4.9\5.3	4.5\4.1	2.9\2.6	1.1\1.1	7.7\7.7
14	5.4\6.4	2.3\2.6	1.6\2.1	1.8\2.1	5.4\5.1	4.6\2.9	5.5\5.8
15	1.9\1.9	2.9\3.1	4.1\3.0	2.6\2.1	2.6\2.3	5.5\6.5	3.2\2.9
16	4.9\5.3	2.7\3.6	0.8\0.8	2.8\2.3	9.8\8.8	4.5\5.2	2.0\2.8
17	2.0\2.3	2.8\2.4	3.9\3.5	1.8\2.5	1.2\2.2	4.1\4.2	2.1\1.8
18	2.7\2.0	1.6\1.8	1.9\2.3	1.2\0.8	2.3\2.9	3.0\3.5	2.2\1.7
19	1.7\1.2	2.7\2.0	2.7\2.1	1.9\2.1	5.5\4.4	3.3\2.9	0.7\0.9
20	3.0\3.8	2.3\2.3	5.8\6.2	1.8\1.5	2.5\2.6	4.0\3.8	0.6\0.8
21	3.3\3.0	1.2\1.3	6.7\6.9	1.9\2.3	1.7\2.7	3.2\2.4	1.9\1.5
22	3.7\3.7	4.0\3.9	3.7\3.7	3.1\2.9	1.7\1.7	5.7\6.2	1.8\1.8
23	2.5\2.3	3.0\2.5	2.7\2.1	3.9\4.6	1.9\2.5	1.4\1.8	3.7\2.7
24	4.4\4.9	4.8\5.3	4.0\4.5	1.4\1.6	2.4\2.5	11.4\10.3	2.3\2.2
25	3.2\2.9	3.9\2.1	5.0\5.1	3.1\2.1	2.0\2.3	3.8\4.9	1.8\2.0
26	4.1\4.7	2.3\3.1	3.7\4.1	1.7\1.6	4.5\3.5	5.5\5.7	2.0\1.8
27	1.9\1.4	0.7\1.0	2.7\2.8	5.3\5.7	2.9\2.4	1.6\2.4	2.7\3.7
28	6.5\7.2	1.6\1.7	3.1\2.4	3.4\3.6	1.5\1.7	3.2\3.0	2.2\2.3
29	5.4\4.6	1.6\1.8	1.6\1.6	4.0\3.4	1.9\2.9	1.8\1.5	null
30	3.7\3.7	2.1\2.5	3.1\3.3	2.6\2.6	2.8\2.5	1.5\1.0	null

Table I3 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
4.8\4.1	6.8\5.8	2.0\3.0	5.3\4.5	0.8\0.5	0.6\0.8	2.3\1.7	2.4\2.7
1.5\1.0	5.1\6.6	8.3\7.2	2.0\2.2	0.6\0.8	0.9\1.0	5.4\5.2	0.9\0.6
1.5\1.8	4.7\5.4	5.1\5.8	2.1\3.0	0.6\0.4	1.3\1.2	1.7\1.5	2.4\2.6
3.3\3.0	1.8\1.5	7.0\7.3	0.9\0.5	1.5\1.2	0.8\0.6	1.2\1.9	2.3\2.9
2.2\2.7	7.7\6.6	6.0\7.1	2.0\1.2	3.8\3.1	1.9\2.1	4.9\4.2	1.5\0.9
3.7\3.6	3.7\4.6	7.2\8.3	2.3\2.4	1.2\1.5	1.6\2.1	3.9\3.5	2.0\2.4
9.4\7.8	1.6\1.9	5.5\5.1	6.4\7.8	5.7\5.1	2.2\2.7	3.2\3.0	3.1\2.8
4.8\4.9	1.2\0.9	7.1\6.0	10.3\10.5	1.3\2.4	2.8\2.6	3.8\3.2	1.8\1.4
7.0\8.6	3.3\3.6	7.3\7.0	12.1\12.7	3.1\3.8	1.7\1.6	5.8\6.1	3.8\3.6
4.9\4.8	1.9\1.6	2.5\2.5	1.9\1.2	0.5\0.8	5.5\5.5	6.1\5.8	1.7\1.8
3.0\2.4	0.8\0.7	5.8\5.1	8.5\8.5	2.4\2.0	5.8\5.4	1.4\2.0	3.1\3.1
5.2\5.2	1.5\1.8	5.1\5.5	2.7\3.9	2.5\2.5	8.8\8.1	5.9\6.3	1.8\1.7
3.6\3.7	3.6\3.3	2.6\2.6	3.9\2.1	1.3\1.9	8.4\8.6	3.4\3.0	2.4\2.0
3.3\3.8	1.2\1.3	4.1\3.8	2.4\1.8	1.9\2.8	6.9\7.4	1.9\1.2	3.1\3.5
2.4\3.0	1.8\2.3	3.8\4.1	4.3\3.3	1.9\1.3	3.4\4.7	1.5\1.7	1.6\1.5
3.6\3.9	0.9\1.2	2.5\1.2	3.8\3.1	3.4\3.8	3.3\2.8	5.2\5.4	2.9\2.3
3.8\3.3	0.7\0.8	2.2\1.8	3.7\2.9	2.6\2.1	1.9\2.8	6.3\5.9	3.6\3.8
5.2\5.2	2.8\2.5	1.5\1.1	2.2\3.2	3.9\5.8	2.1\1.9	2.1\2.5	2.8\3.1
4.1\4.8	1.3\1.2	2.2\2.5	1.4\2.4	4.4\4.3	2.1\1.6	2.4\2.0	8.6\9.4
2.7\2.2	5.8\6.8	0.7\0.4	3.4\3.1	2.4\1.3	2.8\1.9	1.6\1.1	13.8\12.3
1.2\0.9	6.6\7.7	1.0\1.4	2.3\1.8	15.1\16.0	1.2\1.3	2.0\1.4	2.6\2.4
1.8\1.5	3.3\2.9	1.1\0.8	1.7\2.1	4.9\4.3	2.7\2.2	4.2\4.9	4.1\5.3
3.1\3.6	5.4\4.7	1.1\0.8	1.3\2.0	4.5\3.9	2.8\3.3	2.1\1.8	2.7\2.4
1.5\1.4	4.6\3.7	0.4\0.7	0.8\0.4	5.8\3.9	3.6\4.3	3.2\3.8	10.5\12.0
1.9\1.6	2.3\1.8	0.4\0.5	3.7\3.6	4.3\4.4	2.6\2.8	3.0\3.4	5.3\4.1
1.0\1.5	4.2\3.4	1.1\1.5	1.4\2.4	5.1\5.7	4.4\3.4	3.5\3.9	5.3\4.5
3.0\3.3	6.6\5.1	0.7\0.5	1.4\2.5	3.8\3.4	4.7\3.4	3.0\3.2	1.4\1.8
1.6\1.9	2.9\3.3	1.2\2.5	2.6\2.8	3.9\4.5	4.3\3.6	6.2\6.5	1.5\1.6
3.6\3.1	2.5\2.8	3.0\2.0	1.1\0.6	2.8\1.9	3.4\3.4	1.1\1.6	0.6\0.9
1.4\1.5	3.4\4.2	1.8\2.2	1.9\1.5	4.3\4.9	5.4\5.8	1.7\2.3	0.8\1.0

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I4 Densitometric Data for Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Freedom Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	0.5\0.8	4.1\4.6	0.4\0.8	8.7\8.1	2.8\2.2	1.3\1.9	3.0\2.8
2	7.9\7.6	4.9\5.6	5.9\5.4	8.2\8.7	6.4\6.8	0.8\1.1	4.9\4.6
3	2.5\2.5	5.1\4.8	4.5\3.6	5.0\5.1	9.4\8.4	1.1\1.3	3.9\4.0
4	1.9\2.2	5.3\4.8	3.0\3.5	4.7\4.3	3.5\3.7	1.5\1.9	6.5\6.2
5	2.1\2.1	5.6\4.9	12.9\11.4	8.1\8.7	4.7\3.9	4.1\4.2	3.3\2.5
6	1.6\1.4	6.1\5.0	3.5\4.5	2.9\2.6	6.6\6.1	1.1\0.8	6.6\7.6
7	3.3\3.7	6.9\8.0	5.4\5.9	6.6\6.1	3.8\3.4	0.9\0.9	5.5\4.8
8	2.4\2.2	3.1\3.7	3.6\4.5	4.6\3.0	6.8\6.4	2.6\2.7	4.0\3.9
9	2.8\2.7	10.1\8.5	1.7\1.9	8.7\8.2	3.4\4.4	2.0\3.0	6.6\5.6
10	1.6\2.3	4.9\5.9	1.5\1.1	6.1\6.6	4.7\4.2	1.3\1.1	4.6\4.9
11	4.5\3.6	4.8\5.1	3.4\4.5	6.3\6.3	2.8\2.6	1.9\1.5	6.2\6.5
12	5.0\4.8	4.6\.4.1	1.0\0.9	3.0\4.6	3.7\3.5	1.0\1.5	4.0\3.3
13	4.8\5.0	1.6\1.0	3.4\2.8	4.3\4.7	2.5\1.8	3.0\2.0	2.5\3.3
14	3.6\4.5	4.0\3.7	5.9\4.9	5.1\5.0	2.2\2.8	4.7\4.8	3.3\4.0
15	6.7\6.5	2.9\2.1	0.9\1.0	1.8\1.5	2.6\2.8	2.1\2.5	4.8\5.5
16	8.1\8.1	1.6\2.2	4.9\5.9	1.9\1.3	0.7\1.0	5.9\6.4	2.2\1.9
17	5.7\4.7	4.8\5.3	1.9\2.6	1.8\2.1	3.9\4.7	2.5\2.1	3.0\2.9
18	2.4\2.0	1.3\1.0	8.2\8.2	1.3\1.9	2.6\1.7	6.5\7.0	1.2\1.8
19	2.7\2.8	2.1\2.9	4.7\5.3	0.9\0.8	4.2\4.7	7.1\6.5	2.1\1.7
20	2.3\1.6	3.7\4.0	2.6\1.9	2.6\2.9	1.6\1.9	11.5\10.5	1.8\1.8
21	2.0\2.4	1.1\0.8	2.8\3.4	1.0\0.9	3.4\3.8	4.3\4.0	2.9\2.8
22	3.7\3.3	1.5\0.8	4.5\3.4	1.0\0.8	2.7\3.2	4.2\4.1	1.8\1.9
23	1.4\1.6	2.9\2.1	5.3\4.7	1.0\0.6	1.9\1.6	4.8\4.7	1.2\1.0
24	2.2\2.4	1.4\0.9	1.5\2.1	0.4\0.6	2.0\2.5	4.0\4.3	2.0\2.0
25	4.7\5.7	2.1\2.9	1.1\1.5	0.5\0.3	1.8\2.5	1.5\1.0	1.8\1.2
26	2.2\1.6	0.8\1.1	2.1\1.5	0.8\0.9	1.0\0.7	2.7\2.6	1.0\1.2
27	1.4\1.9	0.8\1.5	1.9\1.7	0.6\1.0	1.7\2.6	3.5\3.8	1.7\2.1
28	1.9\1.9	1.0\1.3	0.5\0.3	0.4\0.4	1.8\1.7	6.5\7.1	2.8\3.0
29	1.6\2.2	0.9\1.4	0.3\0.5	0.9\1.0	3.2\2.7	1.9\1.3	2.9\3.0
30	6.5\6.7	null	0.8\0.4	0.8\1.0	1.7\1.8	3.8\3.5	1.9\2.2

Table I4 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
7.2\8.4	3.8\3.2	5.9\5.1	7.9\6.8	1.0\1.2	0.8\0.7	10.2\9.7	3.0\2.2
8.1\7.5	2.1\1.6	3.8\3.9	2.7\3.3	0.9\0.5	4.1\4.6	10.2\9.3	1.4\0.7
8.4\8.2	3.0\2.4	3.3\3.0	2.7\2.4	0.9\0.6	5.5\6.0	13.3\13.1	3.1\3.9
3.8\4.0	4.6\4.4	2.3\2.3	5.5\5.8	0.8\1.0	4.6\4.1	5.8\5.0	2.7\3.1
6.1\5.1	5.4\4.9	5.0\4.6	5.8\6.2	0.6\0.9	6.0\5.5	3.5\3.1	3.6\4.0
10.6\11.6	3.4\2.8	5.1\5.9	13.8\13.1	2.2\2.6	8.9\8.2	8.1\8.6	4.1\4.6
4.9\4.4	4.9\4.7	4.4\4.3	2.8\2.6	1.2\1.0	6.0\5.5	2.1\2.6	4.0\3.6
4.4\4.9	4.9\4.0	4.6\5.0	2.5\3.7	8.5\9.6	3.4\3.1	2.8\3.1	2.6\3.1
5.1\5.3	1.6\2.1	7.5\8.2	3.3\2.7	1.5\1.3	5.6\4.9	2.1\2.4	2.5\2.6
2.9\2.4	2.4\3.0	7.3\7.6	3.7\2.5	2.2\1.9	6.3\7.2	3.1\2.8	0.7\1.4
1.9\1.6	2.0\2.3	4.1\4.2	3.1\2.2	2.6\2.6	3.1\3.4	1.5\2.0	1.8\2.2
5.3\5.1	1.3\1.2	8.2\7.5	2.6\2.8	2.7\3.0	4.9\5.6	2.4\2.1	2.6\2.6
2.1\1.4	1.4\1.0	4.2\4.1	2.4\2.5	1.4\1.7	3.0\2.9	2.0\1.5	2.6\2.5
1.8\1.4	1.4\1.8	5.6\5.0	2.2\3.1	1.7\1.4	7.2\6.3	1.5\1.5	3.1\2.7
2.1\2.3	0.7\0.5	2.3\2.9	4.5\3.8	1.3\1.0	8.2\8.9	2.5\2.2	2.2\1.8
1.0\1.3	6.4\7.1	3.0\3.4	1.2\1.5	1.9\2.2	1.6\1.0	1.2\1.5	3.7\3.4
2.3\2.1	1.0\1.4	1.8\1.4	2.4\2.7	3.3\2.8	4.1\4.6	2.1\2.3	1.2\1.8
1.4\1.5	3.2\3.8	1.1\1.0	1.5\1.2	2.1\2.1	1.5\1.9	2.3\2.1	3.2\2.8
2.4\2.9	5.2\5.5	1.5\1.1	2.5\2.4	2.8\3.3	2.9\3.0	1.1\1.4	5.6\5.0
4.5\3.8	1.8\1.4	1.7\1.6	1.6\2.1	6.5\6.8	1.4\1.2	2.2\2.5	6.6\6.0
1.3\1.0	5.5\5.2	2.3\2.1	3.2\3.0	3.0\2.7	1.0\1.2	0.9\0.9	5.0\5.6
1.4\1.8	7.1\6.4	1.1\0.9	1.3\1.1	9.6\8.5	1.0\1.6	1.7\1.9	3.1\2.6
1.6\1.9	4.9\5.4	0.8\0.5	2.1\1.6	7.2\6.3	0.9\0.6	1.9\1.9	6.8\6.3
1.4\2.1	4.0\4.9	0.9\1.1	3.8\4.5	6.3\7.0	0.5\0.8	1.7\1.9	4.6\4.1
1.3\2.0	4.7\4.9	2.1\2.3	2.7\2.9	3.0\3.2	0.7\0.8	1.5\1.2	2.2\3.0
1.5\1.4	2.7\2.9	1.0\1.1	3.0\3.3	2.6\3.1	0.7\0.9	1.4\1.1	3.9\3.1
2.6\2.5	2.8\3.4	1.1\1.5	3.4\3.6	6.6\6.9	1.2\1.4	3.9\3.8	6.3\6.8
0.7\0.9	2.3\2.0	1.6\1.7	3.3\3.0	7.0\6.7	1.3\1.1	3.3\3.4	1.4\1.4
0.6\0.7	4.4\4.6	2.4\2.7	0.9\1.5	4.5\5.0	2.0\1.8	1.9\1.7	2.8\3.2
1.3\1.1	1.2\1.3	4.1\3.5	1.7\2.2	3.9\2.9	1.9\1.5	1.9\1.7	3.4\3.7

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I5 Densitometric Data for Non-Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Blend[1] Flour and Its Different Dough[2]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	0.2\0.4	4.5\4.0	0.9\1.1	0.2\0.4	1.6\1.2	1.6\1.7	2.5\2.2
2	0.6\0.5	8.4\8.8	1.2\1.6	0.4\0.3	1.2\1.2	0.7\0.9	2.8\2.3
3	0.6\0.5	3.3\4.3	1.4\1.9	0.5\0.4	1.3\1.6	1.6\1.4	5.2\5.0
4	0.8\0.8	7.2\6.8	3.5\2.8	1.0\1.4	2.5\2.7	3.1\2.7	2.3\2.0
5	2.9\2.4	5.7\5.0	2.7\2.1	2.4\2.1	1.8\2.0	3.2\3.9	1.7\1.4
6	4.3\4.8	5.3\5.6	2.8\3.4	4.6\4.0	7.0\6.5	1.8\1.6	1.7\1.4
7	4.6\4.1	8.8\8.0	3.6\3.1	6.9\6.4	2.6\2.5	2.8\2.5	1.4\1.6
8	7.5\6.3	2.8\3.3	6.8\6.3	2.3\2.5	6.5\7.0	2.1\2.2	2.8\2.5
9	3.3\3.2	5.0\5.7	5.3\6.1	2.5\2.9	9.3\8.7	4.8\4.2	1.4\1.7
10	8.8\8.0	3.0\3.3	3.2\3.6	13.7\12.6	2.0\1.8	2.5\2.7	2.3\2.8
11	10.2\11.0	3.0\2.5	3.0\3.5	4.1\4.2	2.1\2.2	4.7\5.0	1.5\1.7
12	4.3\3.5	4.0\4.5	1.4\1.2	8.6\9.1	3.3\3.9	1.3\1.1	2.0\2.3
13	4.4\4.9	1.5\1.1	3.1\3.6	2.5\3.0	3.2\3.0	2.2\2.1	1.3\1.0
14	3.5\4.3	2.5\1.9	2.4\2.6	2.6\2.5	2.2\1.8	6.5\7.2	1.4\1.7
15	3.0\2.5	1.2\1.7	1.6\1.2	4.4\4.2	3.1\3.2	4.2\4.1	1.0\1.3
16	2.4\2.0	1.7\1.1	1.1\0.9	4.2\4.4	6.2\6.2	3.8\3.2	3.8\3.3
17	3.2\3.3	2.9\3.0	3.2\3.4	3.6\3.3	3.5\3.6	6.3\6.5	2.2\2.5
18	6.3\7.5	2.3\2.6	1.9\1.4	2.9\2.5	4.9\4.2	3.9\3.2	2.5\2.8
19	4.8\4.3	1.9\2.2	2.6\2.4	4.0\4.6	6.2\6.2	3.2\3.8	3.3\3.8
20	2.1\2.5	3.0\2.9	4.9\4.5	2.3\2.0	1.8\2.2	4.1\4.2	1.7\1.5
21	1.5\1.4	1.1\0.9	4.6\5.0	5.3\5.8	2.5\2.6	4.2\4.8	4.9\5.1
22	4.1\4.6	4.1\3.5	2.1\2.7	2.7\3.0	2.2\2.1	2.7\2.5	5.2\5.4
23	2.1\2.3	2.5\3.0	3.5\3.0	1.4\1.0	3.9\3.3	6.5\6.3	3.9\3.9
24	2.0\2.4	4.3\3.3	5.0\4.6	2.5\2.3	4.2\4.9	5.0\4.7	5.7\5.9
25	2.3\2.1	1.7\1.2	2.8\3.5	2.5\2.6	2.7\2.7	1.7\1.6	7.8\7.4
26	2.4\2.9	1.9\2.5	6.3\6.8	2.3\2.5	5.6\6.2	7.7\7.0	3.7\4.0
27	2.4\2.9	3.3\3.0	6.1\5.3	2.1\2.4	2.7\2.5	2.7\3.1	2.7\2.9
28	1.5\1.0	0.9\1.1	3.4\2.8	3.1\3.3	1.6\1.3	1.6\1.8	3.5\3.8
29	1.4\1.5	1.0\1.7	6.2\6.6	1.3\0.9	1.2\1.6	1.1\1.3	6.2\6.3
30	2.5\2.1	1.1\1.5	3.6\3.2	3.3\3.6	1.2\1.2	2.5\2.8	11.3\10.2

Table I5 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
4.0\4.1	2.3\2.1	1.0\1.8	5.9\5.4	7.9\8.3	10.0\9.2	6.4\5.5	2.0\1.8
4.2\4.8	1.1\1.3	9.7\9.1	5.7\5.8	6.0\6.4	4.5\4.9	2.0\2.2	3.4\3.2
1.5\1.3	1.4\1.9	5.4\6.4	4.6\4.3	2.3\2.4	8.2\7.9	2.0\2.3	1.1\1.6
2.6\2.3	0.8\0.4	2.9\3.4	3.3\2.9	2.3\2.2	1.8\1.9	3.4\3.8	1.8\2.0
2.8\3.5	0.3\0.5	4.0\4.2	7.9\7.5	3.3\3.5	2.6\2.9	3.2\3.4	1.5\2.0
3.3\3.1	0.8\0.7	3.1\2.8	3.5\3.9	3.1\3.8	2.3\2.4	2.9\3.1	0.5\0.9
2.0\1.6	0.4\0.8	4.2\4.2	3.6\4.0	3.8\4.2	4.0\4.2	3.3\3.5	4.0\3.6
2.4\2.8	0.8\0.7	6.4\5.4	3.3\3.5	2.3\2.6	1.9\1.5	4.4\4.0	1.3\1.9
2.7\3.0	1.5\1.4	6.3\6.9	3.5\3.3	3.5\3.6	3.8\3.9	4.0\4.4	1.8\1.9
7.4\7.4	1.2\1.1	4.2\4.0	7.9\7.0	5.3\4.8	2.1\2.2	2.4\2.0	3.6\4.0
3.9\3.2	3.0\3.4	2.1\1.8	4.3\3.6	2.6\1.9	2.1\2.3	4.9\5.2	1.6\1.1
4.2\4.0	1.7\1.4	3.2\2.8	2.6\2.3	2.3\1.9	4.0\3.5	2.5\2.6	5.1\4.7
4.8\4.2	3.2\3.8	3.1\3.1	2.4\2.8	1.4\1.1	2.4\2.3	2.7\2.2	3.2\3.4
5.0\5.7	5.3\5.5	3.9\4.1	4.7\5.2	1.9\2.6	3.0\2.8	7.6\7.1	2.0\2.5
1.6\2.0	2.4\2.5	3.5\3.1	2.7\2.9	3.3\3.5	2.0\2.4	2.0\2.4	2.2\2.5
3.1\3.4	2.8\2.7	3.4\2.9	1.7\1.0	6.5\6.0	2.5\2.9	5.9\6.0	2.6\2.9
3.0\2.7	5.6\5.3	1.3\1.6	3.6\4.3	3.8\3.1	1.7\2.1	1.2\1.5	2.5\2.2
3.9\3.9	7.1\7.6	1.5\1.9	1.1\1.5	2.7\2.3	3.4\3.0	2.2\2.7	1.9\1.8
2.8\2.4	3.4\3.0	2.0\2.1	2.5\2.1	4.8\5.3	2.2\2.0	4.0\4.4	4.0\4.1
4.0\4.2	5.3\4.8	4.1\3.9	1.2\1.1	1.9\2.3	3.3\3.5	3.1\3.3	2.9\3.4
3.4\3.4	5.3\5.6	2.8\3.2	2.0\2.3	6.4\6.0	2.4\2.1	3.4\3.3	4.3\4.6
3.1\3.3	9.9\8.9	1.8\1.0	2.9\3.3	3.5\3.3	2.5\2.6	2.3\2.3	4.8\5.0
3.4\3.1	6.9\7.9	2.5\2.5	4.3\4.6	2.6\2.3	3.3\3.5	6.1\5.7	11.1\10.1
3.2\3.9	5.5\5.3	2.1\2.7	1.0\1.7	2.2\2.3	3.5\3.5	1.6\1.8	2.9\2.6
3.5\2.8	8.3\7.8	3.1\3.5	2.9\2.7	3.5\3.3	2.2\2.0	5.3\4.9	5.5\5.3
5.7\5.0	4.8\5.3	2.8\3.1	2.3\2.6	2.4\2.3	4.1\4.6	1.8\1.6	8.3\8.0
2.3\2.6	3.8\3.2	2.1\2.0	2.8\2.4	2.3\2.7	3.3\3.5	2.4\2.5	7.8\8.3
0.9\0.9	2.1\2.3	1.9\1.5	1.1\1.2	4.2\3.8	4.0\3.7	2.3\2.3	1.9\1.3
1.3\1.5	1.4\1.7	2.8\2.8	2.1\2.5	1.1\1.4	2.3\2.6	1.5\1.2	2.5\2.0
4.1\4.0	1.9\1.4	2.7\2.1	2.3\2.0	0.7\0.7	4.6\4.1	3.3\3.1	2.0\1.5

[1]Blend: The mixture of 50% soft red winter and 50% hard red winter.

[2]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I6 Densitometric Data for Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Frankenmuth Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	5.2\5.4	1.0\1.4	0.6\0.4	7.2\7.5	3.2\3.7	0.7\0.8	4.7\4.0
2	3.1\3.4	0.2\0.5	1.0\1.1	2.0\1.5	1.4\1.0	1.3\1.6	1.9\1.7
3	2.4\2.7	0.9\1.2	1.0\1.4	1.0\1.6	0.8\0.9	0.3\0.6	2.8\2.4
4	2.7\2.4	0.5\0.2	1.2\1.3	1.3\1.7	1.0\1.4	0.9\0.8	4.3\4.6
5	1.3\1.1	2.1\2.0	0.4\0.6	1.6\1.8	0.8\1.1	0.6\0.8	1.7\2.2
6	2.0\2.4	2.0\2.1	1.3\1.0	2.5\2.5	0.6\0.5	1.4\1.1	3.1\2.9
7	1.0\1.6	1.8\2.1	1.1\1.0	1.7\1.3	1.3\1.0	1.5\1.7	3.5\3.1
8	0.8\1.2	4.6\3.8	5.3\5.1	1.6\1.0	0.9\1.2	0.5\0.7	2.6\2.1
9	0.6\0.8	2.0\2.3	2.4\2.0	4.4\4.8	1.3\1.5	0.8\1.0	2.6\3.1
10	1.1\1.3	3.8\3.2	2.1\2.3	0.9\1.3	3.0\3.6	0.6\0.8	5.0\4.7
11	1.2\0.8	2.4\1.6	1.8\2.0	0.8\1.0	8.5\8.6	8.6\7.8	4.3\3.5
12	2.4\2.0	10.7\10.1	1.1\1.1	1.3\0.9	5.8\6.4	8.5\8.6	1.3\1.6
13	4.5\4.3	8.8\8.6	2.1\2.5	1.5\2.0	7.5\6.5	12.1\11.1	3.5\4.3
14	1.6\1.0	5.6\6.2	9.5\9.0	7.5\7.2	5.9\5.3	3.8\3.3	1.9\1.8
15	3.4\3.1	3.7\3.0	9.8\9.9	5.0\5.2	5.8\5.5	3.3\3.8	2.4\2.8
16	3.7\3.3	4.9\5.5	6.4\7.1	0.8\1.3	4.0\4.1	3.2\3.7	2.1\2.6
17	3.3\3.7	2.3\2.0	4.8\4.8	2.4\2.8	2.5\3.1	4.0\4.7	1.8\1.9
18	3.8\3.8	7.6\7.0	9.4\8.7	4.4\5.1	3.6\4.0	5.5\4.9	2.9\3.0
19	2.7\2.0	3.0\3.7	6.7\7.0	4.6\4.4	5.3\5.9	6.0\5.3	3.1\3.5
20	2.0\2.7	5.3\5.3	2.8\2.5	3.2\3.0	8.6\8.5	8.6\8.5	2.9\3.1
21	6.5\6.2	2.5\2.4	3.6\3.4	1.8\1.6	6.4\5.8	5.3\6.0	1.6\1.3
22	5.4\5.2	3.2\3.8	6.3\6.5	2.8\2.4	3.6\3.0	1.1\1.4	4.0\4.7
23	3.0\3.1	2.4\2.5	2.6\2.0	5.2\5.0	4.1\4.0	4.3\4.0	1.7\1.9
24	7.5\8.1	1.6\2.4	1.5\1.8	4.8\4.4	3.1\2.5	0.8\0.7	7.4\7.2
25	5.5\6.0	8.6\8.8	1.9\2.2	4.4\4.6	1.0\1.3	0.8\0.9	5.1\4.6
26	6.2\6.5	1.2\0.9	1.0\1.5	6.9\6.3	2.6\2.1	1.6\1.3	7.2\7.4
27	8.1\7.5	3.8\4.6	2.5\3.1	6.3\6.9	0.5\0.6	0.8\0.6	2.2\1.7
28	3.1\3.0	2.1\1.8	4.7\4.2	7.0\6.5	0.9\0.8	4.7\4.0	3.0\2.9
29	6.0\5.5	1.4\1.0	5.1\4.5	5.1\4.4	2.1\2.6	3.3\3.8	4.7\5.0
30	null	null	null	Null	4.0\3.6	4.9\5.5	4.6\4.3

Table I6 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
1.1\1.3	0.9\0.9	2.3\2.8	0.9\0.7	1.6\1.4	0.7\0.5	0.5\1.0	4.1\4.4
0.9\1.1	0.6\0.9	3.3\2.9	1.4\1.6	0.9\1.1	2.3\2.5	1.2\1.6	1.2\1.1
3.2\3.3	0.6\0.5	4.4\4.3	5.6\5.3	1.7\1.4	1.8\1.5	2.4\2.8	1.9\2.2
3.2\3.4	1.1\1.0	1.6\1.9	5.8\6.1	1.4\1.7	3.0\3.3	1.2\1.5	1.4\1.7
3.6\3.6	0.8\0.9	1.3\1.7	7.8\7.4	0.5\0.7	1.6\1.4	4.0\4.0	1.1\1.5
3.4\3.7	0.5\0.6	4.3\4.1	1.1\1.5	0.4\0.7	1.1\1.5	3.9\3.5	3.9\3.7
3.1\3.7	0.9\0.5	0.8\1.0	1.5\1.0	1.3\1.0	5.1\4.6	2.8\2.2	1.6\1.7
2.2\2.7	0.5\0.9	1.4\1.0	1.2\1.7	0.6\0.8	2.1\2.6	1.4\1.6	0.9\1.1
2.8\2.9	0.5\0.6	0.8\1.0	7.7\7.6	0.8\1.0	4.8\4.6	1.4\1.7	1.1\0.9
1.1\1.3	1.7\1.8	2.0\1.9	1.2\1.8	1.5\1.5	5.3\5.5	2.8\2.3	6.3\6.0
3.5\3.2	0.6\0.5	3.8\4.4	5.5\4.7	8.5\7.9	1.0\0.7	8.4\7.9	8.1\7.8
3.9\3.2	1.0\1.5	1.3\1.6	2.5\3.2	8.9\9.4	1.9\2.2	5.1\5.6	3.5\3.8
5.6\5.2	1.3\1.8	4.1\4.3	3.0\2.5	11.4\10.9	1.7\1.3	10.5\9.7	11.8\10.8
7.7\7.0	4.4\3.7	5.8\6.0	5.1\5.6	4.1\4.2	4.2\4.6	3.5\3.0	7.4\6.8
3.8\4.3	2.9\3.7	6.4\6.0	5.1\5.1	4.3\4.2	4.1\3.6	4.0\4.7	5.4\5.7
2.1\1.9	2.8\3.2	5.3\5.7	2.7\2.8	3.8\4.0	1.2\1.7	3.9\4.3	3.1\2.7
3.7\3.4	0.9\0.6	4.9\5.4	3.8\3.7	10.0\9.8	2.4\2.0	5.3\5.7	3.6\3.9
3.7\3.1	1.8\2.2	1.9\1.6	6.0\6.2	1.4\1.7	4.7\5.1	5.7\5.9	3.8\4.1
3.2\3.5	6.0\5.9	1.7\1.3	3.6\3.4	2.1\1.8	3.2\3.7	6.1\5.9	1.7\1.4
3.2\3.9	6.9\7.1	5.4\4.9	5.7\6.0	2.3\2.7	3.8\4.3	2.3\2.8	2.5\3.0
2.9\2.8	7.3\7.5	6.0\5.8	2.6\2.3	2.8\2.4	12.4\11.3	1.5\1.2	2.9\3.4
3.6\3.6	3.7\2.9	4.3\4.4	1.8\2.2	2.8\3.5	8.9\9.0	1.7\1.4	1.6\1.9
4.8\4.3	6.4\5.8	6.9\6.9	2.6\2.2	3.5\3.0	1.8\1.7	1.6\1.4	1.5\1.0
6.4\7.1	10.7\10.9	1.9\2.0	1.2\1.7	3.6\4.2	3.3\3.4	1.6\1.2	2.7\3.1
5.2\5.6	11.4\10.2	3.4\3.0	1.3\0.8	2.8\2.2	5.1\4.9	3.0\3.5	3.7\3.9
3.3\3.2	4.7\4.3	2.8\2.3	1.3\0.9	2.3\2.5	2.5\2.7	3.5\3.9	4.4\4.1
2.7\2.2	7.5\7.3	2.9\3.3	1.9\2.4	3.5\3.3	3.7\3.3	2.2\2.8	1.7\1.6
3.4\3.2	5.9\6.0	3.0\3.4	4.5\4.0	2.8\3.1	2.1\2.3	2.8\2.4	3.9\3.6
1.3\1.1	1.8\1.7	1.6\1.3	2.9\3.1	2.3\2.0	3.9\4.1	1.0\0.5	1.1\1.2
1.1\0.9	3.7\4.4	4.4\3.8	2.7\3.0	5.9\5.9	null	4.7\4.0	2.2\1.9

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Talbe I7 Densitometric Data for Reduced Total Proteins from Each Protein FractionObtained from Gel Filtration Chromatography of Cracker Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	1.2\1.6	0.4\0.6	0.9\1.4	1.2\0.9	0.9\0.5	4.7\5.3	7.5\7.1
2	1.9\2.1	0.4\0.7	1.0\1.3	1.6\1.1	0.5\0.9	1.4\1.6	1.9\1.5
3	1.8\1.9	0.8\0.6	1.6\1.4	0.9\1.2	0.5\0.8	1.5\1.9	4.2\4.0
4	5.4\5.6	1.3\1.0	0.5\0.8	1.9\1.6	0.6\0.8	1.9\1.5	2.6\2.8
5	3.5\3.9	0.8\1.1	1.9\2.1	0.5\0.8	0.8\0.5	1.1\1.5	1.5\1.6
6	3.4\3.3	1.9\1.6	0.6\0.8	0.6\0.8	1.7\1.5	0.4\0.9	1.4\1.0
7	5.8\6.7	0.9\0.8	1.4\1.6	2.7\2.2	3.4\3.0	1.4\1.7	1.9\2.2
8	17.7\16.8	6.2\6.7	0.4\0.8	2.6\2.8	1.7\2.1	2.0\2.5	3.2\2.7
9	3.8\3.4	3.6\3.7	3.1\2.5	3.1\2.6	2.4\2.4	1.3\1.5	5.3\5.5
10	2.6\2.7	2.8\2.4	0.8\0.6	3.0\2.5	3.2\3.5	1.5\1.1	2.8\2.7
11	3.4\3.0	5.1\5.2	0.8\0.5	2.6\3.1	3.0\2.7	2.8\2.6	2.8\2.6
12	5.6\5.4	1.0\1.7	2.8\2.5	1.9\1.8	3.6\3.8	3.5\2.8	1.5\1.9
13	0.8\1.2	1.7\1.0	2.1\1.9	1.1\1.6	1.0\0.8	1.7\1.4	0.8\1.3
14	1.0\1.2	2.9\2.4	4.8\4.6	1.6\1.9	4.5\4.8	3.8\4.3	0.4\0.7
15	7.0\6.7	6.7\6.2	5.1\5.5	2.2\2.7	6.0\5.7	0.9\0.4	1.6\1.5
16	1.3\1.6	5.6\5.2	14.6\14.2	7.1\7.2	6.4\6.0	2.6\3.1	4.4\4.4
17	1.2\1.0	3.7\3.6	8.9\8.1	2.8\2.6	5.2\5.6	7.6\7.8	0.8\1.0
18	2.7\3.1	1.7\1.4	8.2\8.5	1.9\2.3	3.6\4.1	2.8\3.5	2.9\3.2
19	3.4\2.6	4.1\4.8	4.4\4.8	3.1\3.5	5.6\5.1	2.8\2.9	1.0\1.4
20	3.4\3.8	4.6\4.0	3.9\2.8	3.8\4.2	3.1\3.3	4.7\4.5	2.2\1.9
21	1.2\0.8	3.2\3.3	5.2\5.2	5.8\5.2	2.3\2.5	4.2\4.7	8.2\7.7
22	1.8\2.0	11.4\11.9	6.8\6.5	6.9\6.4	4.5\4.1	4.1\4.3	2.7\2.8
23	2.6\3.4	2.4\2.9	4.6\4.8	7.8\7.0	4.5\4.8	7.8\7.6	1.8\2.0
24	3.9\3.5	8.4\7.9	1.3\1.0	3.8\3.7	3.5\3.7	4.3\3.8	3.4\3.5
25	2.1\1.9	4.0\4.6	2.5\3.1	4.0\4.8	3.2\3.7	3.3\3.8	7.1\7.5
26	1.9\1.8	2.6\3.0	2.3\2.7	4.8\4.4	7.4\7.1	2.5\2.0	2.7\3.2
27	2.0\1.8	3.3\3.2	2.8\3.9	6.9\7.4	6.8\6.1	4.0\3.5	4.4\4.4
28	3.3\3.4	4.8\4.1	2.5\2.8	4.8\4.0	3.3\3.8	12.5\11.4	10.8\9.5
29	1.6\1.2	1.4\1.7	2.7\2.3	3.7\3.8	2.5\2.0	1.6\1.4	4.0\4.0
30	2.7\2.6	2.4\2.8	1.4\0.9	5.2\5.8	4.5\4.5	5.3\4.7	4.0\4.2

Table I7 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
0.4\0.6	0.4\0.8	2.3\2.8	0.9\0.7	1.6\1.4	4.3\4.5	1.4\1.4	2.2\2.6
0.3\0.6	0.5\0.9	3.3\2.9	1.4\1.6	0.9\1.1	3.9\3.1	0.8\0.8	1.0\0.8
0.3\0.5	0.8\1.0	4.4\4.3	5.6\5.3	1.7\1.4	1.0\1.6	0.8\0.8	1.4\1.2
0.6\0.7	0.8\0.4	1.6\1.9	5.8\6.1	1.4\1.7	1.5\1.1	0.4\0.4	0.5\0.9
1.3\1.0	1.4\1.9	1.3\1.7	7.8\7.4	0.5\0.7	2.0\2.5	0.7\0.7	2.0\2.2
5.7\5.2	4.2\4.6	4.3\4.1	1.1\1.5	0.4\0.7	1.3\1.6	1.5\1.5	1.2\1.0
5.2\4.9	1.2\1.1	0.8\1.0	1.5\1.0	1.3\1.0	2.6\2.3	1.4\1.4	0.9\1.2
1.2\1.5	1.5\1.0	1.4\1.0	1.2\1.7	0.6\0.8	4.5\4.2	1.2\1.2	0.9\0.8
6.8\6.1	1.2\1.5	0.8\1.0	7.7\7.6	0.8\1.0	3.3\2.9	2.2\2.2	1.6\1.9
1.7\1.9	1.1\1.4	2.0\1.9	1.2\1.8	1.5\1.5	2.4\2.7	2.6\2.5	0.8\1.0
2.1\2.6	1.0\1.5	3.8\4.4	5.5\4.7	8.5\7.9	5.7\4.6	4.0\3.9	0.9\0.5
1.1\1.1	3.0\3.1	1.3\1.6	2.5\3.2	8.9\9.4	2.6\2.9	1.7\1.7	1.2\1.4
4.7\4.5	1.0\0.8	4.1\4.3	3.0\2.5	11.4\10.9	4.2\4.7	3.6\3.6	3.5\3.7
11.7\11.9	1.1\1.2	5.8\6.0	5.1\5.6	4.1\4.2	2.9\2.7	3.8\3.7	2.6\2.2
1.4\1.4	5.1\5.4	6.4\6.0	5.1\5.1	4.3\4.2	1.1\1.5	4.1\4.1	1.9\1.6
2.3\2.0	8.5\8.6	5.3\5.7	2.7\2.8	3.8\4.0	4.6\5.6	1.7\1.6	6.8\7.7
3.1\3.4	4.9\4.6	4.9\5.4	3.8\3.7	10.0\9.8	4.4\4.9	4.7\4.7	4.1\3.5
6.1\5.8	8.2\8.1	1.9\1.6	6.0\6.2	1.4\1.7	9.2\8.1	6.4\6.3	6.0\5.7
3.1\3.3	14.0\13.4	1.7\1.3	3.6\3.4	2.1\1.8	1.6\1.0	5.7\5.6	5.9\5.6
3.8\3.9	4.0\3.7	5.4\4.9	5.7\6.0	2.3\2.7	4.7\4.2	2.8\2.7	9.6\9.3
5.6\5.8	6.7\6.7	6.0\5.8	2.6\2.3	2.8\2.4	2.7\2.9	4.3\4.2	5.5\6.0
1.9\1.7	2.6\2.7	4.3\4.4	1.8\2.2	2.8\3.5	2.7\2.4	7.2\7.1	6.0\6.5
3.4\3.0	5.4\5.1	6.9\6.9	2.6\2.2	3.5\3.0	2.3\2.6	7.5\4.3	2.9\3.6
5.9\5.2	4.6\4.2	1.9\2.0	1.2\1.7	3.6\4.2	3.8\3.6	5.2\3.2	7.0\6.5
7.8\8.6	3.1\3.0	3.4\3.0	1.3\0.8	2.8\2.2	2.9\3.3	5.2\5.2	6.9\5.9
2.5\2.6	4.6\4.9	2.8\2.3	1.3\0.9	2.3\2.5	2.5\2.0	2.7\5.1	3.5\4.0
3.6\3.8	3.7\4.0	2.9\3.3	1.9\2.4	3.5\3.3	4.2\4.5	4.4\6.9	3.6\2.9
1.6\1.8	1.9\1.4	3.0\3.4	4.5\4.0	2.8\3.1	3.6\3.8	3.1\3.1	3.5\4.1
2.2\2.5	2.7\2.6	1.6\1.3	2.9\3.1	2.3\2.0	3.1\3.9	2.7\2.6	2.2\2.0
2.3\2.0	0.9\0.5	4.4\3.8	2.7\3.0	5.9\5.9	4.5\4.3	6.2\7.5	3.7\3.5

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Talbe I8 Densitometric Data for Reduced Total Proteins from Each Protein FractionObtained from Gel Filtration Chromatography of Caldwell Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	1.6\1.9	0.8\1.0	1.3\1.5	1.2\0.9	0.9\0.5	4.7\5.3	3.5\3.0
2	2.8\3.2	1.8\1.6	1.0\1.1	1.6\1.1	0.5\0.9	1.4\1.6	2.5\3.0
3	2.1\1.8	1.7\2.0	0.9\0.9	0.9\1.2	0.5\0.8	1.5\1.9	1.3\1.8
4	2.6\2.4	0.7\0.4	0.9\0.6	1.9\1.6	0.6\0.8	1.9\1.5	1.8\1.7
5	2.6\2.5	1.5\2.0	0.6\0.9	0.5\0.8	0.8\0.5	1.1\1.5	0.9\1.4
6	1.7\1.6	2.3\1.8	1.9\1.7	0.6\0.8	1.7\1.5	0.4\0.9	0.6\0.8
7	3.1\3.3	2.7\2.0	1.3\1.2	2.7\2.2	3.4\3.0	1.4\1.7	1.7\1.8
8	3.7\3.3	3.7\4.4	1.4\1.7	2.6\2.8	1.7\2.1	2.0\2.5	1.4\1.2
9	3.3\3.3	3.0\3.0	1.7\1.9	3.1\2.6	2.4\2.4	1.3\1.5	2.3\2.6
10	4.0\4.5	4.0\3.5	1.9\1.9	3.0\2.5	3.2\3.5	1.5\1.1	3.0\2.5
11	2.1\1.6	2.8\3.3	1.2\1.3	2.6\3.1	3.0\2.7	2.8\2.6	2.2\2.9
12	5.2\5.5	2.2\2.1	1.9\1.7	1.9\1.8	3.6\3.8	3.5\2.8	1.8\1.3
13	2.4\2.6	4.1\4.2	1.7\1.4	1.1\1.6	1.0\0.8	1.7\1.4	2.6\2.3
14	2.5\2.6	9.0\8.2	5.1\5.0	1.6\1.9	4.5\4.8	3.8\4.3	0.8\0.6
15	3.5\3.9	2.4\2.8	1.1\1.4	2.2\2.7	6.0\5.7	0.9\0.4	2.9\2.2
16	0.9\1.2	5.1\5.5	10.0\10.2	7.1\7.2	6.4\6.0	2.6\3.1	1.2\1.4
17	4.3\4.7	3.2\3.0	7.2\7.7	2.8\2.6	5.2\5.6	7.6\7.8	1.2\1.5
18	5.8\5.1	4.6\4.8	9.1\8.1	1.9\2.3	3.6\4.1	2.8\3.5	1.8\2.0
19	3.3\3.1	4.0\3.5	5.0\5.1	3.1\3.5	5.6\5.1	2.8\2.9	3.4\3.6
20	3.3\3.7	3.2\3.7	3.8\4.0	3.8\4.2	3.1\3.3	4.7\4.5	4.5\4.0
21	1.6\1.7	6.1\5.8	3.8\3.6	5.8\5.2	2.3\2.5	4.2\4.7	1.4\1.6
22	5.5\5.2	5.4\5.1	10.2\10.0	6.9\6.4	4.5\4.1	4.1\4.3	2.7\2.6
23	12.9\12.1	4.1\4.7	3.2\3.4	7.8\7.0	4.5\4.8	7.8\7.6	2.5\2.8
24	1.6\2.1	5.2\5.0	3.6\3.7	3.8\3.7	3.5\3.7	4.3\3.8	3.6\3.5
25	3.2\2.8	4.7\4.9	7.4\6.9	4.0\4.8	3.2\3.7	3.3\3.8	30.3\31.4
26	4.5\4.0	2.3\2.0	4.0\4.4	4.8\4.4	7.4\7.1	2.5\2.0	2.9\2.0
27	1.2\0.9	2.5\2.8	1.8\2.0	6.9\7.4	6.8\6.1	4.0\3.5	2.5\2.4
28	5.1\5.8	3.3\2.9	4.6\4.4	4.8\4.0	3.3\3.8	12.5\11.4	3.6\3.4
29	1.8\2.1	1.9\2.1	1.1\1.0	3.7\3.8	2.5\2.0	1.6\1.4	2.6\2.7
30	1.9\1.6	1.7\1.9	1.5\1.3	5.2\5.8	4.5\4.5	5.3\4.7	6.5\6.0

Table I8 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
0.8\0.8	1.1\1.5	3.9\3.5	1.1\1.6	3.1\2.9	8.8\8.2	0.1\0.3	4.3\3.6
4.2\3.7	2.3\2.9	4.1\3.6	1.0\0.7	2.1\2.3	4.7\4.5	0.2\0.5	2.8\2.7
5.1\5.1	1.6\1.1	4.3\4.3	1.1\0.9	1.0\0.9	5.1\5.7	1.1\1.3	0.5\0.3
6.5\5.9	2.8\3.6	2.6\2.4	0.5\0.4	1.0\0.8	2.0\2.3	3.1\2.9	0.6\0.5
2.3\2.7	2.2\1.7	3.6\4.0	0.5\0.6	0.6\0.9	4.7\4.4	5.8\5.2	0.6\0.7
5.7\5.9	2.8\2.4	4.8\4.8	0.7\1.0	0.5\0.7	1.8\1.9	6.3\6.5	0.8\1.0
6.5\6.1	1.9\2.2	5.8\6.0	0.9\1.1	0.9\0.7	3.4\3.8	2.2\2.6	0.8\1.1
4.5\4.7	2.2\1.6	2.0\2.3	1.0\1.2	0.5\0.9	4.4\4.4	6.8\5.9	0.9\0.7
2.0\2.1	3.0\3.7	4.5\4.3	1.9\1.7	0.9\1.0	3.1\2.7	4.8\5.4	1.8\1.3
3.6\3.4	3.7\3.0	3.0\2.8	3.4\3.6	1.2\1.0	3.5\3.3	1.3\1.7	2.1\2.3
3.9\4.2	1.4\1.1	3.7\3.9	3.2\3.6	1.3\1.0	3.4\3.5	1.8\1.2	3.5\3.2
5.7\5.5	3.6\4.2	3.4\3.0	2.3\2.4	0.8\1.3	6.1\5.6	4.7\4.8	4.5\4.3
2.4\2.1	1.1\1.4	2.3\2.1	3.8\4.4	1.5\1.4	4.3\4.5	1.0\1.3	1.3\1.8
5.0\4.7	1.6\2.2	1.0\0.7	3.3\3.4	3.1\2.7	4.1\4.3	5.6\5.4	1.6\1.8
5.0\5.0	6.3\6.6	2.0\2.3	5.2\5.7	2.3\3.0	1.6\2.5	4.1\4.5	4.3\4.5
1.9\2.3	1.7\2.2	4.3\4.5	3.4\3.3	2.4\2.2	5.4\6.4	7.7\7.0	3.9\4.5
3.9\4.1	2.2\1.9	1.3\1.8	5.9\5.5	1.3\1.5	3.3\3.5	2.6\2.3	11.0\12.1
1.7\1.9	1.1\1.6	3.0\3.4	2.4\2.3	1.3\1.7	2.5\1.6	2.4\2.6	5.5\6.1
2.3\1.9	1.5\1.1	2.1\2.3	3.6\3.4	7.2\6.5	3.8\3.4	5.8\6.0	9.9\8.7
2.1\2.4	9.1\8.5	4.0\3.6	3.6\3.2	4.2\3.8	1.5\1.7	6.3\5.9	14.3\13.2
3.7\4.2	2.4\2.8	6.0\5.8	5.7\5.2	10.5\11.6	2.7\3.1	2.9\3.1	2.6\2.7
2.1\2.0	10.9\10.1	2.3\2.0	5.5\5.9	5.7\6.2	2.0\1.7	4.8\4.7	4.4\4.0
2.7\2.3	3.6\4.0	1.8\1.9	4.4\3.8	7.5\8.0	1.4\0.9	2.6\2.2	2.3\2.5
3.4\3.6	2.5\2.5	2.4\2.6	4.2\4.4	7.5\7.6	0.7\1.0	1.2\1.6	3.6\4.3
5.9\6.5	7.4\7.8	3.6\4.1	4.8\5.0	15.7\13.5	1.7\1.5	6.5\6.3	1.1\0.8
1.9\1.7	3.0\3.0	3.5\3.9	5.8\5.8	3.7\3.4	0.9\1.4	2.6\2.6	2.7\2.8
3.9\3.6	3.7\3.0	5.2\5.7	6.0\5.6	2.8\2.8	4.5\4.7	1.7\1.3	2.7\2.6
0.3\0.6	2.9\2.3	1.9\1.8	5.9\6.3	5.3\5.6	1.9\1.8	1.3\1.0	3.2\3.5
0.3\0.5	3.6\2.8	1.8\1.3	7.0\6.6	2.5\2.9	6.4\5.4	1.3\1.6	2.3\2.1
0.8\0.6	6.6\6.3	5.7\5.2	1.6\1.1	1.6\1.2	null	1.2\1.6	0.3\0.5

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I9 Densitometric Data for Reduced Total Proteins from Each Protein FractionObtained from Gel Filtration Chromatography of Freedom Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	1.2\1.6	0.4\0.6	0.9\1.4	14.9\12.4	1.1\0.7	0.9\0.8	7.5\7.1
2	1.9\2.1	0.4\0.7	1.0\1.3	9.9\10.6	1.5\1.8	1.1\1.2	1.9\1.5
3	1.8\1.9	0.8\0.6	1.6\1.4	4.5\4.8	0.4\0.7	0.8\0.6	4.2\4.0
4	5.4\5.6	1.3\1.0	0.5\0.8	10.8\10.2	0.6\0.7	1.0\1.2	2.6\2.8
5	3.5\3.9	0.8\1.1	1.9\2.1	5.9\5.5	1.0\1.4	0.8\0.5	1.5\1.6
6	3.4\3.3	1.9\1.6	0.6\0.8	3.3\2.8	0.7\1.0	1.6\1.9	1.4\1.0
7	5.8\6.7	0.9\0.8	1.4\1.6	6.1\5.8	1.2\1.0	1.5\1.1	1.9\2.2
8	17.7\16.8	6.2\6.7	0.4\0.8	4.2\4.0	3.3\3.4	1.3\1.7	3.2\2.7
9	3.8\3.4	3.6\3.7	3.1\2.5	2.8\3.3	2.5\2.9	0.7\1.0	5.3\5.5
10	2.6\2.7	2.8\2.4	0.8\0.6	3.1\2.6	1.0\1.2	0.8\1.1	2.8\2.7
11	3.4\3.0	5.1\5.2	0.8\0.5	1.2\2.2	3.0\2.9	1.3\1.3	2.8\2.6
12	5.6\5.4	1.0\1.7	2.8\2.5	3.5\3.7	2.5\2.4	9.1\8.6	1.5\1.9
13	0.8\1.2	1.7\1.0	2.1\1.9	1.0\1.5	15.7\14.7	7.9\8.4	0.8\1.3
14	1.0\1.2	2.9\2.4	4.8\4.6	1.5\1.7	8.4\8.9	12.0\11.4	0.4\0.7
15	7.0\6.7	6.7\6.2	5.1\5.5	1.6\1.6	2.9\3.0	4.0\3.8	1.6\1.5
16	1.3\1.6	5.6\5.2	14.6\14.2	1.2\1.4	7.8\8.3	7.4\7.6	4.4\4.4
17	1.2\1.0	3.7\3.6	8.9\8.1	1.6\1.7	5.3\5.7	5.9\5.6	0.8\1.0
18	2.7\3.1	1.7\1.4	8.2\8.5	0.9\1.1	2.4\2.5	5.4\5.7	2.9\3.2
19	3.4\2.6	4.1\4.8	4.4\4.8	0.9\1.4	4.9\5.3	6.6\6.0	1.0\1.4
20	3.4\3.8	4.6\4.0	3.9\2.8	0.9\1.2	4.8\4.2	3.6\4.2	2.2\1.9
21	1.2\0.8	3.2\3.3	5.2\5.2	4.0\3.6	12.0\11.2	6.8\6.1	8.2\7.7
22	1.8\2.0	11.4\11.9	6.8\6.5	2.8\2.5	4.2\4.8	1.4\2.1	2.7\2.8
23	2.6\3.4	2.4\2.9	4.6\4.8	1.6\1.9	3.4\3.3	1.1\1.6	1.8\2.0
24	3.9\3.5	8.4\7.9	1.3\1.0	1.6\1.8	2.9\2.5	4.3\3.8	3.4\3.5
25	2.1\1.9	4.0\4.6	2.5\3.1	1.2\1.4	1.0\0.7	1.7\1.9	7.1\7.5
26	1.9\1.8	2.6\3.0	2.3\2.7	2.6\3.1	1.4\1.0	2.6\2.4	2.7\3.2
27	2.0\1.8	3.3\3.2	2.8\3.9	2.2\2.0	0.7\0.4	1.6\2.0	4.4\4.4
28	3.3\3.4	4.8\4.1	2.5\2.8	1.6\2.0	0.7\1.1	2.2\1.8	10.8\9.5
29	1.6\1.2	1.4\1.7	2.7\2.3	2.4\2.0	0.7\0.6	3.6\3.1	4.0\4.0
30	2.7\2.6	2.4\2.8	1.4\0.9	null	1.8\1.5	0.9\1.4	4.0\4.2

Table I9 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
0.4\0.6	0.4\0.8	8.0\8.0	2.8\2.4	1.4\0.9	7.5\6.6	0.3\0.5	1.1\1.5
0.3\0.6	0.5\0.9	4.0\4.4	1.4\1.7	0.9\1.4	3.5\3.4	0.7\0.9	1.1\1.5
0.3\0.5	0.8\1.0	7.1\7.5	1.7\2.3	1.4\1.2	2.2\2.5	0.6\0.8	2.1\1.9
0.6\0.7	0.8\0.4	4.0\4.1	1.7\1.9	0.6\0.8	3.5\4.2	1.0\1.3	1.3\1.0
1.3\1.0	1.4\1.9	5.7\5.6	1.7\1.8	1.8\1.5	2.1\1.9	0.6\0.7	3.0\2.6
5.7\5.2	4.2\4.6	7.3\6.9	2.6\2.4	0.7\1.0	1.4\1.6	2.5\2.0	1.8\1.5
5.2\4.9	1.2\1.1	4.6\4.8	1.9\1.7	0.7\1.1	1.1\1.1	1.6\1.8	1.5\1.6
1.2\1.5	1.5\1.0	2.7\2.9	3.8\3.2	1.1\0.9	0.8\1.1	6.3\5.8	1.5\1.8
6.8\6.1	1.2\1.5	3.4\2.9	2.4\2.4	1.7\1.5	0.7\0.9	1.4\1.2	0.9\1.0
1.7\1.9	1.1\1.4	3.7\3.2	0.9\1.1	0.7\0.7	2.1\1.9	3.6\3.1	1.8\2.2
2.1\2.6	1.0\1.5	2.6\2.9	1.8\1.7	1.7\2.0	1.3\1.0	7.9\8.4	4.4\3.9
1.1\1.1	3.0\3.1	2.9\3.1	7.9\6.9	1.9\1.6	1.9\3.0	3.8\4.3	2.3\2.5
4.7\4.5	1.0\0.8	2.9\2.4	1.7\2.2	0.6\1.0	2.6\2.5	1.9\1.7	2.2\2.4
11.7\11.9	1.1\1.2	1.9\2.1	2.3\2.4	6.4\6.0	5.8\4.8	2.7\2.4	2.8\3.2
1.4\1.4	5.1\5.4	1.1\1.6	7.3\6.7	17.0\15.9	1.9\1.6	4.3\3.9	4.4\3.8
2.3\2.0	8.5\8.6	1.1\1.4	6.3\5.9	11.6\10.1	1.3\1.6	7.4\7.8	8.0\7.5
3.1\3.4	4.9\4.6	1.8\1.8	1.9\1.7	6.0\6.5	5.9\5.2	5.2\5.2	14.1\13.0
6.1\5.8	8.2\8.1	1.9\2.1	5.7\6.1	2.1\2.2	8.4\7.5	6.0\5.7	5.1\5.6
3.1\3.3	14.0\13.4	2.7\2.5	2.0\2.5	2.5\3.0	5.7\6.1	9.1\9.4	7.1\7.4
3.8\3.9	4.0\3.7	0.9\1.2	2.7\2.9	2.0\2.3	5.6\6.1	1.7\1.9	4.1\4.4
5.6\5.8	6.7\6.7	1.9\1.6	14.8\13.6	2.0\2.5	2.5\3.2	2.6\2.4	3.8\4.4
1.9\1.7	2.6\2.7	2.3\2.5	6.7\7.3	6.2\5.9	3.4\3.0	2.6\2.7	7.4\7.1
3.4\3.0	5.4\5.1	3.4\3.2	3.2\3.8	1.9\1.6	3.0\3.4	2.7\2.6	3.9\4.4
5.9\5.2	4.6\4.2	1.8\2.0	2.2\2.2	2.0\2.3	3.7\3.2	3.1\2.5	2.4\2.2
7.8\8.6	3.1\3.0	2.5\2.7	2.4\2.6	4.7\5.0	3.6\3.6	1.9\2.2	3.2\2.8
2.5\2.6	4.6\4.9	2.2\2.4	2.3\1.7	7.9\7.2	2.1\2.3	2.6\2.9	2.6\3.0
3.6\3.8	3.7\4.0	2.7\3.3	1.7\1.9	5.0\5.4	3.8\4.1	2.9\2.5	1.0\1.3
1.6\1.8	1.9\1.4	4.4\4.2	2.4\2.3	2.2\2.5	3.3\3.0	1.2\1.4	1.5\1.1
2.2\2.5	2.7\2.6	1.8\2.0	2.4\2.8	2.9\2.7	5.2\5.8	5.6\5.8	1.9\2.1
2.3\2.0	0.9\0.5	5.9\5.1	1.7\1.4	2.4\2.3	4.4\3.8	6.1\6.1	1.5\1.1

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I10 Densitometric Data for Reduced Total Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Blend[1] Flour and Its Different Dough[2]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	4.7\4.0	1.1\1.5	0.7\0.7	1.7\1.2	1.6\1.9	3.7\3.6	1.7\1.5
2	1.1\1.6	2.2\2.5	2.3\1.7	2.0\1.4	1.0\1.5	1.0\1.6	2.2\2.0
3	2.8\3.0	1.0\1.2	1.4\2.2	4.4\3.1	2.6\2.9	1.1\1.3	3.2\4.9
4	5.0\4.4	1.1\1.7	1.0\2.0	3.3\2.3	2.2\2.3	1.7\1.5	2.3\1.9
5	1.8\2.1	1.6\2.4	1.4\2.0	1.9\1.6	2.5\1.9	1.5\1.0	0.9\0.8
6	1.5\1.8	1.5\1.1	1.5\2.1	3.5\3.7	4.2\4.3	0.8\1.3	2.1\3.1
7	5.0\5.5	2.2\2.4	0.8\1.2	2.3\1.6	2.2\2.0	0.6\0.7	5.2\4.7
8	4.4\3.9	1.2\1.5	0.7\1.0	5.0\6.1	3.9\3.1	1.3\1.2	3.5\2.9
9	4.2\4.1	3.2\3.3	2.2\1.4	3.9\3.1	1.7\1.4	0.6\0.8	4.6\4.2
10	5.4\5.5	3.3\3.1	3.7\4.6	2.2\2.9	2.4\2.4	1.3\1.1	3.2\2.2
11	3.2\2.9	2.5\2.2	4.4\5.3	2.4\1.8	2.0\2.2	1.0\1.3	2.2\2.0
12	3.8\4.1	5.3\5.9	0.7\0.7	2.2\1.1	1.3\1.8	3.0\2.7	2.5\3.0
13	1.3\1.6	2.4\2.2	2.9\3.1	4.2\3.0	1.4\1.7	1.8\2.2	4.9\4.4
14	1.6\1.8	1.2\1.0	1.7\2.3	1.6\1.4	1.9\2.5	1.9\1.5	2.1\2.6
15	3.4\2.9	1.7\1.1	1.0\0.7	2.6\2.3	2.3\2.2	1.8\2.3	1.4\1.9
16	1.8\1.3	3.3\3.2	1.2\0.8	4.3\3.9	3.6\4.7	2.3\1.8	2.9\1.7
17	4.6\5.1	3.1\3.3	7.1\7.3	1.9\2.4	3.1\3.9	5.0\5.1	2.1\1.7
18	2.0\2.2	2.4\1.6	9.4\8.8	1.4\0.9	7.9\6.7	9.3\9.9	1.9\1.8
19	1.2\1.1	2.6\3.5	5.5\5.7	2.0\3.1	5.1\4.7	3.9\3.6	1.9\2.7
20	2.6\2.5	3.4\2.7	7.3\7.1	5.6\4.4	1.8\1.3	6.8\6.2	5.5\5.6
21	5.6\5.2	10.9\9.9	5.3\4.4	4.4\5.1	4.7\5.1	7.1\7.8	8.2\7.4
22	4.3\4.7	2.7\3.7	4.6\3.7	6.4\7.3	4.7\3.6	6.4\5.4	3.9\4.6
23	2.2\2.5	3.4\3.1	5.0\5.6	1.4\1.7	6.7\7.9	5.4\4.7	3.0\4.2
24	3.5\3.2	6.0\5.8	6.3\6.9	3.5\3.9	4.0\3.7	7.0\6.2	3.7\4.9
25	5.4\6.0	6.0\6.8	5.6\5.0	1.4\1.0	6.4\6.1	4.7\5.5	3.3\4.0
26	3.2\2.8	6.8\6.0	5.7\5.5	7.1\7.8	1.5\1.0	3.6\3.9	3.0\3.5
27	3.2\3.0	2.7\3.4	3.1\2.9	4.3\4.9	2.9\2.6	5.4\6.4	2.9\3.4
28	3.6\3.8	3.5\2.6	3.4\2.4	2.4\3.3	4.3\4.2	3.6\3.7	1.8\1.5
29	4.8\4.2	5.8\6.0	2.1\1.5	1.7\2.9	8.3\8.9	1.6\1.0	5.7\5.1
30	3.0\3.4	5.9\5.3	2.0\1.4	9.0\11.0	1.9\1.6	5.1\5.0	8.5\5.8

Table I10 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
2.2\2.5	3.5\3.1	5.0\3.5	2.0\2.2	1.4\1.5	4.3\4.5	1.4\1.4	2.2\2.6
0.9\1.1	1.0\1.4	3.5\5.0	1.3\1.6	0.8\0.9	3.9\3.1	0.8\0.8	1.0\0.8
1.7\2.3	1.5\1.0	3.6\1.6	1.2\1.4	1.3\1.4	1.0\1.6	0.8\0.8	1.4\1.2
2.7\2.8	1.0\1.5	2.0\1.5	1.1\1.3	0.6\0.8	1.5\1.1	0.4\0.4	0.5\0.9
1.1\0.9	0.5\0.7	2.3\1.1	0.5\1.1	0.9\0.9	2.0\2.5	0.7\0.7	2.0\2.2
1.5\1.7	0.5\0.8	1.1\0.8	1.8\2.1	1.2\1.1	1.3\1.6	1.5\1.5	1.2\1.0
4.0\3.7	0.9\1.4	1.6\1.1	2.3\2.5	2.4\2.0	2.6\2.3	1.4\1.4	0.9\1.2
3.1\2.7	0.9\1.3	1.5\1.3	5.2\4.7	0.7\1.0	4.5\4.2	1.2\1.2	0.9\0.8
1.3\1.6	2.2\2.3	1.8\1.4	1.5\1.2	0.8\1.0	3.3\2.9	2.2\2.2	1.6\1.9
4.3\4.7	2.1\2.6	1.3\1.7	2.2\2.5	1.3\1.5	2.4\2.7	2.6\2.5	0.8\1.0
3.1\3.4	1.2\1.0	0.7\0.9	1.6\1.2	0.7\0.8	5.7\4.6	4.0\3.9	0.9\0.5
1.5\1.8	2.4\2.2	2.3\2.6	4.0\4.4	1.9\1.1	2.6\2.9	1.7\1.7	1.2\1.4
1.5\2.3	1.5\1.3	1.3\1.0	3.0\2.7	2.4\2.4	4.2\4.7	3.6\3.6	3.5\3.7
4.1\3.7	3.6\3.3	1.4\2.6	3.5\3.8	0.6\0.5	2.9\2.7	3.8\3.7	2.6\2.2
2.3\1.5	3.8\4.0	1.6\2.4	6.8\5.8	3.1\3.2	1.1\1.5	4.1\4.1	1.9\1.6
1.8\1.5	2.7\3.6	2.1\2.7	13.2\12.1	10.5\10.9	4.6\5.6	1.7\1.6	6.8\7.7
4.9\4.7	4.4\4.2	5.6\4.6	4.8\4.9	4.7\5.0	4.4\4.9	4.7\4.7	4.1\3.5
5.4\4.7	6.3\5.8	5.3\4.0	3.6\4.1	3.2\2.6	9.2\8.1	6.4\6.3	6.0\5.7
10.3\11.1	4.5\4.0	6.8\4.9	1.6\2.1	8.4\8.3	1.6\1.0	5.7\5.6	5.9\5.6
4.7\5.4	3.8\3.5	6.4\5.8	3.8\4.0	4.7\4.9	4.7\4.2	2.8\2.7	9.6\9.3
3.4\3.1	9.5\10.8	3.7\4.3	5.0\4.8	5.1\4.9	2.7\2.9	4.3\4.2	5.5\6.0
8.8\8.0	6.9\6.6	3.4\4.4	4.5\5.1	6.0\6.4	2.7\2.4	7.2\7.1	6.0\6.5
4.7\4.9	7.3\6.3	6.0\8.4	8.2\7.6	7.3\6.9	2.3\2.6	7.5\4.3	2.9\3.6
3.7\4.1	4.3\4.6	2.2\4.0	2.6\2.3	7.5\7.1	3.8\3.6	5.2\3.2	7.0\6.5
4.7\4.3	3.1\3.3	2.2\2.5	5.3\5.6	6.4\6.8	2.9\3.3	5.2\5.2	6.9\5.9
2.7\3.1	8.6\7.6	2.5\3.3	2.2\2.0	4.7\4.2	2.5\2.0	2.7\5.1	3.5\4.0
2.8\2.7	2.9\3.0	7.4\7.1	2.2\2.4	2.3\2.8	4.2\4.5	4.4\6.9	3.6\2.9
2.3\1.7	5.4\4.8	5.6\4.4	1.5\1.0	3.7\3.6	3.6\3.8	3.1\3.1	3.5\4.1
1.7\1.5	2.4\2.4	3.6\2.6	1.9\2.4	3.9\3.6	3.1\3.9	2.7\2.6	2.2\2.0
2.5\2.2	1.5\1.8	6.1\7.2	1.5\1.0	1.4\1.8	4.5\4.3	6.2\7.5	3.7\3.5

[1]Blend: The mixture of 50% soft red winter and 50% hard red winter.

[2]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I11 Densitometric Data for Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Frankenmuth Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	3.7\3.3	5.1\4.7	4.6\5.0	2.5\2.5	3.6\3.4	2.6\3.1	1.9\1.1
2	3.4\3.8	2.4\2.8	1.7\1.5	3.7\3.7	1.6\1.8	1.8\1.3	3.1\3.6
3	2.6\2.7	2.2\1.6	1.6\1.1	2.2\2.1	5.3\5.3	4.7\5.3	2.9\3.2
4	2.4\2.0	3.2\2.7	2.6\2.1	5.3\5.4	1.0\0.9	1.3\1.8	2.7\3.0
5	4.2\4.8	2.7\3.2	1.1\1.6	3.3\3.3	4.6\4.7	4.2\4.0	2.2\2.6
6	5.2\4.5	1.7\1.3	3.1\3.7	9.2\9.1	2.0\2.2	1.7\2.0	2.5\1.7
7	5.4\5.0	4.4\4.1	4.4\4.7	3.0\3.1	3.1\3.2	3.2\3.8	4.5\4.0
8	4.2\4.6	1.8\1.5	1.4\1.4	4.5\4.6	6.5\6.2	2.4\2.9	3.9\4.4
9	6.9\5.9	2.1\2.7	2.6\2.7	2.2\2.3	7.2\6.8	0.9\0.8	4.3\4.3
10	6.1\6.6	6.2\5.7	2.9\2.7	5.3\5.4	3.9\4.4	2.6\2.4	2.6\2.2
11	4.5\5.2	2.5\3.0	3.3\3.6	1.7\1.8	1.3\1.2	1.9\2.5	6.9\6.7
12	1.0\1.4	2.8\3.3	1.6\1.9	1.6\1.4	2.8\2.8	0.8\0.9	1.7\1.9
13	3.8\3.4	4.3\3.9	3.7\3.1	4.2\4.0	6.4\6.5	1.4\1.9	4.3\3.9
14	2.7\2.6	2.4\3.2	4.5\5.9	1.6\1.6	3.2\3.1	5.6\5.8	1.7\2.5
15	2.0\2.4	2.8\2.4	2.7\3.2	5.1\4.8	6.5\6.1	5.3\4.7	2.6\3.0
16	2.2\2.1	9.7\8.8	2.4\3.2	2.4\2.5	3.3\3.7	2.5\1.9	3.0\2.7
17	5.1\5.6	8.1\8.5	3.0\3.4	4.8\5.0	5.0\4.7	1.9\1.4	3.2\3.0
18	4.8\4.2	1.6\2.2	1.5\1.7	4.2\4.0	1.6\1.7	7.1\6.5	2.9\3.1
19	5.2\5.5	8.3\8.3	5.9\5.3	1.6\1.8	3.8\4.0	7.1\6.5	2.6\2.6
20	3.3\3.7	4.1\4.4	4.7\4.4	1.1\1.1	4.2\4.2	9.3\9.9	3.2\2.9
21	1.4\1.0	2.7\2.1	3.2\2.4	5.0\5.3	5.3\5.1	5.8\5.6	3.3\3.5
22	6.8\6.3	4.7\5.1	5.0\4.6	2.4\2.6	1.7\1.8	2.9\2.4	3.7\3.9
23	1.7\1.8	1.5\1.8	3.4\3.0	2.8\2.9	3.5\3.6	3.8\3.2	1.2\0.8
24	2.1\2.2	3.3\2.8	2.7\2.6	2.2\2.3	2.0\2.0	2.4\2.6	5.7\5.2
25	2.2\2.5	1.3\1.7	5.9\4.5	3.3\3.0	2.4\2.8	2.0\1.7	1.9\2.0
26	1.8\1.7	3.9\4.3	3.2\2.7	5.3\4.9	2.3\2.2	4.6\5.1	3.6\3.1
27	1.2\0.8	1.5\1.1	2.7\2.9	3.6\3.2	1.4\1.2	4.0\4.2	6.2\6.6
28	2.1\2.3	1.0\0.8	6.0\6.4	3.0\3.4	2.2\2.1	1.8\1.3	1.3\2.0
29	0.8\1.2	1.1\1.5	2.1\2.6	1.6\1.7	0.9\0.9	3.1\2.6	9.5\8.8
30	1.5\1.3	0.8\1.0	6.4\6.0	1.6\1.5	1.2\1.2	1.3\1.8	1.1\1.9

Table I11 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
5.7\5.7	5.2\4.9	4.7\4.6	1.8\1.8	2.7\2.2	5.8\5.4	3.6\3.8	4.2\4.2
4.7\4.2	2.0\1.9	1.9\1.8	2.1\2.1	4.5\5.0	4.0\4.6	2.2\2.0	1.4\1.4
3.2\3.7	5.0\4.9	6.6\6.5	1.3\1.2	1.6\2.2	6.2\7.2	1.2\1.5	1.4\1.3
1.3\1.7	5.1\5.6	5.0\5.3	1.8\1.7	4.1\4.4	4.5\3.6	4.0\3.7	0.5\0.6
4.6\4.2	1.7\1.9	4.5\4.4	4.8\5.0	1.6\2.2	1.3\1.9	1.2\1.5	0.8\0.9
2.9\2.6	0.9\1.1	3.2\3.1	1.5\1.5	2.5\1.8	2.0\1.9	1.6\1.3	2.3\2.2
1.2\1.5	0.8\0.9	1.1\1.0	4.8\4.8	2.5\3.3	4.4\3.6	1.1\1.5	1.0\1.2
3.6\3.4	1.7\1.2	1.8\1.6	5.3\5.3	2.6\3.0	4.0\3.6	1.4\1.0	2.0\1.8
4.4\4.6	1.7\1.6	2.2\2.1	1.4\1.3	1.5\2.0	4.6\4.8	3.9\3.4	2.0\1.7
3.4\3.3	0.7\0.6	1.9\1.8	4.3\4.2	5.3\5.6	1.7\2.3	2.5\3.0	1.6\1.6
3.8\3.9	1.8\1.6	1.7\2.4	2.7\2.6	6.7\5.8	2.5\2.7	3.4\4.0	1.5\1.8
5.5\5.0	3.5\3.9	2.7\2.5	2.3\2.2	4.6\5.3	1.8\2.5	4.4\3.8	2.2\2.6
1.5\2.0	4.9\4.1	0.6\0.8	3.3\3.7	3.2\2.7	2.5\2.5	1.3\2.0	4.2\3.8
3.7\3.4	2.4\3.2	4.1\3.8	8.3\8.9	1.6\1.9	2.5\1.8	2.8\2.1	1.0\1.6
3.0\3.3	6.0\6.7	2.2\2.0	5.2\5.0	5.2\4.1	8.2\7.2	9.0\8.2	1.6\1.3
3.1\3.1	2.7\2.8	5.6\5.1	3.8\3.5	5.3\5.0	5.9\6.1	1.8\2.6	1.5\1.2
5.8\5.9	1.8\1.1	5.3\6.3	9.8\9.7	5.6\5.3	1.9\1.3	4.7\3.8	6.8\6.1
8.7\7.6	3.1\3.0	3.6\3.8	4.1\3.8	2.7\3.2	5.4\5.8	4.4\5.3	6.3\7.0
2.1\2.2	3.7\3.6	3.5\3.6	4.0\4.3	3.0\2.6	2.7\3.0	10.5\9.6	11.5\12.1
3.7\3.9	1.4\1.3	2.4\2.6	2.0\2.0	4.4\4.1	2.7\2.5	2.8\3.2	4.9\4.9
2.2\2.4	3.8\3.7	2.6\2.1	2.4\2.4	3.3\2.5	2.3\1.7	6.1\6.6	10.9\10.3
2.2\2.5	7.1\6.8	2.9\3.2	3.9\3.8	3.5\3.7	4.6\4.0	3.6\4.0	2.0\1.8
1.7\1.9	7.0\6.7	5.0\5.2	4.6\4.1	5.3\4.6	3.6\4.5	7.2\6.8	3.5\3.2
3.4\3.9	5.2\5.5	3.7\3.2	3.2\3.8	4.1\5.2	3.6\4.4	2.7\3.0	2.2\2.0
3.2\3.0	7.2\6.6	3.3\3.3	4.0\3.8	2.2\1.6	0.7\1.4	5.0\4.7	5.3\4.6
3.7\3.4	2.4\2.7	8.1\7.6	2.1\2.3	1.8\2.5	2.2\1.9	2.5\2.7	5.1\5.0
1.1\1.1	2.6\2.9	4.3\4.5	1.4\1.5	3.7\3.5	3.0\2.7	2.0\1.8	1.9\2.0
2.7\2.5	5.8\5.4	3.8\4.1	1.1\1.2	0.5\1.4	1.9\2.0	1.5\1.4	2.8\2.6
1.7\1.8	2.0\2.2	1.4\1.3	1.2\1.3	2.0\1.5	1.9\2.2	0.8\0.9	4.9\4.8
2.4\2.5	0.6\0.8	0.6\0.7	1.5\1.2	2.2\1.6	1.4\0.7	0.8\0.8	2.5\2.8

[1]Blend: The mixture of 50% soft red winter and 50% hard red winter.

[2]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I12 Densitometric Data for Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Cracker Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	0.7\0.9	1.0\0.9	3.0\3.1	2.9\3.3	2.4\2.1	4.4\4.3	1.6\1.5
2	1.3\1.4	2.3\2.8	1.7\1.8	1.0\1.3	1.5\1.8	1.8\1.7	1.5\1.7
3	2.3\2.5	2.5\2.7	2.6\2.7	1.6\1.4	0.7\0.8	0.8\0.7	2.1\2.0
4	1.1\1.3	5.4\5.9	2.5\2.2	1.3\1.0	0.8\0.9	2.5\2.4	5.0\4.8
5	2.6\2.7	2.0\2.2	3.2\2.8	2.3\2.5	2.8\2.9	1.6\1.4	3.0\3.2
6	4.0\4.1	3.9\4.2	4.7\5.0	3.6\3.4	2.1\1.9	5.5\5.3	9.4\8.9
7	4.9\4.9	3.0\3.5	0.7\0.9	2.3\2.3	1.7\1.6	4.3\4.5	4.6\5.1
8	2.8\2.6	1.3\1.1	3.3\2.8	3.8\3.2	6.2\5.7	1.3\1.5	3.0\3.2
9	3.0\2.8	2.9\3.3	1.4\1.9	1.4\1.6	3.6\3.4	2.8\2.9	6.6\6.4
10	3.0\2.9	3.1\3.5	2.3\2.8	5.2\5.0	6.3\6.0	2.7\2.8	4.5\4.5
11	3.4\3.3	5.2\4.3	3.8\3.1	4.8\4.5	1.5\1.7	0.9\1.0	2.5\2.5
12	3.8\3.7	3.3\3.7	1.6\1.8	4.6\5.3	1.4\1.8	4.7\4.9	2.2\2.3
13	2.7\2.6	2.6\1.8	2.4\2.2	1.3\1.2	3.0\3.4	4.9\5.0	2.4\2.5
14	6.6\6.5	3.5\3.0	2.8\2.3	3.2\3.4	2.4\2.4	3.5\3.7	3.7\3.8
15	4.1\4.1	3.1\2.9	9.8\10.5	2.1\2.1	5.4\5.2	1.7\1.8	2.8\2.9
16	2.6\2.9	3.8\4.7	4.7\5.2	2.5\2.0	2.2\2.4	1.7\1.2	1.7\1.9
17	2.4\2.1	5.9\5.4	2.8\3.3	3.5\4.0	4.6\4.9	4.1\3.9	7.0\6.4
18	5.1\4.8	11.8\10.9	6.0\6.1	3.8\3.8	3.1\2.8	6.1\5.8	1.3\1.3
19	1.3\1.6	2.9\3.1	1.9\1.5	2.5\2.3	6.3\6.0	3.6\3.7	3.0\2.9
20	2.9\2.8	3.5\3.1	2.8\3.3	3.1\2.9	4.1\4.4	3.3\3.5	2.0\1.9
21	4.4\4.5	3.3\2.9	1.3\1.1	2.3\2.5	4.3\4.2	4.0\4.1	1.9\1.8
22	5.3\5.0	2.2\2.0	2.8\2.2	3.2\3.8	4.3\4.4	1.4\1.5	3.0\2.8
23	8.0\8.3	2.7\2.5	6.0\5.5	1.2\1.3	1.0\1.2	4.2\4.2	3.3\3.5
24	3.6\3.6	1.8\2.6	5.2\4.7	5.3\4.6	3.0\2.8	7.0\6.7	3.8\4.1
25	4.0\4.2	3.7\3.3	2.2\2.5	3.4\3.6	5.8\5.8	5.6\5.9	3.6\3.8
26	1.8\1.9	4.3\5.2	2.7\2.6	6.3\6.6	6.1\6.7	2.3\2.3	4.2\4.4
27	7.2\6.7	2.8\2.3	3.1\3.0	6.6\7.3	2.0\2.2	2.2\2.0	4.1\3.8
28	0.8\1.0	1.1\1.3	6.1\6.0	4.5\4.8	6.5\5.9	6.3\6.5	2.2\2.1
29	2.6\2.4	4.2\3.9	5.0\4.7	7.3\6.3	1.1\1.3	2.7\2.7	1.3\1.1
30	1.9\2.1	0.9\1.0	1.8\1.7	3.3\2.9	3.5\3.1	2.2\2.2	2.7\2.9

Table I12 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
0.6\0.9	1.2\1.0	1.0\1.3	2.0\1.8	1.1\1.2	3.7\4.3	3.0\2.5	6.5\6.6
2.3\2.5	1.0\0.9	0.7\0.9	2.6\2.8	3.1\3.2	1.8\2.1	0.8\0.7	0.6\0.7
5.6\5.9	2.4\2.3	1.7\1.5	2.9\3.0	3.0\3.1	3.8\3.4	0.9\1.0	2.0\2.2
7.0\7.1	2.1\2.5	2.8\2.1	1.2\1.1	3.0\3.2	1.7\2.0	0.7\0.8	1.0\1.1
6.4\6.0	1.5\1.7	1.8\2.1	3.4\3.3	4.8\4.6	4.5\3.7	1.0\0.9	1.9\1.4
9.2\9.6	3.3\3.5	9.9\10.8	8.8\8.9	1.5\1.3	3.0\3.4	2.1\1.8	2.0\2.0
3.2\3.4	2.3\1.9	7.7\7.2	3.9\3.7	2.2\2.0	3.9\3.7	1.7\1.8	0.9\0.9
1.6\1.4	1.9\1.9	7.1\6.7	1.8\2.0	5.2\5.4	8.9\8.7	6.0\6.7	0.5\0.7
3.0\2.8	2.0\2.1	2.6\2.7	9.0\8.1	2.5\2.1	9.2\9.6	4.0\3.7	1.0\0.8
7.1\7.0	4.6\4.7	1.4\1.1	4.0\3.3	6.9\6.4	2.9\3.0	9.6\10.1	0.8\0.8
1.9\2.1	2.2\2.3	3.0\2.6	1.8\2.7	4.2\4.1	6.1\6.3	1.1\1.5	2.1\2.0
2.1\2.5	2.7\2.4	4.0\4.0	2.7\2.9	2.3\2.4	1.9\2.1	2.3\2.8	2.2\2.3
2.8\3.0	3.1\2.8	4.8\4.6	6.8\6.3	4.7\4.9	1.6\1.1	1.5\1.1	3.9\4.4
5.9\5.6	1.6\1.9	1.1\1.4	1.9\1.6	5.4\5.5	3.4\3.8	3.7\4.0	1.7\1.5
1.4\1.3	1.7\1.5	1.0\1.0	1.9\2.4	1.5\1.7	3.4\3.0	9.7\7.2	2.6\2.3
2.5\2.4	4.2\4.4	5.2\5.0	2.7\2.3	7.0\6.3	1.2\1.0	4.0\3.8	3.3\3.0
1.2\1.1	2.9\2.8	5.7\5.9	4.7\3.9	3.7\3.9	1.7\1.5	4.5\4.3	7.9\8.2
3.5\3.4	6.1\6.2	2.9\3.3	3.5\3.9	4.1\4.1	1.8\1.6	2.8\2.3	13.3\12.9
2.4\2.3	7.8\7.0	3.1\2.9	3.2\3.5	3.0\3.2	3.7\4.5	4.7\5.4	8.4\8.6
2.5\2.4	1.8\2.2	5.7\5.1	6.4\5.8	2.5\2.7	9.0\8.3	2.5\2.5	6.6\6.8
2.8\2.4	6.2\6.6	1.3\1.3	3.1\3.9	2.3\2.4	3.8\4.4	5.4\5.1	3.5\3.1
2.1\2.4	6.0\5.3	2.1\1.8	2.7\2.5	7.6\6.8	2.9\3.0	6.7\6.0	2.4\2.5
4.4\4.5	3.2\3.9	2.7\2.6	1.9\2.6	2.1\2.1	2.5\2.6	7.9\7.9	5.3\5.4
1.3\1.5	9.2\10.1	2.6\3.0	1.0\1.6	3.0\2.7	1.2\1.3	2.9\2.3	3.7\3.9
4.3\4.1	4.8\4.0	1.6\1.8	3.8\3.3	1.9\1.8	1.2\1.3	1.2\1.0	2.8\2.6
3.4\3.2	1.7\1.6	5.0\5.2	1.6\2.1	6.4\5.8	1.5\1.6	1.8\2.1	4.2\4.4
0.9\0.6	5.8\5.3	3.3\2.9	2.6\3.0	1.6\1.8	1.3\1.5	2.3\2.9	3.6\3.7
4.5\4.4	4.3\4.3	2.1\2.8	4.6\4.2	1.3\1.4	2.0\1.7	1.0\1.2	1.3\1.2
1.4\1.6	0.8\1.0	5.1\5.7	1.7\2.0	0.9\1.0	2.1\1.8	1.8\1.7	1.3\1.6
2.5\2.3	1.5\1.8	1.3\1.0	1.8\1.5	1.3\1.4	4.3\3.7	2.5\3.0	2.8\2.5

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I13 Densitometric Data for Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Caldwell Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	3.1\3.0	4.0\4.4	3.4\3.2	2.2\2.1	1.2\1.1	1.6\1.5	1.6\1.4
2	0.9\1.0	1.4\1.0	0.8\1.0	0.9\1.0	2.3\2.1	0.6\0.7	1.4\1.2
3	1.9\1.5	3.2\3.2	2.7\2.7	1.6\1.6	2.4\1.8	1.1\1.1	1.9\1.7
4	3.7\4.1	1.3\1.3	3.4\3.3	1.8\1.8	1.9\1.4	1.6\1.5	3.1\3.8
5	1.8\2.2	3.4\3.3	2.7\2.8	1.6\1.8	3.2\3.7	1.0\1.1	2.6\2.9
6	3.0\2.6	4.7\4.6	1.2\1.3	4.5\4.3	4.0\4.6	3.0\3.0	3.0\3.2
7	3.1\3.0	2.3\2.2	3.6\3.5	3.9\3.9	2.9\2.5	1.3\1.6	5.4\5.3
8	3.5\3.6	4.1\4.0	2.0\2.1	2.9\2.9	3.3\3.9	1.9\1.6	3.6\4.2
9	4.7\4.9	3.7\3.6	1.6\1.5	2.3\2.6	3.4\4.2	4.4\4.9	5.0\4.6
10	9.4\9.2	2.2\2.1	2.4\1.9	5.8\5.5	4.1\4.1	2.0\1.5	3.9\4.4
11	3.8\3.5	4.7\4.4	1.4\1.9	2.7\2.7	1.8\2.2	2.9\2.8	4.8\4.5
12	1.2\1.5	3.4\3.9	2.8\2.6	1.6\1.8	2.7\3.4	1.5\1.4	5.3\5.4
13	1.9\2.1	2.6\3.0	4.1\3.9	1.6\1.4	3.4\3.2	1.2\1.1	1.8\2.1
14	4.8\4.6	4.3\4.3	3.1\3.5	4.2\4.0	2.7\2.9	4.1\4.4	1.7\2.2
15	2.7\2.5	2.6\2.6	6.6\5.9	3.7\3.5	2.7\2.8	2.5\2.6	4.6\5.0
16	3.6\3.4	5.0\4.8	4.9\5.1	3.9\4.3	4.6\4.5	2.4\2.5	3.8\3.1
17	2.6\2.5	4.0\3.8	4.6\5.1	4.3\4.0	5.8\5.4	3.4\3.6	4.4\3.9
18	2.8\2.9	2.4\2.2	4.0\3.8	8.2\7.8	4.6\4.6	2.2\1.8	2.1\1.8
19	6.6\6.2	2.2\2.8	5.8\5.6	2.4\2.7	3.9\3.3	4.7\4.3	7.7\6.8
20	3.2\3.6	2.3\2.2	2.8\3.2	5.2\5.5	2.2\1.8	6.1\6.6	11.8\12.7
21	5.5\6.0	7.0\7.8	4.5\4.9	2.8\3.2	8.5\8.9	11.8\10.3	1.3\0.9
22	3.7\3.5	2.0\1.9	7.7\6.9	1.5\1.2	4.2\3.4	6.0\6.4	4.2\3.6
23	4.3\4.0	2.3\2.5	3.1\3.3	2.6\2.6	4.6\4.0	2.6\3.6	3.2\3.0
24	2.4\2.1	7.8\7.2	5.1\5.2	4.2\4.1	7.0\6.3	4.5\3.8	2.2\1.7
25	4.8\5.1	2.2\2.0	4.2\4.3	1.4\1.5	2.5\2.9	2.3\2.1	2.9\2.6
26	1.8\1.5	2.3\2.1	1.6\1.8	4.0\3.8	1.4\1.9	8.1\8.9	1.5\1.8
27	1.4\1.7	4.1\3.7	4.3\3.8	3.7\3.9	3.7\3.2	3.3\3.1	0.9\1.3
28	3.5\3.6	2.2\2.4	1.7\1.8	6.0\6.4	1.8\2.4	3.6\3.4	1.7\1.9
29	2.9\3.1	1.8\2.0	2.5\2.9	7.1\7.2	1.1\1.2	4.5\4.3	1.2\1.4
30	1.3\1.0	4.5\4.7	1.5\1.3	1.4\0.9	2.1\2.3	3.8\4.5	1.4\1.6

Table I13 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
2.8\2.6	2.0\2.4	8.3\7.1	2.2\2.4	3.0\2.9	3.9\3.5	1.4\1.6	1.8\1.3
1.8\2.0	0.4\0.9	0.6\1.2	1.7\1.9	2.0\1.9	1.3\1.7	1.3\1.3	0.5\1.2
0.6\1.0	1.4\1.0	1.6\2.2	1.6\1.7	0.4\0.3	0.9\1.4	1.5\1.8	0.4\0.6
2.6\2.2	3.1\2.6	1.4\1.4	2.0\1.5	1.7\1.6	2.2\1.7	1.3\0.6	0.9\1.3
2.9\2.9	1.1\1.1	2.5\3.0	1.0\1.0	2.6\2.4	0.6\0.9	1.4\0.9	1.2\0.5
1.9\1.9	1.1\1.3	2.1\1.6	3.1\3.2	1.4\1.2	2.1\1.8	2.1\2.7	1.6\1.0
3.1\3.0	0.9\0.9	2.2\2.0	3.1\3.6	6.3\6.1	2.6\3.0	3.2\2.8	2.4\2.9
4.1\4.2	2.6\2.4	2.7\2.9	4.7\4.1	2.9\3.4	4.2\3.8	3.9\4.4	1.7\1.6
3.2\3.1	3.2\3.1	7.7\7.1	1.9\2.1	1.6\2.1	3.9\3.8	3.0\2.8	5.3\4.8
4.4\4.3	1.8\1.9	4.9\5.0	3.5\3.7	1.5\1.6	1.9\2.0	4.6\3.8	1.8\2.2
2.9\2.8	1.5\1.5	2.3\2.5	4.3\3.9	2.1\2.2	2.5\2.3	3.4\3.0	2.6\3.0
4.5\4.4	2.2\2.2	3.6\3.9	2.3\2.2	3.6\3.7	2.5\2.7	3.0\3.7	3.3\2.9
3.5\3.3	1.7\2.2	3.3\3.2	1.3\1.2	5.5\5.7	1.3\1.2	3.8\4.6	2.9\3.1
3.3\3.9	4.4\4.2	2.1\2.2	3.0\2.9	2.2\2.4	1.7\1.6	6.2\6.7	5.1\4.7
5.5\5.2	3.3\3.0	5.0\5.7	6.2\6.5	0.9\1.2	1.5\1.7	3.7\3.0	4.2\4.4
4.0\4.3	0.8\1.4	2.1\1.9	4.8\4.3	1.2\1.3	2.3\2.1	2.3\3.0	5.8\5.9
4.5\4.8	1.8\1.2	3.0\2.5	6.0\5.5	2.0\2.1	3.9\3.7	5.0\4.4	1.6\1.7
7.5\7.2	7.1\8.3	3.0\3.3	2.6\3.6	1.2\1.4	2.1\1.9	6.8\7.6	2.9\2.4
3.3\3.3	5.9\5.3	1.7\1.4	10.8\11.7	3.8\4.0	17.2\16.1	9.2\8.5	4.8\5.3
4.5\4.4	5.0\4.4	4.0\3.8	3.4\3.0	9.0\8.1	2.7\2.8	4.4\5.0	4.6\4.5
2.1\2.2	3.8\3.8	2.7\2.9	2.4\1.9	2.7\2.9	4.0\4.6	4.4\3.9	5.5\5.9
2.6\2.5	9.0\9.8	10.8\9.7	9.6\8.2	5.2\5.2	1.0\1.5	7.6\6.8	9.7\10.3
3.7\3.6	2.8\2.9	2.9\3.9	1.9\2.9	5.5\6.0	4.2\4.7	2.8\3.0	5.5\5.2
5.7\5.5	4.0\4.1	3.2\3.3	4.4\4.8	13.3\11.9	6.6\5.9	3.0\3.4	3.3\3.5
3.9\4.4	3.0\2.8	2.8\2.6	2.1\2.3	2.1\2.1	4.3\4.7	2.7\2.1	3.8\3.9
2.8\2.7	10.6\9.6	2.4\2.6	4.6\4.4	2.4\2.8	3.8\4.1	1.8\1.5	3.3\3.0
2.1\2.0	5.7\5.4	3.6\3.4	2.2\2.2	2.1\2.2	2.7\2.9	2.8\3.2	3.5\3.2
1.8\1.9	4.0\4.5	1.9\2.1	0.9\1.1	5.7\5.2	2.4\2.7	1.3\1.3	1.3\1.8
1.8\1.6	4.3\4.1	1.3\1.0	0.8\0.9	3.4\3.2	4.7\4.9	1.6\1.4	5.9\5.5
2.6\2.8	1.3\1.5	4.5\4.8	1.4\1.1	2.5\2.7	5.0\4.3	0.6\0.3	3.0\2.6

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I14 Densitometric Data for Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Freedom Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	3.0\2.6	1.6\1.2	2.1\2.2	3.4\3.1	1.6\1.8	3.3\3.4	1.2\1.9
2	1.2\1.9	1.4\1.2	0.3\0.4	1.4\1.7	0.3\0.6	1.7\1.5	2.1\2.3
3	2.8\2.5	3.0\2.8	0.8\0.6	1.6\1.8	0.7\0.8	0.6\0.8	1.9\1.2
4	1.2\1.9	2.9\3.1	0.6\0.7	1.7\1.5	0.9\1.0	1.5\1.9	3.1\3.3
5	2.5\2.3	4.0\4.0	0.7\0.8	1.0\0.9	2.8\2.6	1.8\2.4	3.5\3.7
6	3.2\2.4	3.4\3.0	1.3\1.4	3.8\3.9	1.8\1.3	3.3\3.5	3.5\3.1
7	2.0\2.5	8.7\9.1	0.5\0.7	4.3\4.4	4.7\4.9	3.9\3.7	4.4\4.0
8	1.1\1.6	4.1\4.4	3.4\2.9	3.4\3.3	4.0\4.2	1.8\1.5	2.8\3.0
9	5.9\6.7	1.6\1.3	2.4\2.2	2.7\2.6	0.8\0.9	3.9\3.8	3.5\3.7
10	2.1\1.9	4.3\4.5	1.4\1.2	3.6\3.7	6.1\5.6	1.3\1.6	4.8\5.2
11	5.8\6.0	4.2\4.0	1.9\2.3	2.7\2.5	0.4\0.8	5.2\4.8	2.8\3.2
12	4.6\4.1	1.5\1.6	1.1\1.3	0.6\0.8	1.9\2.0	1.1\1.5	2.7\2.1
13	2.4\3.2	2.4\2.3	2.8\2.6	4.4\4.0	2.6\2.5	4.5\4.0	1.7\1.8
14	3.3\3.8	3.8\3.8	3.1\3.1	1.7\2.1	6.9\6.8	1.9\2.4	2.0\2.3
15	3.0\3.6	3.1\3.1	2.3\2.2	2.1\2.6	3.2\3.1	3.4\3.8	2.6\2.3
16	3.6\3.0	3.5\3.4	2.1\2.2	2.6\2.1	1.5\1.4	5.9\5.3	5.5\5.1
17	4.1\4.6	3.7\3.6	1.7\1.8	9.0\8.3	6.9\6.3	4.2\4.8	5.9\6.2
18	1.6\1.1	2.7\2.6	6.4\6.3	3.5\3.7	5.0\4.9	6.2\5.5	3.0\2.8
19	3.8\3.3	5.5\5.3	10.0\10.2	4.8\5.3	3.9\3.8	2.6\2.0	5.9\6.5
20	1.9\2.1	3.4\3.9	5.5\5.7	3.3\3.1	5.7\5.0	2.9\3.6	2.3\2.6
21	6.0\5.8	4.5\4.2	5.0\4.6	6.1\6.3	2.0\2.7	3.8\3.9	3.2\2.8
22	7.7\6.7	3.6\3.3	4.6\4.6	2.9\2.7	7.3\8.4	3.8\3.4	5.1\5.5
23	1.9\1.2	6.7\5.9	8.6\7.3	3.6\3.8	1.1\1.8	2.4\1.8	1.5\1.9
24	6.7\5.9	2.7\2.9	3.8\4.1	3.6\3.5	3.4\3.1	8.9\8.3	7.8\6.9
25	2.5\2.0	3.9\4.1	5.0\5.6	3.3\3.4	2.3\2.0	1.9\1.5	2.3\2.0
26	2.5\2.8	2.1\2.3	6.9\7.3	6.3\5.7	3.1\3.7	7.9\8.5	2.1\2.7
27	2.3\2.5	3.9\4.1	6.5\6.6	2.2\2.3	8.4\7.3	3.5\3.3	3.7\3.5
28	6.8\7.8	1.6\2.2	6.9\6.8	3.2\3.2	5.7\4.9	2.0\2.6	5.2\4.8
29	1.9\1.2	0.7\0.9	1.6\1.4	5.9\6.0	2.1\2.6	1.5\1.7	1.8\1.7
30	2.6\3.0	1.2\1.6	0.7\0.9	1.6\2.0	3.1\3.4	3.4\3.3	2.3\2.1

Table I14 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
1.5\1.3	2.2\2.4	2.1\2.1	0.7\0.9	1.3\1.0	0.5\0.6	3.1\3.1	1.1\1.0
0.3\0.5	0.7\0.9	0.5\0.5	3.4\3.2	1.7\1.6	1.2\1.3	1.0\1.0	3.6\3.7
1.3\1.0	0.6\0.8	0.4\0.3	0.4\0.5	1.2\1.4	1.3\1.4	0.4\0.6	0.9\0.9
2.3\2.6	1.1\1.3	0.9\1.0	2.0\1.9	0.3\0.5	0.6\0.7	0.6\0.4	0.9\0.7
3.6\3.4	0.6\0.8	0.9\0.9	1.1\1.1	2.8\2.2	1.5\1.7	1.4\1.6	2.3\2.5
4.8\5.0	2.6\2.3	1.7\1.5	2.3\2.3	1.5\1.5	3.4\3.5	2.9\2.6	1.7\1.6
6.8\6.3	1.7\1.5	3.4\3.6	4.5\4.1	2.1\2.1	1.5\1.8	3.7\3.9	2.4\2.5
1.9\2.4	1.6\1.1	1.7\2.0	2.8\2.6	0.8\1.0	3.8\3.9	0.9\1.2	2.2\2.4
1.1\1.1	2.1\2.2	1.9\1.8	1.7\1.1	1.4\1.0	4.0\3.5	4.5\3.7	3.0\2.8
2.8\2.7	0.4\0.5	1.7\1.6	2.2\2.4	1.0\1.4	1.8\2.0	1.9\2.2	3.6\3.6
2.3\2.2	3.6\3.7	3.0\2.9	2.0\2.2	3.6\3.4	1.1\1.3	1.2\1.3	2.9\2.9
10.3\10.9	1.2\1.3	1.0\0.9	4.9\5.0	5.1\5.0	1.0\0.8	1.3\1.0	1.1\1.4
2.3\2.4	4.3\3.9	1.7\1.5	1.7\2.0	7.4\7.6	2.2\2.0	4.1\3.4	5.7\5.4
4.5\4.6	3.9\3.8	3.4\3.7	9.4\9.8	1.9\2.5	4.0\3.9	10.8\10.5	4.1\4.0
6.2\6.4	2.3\2.1	1.3\1.5	1.5\1.6	5.8\5.7	1.2\1.1	1.3\1.3	1.4\1.5
9.0\8.1	3.2\3.0	2.1\2.0	6.5\6.4	7.9\8.6	1.7\1.6	7.6\7.9	6.0\5.8
1.7\1.5	4.7\4.8	4.5\4.3	6.3\5.8	4.2\4.0	3.5\3.4	8.5\8.2	4.0\3.8
3.2\3.2	6.0\6.2	2.1\2.3	2.5\3.1	4.0\3.5	6.4\6.0	3.4\4.1	2.0\2.4
1.7\2.0	5.5\5.7	3.1\2.9	7.2\6.7	5.1\4.7	9.7\8.8	2.6\2.9	6.7\6.5
2.3\2.6	6.4\6.4	11.0\11.4	1.4\1.6	5.5\5.9	8.5\8.7	10.5\10.8	7.4\7.6
1.8\2.1	2.5\2.4	5.6\5.3	5.4\5.8	5.0\5.1	5.9\6.1	5.8\5.4	1.9\2.3
4.2\4.1	4.3\4.4	2.3\2.0	1.8\1.7	2.5\1.9	6.5\6.6	3.9\3.7	5.8\5.4
3.9\4.0	4.4\4.7	8.3\8.7	2.2\2.2	5.7\5.8	3.2\3.3	3.7\4.5	6.6\6.8
2.9\3.1	5.8\5.5	7.5\7.4	3.0\2.7	7.6\7.4	2.2\2.3	2.2\2.2	2.9\3.0
5.0\4.8	2.6\2.6	3.4\3.4	2.6\2.4	3.9\3.3	7.4\7.4	2.2\1.9	3.8\4.1
3.2\3.3	9.4\8.9	6.3\6.1	4.7\4.5	2.5\2.5	5.1\5.0	5.4\5.8	4.9\4.6
3.6\3.7	3.4\3.9	6.7\6.9	3.7\3.6	3.3\3.9	3.1\3.0	1.3\1.2	4.8\4.5
1.7\1.5	7.1\7.8	6.9\6.9	3.1\3.1	1.3\1.5	3.8\4.0	1.2\0.9	2.7\2.5
2.9\2.6	4.1\3.4	1.4\1.8	6.2\6.7	1.5\1.3	2.4\2.6	1.0\1.3	1.8\1.9
0.9\0.6	1.5\1.5	3.3\2.9	2.9\3.1	2.2\2.8	1.7\1.9	1.6\1.4	2.0\2.1

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I15 Densitometric Data for Reduced Glutenin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Blend[1] Flour and Its Different Dough[2]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	1.3\1.3	1.5\1.4	2.7\2.7	1.5\1.5	1.6\1.9	2.1\1.9	1.1\1.0
2	1.5\1.5	0.6\0.8	1.8\1.8	2.4\2.3	1.4\1.2	2.7\2.8	2.1\2.0
3	3.8\4.0	1.3\1.6	1.5\1.6	2.0\2.0	1.7\1.4	2.9\3.3	1.1\1.3
4	2.2\2.5	4.1\3.7	3.2\3.1	3.7\3.3	3.2\3.4	3.9\3.3	3.7\3.7
5	5.4\5.8	2.0\2.2	0.9\1.0	5.4\5.9	4.0\3.3	2.3\2.2	6.5\6.9
6	2.1\2.0	4.2\4.0	2.0\2.2	3.2\2.7	4.1\3.9	3.5\3.3	4.3\3.9
7	3.8\3.6	2.6\3.6	1.3\1.3	3.9\3.9	3.3\3.7	0.4\0.9	4.6\4.4
8	3.5\3.3	1.0\1.5	1.7\1.5	6.6\6.6	3.6\3.4	3.3\3.9	7.7\7.9
9	1.6\1.3	3.4\3.5	3.1\2.9	5.5\6.1	8.0\7.5	0.8\0.7	5.6\5.8
10	2.0\1.6	2.6\2.6	1.5\1.7	2.6\2.4	2.1\2.3	2.8\2.8	5.5\5.3
11	5.3\5.0	1.7\1.9	1.8\2.0	5.5\5.6	4.1\4.2	0.7\0.8	4.2\4.2
12	4.5\5.0	3.8\4.1	5.8\5.7	0.9\1.1	4.0\4.4	2.6\2.8	6.0\5.9
13	1.3\1.8	2.5\2.2	6.0\5.6	1.5\1.7	1.1\1.6	2.5\2.1	3.4\3.3
14	1.3\1.5	1.9\2.0	5.5\5.5	2.0\2.5	4.3\4.8	3.3\3.5	2.8\2.9
15	4.0\3.8	4.1\4.3	2.4\2.6	1.0\0.9	3.2\2.1	4.8\4.7	7.9\7.4
16	7.8\8.4	3.0\3.0	3.9\3.7	2.0\1.6	4.9\4.9	3.8\3.9	8.3\8.1
17	11.5\10.9	5.7\5.5	4.5\4.8	3.3\3.7	4.8\4.3	5.8\5.1	4.9\5.3
18	1.1\1.3	8.2\7.7	5.2\5.0	11.2\10.1	3.7\3.3	2.1\2.5	2.8\3.0
19	3.0\2.8	5.3\5.2	1.7\1.5	1.7\1.5	3.4\3.6	5.3\5.8	2.0\2.2
20	4.4\3.9	2.1\2.0	2.5\2.4	1.6\2.0	6.7\5.6	7.7\7.2	4.7\5.1
21	5.4\4.9	2.0\2.0	3.7\3.5	2.5\2.0	3.9\4.1	4.6\5.2	6.1\5.7
22	4.7\5.0	4.4\4.3	3.3\3.3	4.1\3.7	5.6\6.7	2.2\2.3	0.9\1.5
23	3.0\3.4	2.0\1.5	6.2\6.4	2.3\2.4	2.3\2.1	2.8\2.6	3.8\3.2
24	2.6\2.9	11.2\10.2	5.2\5.3	5.6\5.5	1.6\1.1	3.9\3.8	null
25	1.9\2.1	2.2\2.4	2.2\2.6	0.9\1.0	2.1\3.2	4.7\4.8	null
26	0.7\0.9	3.1\2.9	8.0\7.7	2.4\2.6	3.3\4.0	10.4\9.8	null
27	2.3\2.4	4.4\4.8	4.8\5.0	1.7\1.5	1.4\1.7	3.3\2.9	null
28	1.8\1.4	3.9\3.6	4.1\3.9	3.7\4.1	3.4\3.2	1.9\2.1	null
29	3.8\3.5	2.2\2.0	2.4\2.9	2.7\3.2	1.2\1.4	2.8\2.7	null
30	2.4\2.2	2.8\2.9	1.6\1.1	6.6\6.6	1.9\1.6	null	null

Table I15 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
0.3\0.3	1.1\1.7	3.7\3.4	1.7\1.5	0.4\0.7	2.0\1.8	1.1\1.1	0.4\0.6
1.8\1.8	0.8\0.8	1.7\2.0	1.3\1.5	0.8\0.7	2.5\2.6	1.6\1.5	1.3\1.5
2.6\2.6	1.7\1.9	4.8\4.8	1.8\1.2	0.7\0.8	2.6\2.7	5.3\5.2	1.9\1.5
1.2\1.0	1.1\1.4	3.8\3.9	1.2\1.1	1.7\1.9	1.0\1.3	4.3\4.5	1.7\1.7
1.7\1.9	2.2\2.6	2.1\2.0	1.0\1.8	2.4\2.5	2.5\2.4	10.3\11.2	1.0\1.0
6.5\6.9	2.1\2.3	1.5\1.7	0.4\0.6	1.7\1.8	8.5\8.0	4.0\3.8	0.7\0.8
4.9\5.3	1.9\1.7	3.4\3.2	0.7\0.8	2.8\2.7	7.4\7.7	3.0\2.7	4.0\4.1
2.7\2.9	1.7\1.1	3.2\2.9	0.5\0.7	5.2\4.8	2.3\2.2	3.1\3.2	3.3\3.5
5.8\5.4	4.3\4.7	1.5\1.8	1.8\1.9	4.3\4.2	2.1\2.0	2.2\2.1	4.6\4.5
4.4\4.0	2.3\2.8	4.5\4.6	1.1\1.2	2.9\3.0	4.8\4.9	6.4\5.9	3.4\3.1
3.4\3.2	3.0\3.5	2.6\2.7	1.8\1.0	4.2\4.7	5.8\6.2	9.4\9.0	2.0\2.1
3.3\3.2	2.2\2.3	1.2\1.3	3.9\3.4	1.9\1.7	3.0\2.9	3.2\3.5	5.0\5.3
3.8\3.9	3.5\3.1	1.2\0.9	2.7\2.6	4.9\4.8	2.1\1.9	3.1\3.3	4.1\4.0
4.6\4.2	5.1\5.4	1.2\1.1	1.2\1.8	6.4\7.0	1.0\1.2	2.1\2.1	8.7\8.4
1.5\1.9	2.5\2.0	3.5\3.4	5.5\5.0	1.8\1.7	3.3\3.7	1.6\1.7	2.5\2.5
9.6\8.6	7.0\6.6	4.0\4.2	3.5\3.0	3.2\3.0	6.3\6.5	4.4\3.9	3.3\3.5
2.6\2.8	5.6\6.1	2.4\2.6	4.2\4.8	1.5\1.3	5.3\5.1	1.6\1.7	1.4\1.2
2.7\3.1	1.4\1.1	0.7\0.9	3.0\3.5	4.4\4.2	3.0\3.3	3.2\3.4	3.3\3.1
9.9\8.6	4.7\4.3	1.4\1.5	5.8\6.0	7.9\7.2	4.5\4.7	5.1\5.0	11.5\12.6
4.1\4.1	2.3\2.2	2.0\1.8	6.4\7.2	5.4\5.7	11.4\10.2	2.1\2.6	2.7\2.4
6.5\6.9	8.4\8.2	7.9\7.6	6.0\6.3	4.2\4.6	3.9\4.4	3.6\3.7	6.5\6.2
1.5\1.8	7.7\7.9	18.0\18.9	10.1\8.9	4.6\4.6	1.7\1.7	4.9\4.4	4.7\4.6
2.4\2.1	3.1\3.5	3.3\3.5	5.4\5.8	6.0\6.4	4.0\3.5	1.1\1.2	1.7\1.5
2.0\2.2	5.4\5.1	3.2\3.5	4.4\5.0	3.8\3.9	1.9\1.6	3.7\3.2	4.3\4.6
2.4\2.5	6.6\7.0	2.8\2.7	3.4\3.9	4.4\3.9	0.7\0.5	1.1\1.3	2.3\2.5
2.9\3.1	3.5\3.0	2.2\1.8	6.3\6.0	2.8\2.8	2.4\2.0	2.5\2.8	1.5\1.3
2.6\2.5	2.6\2.2	4.9\4.7	4.8\4.2	2.5\2.5	0.8\1.3	1.2\1.4	2.8\2.6
0.9\1.2	0.8\0.8	1.3\1.1	7.2\6.4	3.1\3.5	0.9\1.1	2.9\2.5	1.4\1.8
0.3\0.6	2.8\2.3	1.6\1.5	1.5\1.7	3.3\2.9	0.5\1.0	1.1\1.2	5.3\5.1
1.0\1.3	2.3\2.1	4.4\4.0	1.5\1.3	0.7\0.4	1.9\1.7	0.7\0.8	2.8\2.5

[1]Blend: The mixture of 50% soft red winter and 50% hard red winter.

[2]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I16 Densitometric Data for Gliadin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Frankenmuth Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	null	3.5\3.4	1.9\1.8	null	8.1\7.7	0.2\0.3	null
2	null	3.9\3.8	2.2\2.3	null	3.0\2.6	2.0\1.8	null
3	null	5.2\5.1	3.2\3.0	null	4.7\4.9	1.0\1.5	null
4	null	7.0\7.3	5.4\5.7	null	4.6\4.9	0.9\0.7	null
5	null	2.4\2.5	2.1\2.4	null	5.2\5.0	1.6\1.5	null
6	null	4.9\5.0	3.5\3.2	null	5.8\6.0	0.3\0.4	null
7	null	7.5\7.3	4.2\3.8	null	2.1\2.4	1.1\1.3	null
8	null	3.0\2.8	2.6\4.0	null	3.7\4.1	3.1\1.9	null
9	null	6.4\6.2	3.7\3.2	null	3.7\4.0	1.7\1.1	null
10	null	2.1\1.9	2.4\2.6	null	2.9\2.7	0.7\0.9	null
11	null	3.6\4.2	1.8\2.1	null	3.4\3.9	1.1\1.7	null
12	null	4.3\4.0	2.3\2.3	null	7.2\7.6	2.6\2.5	null
13	null	1.8\1.5	3.3\3.4	null	4.1\4.6	3.8\2.7	null
14	null	8.3\7.4	3.0\2.9	null	2.1\2.1	7.2\7.5	null
15	null	4.9\4.6	5.2\4.9	null	2.7\2.9	2.9\3.1	null
16	null	3.4\3.5	8.4\7.9	null	3.9\3.4	7.2\7.0	null
17	null	2.7\2.6	2.5\2.8	null	4.6\4.1	6.6\6.3	null
18	null	1.6\1.5	3.2\3.3	null	4.0\3.7	4.4\4.2	null
19	null	1.8\1.9	1.5\1.8	null	2.1\2.7	3.7\3.9	null
20	null	3.3\3.3	2.3\2.8	null	7.0\6.5	6.6\6.8	null
21	null	4.4\4.2	4.1\3.7	null	2.6\3.0	7.9\7.9	null
22	null	2.3\2.5	4.4\4.3	null	2.4\2.1	4.0\4.2	null
23	null	4.4\4.5	3.4\3.4	null	4.1\3.7	4.1\4.3	null
24	null	0.9\0.8	6.4\6.0	null	1.1\1.0	4.4\4.6	null
25	null	0.9\1.0	5.1\5.6	null	2.7\2.1	4.2\4.2	null
26	null	2.7\2.6	1.4\1.8	null	0.9\0.7	9.9\9.1	null
27	null	0.5\0.5	3.1\3.2	null	0.2\0.1	1.5\1.0	null
28	null	1.4\1.2	2.9\2.8	null	0.2\0.4	3.1\2.9	null
29	null	0.3\0.4	3.3\3.1	null	0.1\0.2	1.8\2.0	null
30	null	0.9\1.0	1.1\0.9	null	1.0\1.1	0.3\0.2	null

Table I16 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
6.2\6.0	0.2\0.2	null	4.0\4.2	2.9\2.9	null	3.3\3.5	1.2\1.4
5.1\5.2	0.4\0.3	null	5.8\5.6	4.6\4.7	null	4.4\4.7	0.6\0.8
4.5\4.6	0.2\0.2	null	4.2\3.9	3.6\3.7	null	4.9\5.4	0.6\0.6
4.5\4.5	0.6\0.7	null	5.4\5.7	1.5\1.7	null	5.7\5.6	1.4\1.6
5.1\4.9	3.8\3.6	null	3.7\4.1	1.9\2.0	null	4.2\4.5	1.7\1.7
5.4\5.7	1.4\1.6	null	8.2\7.8	2.0\2.1	null	3.2\3.5	0.9\0.8
8.0\7.9	1.9\1.8	null	4.5\4.6	2.2\2.3	null	4.5\4.5	2.5\2.4
9.2\9.6	2.0\2.1	null	5.5\5.4	3.1\3.3	null	3.6\3.4	2.6\2.5
7.3\7.7	2.9\3.1	null	3.1\3.1	1.4\1.2	null	5.5\5.9	1.4\1.3
6.3\6.3	4.0\3.8	null	2.5\2.5	1.2\1.1	null	3.4\3.7	2.2\2.4
7.1\6.9	3.7\3.4	null	4.7\4.7	1.3\1.2	null	3.2\3.4	5.2\4.9
7.2\7.3	0.7\1.0	null	5.3\5.2	1.1\1.0	null	5.4\4.9	2.4\2.7
6.1\5.9	2.6\2.6	null	4.3\4.2	2.6\2.3	null	3.0\2.5	2.9\2.8
6.6\6.4	3.4\3.2	null	4.9\4.7	8.0\7.9	null	3.7\3.4	4.5\4.6
2.0\2.1	4.4\4.6	null	3.0\3.4	2.8\3.0	null	3.5\3.2	4.0\4.2
2.7\2.5	10.0\10.8	null	1.6\1.8	5.6\5.9	null	4.7\4.4	4.3\4.1
1.0\0.8	4.0\3.8	null	1.1\1.2	5.8\6.2	null	7.7\7.2	4.1\4.1
0.5\0.7	7.0\6.4	null	2.0\1.7	1.9\2.2	null	2.5\3.0	4.3\4.5
0.9\0.7	2.4\2.3	null	1.1\1.5	7.8\7.2	null	3.4\3.6	7.4\7.2
2.3\2.5	5.5\5.6	null	2.5\2.3	5.7\5.5	null	5.6\5.7	12.2\12.8
2.0\1.8	4.0\4.1	null	4.7\2.5	2.3\2.3	null	0.6\0.5	2.2\2.4
null	5.7\5.8	null	3.4\3.5	3.5\3.4	null	0.7\1.0	7.5\6.9
null	1.9\1.7	null	2.9\2.8	4.2\4.1	null	0.5\0.6	6.1\5.9
null	2.6\2.3	null	3.0\2.8	4.6\4.5	null	1.0\0.7	1.8\1.8
null	5.7\5.9	null	1.8\2.0	4.8\4.7	null	5.9\5.5	3.1\3.0
null	1.9\2.0	null	2.3\2.1	6.1\6.5	null	0.3\0.4	3.6\3.7
null	4.6\4.8	null	0.3\0.5	1.6\1.5	null	0.1\0.3	4.5\4.3
null	6.6\6.4	null	1.3\1.3	1.0\0.9	null	0.5\0.4	2.4\2.6
null	3.1\3.1	null	1.4\1.5	3.4\3.1	null	1.6\1.4	1.0\1.1
null	2.7\2.7	null	1.6\1.5	1.5\1.6	null	3.5\3.3	1.4\1.3

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I17 Densitometric Data for Gliadin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Cracker Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	null	6.5\6.4	0.4\0.4	null	6.0\5.8	0.9\0.8	null
2	null	5.0\5.1	0.7\0.8	null	4.4\4.3	3.5\3.6	null
3	null	1.1\1.3	0.6\0.6	null	4.0\4.1	2.1\2.1	null
4	null	5.8\6.0	1.3\1.4	null	2.8\2.9	1.1\1.1	null
5	null	5.5\5.4	2.3\2.1	null	2.7\2.9	1.1\1.0	null
6	null	4.3\4.2	2.5\2.4	null	3.5\3.4	1.0\1.1	null
7	null	5.1\5.3	1.5\1.4	null	3.0\2.8	3.2\2.9	null
8	null	2.9\3.3	3.3\3.5	null	2.6\2.4	2.9\3.0	null
9	null	3.1\2.9	2.4\2.4	null	4.9\5.3	2.0\2.2	null
10	null	4.1\3.9	2.8\2.9	null	10.9\11.3	3.5\3.7	null
11	null	7.1\7.6	1.3\1.2	null	6.9\6.7	1.4\1.3	null
12	null	2.9\2.8	2.9\3.4	null	2.5\2.4	0.6\0.5	null
13	null	2.8\2.7	7.9\7.5	null	5.7\5.6	8.7\9.2	null
14	null	9.8\9.5	6.4\6.8	null	7.8\7.7	2.7\2.8	null
15	null	9.5\9.9	3.9\3.7	null	5.5\5.6	3.6\3.3	null
16	null	4.1\4.4	4.5\4.3	null	4.9\5.0	7.6\7.3	null
17	null	0.9\1.0	4.8\4.8	null	2.4\2.5	6.6\6.1	null
18	null	2.3\1.9	5.6\5.7	null	3.8\3.6	4.0\4.1	null
19	null	0.6\0.6	3.5\3.6	null	0.6\0.8	4.7\4.9	null
20	null	1.1\1.0	2.4\2.2	null	1.6\1.8	2.7\2.9	null
21	null	0.3\0.4	5.1\5.3	null	5.8\6.1	8.1\8.6	null
22	null	1.2\1.1	5.7\5.9	null	5.4\5.0	2.2\2.1	null
23	null	0.6\0.7	9.7\10.4	null	2.4\2.1	1.5\1.1	null
24	null	1.1\1.3	3.7\3.2	null	null	6.6\6.3	null
25	null	0.8\0.7	6.1\5.7	null	null	1.3\1.4	null
26	null	2.4\2.2	2.4\2.5	null	null	2.2\2.4	null
27	null	3.7\3.7	1.4\1.6	null	null	2.3\2.3	null
28	null	1.6\1.7	1.8\1.6	null	null	1.0\1.2	null
29	null	2.2\2.1	0.9\1.0	null	null	5.1\5.6	null
30	null	1.5\1.6	2.0\1.9	null	null	5.9\5.1	null

Table I17 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
5.5\6.1	2.5\2.2	null	1.8\1.8	0.6\0.7	null	7.2\7.9	0.5\0.6
2.3\2.4	4.4\4.7	null	1.8\1.9	4.0\4.1	null	8.5\8.6	0.5\0.7
2.2\2.3	3.5\3.5	null	1.9\2.0	2.9\3.0	null	1.8\1.5	2.5\2.5
3.5\3.6	2.3\1.8	null	3.2\3.4	1.8\1.9	null	5.9\5.7	3.3\3.3
3.1\3.4	2.2\2.4	null	5.1\4.8	2.1\1.9	null	3.4\3.1	1.7\1.8
4.3\4.2	1.4\1.7	null	2.8\2.7	1.9\1.7	null	5.2\5.0	0.8\0.7
10.4\10.8	1.4\1.4	null	6.0\5.7	4.5\4.5	null	6.1\5.9	1.1\0.8
7.0\6.8	1.3\1.2	null	2.3\2.4	2.2\2.1	null	4.0\3.9	4.6\4.8
9.6\9.3	2.3\2.4	null	6.7\6.9	3.3\3.0	null	3.8\4.0	2.5\2.6
3.5\4.5	2.5\2.7	null	7.3\8.0	0.8\1.0	null	3.5\3.8	3.6\3.5
9.8\10.3	0.6\1.1	null	6.6\6.3	1.5\1.6	null	7.4\7.1	2.1\2.0
4.1\3.9	8.6\8.1	null	4.0\3.6	4.9\5.0	null	6.1\6.3	4.5\4.4
2.0\1.7	6.0\6.8	null	7.7\7.4	6.7\7.4	null	2.8\2.9	6.3\5.6
2.8\3.3	8.0\7.5	null	5.1\5.4	4.5\4.6	null	2.0\2.3	6.0\6.4
2.7\2.7	3.5\3.7	null	5.1\5.1	2.2\2.3	null	1.3\1.6	4.0\4.3
3.4\3.9	4.8\5.1	null	6.9\6.6	3.8\3.3	null	3.1\3.4	5.4\5.2
3.1\3.3	7.7\8.1	null	2.3\2.4	7.3\6.9	null	1.7\1.6	2.8\3.0
2.0\1.9	3.2\3.1	null	4.8\5.0	2.1\2.1	null	3.4\3.2	8.2\8.7
1.8\2.0	4.8\4.6	null	4.7\4.6	3.3\3.1	null	3.4\3.2	3.9\4.0
2.3\2.8	4.2\4.1	null	3.2\3.3	4.0\4.2	null	1.0\1.1	2.3\2.4
3.4\3.0	3.7\3.7	null	2.4\2.6	4.4\4.5	null	1.9\2.0	3.0\2.9
4.1\4.5	2.6\2.5	null	4.2\4.0	7.0\6.6	null	3.5\4.1	5.2\4.9
3.0\3.4	1.9\2.0	null	1.9\1.9	5.4\5.6	null	1.3\1.4	8.1\7.8
2.2\null	2.5\2.6	null	2.1\2.1	1.3\1.4	null	2.0\1.8	1.7\1.7
2.0\null	5.1\5.0	null	null	1.6\1.5	null	2.5\2.4	3.6\3.7
null	2.7\2.5	null	null	4.3\4.1	null	0.7\0.7	1.8\1.9
null	2.5\2.6	null	null	3.0\3.2	null	1.7\1.5	1.6\1.8
null	0.5\0.6	null	null	6.2\5.7	null	1.9\1.7	2.0\2.3
null	1.0\1.2	null	null	1.8\2.1	null	0.7\0.9	3.2\2.9
null	2.3\2.1	null	null	0.4\0.7	null	2.1\1.9	3.5\3.1

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I18 Densitometric Data for Gliadin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Caldwell Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	null	5.1\4.9	0.4\0.4	null	7.8\7.1	2.2\1.7	null
2	null	4.6\4.7	3.7\3.6	null	3.7\3.8	5.4\5.2	null
3	null	8.6\8.2	2.4\2.4	null	5.6\5.6	4.1\4.3	null
4	null	4.1\4.2	0.1\0.2	null	5.1\5.3	1.9\2.4	null
5	null	3.8\4.0	0.9\0.9	null	7.0\6.7	4.3\3.8	null
6	null	2.5\2.7	0.8\0.9	null	4.1\4.4	1.3\1.5	null
7	null	3.0\3.1	3.4\3.3	null	8.0\7.7	0.4\0.7	null
8	null	2.9\2.8	8.2\8.0	null	11.2\11.6	0.8\0.7	null
9	null	9.0\9.3	9.5\9.7	null	8.2\7.8	0.7\0.8	null
10	null	2.7\2.5	3.2\3.3	null	1.9\2.1	2.9\2.9	null
11	null	6.3\6.2	9.2\9.1	null	9.8\10.3	5.4\5.5	null
12	null	2.4\2.4	3.3\3.0	null	6.2\6.1	9.8\9.4	null
13	null	5.4\5.5	1.9\2.2	null	6.0\5.9	10.0\10.5	null
14	null	4.2\4.1	4.8\4.9	null	7.7\7.3	2.8\3.1	null
15	null	1.6\1.8	6.9\7.2	null	1.6\1.6	6.5\6.2	null
16	null	4.7\4.9	2.9\2.7	null	0.9\1.1	5.3\5.1	null
17	null	4.2\3.9	4.8\4.6	null	0.8\1.0	2.0\2.2	null
18	null	3.3\3.2	4.6\4.5	null	1.4\1.3	5.8\5.6	null
19	null	3.0\2.9	2.7\2.8	null	0.7\0.8	2.6\2.6	null
20	null	0.9\1.0	2.6\2.6	null	2.1\2.1	4.0\3.9	null
21	null	0.8\0.8	5.1\5.0	null	null\0.7	3.9\3.8	null
22	null	2.4\2.4	3.3\3.4	null	null\0.5	2.7\2.9	null
23	null	1.0\1.1	3.9\3.6	null	null	3.6\3.8	null
24	null	1.9\1.8	4.4\4.2	null	null	4.0\3.9	null
25	null	1.0\1.1	3.2\3.3	null	null	3.8\3.7	null
26	null	0.8\0.9	0.6\0.9	null	null	0.4\0.5	null
27	null	2.9\2.7	2.2\2.1	null	null	1.4\1.2	null
28	null	4.4\4.0	1.1\1.3	null	null	0.4\0.6	null
29	null	0.5\0.7	null	null	null	1.5\1.4	null
30	null	1.8\2.0	null	null	null	null	null

Table I18 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
8.2\8.1	0.9\0.9	null	5.3\5.7	1.2\1.4	null	4.5\4.5	1.7\1.6
5.2\5.2	0.5\0.4	null	4.1\4.0	0.5\0.7	null	3.7\3.6	1.2\1.1
3.2\3.3	1.0\1.0	null	3.5\3.4	0.4\0.6	null	5.8\5.6	1.1\1.0
3.7\3.5	6.7\6.8	null	4.0\3.8	0.6\0.8	null	4.6\4.3	1.3\1.2
3.9\4.1	3.3\3.2	null	8.9\8.4	1.2\1.1	null	2.6\2.2	4.8\4.7
3.1\3.4	1.5\1.6	null	2.5\2.7	2.8\2.7	null	3.3\2.7	2.8\2.6
6.9\6.6	1.3\1.3	null	3.9\3.1	1.8\1.6	null	4.8\4.9	0.9\0.8
3.5\3.9	0.8\0.8	null	5.9\6.0	0.7\0.9	null	3.4\3.2	1.5\1.7
9.7\9.3	1.9\2.1	null	2.9\3.2	1.0\1.2	null	2.6\3.1	2.6\2.7
5.7\5.2	2.0\2.1	null	3.4\3.3	2.1\2.3	null	6.0\6.3	1.2\1.3
3.8\4.3	1.8\1.9	null	2.4\2.2	1.1\1.0	null	3.6\4.0	1.8\2.0
3.2\3.2	0.6\0.6	null	2.5\2.7	0.3\0.5	null	3.9\4.1	0.7\0.9
2.5\2.6	1.0\1.1	null	3.6\3.5	0.6\0.4	null	5.8\5.6	2.1\2.1
3.6\3.7	0.4\0.6	null	2.3\2.2	0.7\0.5	null	3.2\3.0	1.2\1.1
2.9\3.0	6.6\6.2	null	3.7\3.8	1.0\0.9	null	6.1\5.6	1.4\1.3
8.7\8.3	4.4\4.6	null	10.3\10.2	10.4\10.9	null	2.4\2.1	4.2\4.4
3.8\3.9	8.9\8.6	null	5.0\5.3	7.6\7.1	null	6.7\7.0	5.0\5.5
3.7\3.7	2.9\3.1	null	3.0\3.1	15.4\15.8	null	3.3\3.8	2.9\2.6
1.6\1.8	7.4\6.9	null	4.4\4.0	5.3\5.0	null	1.2\1.4	15.2\15.0
2.5\2.6	3.5\3.6	null	0.5\0.6	4.2\4.0	null	7.1\6.7	2.8\2.8
1.4\1.3	3.9\3.9	null	1.4\1.3	3.6\3.9	null	2.8\2.5	7.0\7.6
2.2\2.0	4.8\4.9	null	1.0\1.2	5.7\5.3	null	8.2\7.7	5.0\4.7
0.9\0.8	4.0\4.1	null	1.4\1.2	7.5\7.9	null	0.3\0.5	6.1\5.8
1.1\1.2	8.5\8.8	null	3.3\3.6	2.2\2.7	null	0.4\0.5	1.8\1.8
0.2\0.4	2.8\2.9	null	1.7\1.4	3.9\3.6	null	0.4\0.9	7.7\7.4
0.5\0.5	14.5\14.1	null	2.4\2.4	7.9\7.5	null	0.1\0.5	5.2\5.5
0.3\0.4	0.8\1.0	null	4.4\4.3	5.0\5.3	null	1.4\1.7	5.7\5.9
1.3\1.2	2.6\2.4	null	0.5\0.6	2.7\2.2	null	0.5\0.7	2.9\2.7
0.9\1.0	0.2\0.2	null	0.8\0.9	1.2\1.0	null	0.3\0.4	1.6\1.5
1.9\1.6	0.9\0.7	null	0.9\0.8	1.4\1.2	null	0.7\0.7	0.7\0.8

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I19 Densitometric Data for Gliadin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Freedom Flour and Its Different Dough[1]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	null	4.7\4.8	0.5\0.7	null	7.5\7.4	2.4\2.4	null
2	null	5.5\5.4	1.4\1.2	null	6.5\6.4	2.9\2.8	null
3	null	5.4\5.6	2.2\2.2	null	2.5\2.4	0.4\0.5	null
4	null	4.6\4.4	4.1\4.1	null	4.4\4.2	0.4\0.4	null
5	null	4.6\4.9	5.0\4.9	null	3.7\3.7	1.9\1.8	null
6	null	5.3\5.0	1.5\1.4	null	8.7\9.4	5.5\5.7	null
7	null	5.4\5.4	2.2\2.1	null	10.1\9.7	3.3\3.2	null
8	null	5.5\5.6	5.7\5.8	null	2.6\2.3	5.2\5.0	null
9	null	5.2\5.3	3.6\3.7	null	6.0\5.8	1.6\1.8	null
10	null	2.0\1.8	5.9\5.8	null	5.1\5.2	1.1\1.5	null
11	null	3.5\3.5	3.8\3.6	null	5.0\5.1	1.3\1.1	null
12	null	6.9\6.6	0.6\0.9	null	7.1\7.3	0.9\0.8	null
13	null	4.9\5.1	0.8\1.2	null	6.5\6.3	1.4\1.3	null
14	null	6.2\6.3	14.8\14.2	null	5.5\5.6	1.3\1.3	null
15	null	2.9\2.8	10.0\10.6	null	4.0\4.1	4.0\4.1	null
16	null	3.1\3.0	4.7\4.9	null	3.5\3.4	4.6\4.7	null
17	null	1.9\1.8	3.7\3.7	null	1.3\1.2	8.8\8.4	null
18	null	2.5\2.4	6.7\6.5	null	1.2\1.0	5.2\5.4	null
19	null	1.2\1.4	4.5\4.2	null	0.9\1.1	6.5\6.5	null
20	null	1.8\2.0	7.2\7.7	null	1.8\2.0	4.5\4.6	null
21	null	7.0\6.6	5.3\5.0	null	3.4\3.2	2.5\2.6	null
22	null	3.3\3.5	3.4\3.2	null	2.6\2.6	5.6\5.4	null
23	null	1.5\1.6	1.3\1.2	null	null\0.5	8.9\8.5	null
24	null	0.7\0.9	1.2\1.1	null	null	1.6\1.8	null
25	null	2.2\2.1	null	null	null	4.3\4.5	null
26	null	0.4\0.3	null	null	null	2.1\2.1	null
27	null	0.2\0.3	null	null	null	6.1\5.9	null
28	null	0.3\0.3	null	null	null	2.8\2.9	null
29	null	1.2\1.0	null	null	null	1.8\1.9	null
30	null	null	null	null	null	1.3\1.3	null

Table I19 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
6.2\6.0	0.2\0.4	null	8.3\7.3	1.2\1.0	null	3.2\3.4	4.7\4.7
5.1\5.2	2.9\3.0	null	6.1\6.5	0.6\0.8	null	7.0\6.8	4.7\4.9
4.5\4.6	3.4\3.3	null	7.7\8.1	1.3\1.3	null	9.2\9.5	1.8\1.7
4.5\4.5	1.1\1.0	null	4.0\4.2	4.3\4.4	null	3.0\2.9	2.7\2.6
5.1\4.9	0.3\0.2	null	4.4\4.3	3.0\3.2	null	6.2\6.0	5.6\5.4
5.4\5.7	1.6\1.5	null	4.2\4.3	3.4\3.5	null	4.2\4.2	1.4\1.6
8.0\7.9	4.7\4.5	null	6.5\6.9	1.2\1.1	null	3.6\3.6	4.2\3.6
9.2\9.6	3.2\3.1	null	3.6\3.3	5.3\5.2	null	8.2\8.8	3.1\3.4
7.3\7.7	4.1\3.9	null	2.8\2.7	3.7\3.5	null	2.1\1.9	3.6\3.9
6.3\6.3	1.4\1.7	null	5.9\5.3	4.0\4.3	null	5.5\5.3	4.3\4.5
7.1\6.9	2.1\2.4	null	3.8\3.9	2.7\2.4	null	3.8\3.7	2.5\2.3
7.2\7.3	0.6\0.8	null	4.4\4.4	2.1\2.1	null	1.4\1.3	4.0\4.4
6.1\5.9	0.8\0.7	null	6.4\6.1	1.5\1.6	null	3.3\3.2	6.8\6.6
6.6\6.4	8.1\8.2	null	3.5\3.6	1.3\1.4	null	2.9\2.8	5.1\4.9
2.0\2.1	6.4\6.2	null	2.4\2.6	2.6\2.8	null	1.9\1.8	2.8\2.8
2.7\2.5	8.3\8.8	null	4.1\3.9	7.2\7.5	null	6.8\6.6	2.9\2.6
1.0\0.8	3.9\3.6	null	4.4\4.3	8.1\7.6	null	4.1\4.3	2.5\2.8
0.5\0.7	5.7\5.7	null	3.3\3.1	5.0\4.9	null	2.1\2.4	3.6\3.3
0.9\0.7	5.5\5.4	null	1.2\1.4	2.3\2.8	null	1.4\1.6	2.9\3.0
2.3\2.5	2.5\2.6	null	0.9\1.1	8.1\8.6	null	0.9\0.7	4.5\4.7
2.0\1.8	3.7\3.5	null	1.9\2.0	2.0\2.0	null	1.8\1.8	3.0\3.2
null	2.5\2.7	null	0.7\0.9	4.9\4.7	null	2.8\3.1	7.2\7.0
null	4.5\4.4	null	2.6\2.7	1.8\1.7	null	1.3\1.2	2.1\2.1
null	5.2\5.1	null	3.5\3.4	3.5\3.4	null	0.6\0.8	3.2\3.3
null	4.5\4.3	null	1.4\1.2	4.0\3.8	null	2.4\2.2	2.5\2.6
null	1.5\1.9	null	0.1\0.4	2.0\1.9	null	5.3\5.1	3.1\3.2
null	4.5\4.1	null	0.7\1.0	4.4\4.2	null	1.8\1.7	0.9\1.0
null	2.1\2.1	null	1.1\1.0	4.3\4.3	null	1.5\1.6	2.0\1.7
null	2.7\2.9	null	null	2.2\2.4	null	0.7\0.8	1.2\1.2
null	2.0\2.2	null	null	2.0\1.8	null	1.2\1.1	1.1\1.0

[1]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

Table I20 Densitometric Data for Gliadin Proteins from Each Protein Fraction Obtained from Gel Filtration Chromatography of Blend[1] Flour and Its Different Dough[2]

Peak #	F(%)			N(%)			
	I-A	I-B	II	I-A	I-B	II	I-A
1	null	3.0\2.4	1.3\1.3	null	3.8\4.0	2.1\2.1	null
2	null	2.7\2.4	1.1\1.2	null	5.9\5.7	1.6\1.6	null
3	null	5.1\5.6	4.0\4.1	null	6.7\6.5	2.1\1.5	null
4	null	2.4\2.7	3.5\3.3	null	8.6\8.8	2.0\2.2	null
5	null	3.7\4.2	3.3\3.0	null	2.7\2.0	4.8\5.1	null
6	null	2.6\2.2	2.0\2.2	null	7.6\7.9	4.8\4.9	null
7	null	5.0\5.7	4.0\4.1	null	3.5\3.4	2.2\2.1	null
8	null	4.5\4.9	2.3\2.3	null	2.8\3.1	4.2\3.9	null
9	null	9.7\9.3	3.2\3.3	null	4.0\3.8	1.7\1.9	null
10	null	5.3\5.9	1.5\1.7	null	2.7\2.6	5.6\5.7	null
11	null	5.6\5.1	3.0\2.6	null	5.7\5.9	2.9\3.0	null
12	null	1.8\1.9	3.4\3.3	null	5.9\5.3	3.0\2.7	null
13	null	5.9\5.3	10.7\11.2	null	6.9\6.4	2.0\2.2	null
14	null	5.9\5.8	5.4\5.1	null	3.5\4.0	7.3\7.9	null
15	null	1.9\1.8	3.6\3.4	null	3.0\3.0	3.7\3.5	null
16	null	5.8\5.9	2.7\2.8	null	3.9\4.5	3.9\3.5	null
17	null	5.7\5.0	2.9\2.8	null	1.2\1.8	4.1\3.9	null
18	null	4.2\3.7	4.5\4.3	null	2.5\1.8	5.7\5.9	null
19	null	1.8\1.3	4.1\4.3	null	4.5\3.9	2.5\2.5	null
20	null	0.9\0.7	2.9\2.7	null	2.0\2.7	2.8\2.9	null
21	null	2.7\2.3	5.2\2.7	null	0.8\0.5	4.9\5.1	null
22	null	2.1\2.2	4.5\4.7	null	1.8\2.5	5.6\5.3	null
23	null	0.3\0.2	1.2\1.0	null	3.4\3.5	5.1\5.1	null
24	null	2.2\2.6	5.8\5.6	null	1.8\1.2	2.7\2.9	null
25	null	0.7\0.9	3.8\4.0	null	0.3\0.2	1.0\1.0	null
26	null	0.2\0.3	1.1\1.2	null	0.5\0.8	2.7\2.8	null
27	null	2.2\2.1	3.3\3.3	null	0.5\0.8	3.0\3.2	null
28	null	2.3\2.7	1.3\1.2	null	0.2\0.3	1.6\1.9	null
29	null	1.3\1.8	2.6\2.4	null	2.6\2.7	3.4\2.8	null
30	null	2.4\3.0	1.9\2.2	null	0.8\0.5	1.0\0.8	null

Table I20 (cont' d)

S(%)		E(%)			D(%)		
I-B	II	I-A	I-B	II	I-A	I-B	II
3.1\3.2	0.9\0.8	null	2.9\2.8	2.8\2.7	null	4.2\4.2	0.3\0.5
2.1\2.3	0.5\0.2	null	4.3\4.1	1.8\1.7	null	4.8\5.0	1.8\1.7
1.5\1.6	0.6\0.8	null	2.3\2.6	0.6\0.8	null	3.7\3.8	0.6\0.5
1.3\1.4	1.3\1.4	null	1.8\2.0	0.3\0.5	null	2.2\2.4	0.2\0.3
1.5\1.3	0.4\0.5	null	3.5\3.1	0.7\0.9	null	5.3\5.4	0.2\0.3
3.5\3.3	3.6\4.4	null	4.9\5.1	1.0\1.1	null	3.6\3.7	0.6\0.7
2.1\2.2	10.1\9.3	null	3.4\3.5	4.6\4.1	null	1.4\1.7	1.8\1.7
1.8\1.6	11.0\11.5	null	9.0\8.6	4.4\4.6	null	3.4\3.1	1.0\0.9
8.4\8.2	2.9\2.9	null	2.9\3.0	4.9\4.7	null	2.7\2.6	0.8\0.7
5.8\6.4	7.0\6.5	null	6.2\6.4	0.8\0.9	null	1.6\1.5	3.3\3.3
2.5\2.7	4.1\4.0	null	3.2\3.3	0.4\0.6	null	4.1\3.8	5.0\4.6
2.7\2.9	5.8\5.9	null	5.6\5.8	3.6\3.5	null	2.1\1.9	4.4\4.5
2.7\2.7	5.5\5.8	null	4.9\4.6	5.0\4.8	null	2.7\2.7	10.2\10.5
10.3\9.5	15.5\15.2	null	4.1\4.1	3.3\3.2	null	5.1\5.6	3.3\3.4
12.1\12.7	11.6\12.5	null	4.4\4.5	8.6\8.3	null	1.8\1.6	3.7\3.5
5.8\6.0	5.0\4.7	null	3.5\3.4	3.2\3.0	null	6.8\6.5	4.4\4.6
6.6\6.5	3.1\2.8	null	7.5\7.8	3.1\3.5	null	2.5\2.2	5.9\6.1
3.8\3.9	5.2\5.5	null	5.3\5.0	5.7\5.9	null	7.5\7.8	6.8\6.5
8.3\8.7	5.9\5.3	null	8.4\7.9	3.2\3.2	null	6.8\6.4	1.4\1.2
4.0\3.6	null	null	2.5\2.9	3.4\3.1	null	7.0\7.2	4.5\4.4
1.0\0.9	null	null	3.9\4.0	4.4\5.1	null	1.6\1.7	3.5\3.4
2.3\2.1	null	null	1.8\1.8	2.4\2.3	null	2.6\2.7	2.2\2.1
0.5\0.8	null	null	0.5\0.4	3.9\3.7	null	1.4\1.4	12.3\12.7
2.5\2.7	null	null	0.4\0.4	3.5\3.4	null	0.9\1.1	2.8\2.9
3.7\3.5	null	null	0.3\0.4	4.9\4.9	null	1.7\1.6	2.4\2.4
null\0.8	null	null	2.5\2.5	2.8\3.1	null	2.1\2.0	3.9\4.0
null	null	null	null	2.5\2.5	null	4.7\4.4	4.3\4.3
null	null	null	null	8.1\7.8	null	1.8\2.2	2.2\2.0
null	null	null	null	3.4\3.7	null	4.3\4.2	4.5\4.3
null	null	null	null	2.6\2.3	null	null	1.5\1.8

[1]Blend: The mixture of 50% soft red winter and 50% hard red winter.

[2]F: Native flour; N: Non-developed dough; S: Dough partially developed with shear deformation; E: Dough partially developed with extensional deformation; D: Developed dough.

J. Cracker Data

Table J1 Cracker Data Using a Two-Stage Fermentation Procedure

Cracker Sample	Wt[1] (g)	L[1] (cm)	W[1] (cm)	T[1] (cm)	V[1] (cc)	M[1] (%)	PBF (N)[1]
Cake Flour							
1	2.72	5.37	4.90	0.34	15	1.57	6.4\6.5
2	2.56	5.31	4.87	0.23	14	1.82	6.5\6.5
3	2.74	5.30	4.95	0.28	14	1.09	7.2\5.9
4	2.66	5.37	4.89	0.25	14	1.45	7.0
5	2.69	5.34	4.77	0.3	15	1.19	5.6
6	2.72	5.28	4.86	0.28	14	1.55	6.1
Cookie Flour							
1	2.71	5.38	5.02	0.30	16	1.79	5.0\6.0
2	2.80	5.46	4.91	0.35	17	1.86	5.5\6.0
3	2.78	5.44	5.00	0.30	15	2.72	7.7\6.1
4	3.04	5.40	5.08	0.34	17	3.67	7.5
5	2.99	5.40	5.01	0.34	15	3.90	5.5
6	2.89	5.34	4.97	0.35	16	3.50	5.4
Cracker Flour							
1	2.51	5.42	5.10	0.30	16	1.59	10.0\4.9
2	3.69	5.44	5.05	0.33	16	1.50	4.5\12.0
3	2.6	5.39	5.01	0.41	16	1.11	9.5\12.6
4	2.75	5.37	5.00	0.37	16	2.56	8.8\9.4
5	2.72	5.45	5.02	0.39	16	2.28	7.0\9.3
6	2.62	5.40	4.95	0.39	16	1.81	9.9
Bread Flour							
1	4.79	5.50	4.73	0.57	23	10.04	16.7
2	4.80	5.59	4.61	0.68	24	9.44	14.2
3	4.57	5.50	4.60	0.67	23	9.92	15.3
4	5.07	5.48	4.72	0.61	24	10.79	14.4
5	4.75	5.46	4.60	0.69	24	9.39	16.5
6	5.08	5.38	4.60	0.66	24	9.91	12.6

Table J1 (cont' d)

Hard Red Spring Flour							
1	5.34	5.37	5.08	0.80	26	12.94	17.6
2	5.46	5.32	5.03	0.74	27	13.47	19.2
3	5.12	5.30	5.00	0.80	26	13.45	15.8
4	5.31	5.60	4.90	0.73	27	13.25	16.3
5	5.59	5.61	4.83	0.77	27	13.53	17.2
6	5.00	5.57	4.82	0.7	28	14.31	---

[1]Wt: Weight; L: Length; W: Width; T: Thickness; V: Volume; M: Moisture; PBF: Peak breaking forces (N: Newtons).

Table J2 Cracker Data Using a One-Stage Fermentation Procedure

Cracker Sample	Wt[1] (g)	L[1] (cm)	W[1] (cm)	T[1] (cm)	V[1] (c.c.)	M[1] (%)	PBF (N)[1]
Blend[2] Flour							
1	3.53	5.37	4.85	0.54	20	5.54	11.9\17.0
2	3.38	5.40	4.65	0.55	19	5.11	12.7\13.8
3	3.82	5.38	4.85	0.49	20	4.48	10.4\10.1
4	3.63	5.30	4.73	0.54	20	5.59	11.5
5	3.60	5.30	4.68	0.54	19	5.46	15.1
6	3.72	5.35	4.81	0.51	20	5.35	10.8
7	3.58	5.38	4.70	0.50	19	5.51	10.3
8	3.40	5.45	4.78	0.50	20	5.48	10.0
9	3.67	5.40	4.86	0.50	19	4.59	10.8
Dynasty Flour							
1	3.32	5.44	4.98	0.50	20	7.48	7.1\6.3\5.7
2	3.58	5.45	5.08	0.45	20	5.71	8.6\6.5\5.3
3	3.62	5.38	4.80	0.55	21	5.83	6.6\6.4\12.5
4	3.58	5.47	4.90	0.50	20	6.41	8.4\9.6\8.4
5	3.53	5.48	4.97	0.46	20	6.16	7.8\5.5
6	3.57	5.47	5.07	0.51	20	6.23	7.0\8.0
Clark Flour							
1	3.75	5.44	5.00	0.50	21	7.71	9.4\10.0\8.3
2	3.52	5.43	4.95	0.55	21	7.74	10.0\8.8
3	3.85	5.40	4.80	0.55	21	8.24	9.4\9.3
4	3.87	5.48	4.92	0.53	21	7.03	11.3\8.7
5	3.62	5.40	5.02	0.53	20	7.28	9.0\8.8
6	3.68	5.41	4.82	0.55	20	7.53	9.2\8.5
Cracker Flour							
1	3.44	5.46	5.04	0.53	18	4.89	9.8\9.7
2	3.26	5.51	5.10	0.46	19	4.98	9.4\11.6
3	3.32	5.40	4.96	0.50	17	5.06	12.5\8.1
4	3.46	5.38	4.93	0.50	18	4.97	10.4\17.1
5	3.24	5.47	5.02	0.55	19	4.98	10.1
6	3.38	5.45	5.07	0.48	18	4.92	10.0
7	3.31	5.40	5.07	0.46	17	4.73	11.2
8	3.17	5.45	4.85	0.45	18	4.86	11.9
9	3.19	5.38	4.86	0.55	18	4.89	10.2
10	3.08	5.40	5.07	0.46	18	4.47	7.9
11	2.98	5.43	5.17	0.48	18	4.81	11.6
12	3.27	5.49	5.08	0.49	18	4.22	8.7

Table J2 (cont' d)

Soft Red Winter Flour							
1	3.43	5.40	4.96	0.45	16	4.58	5.5\6.7
2	3.41	5.41	4.96	0.46	17	4.55	5.9\6.9
3	3.55	5.45	4.84	0.48	18	4.58	6.8\6.8
4	3.46	5.34	4.92	0.46	17	4.6	6.4
Cookie Flour							
1	3.72	5.40	4.90	0.45	18	6.78	8.5\8.4
2	3.89	5.42	4.82	0.50	20	7.28	8.1\9.9
3	3.67	5.37	5.05	0.46	19	7.10	8.1\7.1
4	3.64	5.47	4.86	0.48	19	7.38	8.0\8.3
5	3.77	5.42	4.93	0.49	18	7.43	10.1\10.2
6	3.65	5.45	5.05	0.48	20	7.98	10.9\10.2
7	3.77	5.43	5.08	0.34	16	7.73	8.6\10.3
8	4.03	5.39	4.96	0.49	20	7.12	8.9
9	3.62	5.38	5.05	0.41	18	6.06	8.5
10	3.68	5.39	5.10	0.41	18	6.41	12.5
11	3.52	5.37	4.82	0.46	19	8.19	9.5
12	3.74	5.42	4.96	0.47	17	7.05	8.7
Lewjain Flour							
1	4.04	5.41	4.76	0.54	20	10.00	10.6\10.4
2	3.79	5.45	4.93	0.45	19.5	9.93	8.9\9.5
3	4.24	5.40	4.80	0.45	22	9.61	7.9\8.6
4	4.02	5.43	4.80	0.48	20	8.21	8.3\9.1
5	4.03	5.45	4.88	0.49	20	8.46	7.1\9.5
6	3.96	5.46	4.92	0.47	21	8.79	8.9
Freedom Flour							
1	3.78	5.40	4.90	0.44	21	6.55	7.9\7.9\8.5
2	3.48	5.37	4.85	0.51	21	8.75	7.1\7.5\7.7
3	3.59	5.37	4.80	0.55	21	6.94	9.0\8.1
4	3.70	5.32	4.85	0.50	20	7.40	8.7\7.7
5	3.62	5.30	4.90	0.51	20	7.06	8.5\8.0
6	3.63	5.33	4.96	0.50	21	7.40	7.2\7.0
Hyak Flour							
1	3.79	5.37	4.82	0.55	19	7.12	9.3\10.2
2	3.76	5.37	4.86	0.50	20	7.45	7.6\9.3
3	4.06	5.40	4.82	0.50	19	6.43	9.0\9.2
4	4.17	5.37	4.75	0.51	20	8.01	6.7\9.5
5	4.20	5.41	4.78	0.50	19	7.90	9.8\8.3
6	4.16	5.47	4.70	0.54	19	8.54	7.7

Table J2 (cont' d)

Caldwell Flour							
1	3.49	5.37	4.84	0.55	17	5.46	12.4\9.6
2	3.51	5.43	4.87	0.54	19	6.30	11.2\9.4
3	3.73	5.44	5.04	0.49	20	6.84	9.5\8.2
4	3.72	5.38	4.75	0.58	18	6.78	9.3\9.6
5	3.66	5.40	5.05	0.46	19	7.00	7.5\8.2
6	3.68	5.45	5.00	0.50	19	6.85	13.1
Cake Flour							
1	3.80	5.35	4.84	0.40	16	6.28	11.3\9.7
2	3.56	5.37	4.84	0.45	17	5.62	9.2\11.0
3	3.75	5.57	4.85	0.40	16	6.21	13.9\10.3
4	3.81	5.38	4.87	0.43	17	6.57	8.0
5	3.71	5.37	4.82	0.45	16	6.56	8.4
6	3.66	5.37	4.82	0.41	17	6.18	8.8
7	3.51	5.38	4.91	0.46	16	6.42	8.4
8	3.71	5.25	4.87	0.40	16	6.32	9.9
9	3.65	5.40	4.92	0.34	16	5.20	11.6
10	3.58	5.28	4.97	0.38	18	6.13	11.1
11	3.57	5.37	4.90	0.41	16	4.85	11.0
12	3.44	5.40	4.80	0.38	14	5.72	8.9
Chelsea Flour							
1	4.38	5.40	4.85	0.46	22	10.20	6.9\8.2
2	4.37	5.39	4.90	0.43	21	9.33	8.2\7.0
3	4.28	5.41	4.73	0.50	22	8.15	9.5\8.4
4	4.08	5.40	4.90	0.48	22	8.05	9.0\7.4
5	4.09	5.37	4.90	0.45	21	8.05	7.0\9.8
6	4.10	5.43	4.76	0.55	20	8.03	9.1\9.8
Frankenmuth Flour							
1	3.49	5.46	4.90	0.42	19	6.10	6.3\5.2\7.3
2	3.28	5.48	4.78	0.41	17	6.98	6.0\5.6
3	3.39	5.43	4.94	0.38	18	6.63	5.3\5.8
4	3.41	5.45	5.05	0.40	18	6.01	6.6\6.6
5	3.39	5.40	5.00	0.40	19	6.09	6.7\5.9
6	3.27	5.43	4.90	0.41	17	6.38	7.1\6.7
Excel Flour							
1	3.51	5.37	4.96	0.48	19	6.18	6.9\8.5
2	3.28	5.32	5.06	0.45	19	4.91	5.9\7.3
3	3.43	5.40	5.07	0.43	19	5.75	5.7\6.1
4	3.54	5.40	5.05	0.45	19	5.98	5.9\6.1
5	3.51	5.38	4.98	0.46	20	5.78	7.2\7.2
6	3.53	5.38	4.94	0.45	19	5.67	7.2\7.2

Table J2 (cont' d)

Tres Flour							
1	3.43	5.37	4.87	0.50	19	4.17	11.3\9.3
2	3.35	5.35	4.96	0.42	18	3.60	8.1\9.4
3	3.26	5.37	4.76	0.54	19	3.82	8.7\8.0
4	3.44	5.37	5.00	0.45	18	4.66	8.7\9.8
5	3.42	5.35	5.00	0.40	18	4.61	7.4\9.2
6	3.47	5.37	4.90	0.52	19	4.11	10.5
Nabisco							
1	3.01	5.04	4.85	0.53	19	4.32	12.5\12.8
2	2.98	5.08	4.86	0.51	18	4.38	16.3\14.6
3	2.96	5.02	4.93	0.53	18	4.36	17.6
4	3.06	5.15	4.85	0.58	19	4.95	14.2
5	3.05	5.17	4.90	0.50	18	5.10	13.6
6	3.05	5.14	4.90	0.53	18	5.33	12.8
7	3.05	5.02	4.81	0.49	19	4.32	16.1
8	3.02	4.99	4.86	0.48	18	4.65	15.6
9	3.01	5.03	4.83	0.50	18	4.44	13.8
Meijer							
1	2.94	5.08	4.91	0.49	18	5.08	12.6\14.6
2	2.82	5.00	4.90	0.45	18	5.07	14.6
3	2.94	5.13	4.94	0.51	18	5.02	12.8
4	3.00	5.28	4.93	0.50	18	5.31	14.2
5	3.04	5.28	4.92	0.51	18	5.25	12.4
6	3.05	5.24	4.95	0.51	18.5	4.84	11.6
7	2.89	5.15	4.96	0.41	18	5.22	11.1
8	2.86	5.07	4.96	0.48	18	5.12	16.4
9	2.91	5.06	4.88	0.46	18	5.08	11.0

[1]Wt: Weight; L: Length; W: Width; T: Thickness; V: Volume; M: Moisture; PBF: Peak breaking forces (N: Newtons).

[2]Blend: 50% soft red winter and 50% hard red winter.

Table J3 Ice Powder Cracker Data Using a One-Stage Fermentation Procedure

Cracker Sample	Wt[1] (g)	L[1] (cm)	W[1] (cm)	T[1] (cm)	V[1] (cc)	M[1] (%)	PBF[1] (N)[1]
Blend[2] Flour							
1	4.28	5.46	4.80	0.48	18	8.2	10.3
2	4.25	5.44	4.85	0.44	17	8.06	14.1
3	4.18	5.45	4.75	0.52	17.5	8.44	14.3
4	4.15	5.55	4.72	0.53	17	8.29	12.3
5	4.22	5.56	4.88	0.43	17.5	8.27	11.7
6	4.38	5.49	4.83	0.48	18	8.31	12.7
7	4.15	5.50	4.77	049	18.5	8.16	11.5
8	4.20	5.49	4.81	0.47	17	8.37	13.2
Dynasty Flour							
1	4.22	5.62	5.00	0.45	18	8.81	8.1
2	4.25	5.59	4.99	0.47	18	8.90	7.9
3	4.18	5.57	5.10	0.45	17.5	8.87	6.8
4	4.15	5.54	4.91	0.40	17.5	8.81	7.7
5	4.29	5.50	4.99	0.44	17	8.85	7.8
6	4.43	5.58	4.98	0.49	18.5	8.76	7.9
7	4.10	5.63	5.00	0.45	17.5	8.82	7.7
8	4.15	5.62	4.91	0.42	17	8.80	7.7
Clark Flour							
1	4.57	5.59	4.85	0.53	18	9.82	11.1
2	4.55	5.49	4.95	0.52	18	9.96	9.2
3	4.43	5.50	4.85	0.49	17	10.29	11.9
4	4.28	5.52	4.91	0.50	19	9.87	7.3
5	4.20	5.56	4.93	0.46	18	10.21	8.6
6	4.33	5.58	5.00	0.54	18	10.15	9.6
7	4.22	5.54	4.92	0.52	18.5	9.85	8.8
8	4.29	5.54	4.92	0.51	17.5	9.94	9.0
Cracker Flour							
1	3.98	5.56	4.92	0.50	17	7.99	13.1
2	3.82	5.53	4.93	0.48	17	8.05	10.1
3	3.96	5.55	4.90	0.50	16.5	8.10	11.7
4	3.77	5.57	4.80	0.44	16.5	7.92	9.9
5	3.66	5.55	5.00	0.45	16.5	7.86	10.3
6	3.74	5.56	4.96	0.47	16	7.96	11.5
7	3.81	5.56	4.94	0.48	16.5	7.92	11.2
8	3.95	5.54	4.88	0.49	16	8.00	11.1
Soft Red Winter Flour							
1	4.15	5.47	4.94	0.42	16	7.88	7.5
2	4.08	5.46	4.89	0.43	16.5	7.98	6.6

Table J3 (cont' d)

3	4.14	5.49	4.99	0.42	15	8.06	6.0
4	4.08	5.48	4.97	0.45	15.5	7.80	8.1
5	3.98	5.53	4.96	0.41	15.5	7.91	6.4
6	4.09	5.49	4.80	0.39	16	7.93	7.9
7	3.98	5.49	4.82	0.42	16	7.86	7.1
8	4.25	5.48	4.99	0.42	16.5	7.90	7.1
Cookie Flour							
1	4.36	5.48	4.95	0.38	17	9.48	8.2
2	4.48	5.55	5.00	0.35	16.5	9.30	8.4
3	4.29	5.56	4.99	0.40	17	9.34	10.1
4	4.24	5.53	5.00	0.43	17	9.30	10.2
5	4.29	5.52	4.95	0.40	16	9.35	8.8
6	4.33	5.56	5.08	0.43	16.5	9.15	9.5
7	4.40	5.54	4.95	0.39	17.5	9.45	10.1
8	4.35	5.52	4.99	0.41	17.5	9.31	8.7
Lewjain Flour							
1	4.52	5.50	4.87	0.44	18	11.33	9.2
2	4.50	5.55	4.85	0.47	18	11.56	10.0
3	4.55	5.53	4.87	0.41	17.5	11.42	9.9
4	4.49	5.52	4.89	0.40	17	11.78	8.8
5	4.59	5.56	4.80	0.48	17	11.40	7.7
6	4.60	5.55	4.90	0.43	18	11.65	7.8
7	4.65	5.54	4.89	0.45	18	11.52	8.9
8	4.51	5.54	4.88	0.44	18	11.21	8.8
Freedom Flour							
1	4.22	5.46	4.90	0.45	18	9.40	8.0
2	4.26	5.45	4.82	0.46	18.5	9.55	7.9
3	4.28	5.43	4.93	0.48	16.5	9.24	7.8
4	4.20	5.45	4.96	0.46	17.5	9.45	8.3
5	4.30	5.47	4.94	0.40	17.5	9.40	8.1
6	4.28	5.44	4.83	0.45	18.5	9.51	8.4
7	4.35	5.45	4.88	0.42	17.5	9.34	8.3
8	4.18	5.46	4.89	0.45	17.5	9.41	8.1
Hyak Flour							
1	4.40	5.55	4.85	0.50	17.5	9.69	9.6
2	4.43	5.46	4.73	0.46	18	10.11	7.2
3	4.53	5.50	4.83	0.53	17	10.13	9.1
4	4.48	5.50	4.84	0.46	17	9.68	8.9
5	4.58	5.55	4.93	0.45	17	10.05	9.7
6	4.52	5.50	4.82	0.46	17	9.65	8.7
7	4.40	5.56	4.83	0.48	17.5	10.05	8.5

Table J3 (cont' d)

8	4.35	5.48	4.82	0.49	17.5	9.71	8.4
Caldwell Flour							
1	4.23	5.53	4.99	0.47	17	9.26	11.6
2	4.25	5.54	4.87	0.48	17	9.45	10.5
3	4.30	5.52	5.03	0.50	17	9.38	9.7
4	4.31	5.49	4.91	0.47	16.5	9.21	9.4
5	4.25	5.57	4.97	0.47	17	9.34	10.2
6	4.32	5.56	4.93	0.49	17	9.28	8.9
7	4.27	5.50	5.01	0.48	17	9.20	9.4
8	4.32	5.53	5.00	0.46	17.5	9.11	9.3
Cake Flour							
1	4.32	5.42	4.90	0.37	15	8.68	10.7
2	4.40	5.49	4.84	0.41	15	8.77	9.7
3	4.21	5.46	4.85	0.35	16	8.52	9.8
4	4.33	5.40	4.87	0.41	16	8.62	11.0
5	4.34	5.41	4.87	0.40	15	8.65	10.6
6	4.15	5.47	4.85	0.35	16	8.74	9.7
7	4.30	5.43	4.87	0.38	15	8.60	9.8
8	4.42	5.44	4.90	0.39	16	8.65	10.1
Chelsea Flour							
1	4.71	5.56	4.74	0.46	18	10.56	10.2
2	5.06	5.50	4.91	0.47	19	10.57	8.7
3	4.56	5.43	4.90	0.45	19	10.72	8.7
4	5.11	5.55	4.84	0.40	18.5	10.75	8.3
5	4.77	5.46	4.75	0.41	19	10.62	9.0
6	4.67	5.55	4.84	0.44	19	10.51	7.9
7	4.86	5.51	4.83	0.44	18	10.68	8.4
8	4.89	5.51	4.88	0.42	18.5	10.61	8.4
Frankenmuth Flour							
1	4.21	5.59	4.87	0.33	16	9.14	7.0
2	3.82	5.57	5.02	0.37	16	8.78	6.5
3	3.83	5.55	4.97	0.33	16.5	8.92	5.9
4	4.26	5.53	5.05	0.32	15.5	8.95	6.6
5	3.97	5.55	5.02	0.33	15	8.87	6.7
6	4.04	5.54	4.95	0.34	17	8.96	7.3
7	3.93	5.56	4.93	0.33	16	9.02	6.3
8	4.03	5.56	5.00	0.35	16	8.89	6.5

Table J3 (cont' d)

8	4.35	5.48	4.82	0.49	17.5	9.71	8.4
Caldwell Flour							
1	4.23	5.53	4.99	0.47	17	9.26	11.6
2	4.25	5.54	4.87	0.48	17	9.45	10.5
3	4.30	5.52	5.03	0.50	17	9.38	9.7
4	4.31	5.49	4.91	0.47	16.5	9.21	9.4
5	4.25	5.57	4.97	0.47	17	9.34	10.2
6	4.32	5.56	4.93	0.49	17	9.28	8.9
7	4.27	5.50	5.01	0.48	17	9.20	9.4
8	4.32	5.53	5.00	0.46	17.5	9.11	9.3
Cake Flour							
1	4.32	5.42	4.90	0.37	15	8.68	10.7
2	4.40	5.49	4.84	0.41	15	8.77	9.7
3	4.21	5.46	4.85	0.35	16	8.52	9.8
4	4.33	5.40	4.87	0.41	16	8.62	11.0
5	4.34	5.41	4.87	0.40	15	8.65	10.6
6	4.15	5.47	4.85	0.35	16	8.74	9.7
7	4.30	5.43	4.87	0.38	15	8.60	9.8
8	4.42	5.44	4.90	0.39	16	8.65	10.1
Chelsea Flour							
1	4.71	5.56	4.74	0.46	18	10.56	10.2
2	5.06	5.50	4.91	0.47	19	10.57	8.7
3	4.56	5.43	4.90	0.45	19	10.72	8.7
4	5.11	5.55	4.84	0.40	18.5	10.75	8.3
5	4.77	5.46	4.75	0.41	19	10.62	9.0
6	4.67	5.55	4.84	0.44	19	10.51	7.9
7	4.86	5.51	4.83	0.44	18	10.68	8.4
8	4.89	5.51	4.88	0.42	18.5	10.61	8.4
Frankenmuth Flour							
1	4.21	5.59	4.87	0.33	16	9.14	7.0
2	3.82	5.57	5.02	0.37	16	8.78	6.5
3	3.83	5.55	4.97	0.33	16.5	8.92	5.9
4	4.26	5.53	5.05	0.32	15.5	8.95	6.6
5	3.97	5.55	5.02	0.33	15	8.87	6.7
6	4.04	5.54	4.95	0.34	17	8.96	7.3
7	3.93	5.56	4.93	0.33	16	9.02	6.3
8	4.03	5.56	5.00	0.35	16	8.89	6.5

Table J3 (cont' d)

Excel Flour							
1	4.29	5.56	5.10	0.44	17	8.30	7.6
2	4.01	5.46	5.02	0.40	17	8.35	9.1
3	4.24	5.44	5.03	0.39	18	8.39	6.9
4	4.36	5.45	5.09	0.45	17	8.40	7.5
5	4.48	5.55	5.06	0.33	17	8.34	6.9
6	3.89	5.48	5.03	0.37	17	8.39	6.6
7	4.06	5.49	5.05	0.40	17.5	8.31	7.4
8	4.14	5.49	5.03	0.39	17	8.33	7.5
Tres Flour							
1	3.99	5.44	4.93	0.40	16	7.86	10.1
2	4.10	5.50	4.82	0.43	16.5	7.77	10.5
3	4.04	5.41	4.90	0.43	17.5	7.78	10.3
4	4.16	5.46	4.98	0.40	17	7.71	7.7
5	4.06	5.47	4.78	0.43	16.5	7.65	8.1
6	4.24	5.46	4.90	0.48	16	7.82	8.8
7	3.92	5.46	4.87	0.44	17	7.72	9.3
8	3.80	5.45	5.04	0.42	16.5	7.74	9.0
Nabisco							
1	3.00	5.07	4.88	0.50	18	4.60	14.6
2	3.09	5.10	4.78	0.54	18.5	4.77	15.3
3	2.98	5.16	4.85	0.46	18.5	4.32	14.0
4	2.89	5.13	4.80	0.46	18	4.31	11.2
5	2.85	5.08	4.90	0.51	18	4.57	14.7
6	2.98	5.10	4.70	0.54	19	4.45	12.5
7	2.85	5.12	4.81	0.48	18.5	4.72	14.6
8	3.08	5.05	4.92	0.47	18	4.82	15.4
Meijer							
1	3.21	5.19	4.98	0.46	18	5.01	14.4
2	3.25	5.18	5.00	0.52	18	5.12	11.9
3	3.15	5.14	4.96	0.50	18	5.13	13.2
4	3.06	5.14	4.97	0.45	17.5	5.05	13.2
5	3.01	5.10	4.91	0.47	18.5	5.06	11.0
6	3.05	5.20	4.90	0.48	18	5.12	14.3
7	3.01	5.15	4.94	0.50	18.5	5.06	12.2
8	3.15	5.22	4.96	0.48	17.5	5.09	13.2

[1]Wt: Weight; L: Length; W: Width; T: Thickness; V: Volume; M: Moisture; PBF: Peak breaking forces (N: Newtons).

[2]Blend: 50% soft red winter and 50% hard red winter.