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FRACTIONATION AND RECONSTITUTION OF SOFT WHEAT FLOURS, AND GLUTEN QUANTITY AND QUALITY EFFECTS ON THE TEXTURAL CHARACTERISTICS OF PASTRY

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FRACTIONATION AND RECONSTITUTION OF SOFT WHEAT FLOURS, AND GLUTEN QUANTITY AND QUALITY EFFECTS ON THE TEXTURAL CHARACTERISTICS OF PASTRY

By

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ABSTRACT

FRACTIONATION AND RECONSTITUTION OF SOFT WHEAT FLOURS, AND GLUTEN QUANTITY AND QUALITY EFFECTS ON THE TEXTURAL CHARACTERISTICS OF PASTRY

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Soft wheat pastry flours were fractionated into gluten and starch + water-solubles. The gluten was subsequently fractionated by pH according to the method of Shogren et al. (1969). Flours were reconstituted to their original protein contents from whole crude gluten, single gluten fractions and all gluten fractions in their original proportions.

Fractionation patterns among flour cultivars differed significantly. The low pH fractions had a glutenin-like character, whereas the high pH fractions were gliadin-like.

Full restoration of original flour properties upon flour reconstitution was not achieved, as evidenced by differences in textural characteristics of pastry. Among the single pH fraction flours, flakiness, crust shrinkage and surface blistering increased as pH increased, whereas crust surface browning decreased.

Significant correlations were found between flour protein content and flakiness, crust shrinkage, surface blistering and crust surface browning. Breaking strength was found to be clearly flour cultivar-dependent.

To my parents and Mike
for their love and support.

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INTRODUCTION

Although soft white and soft red winter wheats constitute less than one-fourth of the total United States wheat production, soft wheats are utilized in a wide range of commercial products. Cakes, cookies, crackers, doughnuts, pie pastry, and pretzels are some of these. In contrast, hard wheats are used in one major industry - bread-making, which is still the largest flour consumer. Thus, early chemical and functional studies were focused on the hard wheats suitable for bread production. Due to changing economy and lifestyle, a significant increase in the use of soft wheat flour has resulted. A higher average standard of living, plus an increased demand for convenience foods, has led to a larger consumption of soft wheat products such as cake mixes, pastry mixes, and ready-to-eat cookies and crackers.

Soft wheats are suited for chemically-, air-, and steam-leavened products where no fermentation is required for ripening and mellowing of the gluten. The gluten of soft wheat is characteristically soft and produces a light and tender product. Although the functionality of soft wheat has been studied using fractionation techniques, in cookies and cakes, no such studies have been reported for pie pastry.

Protein content and gluten quality required for soft wheat flours vary widely with product application. Thus, the functionality of flour components in pastry would be expected to differ from that of other soft wheat products.

The purpose of this study was to fractionate and reconstitute four soft wheat flours of different protein contents to determine effect of both gluten quantity and quality on textural characteristics of pastry. Each flour was separated into a starch and water-solubles fraction, and gluten. The gluten was further fractionated by pH, such that subfractions varying in glutenin/gliadin ratio were produced. Flours were reconstituted from the gluten subfractions, starch and water-solubles fraction; pie pastry baked from these flours was evaluated for textural properties. Tenderness measurements were made using an F.T.C. Kramer shear press. The height of a stack of four pastry wafers was used as an index of flakiness. Shrinkage was determined by measuring areas of pastry wafers before and after baking. A HunterLab Color Difference Meter was used to obtain lightness, redness and yellowness values as a description of surface browning. Subjective observations were made regarding surface blistering of pastry wafers.

REVIEW OF LITERATURE

All cereals, including wheat, are grasses (Gramineae). The genus Triticum has 14 species, of which only three are commercially important. These are Triticum vulgare, common wheat; Triticum compactum, club wheat; and Triticum durum, durum wheat (Shellenberger, 1982). Triticum aestivum also refers to common wheat and the name is now used in preference to Triticum vulgare (Everson, 1985).

Wheat Classification

Wheats are classified as spring or winter. Winter wheats are planted during fall, become dormant during winter, and are harvested in early summer. Spring wheats are planted during spring in locations where severe winter weather would damage winter wheat. Spring and winter wheats are further classed as red, white or amber based on bran color; color is a varietal characteristic (Zeleny, 1978). Another cultivarietal characteristic is kernel hardness. Wheats are classed as hard or soft according to the way the endosperm breaks down during the milling process. These cultivarietal differences are due to the spatial arrangement of endosperm components during dessication; more continuous, densely packed components result in harder wheat (Stenvert and

Kingswood, 1977). Environment also influences hardness. Miller et al. (1984) found that both soft and hard wheats were "softest" when grown in a soft wheat area and "hardest" when grown in a hard wheat area. Average rainfall and time to grind were positively correlated at the 10% level.

Wheat Composition

The intact wheat kernel consists of three parts: the endosperm, germ and bran; their respective percentages are 83%, 2.5%, and 14% (Shellenberger, 1982). The chemical compositions of the three kernel parts differ greatly.

The germ of wheat contains 28.5% protein, 11.7% moisture, 10.4% fat and 44.5% total carbohydrate. Bran has 14.4% protein, 13.2% moisture, 4.7% fat and 60.8% total carbohydrate. There is an average of 9.6% protein, 14.0% moisture, 1.4% fat, and 74.1% total carbohydrate in the endosperm of wheat (Kent-Jones and Amos, 1967).

Carbohydrate

The individual carbohydrate constituents also vary widely among the three kernel components. The bran contains high percentages of cellulose (21.4%) and hemicellulose (26.7%); germ consists of 7.5% cellulose, 6.8% hemicellulose, 14.0% starch and 16.2% sugars. Starch, the major carbohydrate of endosperm, accounts for 71.0% of total kernel weight (Kent-Jones and Amos, 1967). Wheat starch consists of 25% linear amylose and 75% branched amylopectin.

Effect of Milling on Composition

The process of milling plays a significant role in determining the chemical composition of a flour. The extraction rate, or parts of flour per hundred parts of wheat, describes efficiency of separation of the outer coverings from the endosperm. The outer coverings include the bran, aleurone layer of the endosperm and germ. An increased extraction rate results in more aleurone layer remaining with the endosperm being reduced; since the aleurone layer has higher protein content, more protein is contained in the flour product (Kent-Jones and Amos, 1967). Mineral content also increases with flour extraction rate (Miller and Johnson (1954).

Davis and Eustace (1984) studied milling stages of soft, hard and durum wheats using electron microscopy. Fractures in hard wheat delineated endosperm cells, but in soft wheat the endosperm was more randomly disrupted with additional smaller cracks. By the third break roll stage, the soft wheat had negligible amounts of cell wall structure adhering to the aleurone layer, in contrast to the hard wheat. This suggested that soft wheat was more readily removed from its bran, and disintegration was more rapidly accomplished.

Both protein and starch are subject to heat damage from the friction of break and reduction roll systems. Soft wheat flours, offering less resistance to the break rolls are less susceptible to such damage. Miller et al. (1964) showed that

starch damage is largely responsible for differences in water absorption, handling properties of dough, and sugar production due to increased susceptibility to enzymatic action.

Flour Streams Effect on Composition

Streams from the different reduction stages can be combined to produce different grades of flour. In the U.S. a "straight grade" flour contains all streams and consists of 72% of the whole wheat. By selecting streams "patent" flours result. "Shorter" patents contain a lower proportion of streams and represent a lower extraction (Campbell, 1972).

The application of a flour is based upon the extraction and proximate composition. An average straight grade, hard wheat flour suited for bread production contains 11.8% protein, 1.2% fat, 74.5% total carbohydrate and 0.46% ash. In contrast, a cake flour from soft wheat contains 7.5% protein, 0.8% fat, 79.4% total carbohydrate and 0.37% ash (Adams, 1975).

Total Protein Content

The quantity of protein in a specific flour is largely determined by environmental factors. Swanson (1924) stated that climatic conditions, including amount and distribution of rainfall, temperature, wind velocity, and evaporation, had the greatest influence on quantity and quality of protein in wheat. That varieties adapted to the climatic conditions of

the wheat growing region would have the highest protein content and best quality, was also emphasized.

The amount of available nitrogen is a major determinant of protein production in maturing wheat; environmental conditions influence nitrogen availability. Strbac et al. (1974) studied the effects of applying nitrogen-containing chemicals to samples of Arthur winter and Inia spring wheat. Application of 225 kg nitrogen per hectare to Inia significantly increased the nitrogen content of wheat meal, and also the absolute amounts of the major protein fractions. A foliar application of 70 g per hectare of terbacil increased the total nitrogen content of Arthur winter wheat 14%, and increased the gliadins 24% as compared with the control. Wu and McDonald (1976) found that high nitrogen fertilization at seeding time significantly increased content of protein, gluten, soluble protein, nonprotein nitrogen, and nitrate, but proportions of nonprotein and protein nitrogens were not affected.

Just as environment affects protein content and yield, protein quantity and nutritional quality vary with yield. Protein content is inversely proportional to crop yield (Hänsel and Seibert, 1978; Mesdag, 1979); yet since hexaploid wheats do not have three times as much protein, on a percentage basis, as diploid species, Kasarda et al. (1976) quoted that Wong suggested that there may also be genetic controls limiting the total amount of protein synthesized.

Mitra et al. (1979) stated that enhancing grain yield or grain protein requires extra energy expenditure, with an improvement in one leaving less energy for the other. They also found a negative correlation between achieving a more balanced amino acid composition and energy expenditure required for synthesis of the more nutritious proteins. McDermott and Pace (1960) found an inverse relationship between protein and amount of lysine in the protein. The soft wheats, with lower protein, have a higher content of lysine, arginine, and other essential amino acids (Hepburn and Bradley, 1965; Lawrence et al., 1958; Waggle et al., 1967).

Protein Classification

Wheat proteins are commonly classified as to their solubility. Osborne (1907) designated four solubility classes: the water-soluble albumins, salt-soluble globulins, aqueous alcohol-soluble gliadins, and the glutenins, soluble in dilute acid or alkali.

Soluble Proteins

The albumins constitute 6-12% of the total flour protein, have a high tryptophan content, and are associated with pentosans. Globulins account for 5-12% of the total flour protein, are high in arginine, but are low in tryptophan. These two are often referred to as "soluble proteins". The

majority of the soluble proteins are located in the cytoplasm (Graham, 1963; Graham et al., 1963). The enzymes of wheat are generally albumins or globulins and are, thus, in this soluble fraction.

Pratt (1978) quoted unpublished data of Greenberg that showed the ratio of soluble protein to total protein in soft wheat flours to be substantially higher than that of hard wheat flours. Cluskey et al. (1961) found that the amount of water-soluble protein recovered from soft wheat was approximately the same as that of hard wheat. Baking quality of flours was negatively correlated with percentage of water-soluble protein, in a study by Maes (1966). More salt-soluble proteins were found in better-quality flours by Koenig et al. (1964).

Gluten Proteins

The gluten proteins are also referred to as the storage proteins of wheat since they serve a storage function; they are rapidly hydrolyzed to amino acids and peptides during germination and supply the developing embryo with nitrogen for protein synthesis. The storage proteins account for about 70% of the total wheat flour protein (Kasarda et al., 1976).

Gliadins. Kasarda et al. (1976) described the gliadins as the least charged proteins known; they may also represent the most heterogeneous groups of closely related proteins known. Low electrophoretic mobilities at any pH, due to

their low charge, impede the resolution of gliadin components. Nevertheless, Wrigley (1970) separated the gliadins into over 40 distinguishable components using two-dimensional electrophoresis. Wrigley and Shepherd (1973) similarly found 46 different components. Reversed-phase high-performance liquid chromatography (RP-HPLC) differentiated 30-40 gliadin components (Bietz et al., 1984).

When determined by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE), after reduction of disulfide bonds, molecular weights (M.W.'s) of most gliadin components approached 36,000 (Bietz and Wall, 1972; Ewart, 1973; Hamauzu et al., 1972). Graveland et al. (1982) reported an average M.W. of 35,000 for the gliadins. Moderate amounts of components with M.W.'s of 11,400, 44,200, 69,300, and 78,100 were found by Bietz and Wall (1972); trace amounts of components with M.W.'s of 25,600, 48,800 and 57,300 were also identified by these authors.

From gel filtration of gliadins, M.W.'s ranging from 25,000-50,000 were found (Beckwith et al., 1966; Bernardin et al., 1967; Meredith and Wren, 1966). Two higher M.W. fractions were isolated by Beckwith et al. (1966) from a 70% ethanol gluten extraction. A M.W. of 100,000 was determined for the major of the two fractions; it constituted 6% of the total gliadin, and resembled a low M.W. glutenin.

Békés et al. (1983) found that reversible aggregation of some subunits to form aggregates of higher M.W. was mediated

by the lipids extracted with the gliadin proteins by 70% aqueous ethanol solution. Tighter folding of the polypeptides, and a greater level of hydrophobic bonding were observed by nuclear magnetic resonance spectroscopy in the gliadin-enriched fraction, as compared with the glutenin-enriched fraction (Schofield and Baianu, 1982).

A-gliadin, or aggregable α-gliadin has been extensively characterized (Bernardin et al., 1967). At increasing salt concentrations, and pH's close to neutrality, A-gliadin aggregated to microfibrillar forms having diameters of 70-80 Å. Particle weights in the millions were found for A-gliadin in the aggregated form. In 0.001 M HCl, a reversible dissociation into monomeric subunits occurred. Kasarda et al. (1968) determined from optical activity measurements that the polypeptide chain of monomeric subunits was comprised of about one-third α-helical conformation, 10% β-structure, and the remainder, flexible random structure. Greene and Kasarda (1971) studied the binding of 2-p-toluidinylnaphthalene-6-sulfonate (TNS). Binding at pH 3 was more than double of that at pH 5, suggesting that aggregation at pH 5 possibly caused steric hindrance of binding sites. The partial unfolding of A-gliadin at pH 3 (Kasarda et al., 1968) may have exposed hydrophobic regions to TNS. Ion-exchange chromatography was used by Platt and Kasarda (1971) to separate A_2-gliadin from A_1-gliadin, and the latter into three fractions. Cole et al. (1983) observed enhanced

aggregation of A-gliadin with increased ionic strength, and dissociation of A-gliadin with increasing temperature. These results implicated hydrogen bonding as the major stabilizing force among aggregates, with possible lesser contributions from salt linkages and hydrophobic interactions.

Glutenin. Glutenin represents about 50% of the total protein of wheat flour and is the least soluble half. The terminology used to describe glutenin was clarified by Kasarda et al. (1976). Glutenin fraction refers to any preparation including less than a third of the total protein. A preparation including a third to a half of the total protein is referred to as the glutenin complex. A clearly defined, single polypeptide chain derived from the glutenin complex or glutenin fractions, is termed a glutenin subunit.

Use of different glutenin preparation methods result in large quantitative differences. In the classical glutenin separation of Osborne (1907, 1924), dilute salt solutions are used to extract albumins and globulins, 70% aqueous ethanol removes gliadins, and the residue is extracted with acid or alkali to solubilize glutenin. Only a small amount of glutenin is isolated with this method. Jones et al. (1959) directly extracted a gluten ball with 70% aqueous ethanol, leaving glutenin as a residue. A second method by these workers involved the dispersing of gluten ball in 0.01 M acetic acid, making the dispersion 70% in ethanol, then adding NaOH to pH 6.5; this precipitated half the gluten as

glutenin. Glutenin obtained by the method of Orth and Bushuk (1973) constituted only 10% of the total protein. This procedure entailed a gluten extraction using A.U.C. solvent (0.1 M acetic acid, 3 M urea, and a cationic detergent, 0.01 M cetyltrimethylammonium bromide), ethanol addition to a 70% concentration, and lastly, addition of 1 M NaOH to pH 6.4, with subsequent glutenin precipitation. An ammonium sulfate precipitation of an A.U.C. extract of flour yielded 27% of the total protein as glutenin (Wasik and Bushuk, 1974).

Glutenin has also been fractionated by gel filtration and SDS-PAGE. Huebner and Wall (1976) used agarose columns to separate A.U.C. extracts of flour into two peaks - glutenin I and glutenin II. Increased dough strength was correlated with larger amounts of glutenin I and insoluble residue by these authors. Gel filtration was also performed on reduced glutenin by Huebner and Wall (1974), yielding three fractions, A, B, and C. When subjected to SDS-PAGE, fraction A displayed streaking characteristic of aggregation from strong secondary bonding. The M.W. of this fraction ranged between 200,000 - 800,000. Fractions B and C had M.W.'s near 100,000 and 40,000, respectively.

Jones et al. (1961) determined M.W.'s for the glutenin complex. They found a broad range of M.W.'s from 40,000 to many millions, indicating heterogeneity. A weight-average-M.W. of 2 million was reported by these workers. A

number-average-M.W. of 121,000 was reported by Wu et al. (1967). Bietz and Wall (1972) identified 15 subunits of glutenin having M.W.'s of: 133,000, 124,000, 102,000, 87,000, 79,100, 71,000, 64,300, 49,400, 44,600, 42,200, 36,000, 32,600, 27,500, 18,000, and 11,600. Different estimates of M.W.'s have been given by other investigators. SDS-PAGE and densitometric tracing revealed that the glutenin subunits with M.W.'s near 44,000 and 36,000 constituted a major portion of the glutenin complex (Huebner and Wall, 1974).

Less α-helical, but more flexible random structure is found in glutenin proteins than gliadin proteins (Wu et al., 1967). Kasarda et al. (1978) suggested that significant differences in the primary structure of glutenin and gliadin may account for differences in secondary structure; gliadin molecules tend to form intramolecular disulfide bonds and tightly folded structures, as opposed to glutenin molecules, which form intermolecular disulfide bonds and loosely folded structures.

Cleavage of disulfide bonds leads to rapid viscosity decreases in glutenin preparations (Nielsen et al., 1962; Pence and Olcott, 1952) corresponding to dissociation of high M.W. glutenin to low M.W. components (Nielsen et al., 1962). This sensitivity to disulfide-bond cleaving agents has led to structural models emphasizing intermolecular disulfide bonds. Ewart (1979) proposed a linear model for glutenin, in which adjacent chains are joined by only one

interchain disulfide bond, and an average of one strained intrachain disulfide bond per chain. Glutenin molecules are prevented from aligning themselves with one another along their entire lengths by gliadin, which acts as a plasticizer. Khan and Bushuk (1979) postulated that the glutenin complex or aggregate (micelle) consists of many noncovalently bound subunits of glutenin. Smaller subunits are non-covalently bound in a network of high M.W. glutenin. This network is held together by either covalent disulfide bonds or extremely strong noncovalent forces.

An alternate model was proposed by Kasarda et al. (1976). They suggested glutenin proteins strongly aggregate through such secondary interactions as hydrogen, ionic, or hydrophobic bonds to form microfibrils. These microfibrils also aggregate into sheet-like structures called macrofibrils, which in turn interact to form a lattice.

Role of Sulfhydryls and Disulfides in Gluten and Dough. Cysteine side chains of gluten and nongluten proteins, and low-M.W. thiols present in doughs contribute free sulfhydryl (SH) groups that provide sites for sulfhydryl-disulfide (SH-SS) interchange (McDermott et al., 1969). Pomeranz (1978) quoted Goldstein (1957) as postulating that thiol-disulfide interchange allows the breakage and reformation of SS bonds that occur during mixing. If during the mechanical breakdown of SS bonds, SH groups are lacking, free radicals form (Axford and Elton, 1960; Redman et al., 1966). New SH groups are

formed as free radicals remove protons from the surrounding dough (Ewart, 1968). The number of intermolecular SS bonds and their rate of interchange influence the rheological properties of dough (Frater et al., 1960). These authors speculated that oxidizing improvers inhibit SS interchange, thus strengthening the dough; reducing agents lower the number of intermolecular SS bonds, causing breakdown of dough structure.

Hard wheat flours were found by Tsen and Anderson (1963) to contain the most SS bonds. Soft wheat flours contained the fewest SS bonds and SH groups, but these same flours had the most SS bonds per unit protein, and hard wheat flours the fewest. Mecham (1968) stated that there is an inverse relationship between flour protein content and SS content per unit protein.

Role of Other Bonds in Gluten and Dough. The prevalence of amide side chains in the gluten proteins provides ample opportunity for hydrogen bonding (Beckwith et al., 1963; Holme and Briggs, 1959; Ronalds and Winzor, 1969). That the hydrogen-bond breaking agents have a pronounced effect on dough rheology emphasizes the significance of these bonds (Bushuk et al., 1968; Holme and Briggs, 1959).

The many nonpolar side chains present in the gluten proteins similarly allow hydrophobic bonding as both protein-protein and protein-lipid interactions. Wehrli and Pomeranz (1970) identified such bonds using nuclear magnetic resonance spectroscopy.

Addition of salts to doughs results in increased rigidity and resistance to extension (Bennet and Ewart, 1965). This provides evidence of ionic bonds in gluten and dough.

Gluten Washing. Gluten, the cohesive mass obtained by washing starch from dough, essentially consists of storage protein; Kasarda et al. (1978) stated that 85% of endosperm (storage) proteins are gluten proteins. Woychik et al. (1961b) also found albumins in gluten. Membrane proteins have also been observed (Simmonds, 1972). On a dry basis gluten contains 75-85% protein, 5-10% lipids and 10-15% carbohydrates (Kasarda et al., 1971; Shellenberger, 1982). These percentages are dependent upon the thoroughness of washing.

Kasarda et al. (1976) cited that Beccari was first to report the separation of gluten from flour by washing dough with water. Early this century, weights of wet crude and dry gluten were commonly used to estimate protein content; in addition the "feel" of the gluten was used as an index of quality. Dill and Alsberg (1924) attempted to standardize the gluten washing test, and optimize precision. They recommended use of a neutral 0.1% sodium phosphate buffer to prevent gluten dispersion, as is common with the less cohesive soft wheat flours. Fisher and Halton (1936) noted personal error in hand-washing of gluten and recommended a mechanical apparatus. Complete starch removal is not possible, and when the gluten content exceeds the protein

content, this is evident. Greenaway and Watson (1975) suggested a standard automatic gluten method to increase precision, yet still had 3% starch remaining in their gluten samples. In the formation of a gluten ball, about 14% of the total flour protein, corresponding to albumins, globulins and small amounts of gliadins, was lost (Jones et al., 1959).

Gluten Functionality

The strength of gluten is key to determining the potential quality of a particular flour for a given end-use. The strength and viscoelastic properties of gluten, which can be physically and chemically modified, are primarily a function of secondary structure.

Gluten Viscoelasticity and Thermal Stability

Wet crude gluten is heat-sensitive. Alsberg and Griffing (1927) noted decreased swelling of gluten in acid as temperature increased from 50-80^{o}C and suggested denaturation was occurring (no definite coagulation temperature was given). From 30-50^{o}C they observed increased swelling power.

At low moisture contents, rates of denaturation of gluten at 80^{o} and 90^{o}C were negligible, but rose rapidly to maxima at 35-40% moisture (Pence et al., 1953). Rates declined slightly toward intermediate values at higher moistures. Complex relationships were found among pH,

temperature, and rate of denaturation. Damage occurred to baking properties at low pH values which was not caused by heat. No consistent trend was evident between denaturation rate and flour quality.

Moderate heat treatment of gluten, such as 70°C for 1-4 hr., or 80°C for 1 hr, did not significantly affect farinograph curves (Doguchi and Hlynka, 1967). Upon exposure to higher temperatures, or longer mixing times than 80°C for 2.5 hr, gluten lost its cohesiveness and stickiness.

Jeanjean et al. (1980) observed modifications in protein solubility and viscoelastic properties of gluten exposed to the heat of boiling water for 2 min. Decreased compressibility and increased gluten relative elastic recovery resulted. Heating also insolubilized ethanol-soluble proteins possibly through formation of new disulfide bonds. Better quality common wheats had higher tendency of aggregation of ethanol-soluble proteins. Salt-soluble protein decreased similarly among all cultivars.

In a study by Eliasson and Hegg (1980), differential scanning calorimetry was used to locate thermal transitions of gluten between 30-115°C. They observed peaks at 64.6 and 118°C, corresponding to transitions in starch; there was a 7% starch contamination in the gluten. Peaks at 88.4 and 101.4°C corresponded to transitions in gluten. The small enthalpies of the thermal transitions in gluten did not support the concept of protein denaturation as being important

in the baking process.

In early rheological tests on gluten, torsion viscosimeters were used. Gortner (1924) stated that viscosity was a useful measure of gluten quality, and was determined by the quantity and quality of glutenin present in gluten. Smith (1925) found all flours of high viscosity to have excellent baking quality; low viscosity flours ranged from poor to excellent baking quality. Thus, it was concluded that viscosity was not a measure of baking quality.

Force required to entend gluten to the breaking point was used in a study by James and Huber (1927). Hard red spring wheats had the highest breaking point. Fine grinding in a cool grinder had no effect on quality, but chlorine treatments considerably increased breaking force. Baker et al. (1943) used puncture-force to test gluten balls, and found a direct relationship with baking results.

Gluten Rheology and Secondary Bond Structure

Doguchi and Hlynka (1967) studied rheological properties of gluten exposed to various solvents, in the farinograph. Salt, urea, acetamide, and guanidine hydrochloride increased mobility (lowered consistency); weak glutens have a lower consistency at a given water content. Urea also made gluten more sticky, and increased the time needed to reach maximum consistency. The organic solvents acetone, butanone-2, dimethylformamide, dioxane and 4-methylpentanone-2 had an

effect similar to urea. These workers explained that the similarity between urea, a hydrogen bond breaking agent, and acetone, a hydrophobic-bond breaking agent, could be due to their dissociating effects on secondary bond structure of gluten. The possibility of protein-lipid interaction was not dismissed.

Glutens from strong wheat, stretched under constant load, were more resistant to stretch and mixing than glutens from weaker wheats (Butaki and Dronzek, 1979). Tatham et al. (1985) proposed a model for gluten elasticity, in which the high molecular weight (HMW) subunits are major elastic components. They suggested the importance of β-turn conformation in secondary structure, from observations made with circular dichroism spectroscopy. Bietz and Wall (1980) described a model of gluten formation involving six major types of polypeptides, that can interact by disulfide interchange, hydrophobic and hydrogen bonding. These workers also noted changes in the relative proportions of each type of protein would change dough properties.

Electrophoresis of Wheat Proteins

Kasarda et al. (1978) stated that "in general, no report of experimental work on wheat protein fractions or components is adequate without gel-electrophoresis patterns of the proteins or reference to such patterns for material prepared in an identical way." Jones et al. (1959) established

several suitable buffer systems for performing free boundary electrophoresis on wheat gluten proteins. An aluminum lactate-lactic acid buffer at pH 3.1 with an ionic strength of 0.03-0.12 was recommended by these workers. Zonal electrophoresis was performed on starch gels with pH 3.1 aluminum lactate-lactic acid buffer with and without 3 M urea (Woychik et al., 1961a). The presence of urea permitted greater resolution of gluten bonds. A substantial amount of protein remained at the origin, which was further characterized as glutenin. Lawrence et al. (1970) postulated that the accumulation of too much protein at the origin could hinder the entrance of other protein into the gel. These workers also recommended the inclusion of urea in the buffer to prevent formation of protein aggregates.

Variable protein content within a variety had no effect on electrophoretic patterns (Tanaka and Bushuk, 1972). The alcohol-soluble gliadin proteins exhibited obvious varietal differences in patterns. These workers could not relate the genotypic electrophoretic patterns to breadmaking quality. However, Wrigley (1980) stated that the high mobility gliadins were richer in sulfur than those of low mobility. Severe changes in dough properties resulted when high-sulfur gliadin proportions were reduced by sulfur deficiency during grain growth. Differences in dough properties between cultivars were suggested as being partially attributable to genotypic differences in proportions of high- and low-sulfur

proteins. Germination up to 44 hr., equivalent to severe sprout damage, did not affect cultivar identification by gliadin electrophoresis (Lookhart et al., 1984). Gliadin electrophoregrams were also not affected by adverse weather that produced differences in kernel shapes. Thus, gliadin electrophoregrams do not depict wheat quality, rather only genotype.

Wrigley et al. (1982) credited development of procedures for wheat varietal identification using starch gel electrophoresis to Autran (1973), Autran and Bourdet (1973, 1975) and Wrigley and Shepherd (1974). Bushuk and Zillman (1978) developed a procedure using polyacrylamide gels as a support medium rather than starch. These authors stated that polyacrylamide gels, having equal resolving power, were more uniformly reproducible and easier to prepare than starch gels. Wrigley et al. (1982) gave detailed procedures for several electrophoretic techniques used in wheat varietal identification. Further attempts to standardize polyacrylamide gel electrophoresis (PAGE) procedures have been made in various laboratories. Lookhart et al. (1982) developed a procedure for use with a commercially-available vertical slab apparatus; these authors recommended purifying aluminum lactate prior to use. A sodium lactate buffer was recommended by Khan et al. (1983) in preference to aluminum lactate, since some gliadin components were better resolved. Other modifications made by these workers were: use of a shallower

slot former, application of a smaller sample volume, recrystallization of acrylamide and bis-acrylamide, vacuum removal of dissolved oxygen from the gel solution, and a doubling of the methyl green marker dye. Lookhart et al. (1985) also compared sodium lactate and aluminum lactate buffer systems, and found that each resolved certain proteins better. Thus, the sodium and aluminum lactate complexes differed in their interaction with the proteins. A temperature of 7 or 10°C during electrophoresis, rather than 21°C, resulted in less curved, better resolved; and more sharply defined gliadin bonds.

By varying relative amounts of gel catalysts, Khan et al. (1985) produced gels with different firmness, stickiness, pore size, and polymerization times. Gel firmness was most affected by ferrous sulfate, followed by ascorbic acid and hydrogen peroxide. Scanning electron microscopy revealed that pores were more uniform, with thicker walls, in firm gels than soft gels; the latter contained large pores. The firm gels were less sticky, less likely to break, and gave better resolution than soft gels. Increasing the amount of ferrous sulfate or hydrogen peroxide, dramatically reduced polymerization time, ferrous sulfate having a greater effect. Polymerization time was not affected by ascorbic acid.

Computer programs are currently being used in the identification of wheat cultivars by their electrophoregrams.

In all programs, the protein band arrays of all known cultivars stored are compared with the unknown cultivar. Bushuk and Zillman (1978) assigned the center of a heavy single band in the electrophoregram of the cultivar Marquis a relative distance of 50 units; band mobilities were measured against this arbitrary value. Band densities were also considered by Zillman and Bushuk (1979), who subjectively assigned numerical values from 1 (very light) to 5 (very dark). A program by Lookhart et al. (1983) compared bands progressively from low to high mobility, as to correlation of protein band density and mobility; relative percent similarities between the unknown and standard cultivars are assigned and listed. These authors suggested that the unknown and most similar cultivars be electrophoresed on the same gel for absolute confirmation. Sapirstein and Bushuk (1985) designed a program comparing three reference bands of the cultivars Marquis and Neepawa, designated at R24 and R79 in relation to the established R50 reference band. The two additional reference bands should increase precision and interlaboratory agreement, and should also allow better estimates of gliadin heterogeneity.

Fractionation and Reconstitution Studies

Recombined wheat starch and gluten formed doughs that were similar in baking characteristics to the original flour doughs (Sandstedt et al., 1939). Finney (1943)

further fractionated flour into starch, gluten and water-solubles, and extracted fat from some of the glutens. From flour fractions recombined in their original proportions, it was possible to obtain bread equal to that made with the original, unfractionated flour. The water-soluble fraction was found to be essential for two of the three flours tested. With water-solubles present, differences in the gluten fractions were entirely responsible for differences in bread quality. Interchange of fats extracted from glutens did not affect baking tests. Pence et al. (1951) confirmed the importance of the water-solubles to bread-baking, and further separated the solubles into a dialyzable and a non-dialyzable fraction. The dialyzables (sugars, low-molecular weight nitrogenous compounds and ash salts) increased mixing time and produced a smaller volume response than the nondialyzables (albumins and a small amount of globulins). Hoseney et al. (1969a) also dialyzed the water-solubles and stated that their dialyzable fraction contributed to gas production, and that the fraction containing soluble pentosans and glycoproteins contributed to gas retention and/or gluten extensibility. Substitution of yeast food for the dialyzable fraction resulted in equal gas production, demonstrating that albumin and globulin proteins were not involved in breadbaking performance.

Flour separated into gluten, starch, and a combined tailings starch and water-solubles fraction by Walden and

McConnell (1955) gave optimum loaf volumes 15% lower for the reconstituted flours as compared with the original flours. Incorporation of sodium chloride in the mixing water of separation reduced the damage to loaf volume to within experimental error.

Sollars (1956) compared an acid extraction procedure for fractionation with a conventional dough kneading procedure. He found the acid extraction process more time-consuming and recommended it for use only with low protein flours or those with damaged or altered gluten.

In fractionating soft wheat flours into starch, gluten, and water-solubles for cookie baking tests, Yamazaki (1950) found it necessary to mix a dough from the fractions to optimum gluten development, and to then freeze dry and grind it to form a reconstituted flour. Dry blends of fractions baked into poor cookies. Yamazaki and Donelson (1976) found that removal of free lipids by extraction, prior to fractionation into gluten, tailings, starch, and water-solubles, permitted dry blending of fractions without a doughing stage, and obtained resultant good cookies from these blends. Flours were rehydrated to 12-13% moisture prior to baking.

Zaehringer et al. (1956) separated soft wheat into four fractions: starch, gluten, "amylodextrin", and water-solubles. No doughing stage was necessary in reconstituting flours for production of satisfactory baking powder biscuits. Fractions

were rehydrated by leaving them near an open beaker of water.

Cake flours were fractionated into water-solubles, gluten, tailings starch, and prime starch by Sollars (1958a). Extremely poor cakes resulted from simple blends of dry fractions. However, satisfactory white layer cakes could be obtained by mixing a well-developed dough and then incorporating it directly into the baking test; this eliminated time necessary for lyophilization, grinding, rehydration, and redetermination of moisture content. For angel-food cakes it was necessary to fully reconstitute by lyophilizing and grinding the developed dough. Donelson and Wilson (1960a) confirmed the necessity of the preliminary doughing step for cake testing, and suggested that intimate recombination of components occurred during the doughing. Lyophilizing reconstituted doughs before baking gave cakes of very low volume.

Hexane extraction of free lipids from chlorinated and untreated cake flours, prior to acetic acid fractionation into gluten, water-solubles, prime starch and tailings starch, permitted dry blending of the fractions without a doughing step (Johnson and Hoseney, 1979). Cakes produced from the chlorinated dry blends were of good overall quality. By the interchanging of prime starches from chlorinated and untreated flours, the reconstituted flour containing the chlorinated prime starch gave a cake equal in volume to the

chlorinated control. Donelson et al. (1984) also hexane-extracted free lipids, prior to an aqueous fractionation into the above fractions and were able to dry blend fractions without a doughing step. Flour fraction interchange illustrated the primary importance of chlorinated lipids, regardless of source, to cake-quality potential.

Standard fractionation and reconstitution procedure resulted in 10-20% higher water-retention capacities (WRC) of reconstituted flours as compared with those of the original flours (Sollars, 1973a). Longer mixing times, or use of a sodium chloride solution during kneading separation, lowered WRC. Flours reconstituted from fractions of an acetic acid procedure and simple blends of fractions both had higher WRC. Sollars (1973b) also determined WRC for gluten, tailings and starch individually. Gluten, starch and tailings from hard wheat flours all had higher WRC than those from soft wheat flours. Gluten and tailings had lower retentions when dilute sodium chloride was used in kneading separation, and higher retentions when an acetic acid method was used. By using one-fraction-at-a-time interchanges, tailings were shown to be responsible for half of WRC differences. Water-solubles, gluten, and starch contributed equally to the remaining half of the WRC difference. Further study by Sollars and Rubenthaler (1975) showed that very satisfactory farinograph curves could be obtained from blended wheat flours. Reconstituted flours using doughing steps resulted in poorer performance on the farinograph.

These workers concluded that reconstitution procedure, rather than fractionation, may have caused unsatisfactory characteristics in baked products. Differences in farinograph absorption between soft wheat and hard wheat flours were not accounted for by any one fraction, although the tailings produced half the differences.

Fractionation and interchange of starch, gluten, tailings and water-solubles has been used to illustrate importance of each in the differential bromate response of hard wheat flours (Marais and D'Appolonia, 1981). Malecki et al. (1980) used flour fractionation to study components responsible for differences in staling rate of bread. Their findings implicated the gluten fraction.

Shogren et al. (1969) were first to further fractionate the gluten obtained by dough kneading procedures and reconstitute flours from individual gluten fractions with a combined starch and water-solubles fraction. The glutens were ground, solubilized in 0.005 N lactic acid and then the proteins precipitated at various pH levels. Between each pH adjustment with 0.1 N sodium carbonate, lactic acid-insoluble material was removed by centrifugation. As pH was increased the glutenins decreased and gliadins increased and, thus, fractions differing greatly in gliadin/glutenin ratio were obtained. By baking breads from the reconstituted flours, it was found that the pH 6.1 insoluble-fraction reconstituted flour, containing little or no glutenins and a high

concentration of gliadins, baked into bread with a loaf volume higher than the original flour.

Two hard wheat flours of different baking quality were fractionated and component fractions were interchanged (Hoseney et al., 1969b). Gluten governed mixing time and loaf volume; bromate requirement was influenced by both gluten and water-solubles. Gluten soluble at pH 4.7 was also ultracentrifuged at 100,000 x g for 5 hr. The centrifugate (100-5C) and supernatant (100-5S) contained approximately 15% and 85% of the protein, respectively. In baking tests, the 100-5S fraction controlled the loaf volume. Starch gel electrophoresis of the two fractions showed large amounts of protein too large to enter the starch gel contained in the 100-5C fraction, and a high concentration of the seven slowest moving bands in the 100-5S fraction. Thus, the proteins migrating into the starch gel (gliadins) were interpreted as being responsible for loaf volume by these authors.

Finney et al. (1982) also used ultracentrifugation as a fractionation method. A force of 435,000 x g separated gluten, previously hand-washed from flour, into four fractions: a pellet (high molecular weight insoluble glutenins), a gel (low molecular weight soluble glutenins), a viscous layer (high molecular weight, soluble gliadins) and a supernatant (low molecular weight, soluble gliadins). Mixing requirement and baking absorption were controlled by

the gel glutenin proteins. Supernatant gliadin proteins determined loaf volume and crumb grain. Since very short (poor) mixing requirement is almost always associated with low (poor) loaf volume potential, these workers suggested good and poor glutenins are associated with good and poor gliadins, respectively.

Hard Wheat Functionality

The functionality of wheat fractions in bread has been extensively reviewed (Pomeranz, 1978). Bushuk (1985) reviewed research on structure and functionality of flour proteins in dough and bread. Conflicting results have been obtained by different researchers. Doekes and Wennekes (1982) observed gliadin-to-glutenin ratio increases with corresponding loaf volume increases; Orth and Bushuk (1972) and Axford et al. (1978) correlated levels of acid-insoluble (glutenin) proteins with loaf volumes. Preston and Tipples (1980) observed that loaf volume increased similarly when acid-soluble gluten proteins were added. These workers suggested that mechanically disaggregated, acid-insoluble flour proteins that are present in the acid-soluble gluten fraction are of major importance in determining bread-making quality, rather than the more insoluble gluten proteins.

Soft Wheat Functionality

Unlike the hard wheats, where strength and high protein are desirable, soft wheat quality is associated with tenderness and delicacy. Soft wheat flours generally require only mild, gentle mixing action to produce desired results.

Flour specification will vary as to end use. Alexander (1939) noted that very short patent, highly bleached, and finely granulated flours are suited for angel food cake, high sugar/liquid formulas, and for cakes where a very white crumb is desired. A longer patent also well bleached is used for loaf cakes, sponge cakes, and general purposes. Third and fourth grades of flour are suited for pastry and cookies, respectively.

Chlorination is essential to baking performance of cakes. Cakes baked from flours with too high a pH will fall or shrink during cooling. Soft wheat biscuit flours should not be subjected to the gluten-dispersing chlorine action, since gluten strength is needed (Alexander, 1939). For cookies and pastries a low pH flour is also undesirable, since crispness and tenderness are the desired qualities. Cookies baked from chlorinated flours will lack spread, top grain, and crispness.

Alexander (1939) also stated that the most important single factor determining soft wheat character is the flour gluten. A small quantity of somewhat short gluten is needed

for cookies. For angel-food cakes, a small amount of firm, elastic gluten is optimal; other cakes need soft, spongy gluten in slightly larger amounts.

Despite the diversity of soft wheat products and, thus, end-uses for soft wheat flours, milling and baking quality evaluation of breeding lines by the USDA concentrates on cookies and cakes (Yamazaki, 1969). The majority of literature on soft wheat also concentrates on these two products.

Cake

In order to evaluate soft wheat varietal performance in cake, Kissell (1959) developed a lean-formula cake method that eliminated usual structure-producing components, such as egg whites and milk solids. This placed maximum stress on the structure-forming ability of the flour (gluten) and increased the sensitivity of the baking test.

Donelson and Wilson (1960b), using fraction interchange techniques, found that gluten had the greatest effect on cake volume and structure. They noted that gluten acts as a binder rather than as a structural element in the cake batter, and that quality gluten is readily solubilized. Gluten development is minimal due to formulation and mixing procedure; that is, neutral to slightly alkaline pH, very high sugar concentration, and short mixing time.

Gluten addition and air classification were used by Gaines and Donelson (1985a) to vary cake flour protein

content from 7-16%. Flour protein content did not significantly affect volume and tenderness of white layer cakes. In angel food cakes, 2% increases in flour protein content were necessary to effect decreases in height and tenderness.

Gaines (1985) observed greater cake volume among the soft wheat cultivars of low protein content that were capable of producing high break flour yield and smaller flour particle size. These flours required more chlorine to reach the desired pH 4.8, possibly because of the increased surface area from the smaller particle size.

Contributions of the flour fractions to the drop in pH during chlorination were studied by Sollars (1958b). Nearly 50% of the total change in pH was caused by gluten. He concluded that protein of bleached flour caused change in pH. Destruction of normal gluten characteristics are believed indicated by reduction in pH.

Cookies

Cookie spread values of air-classified soft wheat flour fractions (expressed as width divided by thickness, W/T) were reported by Pratt (1963). The high-protein fines fractions had a W/T of 5.1; a W/T of 8.5 was found for the low-protein fines. Cookies baked from the parent flour had a W/T of 7.2. Since larger W/T values are desirable, it would appear that high protein flours, by decreasing cookie spread, are unsatisfactory. Brenneis (1965) stated that

puffed, peaked crown cookies resulted from high-protein flours. More sugar and shortening were required for these flours for production of cookies of eating quality similar to those made with flours of 8.5% protein or less.

Abboud et al. (1985) found, among soft wheat varieties, cookie diameter was not related to protein content. Within a protein series of the soft white winter wheat variety Nugaines, protein content was highly negatively correlated with cookie diameter, however. Whole wheat protein was not significantly correlated with whole wheat cookie spread (Gaines and Donelson, 1985b).

Kissell and Yamazaki (1975) increased cookie-crumb protein levels 150% with commercial gluten addition, before significant reduction in baking performance was incurred. Use of natural surfactants permitted maximum crumb protein increases of 375%, with maintenance of acceptable top grain, cookie spread, and internal appearance in the sugar-snap cookies. Hard wheat flours treated with surfactants produced cookies with higher spread ratios than soft wheat flours (Tsen et al., 1975); top-grain scores were also improved. Children's taste preference for these two types of cookies did not differ at the 5% level.

As with pastry doughs, insufficient water is available in cookie doughs for development of a continuous gluten network (Steel, 1977). Olewnik and Kulp (1984) studied cookie dough behavior in the farinograph. Rotary molded

doughs, containing a relatively low shortening level, had a limited amount of gluten development. With an additional 10% water, gluten formation occurred initially, but as mixing time increased, shortening was dispersed which by coating flour particles prevented further hydration and gluten development. Wire-cut doughs, having an intermediate level of shortening, also had increased gluten formation as a result of additional water. Deposit doughs, with a characteristically high fat content, were unaffected by additional water content.

Pastry

Soft wheat flours to be used for pie pastry ideally should contain 8.0-9.8% protein, 0.38-0.44% ash, and have a pH value of 6 (Tsourides, 1968). Since flour pigments contribute to a desirable crust color, flours should be unbleached; gluten would also be adversely affected by bleaching. Dunn (1930) stated that the shortening requirement for pie crusts could be calculated from the protein content; the protein content multiplied by a factor of ten gave the number of pounds of shortening required per barrel of flour for average crust production. Granulation is inversely proportional to the shortening requirement since finer particles have more surface area to be coated.

A pie crust should exhibit a small amount of blistering which is indicative of some strength in the gluten (Kress,

1932). The pie crust from a good quality flour will remain dry, tender and flaky; conversely, gummy and soft pie crusts result from poor quality flours. It was recommended by Kress (1936) that tests for moisture, ash, protein, color, viscosity and absorption, plus pie crust and filled pie baking, are necessary for determining quality of a pie flour. The pie baking test would also indicate shortening requirements of the flour.

Flakiness. Matz (1972) defined flakiness as "the tendency of the crust to separate into strata or layers when it is broken." Flakiness has also been described as open spaces separating thin layers of dough (Bennion, 1980). Greater and lesser concentrations of fat sandwiched between layers of flour result in flakiness in pastry (Lowe, 1943). Dough coats the fat particles during mixing, and these coated particles are flattened into thin layers during rolling. The fat melts and is absorbed into the dough during baking, leaving open spaces between baked dough layers.

Pyler (1973) noted that hardened shortening resists uniform distribution during mixing, and therefore contributes to flakiness in the finished crust. Use of chilled water in the formula has a hardening effect on shortening. Flour not surrounded by fat absorbs water more readily (Lowe, 1943). The absorbed water allows some gluten development. The unabsorbed water is converted to steam during baking. Greater gluten development possibly helps retain steam needed

to force dough layers apart.

Re-rolling of pastry, by attenuating gluten formation, increases pastry flakiness significantly, but toughness may also result (Lowe, 1943). Due to their weaker gluten, soft wheat flours generally produce less flaky, more mealy pastry than do hard wheat flours. Berger (1970) remarked that in order to achieve sufficient cohesion of pastry for handling and shaping, a minimum gluten network is necessary. A pie dough composed only of flour and shortening, by precluding gluten development, results in a dough lacking in tensile strength and a crust too weak to be handled (Miller and Trimbo, 1970). These workers also found increased flakiness in crusts from high protein flour. Varying shortening level between 40 and 80% did not affect flakiness. Flakiness is decreased by too much or too little water in proportion to the amount of fat (Bennion, 1980).

Flakiness defines the class of a pie crust. Knuepfer (1960) described the mixing process used for each type of crust. Mealy crusts are produced when flour particles are completely surrounded by fat as a result of thorough blending. Matz (1972) stated that mealy crusts fracture in a straight line. Semi-flaky crusts are formed by blending only half the flour with the fat to a uniform consistency, adding the remaining flour, and mixing until lumpy. After adding the water, mixing is continued until absorption is complete. Blending flour and shortening into small lumps produces a

flaky crust. A long-flake crust is produced similarly except that fat lumps must remain the size of walnuts. For both the flaky and long-flake crusts, firm shortening must be used, all ingredients chilled, and doughs refrigerated before rolling for maintenance of discrete shortening particles.

Lack of flakiness in crusts can be caused by addition of too much fat, use of a low-protein flour, too complete a dispersion of fat, too little water, or undermixing the final dough (Gates, 1976). Amendola (1972) cited that insufficient shortening, too much liquid, and baking at too low a temperature can result in a solid crust.

Several methods have been used in flakiness measurement. Lowe (1943) measured the height of the pastry before and after flattening the layers. Height in centimeters of ten wafers (Briant and Snow, 1957), and height of stacks of four wafers (Griswold, 1962; Howard and Morse, 1973; Ostrander et al., 1971) have also been used. Matthews and Dawson (1963) scored flakiness subjectively, with pastry having many thin layers receiving optimum scores; lower scores were given to pastry having thick layers, as they were considered not flaky enough. Scores above 5.0 indicated samples with indistinct layers that were judged too flaky. Miller and Trimbo (1970) photographed cross-sections of pastry and judged these subjectively.

Tenderness. Denton et al. (1933) observed increased breaking strength (using a Bailey shortometer) of pastry as

flour protein content increased; a low-fat formula better distinguished differences among flours. Miller and Trimbo (1970) confirmed that protein content was related inversely to tenderness, and observed that increased water in the dough formula attenuated this relationship. These workers also found increased tensile strength, shear values, and stretchability of pie dough with increased flour protein content; dough stickiness decreased.

Increasing water from 25 to 40% resulted in increased breaking strength (Swartz, 1943). Breaking strength also increased with increased mixing time after water addition, when both fat and water were cold. More complete hydration and development of gluten occurred with both increased water, and increased mixing. At room temperature, the fat, being more plastic, effectively coated the flour particles, impeding hydration of gluten.

Fat has a tenderizing effect on pastry. However, use of different fats resulted in highly significant differences in breaking strengths of pastry (Hornstein et al., 1943). The most tender pastries were produced from the softest, most plastic fats. The amount of liquid glycerides, or the ratio of liquid to solid glycerides were suggested as determinants of the shortening power of a fat, by these workers.

Matthews and Dawson (1963) found a 41% level of fat to be critical for assessing shortening values. The tenderizing effect of the fat at lower levels is of lesser importance.

Taste panel scores for optimum tenderness of pastries made with oils and solid fats occurred at shortening levels of 45 and 51%, respectively. Thus, oils were the more efficient form of shortening. Pastries scored high for tenderness were also scored high for flakiness. Increasing the level of substitution of elaidinized lipid decreased pastry tenderness as measured by both taste panel and shortometer (Ostrander et al., 1971).

Method of fat and water incorporation had a significant effect on breaking strength of pastry (Rose et al., 1952). A water-in-fat emulsion method produced more tender pastry than did the conventional method. Fewer gluten strands were observed in the water-in-fat emulsion method pastry.

Gluten formation in pastry dough was observed by microscopic appearance (Hirahara and Simpson, 1961). In all dough types, oval formations of gluten were found surrounding starch granules. Gluten strands, in standard doughs, had cloudy edges with small finger-like structures attached. Excess dough manipulation formed definitive gluten strands, with a loss of the cloudiness present in standard dough. Dough containing excess water formed a large amount of gluten. Mean breaking strengths were significantly higher for doughs with either excess water or excess manipulation.

Freezer storage of baked pastry and unbaked pastry dough did not significantly affect tenderness as detected by a taste panel (Briant and Snow, 1957). Significant differences were

detected in breaking strength using the shortometer, especially in those frozen unbaked. Flakiness was not affected by freezing. Hirahara and Simpson (1961) found increased breaking strength in pastry baked from dough frozen in aluminum foil, but not from that frozen in waxed paper. Dough frozen in waxed paper had "specks" of gluten appearing throughout. More distinct clumps of gluten were evident in the dough frozen in aluminum foil.

Dough Mixing and Handling. Loving and Brenneis (1981) recommended use of slow-speed mixers in commercial operations, to avoid gluten development. Lowe (1943) stated that increased mixing of fat and flour until an optimum level decreased breaking strength, yet toughness increased with increased mixing after water addition. Noble et al. (1934) found that breaking strength decreased when the fat was creamed to maximum volume. They also found that thoroughly mixing after flour and liquid addition, resulted in more tender wafers. Miller and Trimbo (1970) found that more tender, but mealy crusts resulted from increased mixing at 50, 60 and 70% shortening levels. Crusts baked with 40% shortening increased slightly in toughness with increased mixing.

Doughs are usually subjected to a resting period of several hours to overnight. Bennion (1980) asserted that increased elasticity and extensibility of the dough, after a few minutes standing, facilitates dough handling and rolling.

Preonas et al. (1967) recommended a 3 hr resting period, since increased shrinkage was found in crusts from doughs stored overnight. Other authors (Dietrich, 1967; Gates, 1976; Pyler, 1973) suggested that overnight storage of dough decreased crust shrinkage during baking. Additional advantages in favor of overnight storage were: improved handling properties of dough as a result of being fully hydrated and relaxed, and of the hardened fat being less likely to liquify; an even water distribution throughout the dough. Dietrich (1967) noted that more liquid could be used in such doughs, resulting in crusts both more crisp and puffy. Overnight storage allows enzymatic modification of the gluten and reduces soaking tendency of the crust (Pyler, 1973).

The method of rolling pastry also influences tenderness. Use of additional flour to prevent sticking during rolling increased breaking strength in proportion to the amount used (Noble et al., 1934). They suggested rolling between sheets of waxed paper without such dusting flour.

Crust Shrinkage. Shrinkage of pie crusts during baking is undesirable. Preonas et al. (1967) encountered shrinkage in pie crusts with their continuous production method, which they attributed to over-development of gluten occurring during the final mixing. These workers suggested overnight storage of dough contributed to shrinkage. Amendola (1972) also attributed shrinkage to overmixing and overworking of dough. Insufficient shortening, too much liquid, and

improper flour were cited as additional causes. Pyler (1973) advised against stretching of doughs before baking to avoid shrinkage. Shrinkage was found by Miller and Trimbo (1970) to increase substantially with increasing flour protein content; noticeable thickening of the pie crust accompanied shrinkage. Little effect on degree of shrinkage could be imputed to varying the shortening level between 40-80%, or varying the water level between 12-36%. Less shrinkage occurred when pie doughs were over-mixed by electric mixer.

Miller and Trimbo (1970) measured top surface area of doughs before and after baking and reported per cent decrease in surface area. Ostrander et al. (1971) cut aluminum foil squares to the size of wafers before and after baking. Ratios of weights of solvent-cleaned foil replicas of baked wafers to original wafers were reported as shrinkage index.

Browning Reaction in Wheat Products

Hlynka and Anderson (1951) found that the reaction of reducing carbohydrates with wheat proteins was significantly influenced by the protein level of flour. After 6 mos storage, these high protein flours had the greatest increases in reducing value. All doughs mixed with glucose, air-dried, and then re-ground (dough + glucose) gave the highest initial reducing values, and the largest increases in reducing value after 30 wks storage, as compared with mechanical mixtures of flour and glucose, or flour and dough alone. Greater

reactivity towards added glucose was found for glutens from low protein flour. A positive correlation between protein content and browning was found by Smak (1972) to be variety dependent. Free amino acid content was not correlated with crust color of bread.

Rubenthaler et al. (1963) added the amino acids glycine, lysine and glutamic acid to a bread formula alone and in combination with each of 17 sugars and observed effects on crust color. Glycine and lysine produced marked crust browning. Browning increased slightly with glutamic acid addition. Raffinose and pentose sugars produced deepest crust browning. Effect of each sugar on crust color was augmented by adding certain amino acids.

Increased browning occurred in sugar cookies after addition of 5% glucose (Griffith and Johnson, 1957). The reductones formed during browning conferred antioxidant properties, giving the cookies greater stability to oxidative rancidity. High concentrations of honey or reducing sugars in cakes may produce excessive browning of cake crumb (Miller et al., 1957). By maintaining a pH of ∿6.3, the excessive browning could be inhibited. Increasing the pH enhanced browning reactions.

Textural Studies

In the objective evaluation of tenderness in pastry, the Bailey shortometer has been almost exclusively used

(Briant and Snow, 1957; Denton et al., 1933; Hirahara and Simpson, 1961; Hornstein et al., 1943; Matthews and Dawson, 1963; Noble et al., 1934; and Ostrander et al., 1971). Stinson and Huck (1969) compared the shortometer, Kramer shear press, tenderpen and sensory taste panel as methods of pastry tenderness evaluation. The Kramer shear press had the highest correlation with the sensory panel, the tenderpen, the least. Comparison of relative precision of each method showed the organoleptic panel to be the most precise; the Kramer shear press was the most precise objective method. Therefore, these authors recommended the Kramer shear press for tenderness measurement of pastry. Comparable results between the Kramer shear press and taste panel methods of evaluating pastry tenderness were also found by Miller and Trimbo (1970).

The Kramer shear press was used by Funk et al. (1965) to measure compressibility, tensile strength and tenderness of angel cakes; highly significant correlations were found between the shear press and sensory results. Gruber and Zabik (1966) similarly tested butter cakes and also found agreement between sensory and shear press data.

Szczesniak et al. (1970) tested 24 foods varying widely in texture, in the standard shear compression cell, and demonstrated that these products could be grouped into three general categories: those exhibiting a constant force, independent of sample weight, those exhibiting a continuously

decreasing force to weight ratio, and those exhibiting a constant force to weight ratio. Extrusion was found to occur at a significant level in many foods. It was also concluded that foods tested in the shear compression cell are generally subjected to two or more of the following forces: shear, compression and extrusion. Pure shear is uncommon. Friction was considered as another force acting after the blades meshed with the cell bottom.

Voisey (1977a) suggested that adhesion and cohesion also influenced force-deformation curves obtained in the standard shear compression cell. At the cell surface, food may adhere; in the plane of rupture, cohesion may occur between food surfaces. As a result of the compaction necessary for initiation of rupture, changes in sample volume occurred during testing; the properties of the compacted food may be different from those of the original state of the food. Thus, the mode of rupture for each food must be determined experimentally, since it is too complex for prediction.

In order to standardize readings by eliminating friction, Voisey (1977b) reduced blade thickness. He also recommended use of steel blades, rather than the usual aluminum, since they were less variable in thickness. Neither force variation within foods nor the characteristic shape of force-deformation curves was affected by these modifications.

Kramer (1972) stated that in any objective test of texture food sample preparation and loading must be clearly specified. He recommended testing larger sample units in order to improve precision. Peleg (1983) cautioned against reporting instrumental mechanical parameters in terms of sensory properties, without evidence of a correlation. Each individual food must be tested to establish such a correlation.

MATERIALS AND METHODS

This research project was divided into two sections. The first section involved the preparation of soft wheat flours varying in gliadin-to-glutenin ratios through fractionation/reconstitution procedures. The second section was the evaluation of physical characteristics of pie pastry baked from these reconstituted, plus their parent, flours.

Wheat Samples

Wheats grown at Michigan State University from certified seed (1983 crop) were used. Each variety used received 90 lbs/acre of nitrogen topdressing.

Classification

The four soft wheat varieties tested were Augusta, Frankenmuth and Tecumseh, all white wheats, and Hillsdale, a red wheat. The yield (bu/acre) for each variety is provided in the Appendix.

Composition

Wheats were milled at the USDA Soft Wheat Quality Laboratory (Wooster, OH) on a Miag Multomat mill. Extraction rates are given in Table 1. Additional milling, composition

Table 1. Extraction rates of flour samples[1]

Variety	Break Flour (%)	Straight Grade (%)
Augusta	36.4	72.7
Hillsdale	32.3	72.5
Frankenmuth	35.1	72.8
Tecumseh	32.2	75.5

[1]Soft Wheat Quality Laboratory, Wooster, OH.

and baking data are provided in the Appendix.

Flour Fractionation

The overall fractionation scheme is illustrated in Figure 1. Gluten was first separated from the flour, and subsequently fractionated by pH.

Gluten Washing

Gluten was separated from the starch-water solubles (starch + w.s.) by hand-washing using a slight modification of the method of Dill and Alsberg (1924). Approximately 50 g batches of flour were thoroughly mixed with 30 ml aliquots of 0.1% sodium phosphate buffer (pH 6.0) to form dough balls. The dough balls were flattened, covered with additional buffer, and allowed to stand 1 hr. Flour being separated was at room temperature. The buffer was prepared

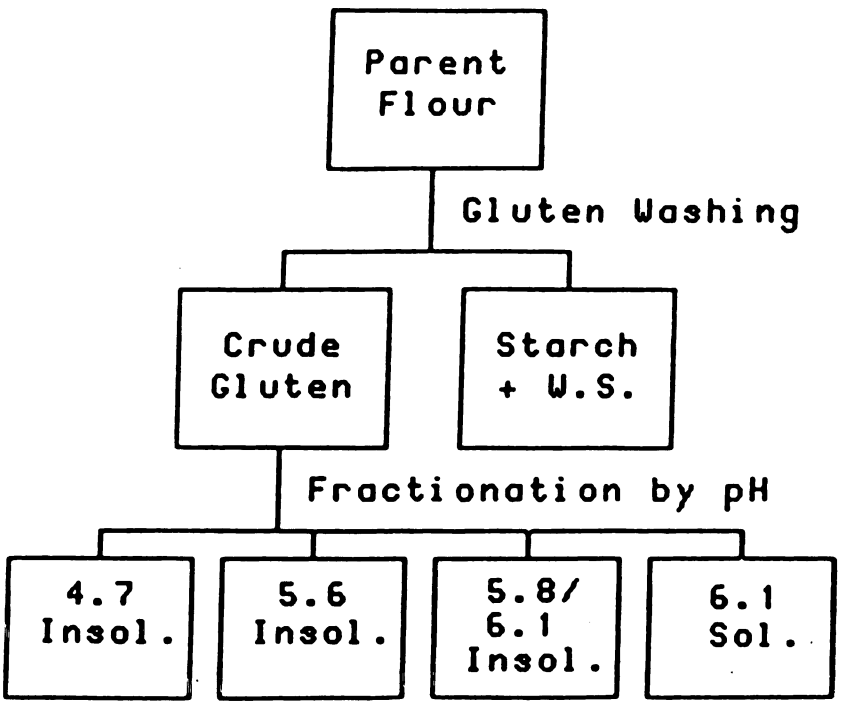


Figure 1. Overall fractionation scheme for parent soft wheat flours.

fresh every 2-3 days, and stored at room temperature. Hand-washing was done under a continuous stream of buffer (ca. 70 ml/min) until the wash water squeezed from the gluten appeared clear. Between 8-10 min. of washing time accomplished this. The starch-water solubles material was passed through a U.S. Standard Sieve No. 80 (W.S. Tyler Co., Mentor, OH) having 177 micron openings (80 mesh), in order to remove particles of gluten. The gluten sediment remaining on the screen was combined, after rinsing with buffer, with the gluten ball obtained. Gluten was allowed to relax overnight under refrigeration, was then frozen and freeze-dried. The starch-water solubles material was frozen in thin layers in aluminum foil pans and also freeze-dried. A Stokes Model 2003F2 freeze dryer (F.J. Stokes Co., Philadelphia, PA) was used for all freeze-drying. Only slight heating was used in order to prevent heat damage. All freeze-dried starch-water solubles material and gluten were stored at -10°C. Approximately 5100 g of each flour were separated.

Grinding of Fractions

Starch + water-solubles material and gluten were ground in a Udy Cyclone Sample Mill Model 3010-030 (Udy Co., Fort Collins, CO) equipped with a 40-mesh screen (470-micron openings). The mill was carefully cleaned between sample grindings by forcing air through the screen, blades and air filter.

Fractionation of Gluten by pH

Glutens were fractionated using a slight modification of the method of Shogren et al. (1969). A flow diagram (Figure 2) shows the fractionation process. Ground gluten was divided into 5 batches for fractionation. Between 95-135 g (depending on flour type) was wetted with distilled water and scissored into 2856 ml of 0.005 N lactic acid placed on a magnetic stirrer. Stirring was continued at a moderately fast speed for 5 hr after all the gluten had been added. The solubilized gluten was then stored under refrigeration overnight and fractionated over a 2-day period.

The solubilized gluten was adjusted to pH 4.7 with 0.1 N Na_2CO_3 and then centrifuged for 20 min at 1,000 x g. The supernatant, pH 4.7-soluble material, was decanted and adjusted to pH 5.6 with 0.1 N Na_2CO_3 and centrifuged for 20 min at 1,000 x g. The precipitate from this, and each subsequent centrifugation, was resuspended in 0.005 N lactic acid, and then neutralized to pH 6.1 with 0.1 N Na_2CO_3. The pH 5.6-soluble supernatant was adjusted to pH 5.8 with 0.1 N Na_2CO_3, and then centrifuged for 20 min at 1,000 x g. The 5.8-soluble supernatant was adjusted to pH 6.1 with 0.1 N Na_2CO_3, but not centrifuged, since preliminary studies produced insignificant amounts of pH 6.1-insoluble material.

All centrifugation was done in an IEC B-20A refrigerated centrifuge (Damon/IEC Division;Needham Hts., MA) having a 6x250 ml capacity. The rpm setting was calculated to

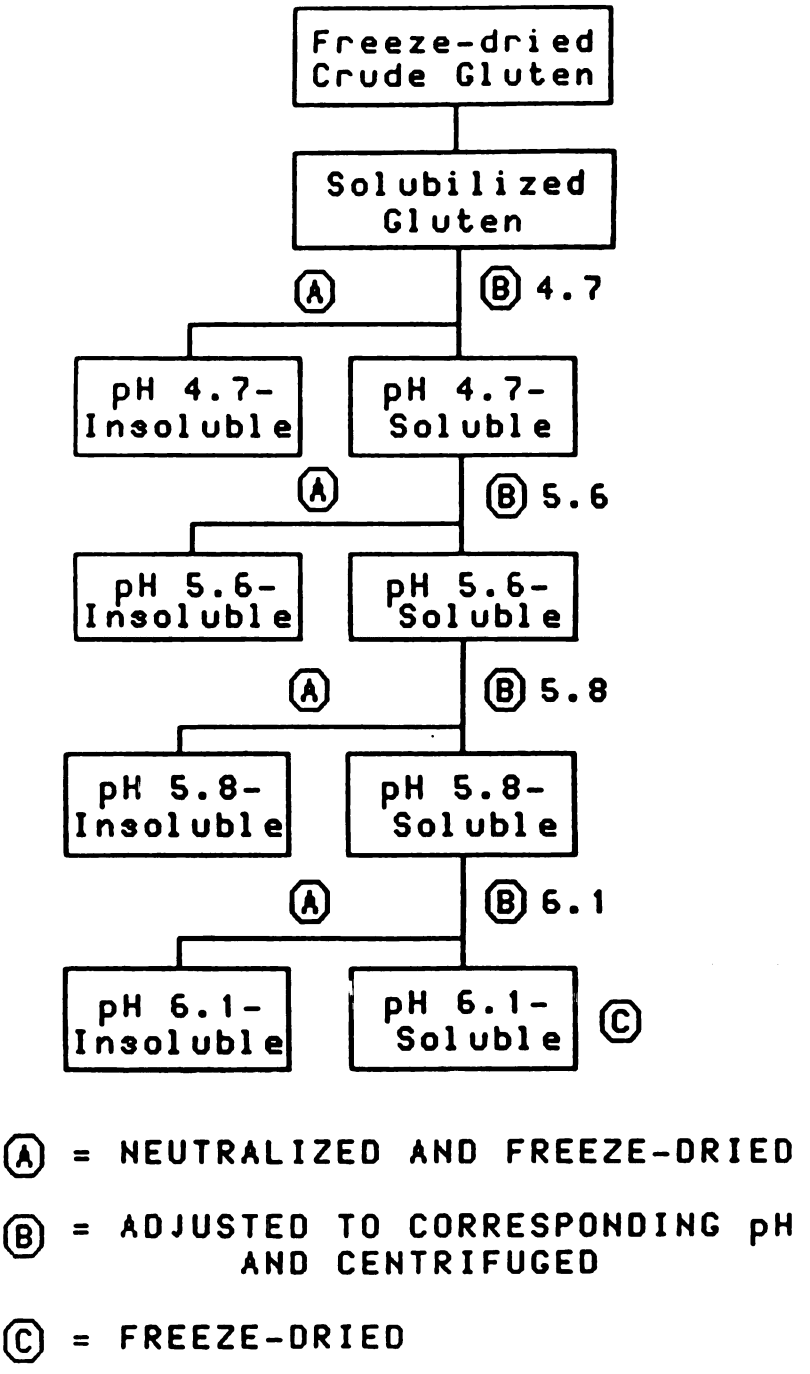


Figure 2. Scheme for fractionation of gluten by pH, following solubilization in 0.005 N lactic acid.

deliver a force of 1,000 x g to the center of the centrifuge bottle. Refrigeration was set at $0^{o}C$.

All pH adjustments were made with a Fischer Accumet Model 810 pH meter (Fischer Scientific Co., Pittsburgh, PA), equipped with a universal glass electrode, a calomel reference electrode and an automatic temperature compensation probe. A two-point standardization was made daily with pH 7.0 and pH 4.0 standard buffer solutions. Solutions and suspensions being adjusted were stirred constantly with a magnetic stirrer.

Neutralized, precipitated fractions were subsequently frozen in thin layers and freeze-dried. Weights of unground fractions were taken in order to calculate recoveries. Percentage of each fraction recovered was calculated as follows:

$$\% \text{ gluten fraction} = \frac{\text{Weight of individual gluten fraction}}{\text{Sum of weights of all gluten fractions}} \times 100$$

These values were corrected to a dry-weight basis following moisture determinations. Gluten fractions were ground in the Udy Cyclone Sample Mill as previously described. Observations regarding appearance of fractions prior to and after freeze-drying were also noted.

Protein Content

Protein contents of fractions and whole flours were determined in duplicate using a slight variation of AACC Method 46-13 (1983), a standard micro-Kjeldahl procedure. Sample size varied with sample type. A 50-mg sample size was used for whole flours and starch-water solubles fractions. For whole gluten and all gluten subfractions, a 20-mg sample size was used, due to their high protein contents. Approximately 50 ml of distillate was collected in 10 ml of boric acid. Methyl red-bromcresol green was used as an indicator in the sample titrations. Percentage nitrogen was calculated as follows:

$$\% \text{ N} = \frac{(\text{ml HCl} - \text{ml blank}) \times \text{normality} \times \text{equiv. wt. N}}{\text{sample wt. (mg)}} \times 100$$

Percentage nitrogen was then multiplied by a 5.7 conversion factor to give total protein. This factor was used for all flour fraction calculations. Protein contents were converted to a dry-weight basis.

Moisture Content

Moisture contents of flours and flour fractions were determined in duplicate using a modification of AACC Method 44-40 (1983). Sample size was determined by sample type,

since some fractions were limited in quantity. One-g samples of whole flours, starch-water solubles fractions, pH 4.7-insoluble and pH 6.1-soluble gluten fractions were used. For whole gluten fractions, 0.5-g samples were used; only 0.2-g of the pH 5.6-insoluble and pH 5.8/6.1-insoluble gluten fractions were available. Samples were dried under a partial vacuum (ca. 25 mm Hg) between 95 and 100°C for 6 hrs., cooled in a desiccator, and then re-weighed. Percentage moisture was calculated as follows:

$$\% \text{ Moisture} = \frac{\text{Wet sample wt.} - \text{Dry sample wt.}}{\text{Wet sample wt.}} \times 100$$

Flour Reconstitutions

According to the method of Shogren et al. (1969), gluten fractions were reconstituted singly with the starch-water solubles fraction, and additionally flours were reconstituted having all fractions in their original proportions. All flours were reconstituted to their original protein contents. No interchanges between fractions of varietal flours were made.

Calculations

The following equations, used to calculate reconstitution of flours, were developed by the author. Percentage of starch-water solubles and percentage of gluten were

back-calculated from their protein contents and that of the parent flour as follows:

1) $a(x + y) = bx + cy$

where a = percentage protein in flour

b = percentage protein in gluten

c = percentage protein in starch + water-solubles

x = amount of gluten

y = amount of starch + water-solubles

x+y = amount of flour

2) $\%\ \text{gluten} = \frac{x}{x+y} \cdot 100$

3) $\%\ \text{starch + water-solubles} = \frac{y}{x+y} \cdot 100$

A flour was reconstituted from whole crude gluten and starch + water-solubles using these proportions.

Amount of protein (g) supplied by each gluten fraction was calculated on a moisture-free basis as follows:

4) amt. (g) protein in fraction =

$$\frac{\text{Amt. (g) fraction}}{\text{100 g crude gluten}} \times \frac{\text{Amt. (g) protein}}{\text{1 g fraction}}$$

Recovery of gluten protein after fractionation was calculated as:

5) % Recovery =

$$\frac{\text{Sum of protein from fractions (g)}}{\text{Amt. (g) protein per 100 g crude gluten}} \times 100$$

Thus, loss of protein, or error from gluten fractionation can be expressed as:

6) % loss of protein = 100 - % Recovery

The total amount of gluten required for reconstituting the all-fractions-in-their-original proportions flours was increased by the percent loss of protein for three of the four flours. Augusta, Frankenmuth, and Tecumseh flours were, thus adjusted 4.99, 4.38, and 5.61%, respectively. For Hillsdale, an adjustment of 3.76% was necessary to obtain the correct flour protein content, rather than the 3.66% calculated protein loss. Calculations for the amount of each fraction required were made as follows:

7) Amt. (g) of fraction =

$$\frac{\text{Amt. (g) gluten fraction}}{\text{100 g crude gluten}} \times \text{total amt. of gluten required}$$

The single gluten fraction flours were calculated algebraically using Eq. 1. Thus, the amount of gluten added to flours varied with fraction type, but protein contents were fixed. Since all calculations were made on a moisture-free basis, amounts of fractions to be weighed were converted back to an "as-is" basis. A 20% random sampling of the reconstituted flours (made following dry blending and humidification) was analyzed for Kjeldahl nitrogen as in the previously described method. The actual protein contents, plus the corresponding calculated protein

contents and error values are reported in the Appendix.

Additional calculations were made in order to determine the percentage of total gluten protein contributed by each gluten fraction, and the percentage of total flour protein contributed by each flour fraction. Percentage of gluten protein supplied by each fraction was calculated as follows:

8) Percentage of gluten protein =

$$\frac{\text{Amt. (g) protein/100 g crude gluten (eq. 4)} \times 100}{\text{Total amt. (g) protein per 100 g crude gluten}}$$

Percentage of total flour protein supplied by each flour fraction was calculated as:

9a) Amt.(g) protein supplied by each gluten fraction per 100 g flour =

$$\frac{\text{g gluten}}{\text{100 g flour}} \times \frac{\text{g gluten fract.}}{\text{1 g crude gluten}} \times \frac{\text{g protein}}{\text{1 g gluten fract.}}$$

b) Amt. (g) protein supplied by starch + water-solubles =

$$\frac{\text{Amt. (g) starch + w.s.}}{\text{100 g flour}} \times \frac{\text{Amt. (g) protein}}{\text{1 g starch + w.s.}}$$

c) Percentage of total flour protein supplied by each fraction =

$$\frac{\text{g protein supplied by flour fraction}}{\text{g protein supplied by all fractions}} \times 100$$

Dry Blending

Appropriate fractions were dry blended by first mixing thoroughly by hand until the material appeared homogeneous.

The mixture was then stirred in an electric blender for 6 min at low speed. The material was scraped from the sides of the container, and again mixed briefly by hand. Finally, the material was mixed on the high speed setting of the electric blender for 1 min.

Humidification of Flours

Moistures of dry blended flours were adjusted into the range for normal flours in a large fermentation cabinet (National Manufacturing, Lincoln, NE). Temperature was maintained at 85^{o}F; a humidity setting of 80 was used. Flour samples were spread evenly in foil pans and stirred every hr. to expose bottom layers of flour to moist air. Flours were left ∿4.5 hrs. Moistures were determined in duplicate on humidified flours using the previously described method. All flours were brought to between 10.1 - 12.8% moisture. Final flour moistures are provided in the Appendix. Humidified flours were stored in glass jars with a layer of parafilm inside and outside the lid to prevent moisture loss.

Final Sample Materials

The final sample materials used in the baking test for pastry consisted of the parent (original) flour plus six reconstituted flours for each varietal flour. The six reconstituted flours included: whole crude gluten, all fractions reconstituted-in-their-original proportions (A.F.R.),

pH 4.7-insoluble, pH 5.6-insoluble, pH 5.8/6.1-insoluble and pH 6.1 soluble. The names given to these flours refer to the type of gluten fraction used in their reconstitution; all reconstituted flours contained the starch + water-solubles fraction. These six, plus the parent flours, are referred to, henceforth, as reconstitution types.

Baking Test for Pastry

Experimental Design

Test bakes for pastry were completely randomized. Samples were assigned random numbers from a table of ten thousand random digits. Mixing and baking orders were the same. Each flour sample type was baked in triplicate.

Ingredients

A commercial shortening - Hyscor all purpose vegetable shortening (P.V.O. Foods, Inc., St. Louis, MO) containing fully refined and partially hydrogenated soybean and cottonseed oils - was used. The shortening contained no emulsifiers. A stock 6.98% salt solution was prepared to deliver the correct amount of water and salt. All ingredients were weighed before beginning the experiment. Humidified flours were weighed into plastic bags; these were then double-bagged to prevent moisture loss. The salt solution was agitated prior to the weighing of each aliquot into culture tubes. The tubes were tightly capped. All

ingredients were stored in a refrigerator (3-4°C).

Formula

A lean, low-fat formula was used to place maximum stress on the flour. The amount of flour used was based on the amount of reconstituted flour available. Actual amounts used for each flour type are given in the Appendix. Formula percentages of each ingredient are given in Table 2.

Table 2. Pie dough formulation

Ingredient	Formula (%)[1]
Flour	100
Shortening	41
Salt solution	(25.8)
Water	24
Salt	1.8

[1]Based on flour weight.

Mixing Procedure

A slight modification of the method of Miller and Trimbo (1970) was used. Chilled shortening (8-12°C) was added in small pieces to chilled flour and blended in a Kitchen Aid Model K5-A mixer (Hobart Mfg. Co., Troy, OH), equipped with a flat beater attachment, for 1 min at speed 6 (ca. 200 rpm). The sides of the bowl were scraped, then

the salt solution (5-12°C) was added. Mixing was continued for 1 min. at speed 6 (ca. 200 rpm). Doughs were placed in plastic zip-lock bags and refrigerated. Ten to eleven samples were mixed on one day, and then rolled and baked the following day. The resting period for the doughs was 21.5-24.5 hrs. (time elapsed between end of mixing and end of rolling).

Baking Procedure

Doughs were removed from the refrigerator for 13-15 min. prior to rolling, to soften dough slightly and facilitate handling. Dough temperatures averaged 12.5°C during rolling. Doughs were flattened slightly and placed between two sheets of parchment paper and rolled with a wooden rolling pin on a wood board. One eighth-inch rolling guides were used. Doughs were cut into square wafers (ca. 5 cm x 5 cm). Using a specially designed tool, each wafer was pricked with 9 equally-spaced holes. Wafers were baked on stainless steel cookie sheets (1/8-inch thick) in a 4-tray rotary oven (Rotary Hearth Test Baking Ovens, National Manufacturing Co., Lincoln, NE) at 450°F (±2°F) for 13 min. After removal from oven, cookie sheets were placed on wire cooling racks.

Physical Testing Procedures

Crust Shrinkage. The areas of 4 wafers were measured before and after baking for each sample (except 20-g test

bakes, where only 2 wafers were available). Crust shrinkage was calculated as:

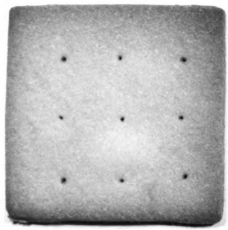
$$\% \text{ shrinkage} = \frac{\text{Area before baking} - \text{Area after baking}}{\text{Area before baking}} \times 100$$

Flakiness. The height of a stack of 4 wafers was used as an index of flakiness. For 20-g test bakes, the values obtained from the height of 2 wafers were doubled, such that comparison could be made with other samples.

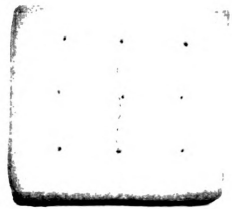
Surface Blistering. Observations of surface blistering, as a measure of gluten strength, were made subjectively. A scale of 1.0 - 5.0 in increments of 0.5 was used. A description of this scale is shown in Figure 3.

Breaking Strength. Breaking strength was measured using an FTC-Kramer Texture-Test system (Model T-2100-C) equipped with a Model FTA-100 force transducer and a Model CA-1 single-blade shear cell (Food Technology Corp., Rockville, MD). Blade thickness was about 1/8-inch. Prior to shearing, wafers were measured for width and thickness of area to be sheared. Samples were tested between 55-70 min. after removal from the oven. Four wafers were broken for each test (except 20 g test bakes, where only one wafer was available). Following each test, debris was removed from the blade and base sample holder with a small brush. Breaking strength was calculated as follows:

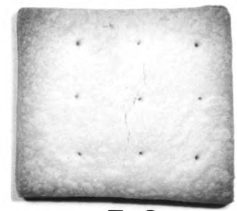
Figure 3. Scores used for evaluating surface blistering. 1.0 = Very slight; 3.0 = moderate; 5.0 = Very high.



1.0



3.0



5.0

$$\frac{\text{lbs force}}{\text{cm}^2 \text{ broken}} = \frac{\text{Transducer x Range x Reading}}{\text{cm}^2 \text{ broken x } 100}$$

Surface browning. Differences in browning reaction were measured using a Hunterlab Model D25-2 Color Difference Meter (Hunter Associates Laboratory, Inc., Reston, VA). The "L", "a", and "b" values obtained represent reflectance ranges from black to white (0 to 100, L value), green to red (-a to +a), and blue to yellow (-b to +b). The instrument was standardized with a yellow tile (Standard No. C2-15327) with assigned values of L = 78.5, a = -3.2, and b = +23.4. Enough sample was placed in the glass holder to cover the aperture of the unit. Three readings were taken for each determination by rotating the glass container one-third.

Statistical Analyses of the Data

Using Mstat (Michigan State University, 1982), a two-factor factorial analysis of variance was performed to determine if any significant differences existed in the main effects of flour variety, and type of reconstituted flour, for the mean values of flakiness, crust shrinkage, surface blistering, breaking strength and surface browning ("L", "a" and "b"). Values for both crust shrinkage and redness ("a") were coded +5.0 in order to eliminate negative values during analysis of variance. Reported means are decoded. Significant interactions between main effects for

these dependent variables were also determined. When significant differences were found among flour variety means, or means for type of reconstituted flour, the Duncan's multiple range test of the ranking subprogram of Mstat was used to compare and rank them. When a significant interaction between main effects was found, a least significant difference (LSD) value was determined, also using Mstat.

Correlations among individual dependent variables, between the dependent variables and flour protein content, and between dependent variables and the percentage of each gluten fraction obtained were also determined with Mstat.

RESULTS AND DISCUSSION

Flour Composition

The moisture and protein contents of the parent flours are shown in Table 3. Moisture contents of the parent flours varied by less than 0.5% (with a relative difference of 4.00%). Protein contents ranged from 8.01 to 10.83%.

The normal ranges of protein and moisture contents for pastry flours is 8.0 - 8.5%, and 13.0 - 13.5%, respectively (Preonas et al., 1967; Pyler, 1973). Matz recommended a lower range for protein contents of 7.0 - 8.5%. An extended range of 8.0 - 9.8% protein and 12.0 - 14.0% moisture was stated by Tsourides (1968) as being ideal for pie baking.

Flour Fractionations

Gluten Washing

The calculated percentages of crude gluten and starch + water-solubles obtained by gluten washing, and their respective protein contents are given in Table 4. Calculated gluten percentages ranged from 12.30 to 15.48; since these values are higher than their corresponding flour protein contents, incomplete starch removal is indicated.

Table 3. Moisture and protein contents of parent soft wheat varietal flours.

Parent flour	Moisture[1] %	Protein[1] (%, dry basis)
Augusta	11.09	8.01
Hillsdale	10.79	8.08
Frankenmuth	10.91	9.01
Tecumseh	11.24	10.83

[1] n = 2

Table 4. Percentages by weight and protein content of crude gluten and starch + water-solubles obtained by gluten washing soft wheat flours.

Varietal flour	Fraction Weight (%)[1]		Protein Content (%)[2]	
	Crude gluten	Starch + water-solubles	Crude gluten	Starch + water-solubles
Augusta	12.30	87.70	55.56	1.33
Hillsdale	12.50	87.50	56.14	1.21
Frankenmuth	13.45	86.55	59.02	1.24
Tecumseh	15.48	84.52	60.97	1.65

[1] Back-calculated using Eq. 1; expressed on a dry basis.

[2] n = 2; expressed on a dry basis.

Dill and Alsberg (1924) reported percentage values of 8.52 and 8.80 for a soft white winter flour; values for soft red winter flours ranged from 8.96 to 11.12%. Higher values were reported for hard wheat flours. Fisher and Halton (1936) recovered 6.85, 12.36, and 12.29% dry gluten for respective weak, medium and strong flours. A yield of 21.5% gluten (14% moisture basis, m.b.) was recovered by Walden and McConnell (1955) from a hard red spring flour. Sollars (1956) obtained yields of 12.6, 9.9, and 8.6% (14% m.b.) from respective hand-kneaded, mechanically-kneaded and acetic acid-extracted doughs. An extremely wide range of 9.0-27.2% dry gluten was obtained by Greenaway and Watson (1975) for hard red spring, hard red winter, and white wheats; with their automatic method, a range of 7.1 to 16.6% dry gluten was obtained for the same flours.

The protein contents of whole crude glutens ranged from 55.56 to 60.97%. Similarly, the lower protein contents of these glutens, as compared with those commercially obtained, and those obtained experimentally by other researchers, confirm the incomplete removal of starch. Protein contents of commercial samples of vital gluten have been reported as 76.3 and 77.8% by Kissell and Yamazaki (1975). Gluten protein contents of 76.0 and 77.7% were reported by Dill and Alsberg (1924) for a soft red winter flour; glutens from the soft white winter flours had protein contents ranging from 74.4 to 78.5%. The weak, medium and strong flours of Fisher

and Halton (1936) had respective gluten protein contents of 83.5, 86.6 and 84.6%. A gluten protein content of 59.8% (14% m.b.) was reported for the hard red spring wheat of Walden and McConnell (1955). The hand-kneaded, mechanically-kneaded, and acetic acid-extracted glutens of Sollars (1956) had respective protein contents of 40.4, 64.3 and 66.4%. Thus, the values of Table 4 are comparable to those reported in the fractionation-reconstitution studies of Walden and McConnell (1955) and Sollars (1956). Values of 80.0, 82.0 and 83.0 were obtained for white, hard red winter and hard red spring flour glutens, respectively, by Greenaway and Watson (1975).

As the protein contents of the parent flours increased, the protein contents of the crude glutens obtained also increased (Table 4). Protein contents of the starch + water-solubles fraction ranged from 1.21 to 1.65%, and thus, varied little.

Fractionation by pH (Isoelectric Precipitation)

The gluten fractions, obtained by solubilizing gluten in dilute lactic acid and adjusting to various pH levels, differed in their recoveries and protein contents. Recoveries and protein contents also differed among the varietal flours. In preliminary studies with both bread and cake flours, insignificant amounts of the pH 6.1-insoluble gluten fraction of Shogren et al. (1969) were recovered.

Thus, the pH 5.8-soluble material was not centrifuged following adjustment to pH 6.1. No pH 6.1-insoluble material precipitated from Augusta gluten. Small amounts of pH 6.1-insoluble gluten settled without centrifugation from Hillsdale and Frankenmuth suspensions. Tecumseh was, however, particularly aberrant. Large amounts of pH 6.1-insoluble material settled.

As compared with the other varieties, Tecumseh has a complex parentage, very similar to that of Arthur soft red winter wheat. One of the crosses for Tecumseh consisted of Purkof, a semihard red winter wheat (Everson et al., 1974). Since the hard winter wheats used by Shogren et al. (1969) similarly contained appreciable amounts of pH 6.1-insoluble material, possibly the inclusion of a semihard variety in the pedigree of Tecumseh influences the type of protein, as characterized by isoelectric precipitation.

The pH 6.1-insoluble material, obtained without centrifugation, was combined with the pH 5.8-insoluble gluten from the corresponding flour. Thus, this fraction is referred to as pH 5.8/6.1-insoluble gluten. Only Augusta is primarily pH 5.8-insoluble material.

Percentage Recoveries of Gluten Fractions. The relative amount of each gluten fraction obtained is shown in Table 5, and in the form of pie graph in Figure 4. The relative amounts of each fraction obtained varied greatly with parent varietal flour. Augusts had a much higher percentage

Table 5. Percentage by weight of each gluten fraction recovered by precipitating at various pH levels.

Gluten fraction	Fraction Weight (%)[1,2]			
	Augusta	Hillsdale	Frank.	Tecumseh
pH 4.7-insoluble	60.99	38.85	45.18	48.13
pH 5.6-insoluble	2.27	5.90	3.73	2.10
pH 5.8/6.1-insoluble	6.10	16.66	14.45	14.25
pH 6.1-soluble	30.68	38.59	36.65	35.52

[1]Expressed on a dry basis.

[2]Pooled from 5 batches of gluten fractions.

of pH 4.7-insoluble material (60.99%) and a far lower percentage of the pH 5.8/6.1-insoluble material (6.10%); as was previously noted, no pH 6.1-insoluble material was present in this varietal flour. Although Hillsdale had a protein content similar to Augusta, its fractionation pattern resembled that of the higher protein flours. As protein content increased from that of Hillsdale to Tecumseh, the percentage of pH 4.7-insoluble material obtained increased from 38.85 to 48.13%. The percentages of other fractions decreased as flour protein content increased; the pH 5.6-insoluble material decreased by more than half, from 5.90 to 2.10%.

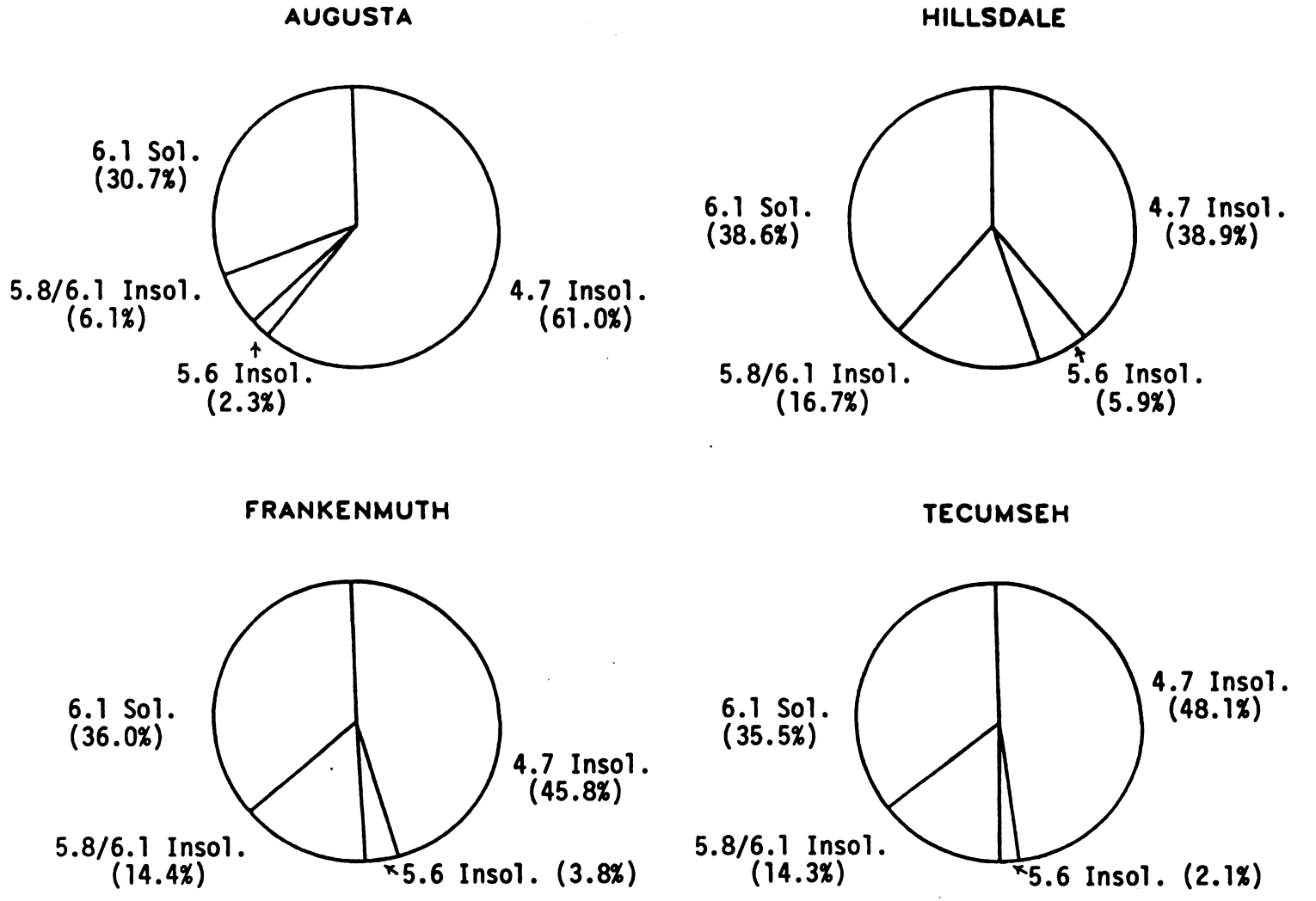


Figure 4. Percentage by weight of each gluten fraction obtained by precipitating at various pH levels.

Protein Content. The protein contents of the various fractions are shown in Table 6, and in the form of a bar graph in Figure 5 (the starch + water-solubles fraction is also shown). As the pH of the gluten fraction increased, protein content similarly increased. Protein contents ranged among varietal flours from 21.00 to 36.39% for pH 4.7-insoluble gluten, from 66.33 to 69.33% for pH 5.6-insoluble gluten, from 74.82 to 78.24% for pH 5.8/6.1-insoluble gluten, and from 77.01 to 79.89% for the 6.1-soluble gluten. No trend was noticed between protein content of the parent flour, and those of the gluten fractions.

Shogren et al. (1969) reported values of 16.3 and 25.2% for the pH 4.7-insoluble fractions of two hard winter wheat flours. Protein contents of 76.5 and 74.8, 78.1 and 76.7, 79.2 and 78.3, 62.1 and 61.7, were reported for the pH 5.6-insoluble, pH 5.8-insoluble, pH 6.1-insoluble, and pH 6.1-soluble fractions, respectively.

Percentage of Total Gluten Protein Supplied by Each Gluten Fraction. The part of total gluten protein contributed by each gluten fraction is given in Table 7, and in the form of pie graphs in Figure 6. Gluten protein recoveries and losses are also provided. The pH 4.7-insoluble gluten ranged from 14.5 to 39.9% among the varieties; ranges were from 2.4 to 7.0%, 8.3 to 22.2%, and 44.0 to 52.9% for the pH 5.6-insoluble, pH 5.8/6.1-insoluble and pH 6.1-soluble glutens, respectively. The data for percentage of gluten

Table 6. Protein contents of gluten fractions obtained from varietal flours by precipitating at various pH levels.[1]

Gluten fraction	Protein Content (%)[2]			
	Augusta	Hillsdale	Frank.	Tecumseh
pH 4.7-insoluble	36.39	21.00	31.07	34.43
pH 5.6-insoluble	66.96	66.34	68.42	69.33
pH 5.8/6.1-insoluble	75.97	74.82	76.75	78.24
pH 6.1-soluble	79.74	77.01	78.48	79.89

[1] n=2.

[2] Nx5.7; expressed on a dry basis.

Table 7. Percentage of total gluten protein contributed by each gluten fraction, obtained by precipitating at various pH levels.[1]

Gluten fraction	Percentage of Total Gluten Protein (%)[2]			
	Augusta	Hillsdale	Frank.	Tecumseh
pH 4.7-insoluble	39.9	14.5	23.8	27.2
pH 5.6-insoluble	2.7	7.0	4.3	2.4
pH 5.8/6.1-insoluble	8.3	22.2	18.8	18.3
pH 6.1-soluble	44.0	52.9	48.7	46.5
Total recovery	94.9	96.6	95.6	94.4
Gluten protein loss	5.1	3.4	4.4	5.6

[1] Expressed on a dry basis.

[2] Calculated using Eq. 8.

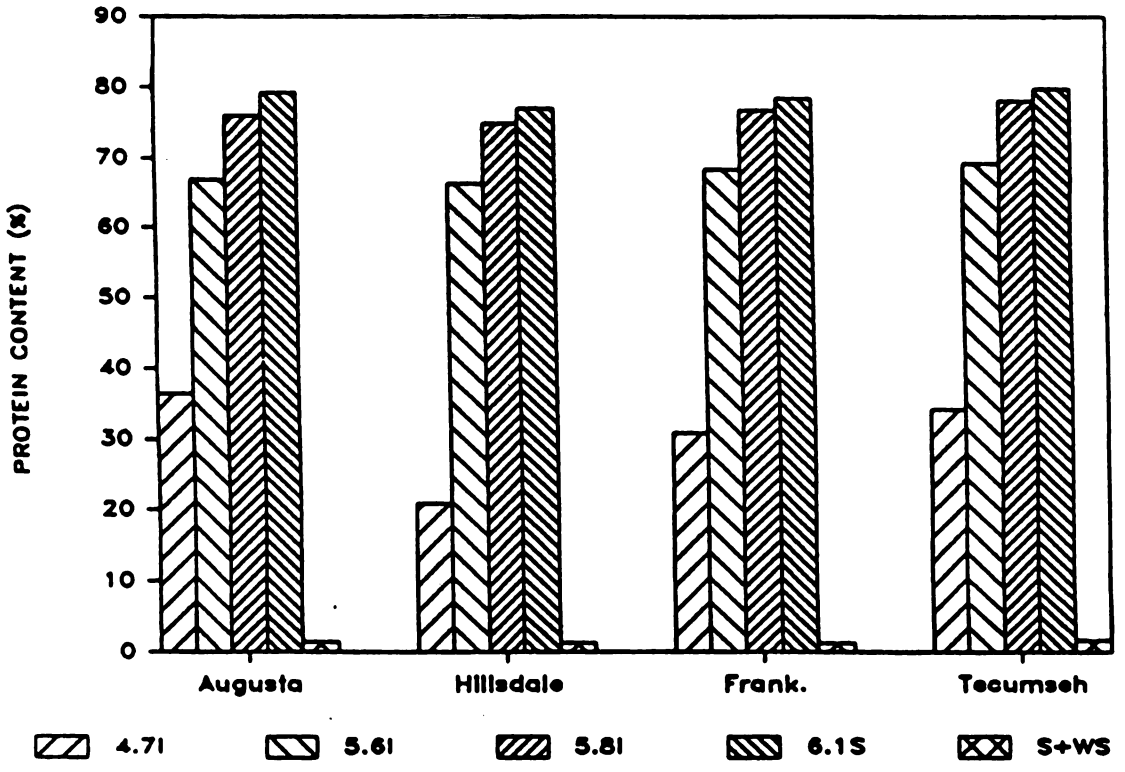


Figure 5. Protein contents of flour fractions obtained by gluten washing and precipitation by pH. I = insoluble, S = soluble, S + WS = starch + water-solubles.

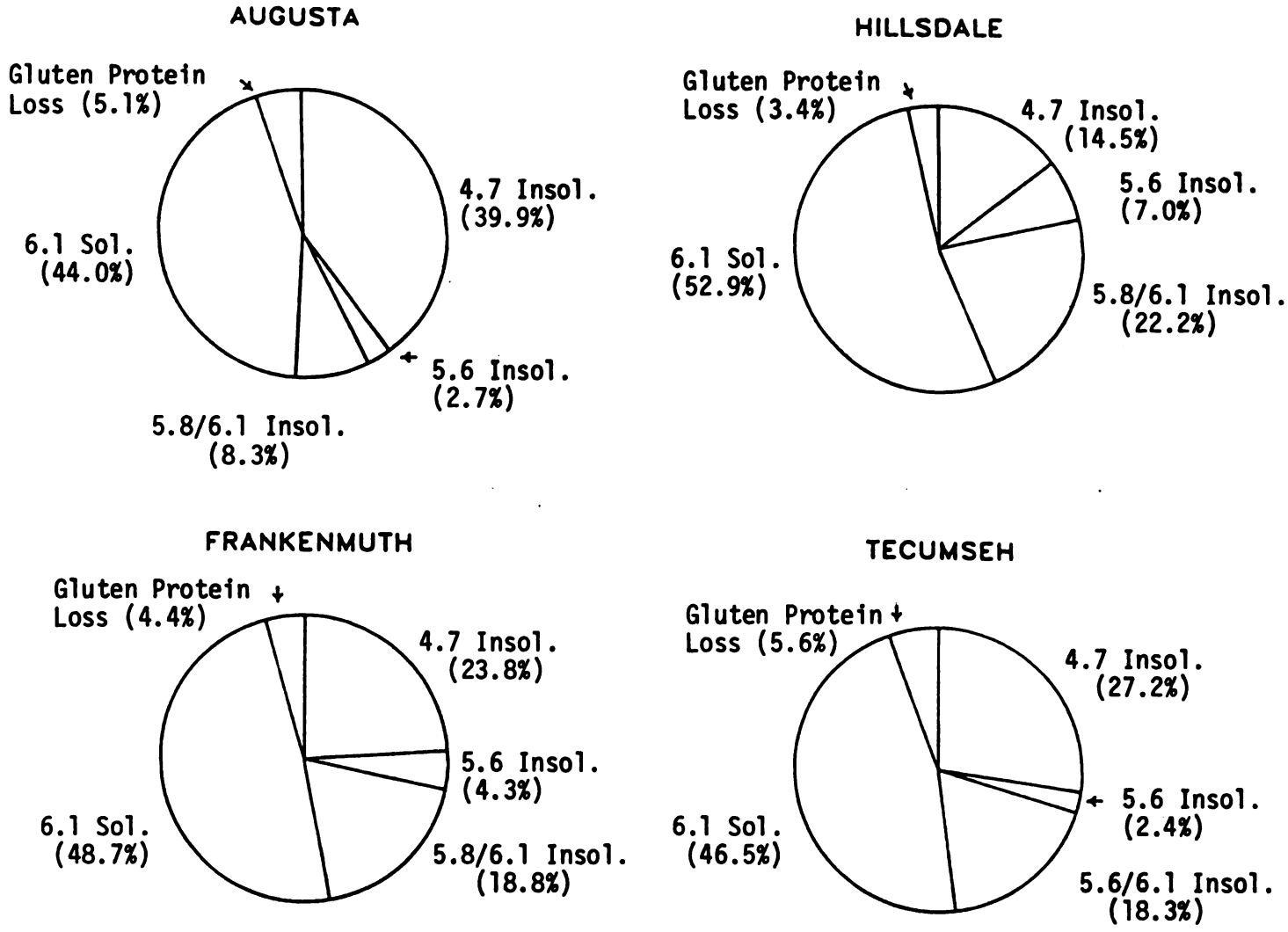


Figure 6. Percentage of total gluten protein contributed by each gluten fraction obtained by precipitating at various pH levels.

contributed by each fraction mirrored the pattern of the percentage by weight of fraction data; thus, Augusta was again the aberrant flour. Gluten protein contributed by pH 4.7-insoluble gluten again increased with flour protein content among the Hillsdale, Frankenmuth and Tecumseh varietal flours. Again, the gluten protein contributed by the other fractions decreased as protein content of these flours increased. Recoveries of gluten protein ranged from 94.4 to 96.6%, and, therefore, percent gluten protein losses ranged from 3.4 to 5.6%. Percentage gluten protein losses increased as flour protein content increased for Hillsdale, Frankenmuth and Tecumseh. Augusta was again the exception.

Percentage of Total Flour Protein Supplied by Each Flour Fraction. Table 8 shows the percentage of total flour protein contributed by each flour fraction. Figure 7 illustrates this in the form of pie graphs. Among the varieties, the pH 4.7-insoluble gluten ranged from 13.0 to 35.6%, whereas ranges of 2.2 to 6.2%, 7.4 to 19.9% and 39.3 to 47.4% were calculated for the pH 5.6-insoluble, pH 5.8/6.1-insoluble and pH 6.1-soluble glutens, respectively. The starch + water-solubles fraction ranged from 12.4 to 15.3% of the total flour protein. The relationship between parent flour protein and that contributed by the gluten fractions to the total flour protein is the same as mentioned in the above percentage of total gluten protein discussion. The total protein contributed by the starch + water-solubles

Table 8. Percentage of total flour protein contributed by each flour fraction obtained by gluten washing and pH fractionation.[1]

Flour fraction	Percentage of Total Flour Protein (%)[2]			
	Augusta	Hillsdale	Frank.	Tecumseh
pH 4.7-insoluble gluten	35.6	13.0	21.8	24.9
pH 5.6-insoluble gluten	2.4	6.2	4.0	2.2
pH 5.8/6.1-insoluble gluten	7.4	19.9	17.2	16.7
pH 6.1-soluble gluten	39.3	47.4	44.7	42.6
Starch + water-solubles	15.3	13.5	12.4	13.6
Flour protein recovery	95.7	97.0	96.2	95.1

[1]Expressed on a dry basis.

[2]Calculated using Eq. 9 (values corrected for flour protein losses).

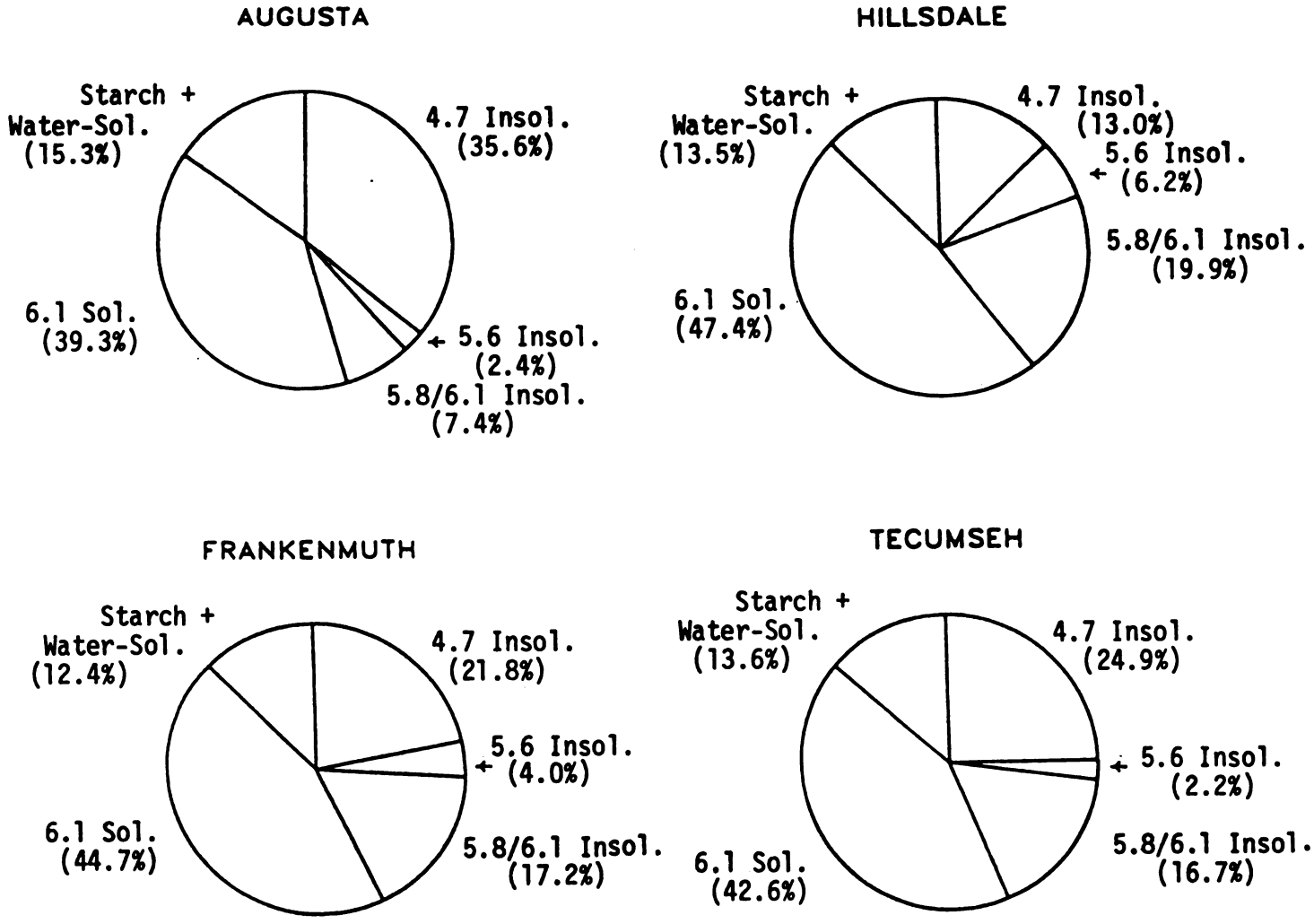


Figure 7. Percentage of total flour protein contributed by each flour fraction obtained by gluten washing and pH fractionation.

increased with increasing flour protein among the Hillsdale, Frankenmuth and Tecumseh varieties. Augusta was anomalous once more.

The percentage of total flour protein data of two hard winter wheats reported by Shogren et al. (1969) differed greatly from the data shown in Table 8. After correcting for flour protein losses for comparison purposes, the values obtained by these workers were 8.5 and 4.8, 20.7 and 19.9, 23.0 and 22.1, 24.5 and 27.9, 8.4 and 11.1, 14.8 and 14.2 for the pH 4.7-insoluble, pH 5.6-insoluble, pH 5.8-insoluble, pH 6.1-insoluble, pH 6.1-soluble and starch + water-solubles fractions, respectively. Thus, the pH 5.8-insoluble and pH 6.1-insoluble fractions combined accounted for 47.5 and 50.0% of the total flour protein of these two hard wheat flours. As compared with the data for soft wheat flours in Table 8, significantly less flour protein was contributed by the pH 4.7-insoluble fraction, whereas significantly more flour protein was contributed by the pH 5.6-insoluble fraction of the hard wheat flours. The greatest differences between flour protein distribution patterns of the soft wheat flours (Table 8) and the hard winter wheat flours of Shogren et al. (1969) were in the combined values of the pH 5.8-insoluble and pH 6.1-insoluble fractions ($\sim$2.5 times higher in the hard wheat flours) and in pH 6.1-soluble fraction ($\sim$4.0 times higher in the soft wheat flours).

Flour Protein Recoveries. Flour protein recoveries ranged from 95.1 to 97.0% (Table 8). Shogren et al. (1969) recovered 97.4 and 100.3% of the flour protein. Recoveries of 94.0, 94.8, and 88.1% flour protein were attained in the respective hand-kneaded, mechanically-kneaded and acetic acid-extracted flour separations of Sollars (1956). Sollars and Rubenthaler (1975) achieved a 99% recovery of flour protein.

Observations on the Appearance of Gluten Fractions. The characteristic appearance of gluten fractions following precipitation was in agreement with observations of Shogren et al. (1969). The pH 4.7-insoluble material contained noticeable starch and bran particles not removed during gluten washing, and lacked any cohesiveness or elasticity. When neutralized to pH 6.1, the material became compact clots. The pH 5.6-insoluble material was a slightly sticky, tough and elastic precipitate. There was no evidence of bran particles, but some starch appeared with this fraction. It became a compact, feathery precipitate upon neutralization to pH 6.1. Both the pH 5.8-insoluble and pH 6.1-insoluble materials were very sticky and extremely extensible before and after neutralization to pH 6.1. The pH 6.1-soluble material, which was in solution following fractionation, was extremely sticky and gum-like when partially freeze-dried. Thin strands could be formed due to its extremely extensible character. Following freeze-drying, the pH 5.6-insoluble

material had a greasy feel, indicating that more flour lipid may have been partioned with this fraction. Glutenin was described by Dimler (1963) as being tough, elastic, and rubbery, with resistance to stretching, whereas gliadin has a sirupy extensible nature, with the ability to flow. Thus, the pH 5.6-insoluble fraction had characteristics similar to those of glutenin, in contrast with the pH 5.8/6.1-insolubles fraction and the pH 6.1-soluble fraction, which both resembled gliadin in character.

The gluten fractions separated from hard wheat flours by Shogren et al. (1969) were characterized by starch-gel electrophoresis. The electrophoretic patterns obtained by these workers are consistent with the viscoelastic properties of the fractions obtained in this study. The pattern for the pH 4.7-insoluble gluten protein contained significant amounts of protein too large to enter the gel (glutenins), whereas only trace amounts of the gliadins were present. In contrast, the pH 6.1-soluble gluten proteins contained a high gliadin concentration, but only traces of glutenin. Thus, these workers asserted that gliadins increased, and glutenins decreased as the pH of each gluten fraction increased.

Flour Reconstitutions

As stated previously, final flour protein (a 20% random sampling) and moisture contents are provided in the appendix. Error values ranged between 1.29 to 2.95%. The reconstituted flour of Finney (1943) had a protein content identical to that of the original flour. Walden and McConnell (1955) reported an experimental protein value of 14.5% as compared with the 14.9% calculated protein value (ca. 2.68% error). The reconstituted flours of Sollars (1958a) contained 6.39 and 6.09% protein as compared with the respective 6.04 and 6.21% protein values of the original flours; thus, error values would be 5.79 and 1.93%, respectively.

Baking Test for Pastry

Results for each dependent variable will first be discussed separately. Analyses of variance tables for each of these dependent variables are provided in the appendix. Correlations among dependent variables, between the dependent variables and flour protein content, and between the dependent variables and percentage of gluten fraction present, will follow. Lastly, the effect of fractionation/reconstitution procedures on pastry textural characteristics, and implications of the data, will be discussed.

Flakiness

Significant differences in the flakiness of pastry wafers were found among varietal flours and reconstitution types at $\alpha = 0.01$. Interaction between the main effects was significant at $\alpha = 0.05$.

Table 9 shows the means for flakiness of pastry wafers baked from the varietal parent and reconstituted flours (interaction). These results are depicted as bar graphs in Figure 8. Pastry wafers from Tecumseh parent flour were significantly more flaky than all other types, except those baked from Tecumseh pH 6.1-soluble reconstituted (reconst.) flour. Conversely, the pastry wafers baked from pH 5.6-insoluble reconst. flour were significantly less flaky than all other types.

Means ranged from 2.0 to 3.4 cm. Ostrander et al. (1971) also used height of a stack of 4 wafers as an index to flakiness. They reported a range of values from 1.89 to 2.31 cm for a soft wheat all-purpose flour baked with, and without, elaidinized lipid. These workers rolled their doughs to a 3.4 mm thickness as compared with a 3.2 mm (1/8-inch) thickness used by the author.

Flakiness means for each reconstitution type are provided in Table 10; they are shown as a bar graph in Figure 9. Pastry wafers from the parent flours were significantly more flaky than all others, except those from pH 6.1-soluble reconst. flours. Wafers baked from the pH 5.6-insoluble

Table 9. Flakiness of pastry wafers baked from varietal parent and reconstituted flours[1]

Reconstitution type	Height of a stack of 4 wafers (cm)			
	Augusta	Hillsdale	Frank.	Tecumseh
Parent Flour	2.7	2.9	2.9	3.4
Whole crude gluten	2.5	2.6	2.4	2.6
A.F.R.[2]	2.6	2.6	2.8	3.0
pH 4.7-insoluble	2.3	2.3	2.3	2.4
pH 5.6-insoluble	2.2	2.3	2.2	2.0
pH 5.8/6.1-insoluble	2.8	2.7	2.5	2.9
pH 6.1-soluble	2.7	2.6	2.9	3.2

[1] n=3, standard error=0.11. LSD=0.32 at α=0.05.

[2] All fractions reconstituted in original proportions.

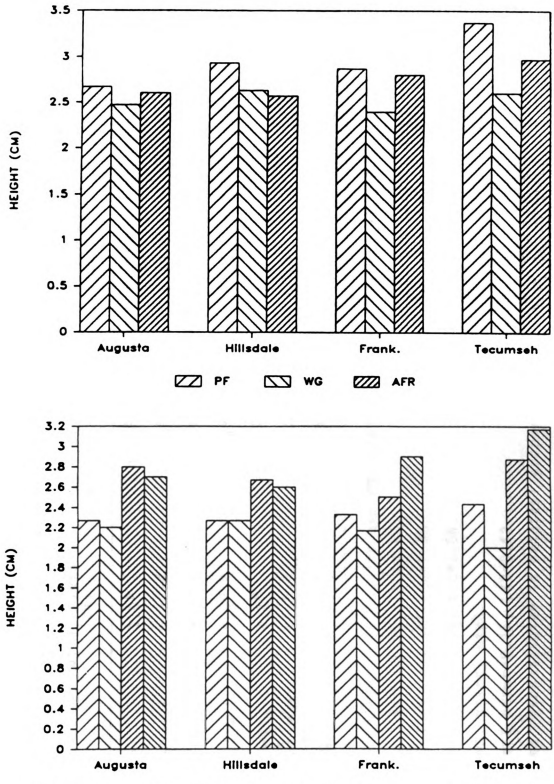


Figure 8. Flakiness of pastry wafers baked from varietal parent and reconstituted flours. Above: PF = parent flour, WG = whole crude gluten, AFR = all fract. reconst. Below: I = insol., S = sol.

Table 10. Flakiness, crust shrinkage, surface blistering score and breaking strength means for reconstitution types.[1]

Reconstitution Type	Height of a Stack[2] of 4 Wafers (cm)	Crust Shrinkage[3] (%)	Surface[4,5] Blistering Score	Breaking Strength[6] (lb force/ cm^2 broken)
Parent Flours	3.0^{a}	11.3^{a}	$2.2^{c,d}$	1.4^{c}
Whole crude gluten	$2.5^{c,d}$	$10.0^{a,b}$	$2.7^{b,c}$	$1.8^{b,c}$
A.F.R.[7]	$2.7^{b,c}$	7.2^{c}	4.4^{a}	$2.2^{a,b}$
pH 4.7-insoluble	$2.3^{d,e}$	2.4^{d}	1.9^{d}	$2.2^{a,b}$
pH 5.6-insoluble	2.2^{e}	3.2^{d}	2.1^{d}	1.7^{c}
pH 5.8/6.1-insoluble	$2.7^{b,c}$	$8.4^{b,c}$	3.2^{b}	1.7^{c}
pH 6.1-soluble	$2.8^{a,b}$	$9.3^{a,b,c}$	4.5^{a}	2.6^{a}

[1]Means having the same superscript are not significantly different at $\alpha=0.01$.

[2]n=12; standard error=0.06; LSD=0.21.

[3]n=12; standard error=0.61; LSD=2.30.

[4]n=12; standard error=0.15; LSD=0.58.

[5]1=very slight; 5=very high.

[6]n=12; standard error=0.11; LSD=0.42.

[7]All fractions reconstituted in original proportions.

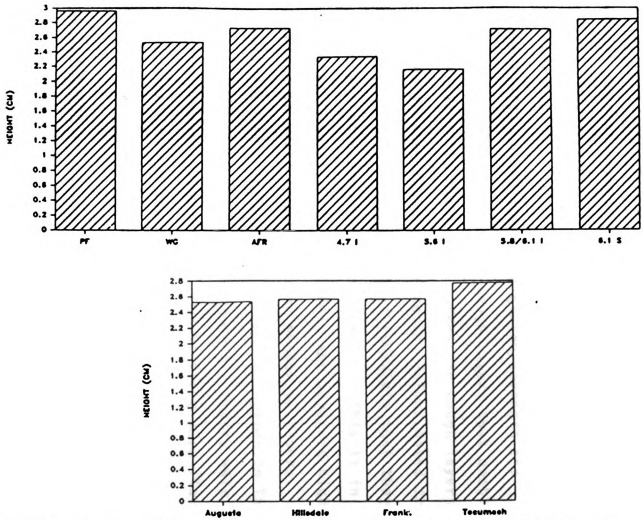


Figure 9. Flakiness of pastry wafers. Above: Means for reconstitution types. PF=parent flour, WG=whole crude gluten, AFR=all fract. reconst., I=insol., S=sol. Below: Means for varietal flours.

reconst. flours were significantly less flaky than all other types, except those from pH 4.7-insoluble reconst. flours. Among the single fraction reconst. flours, flakiness increased with pH, with the exception of the pH 4.7-insoluble reconst. type. Thus, it appears that flakiness of pastry increases with a probable increased gliadin-to-glutenin ratio.

Lowe (1943) stated that some gluten strength and development allows formation of dough layers that enable steam retention; the steam then forces the dough layers apart. The greater flakiness of pastry wafers baked from the higher pH single fraction flours suggests that they have more gluten strength and development. This is in agreement with Shogren et al. (1969), who observed higher loaf volume in bread baked from the higher pH flours.

Flakiness means for varietal flours are given in Table 11, and shown as a bar graph in Figure 9. Pastry wafers baked from Tecumseh flours were significantly more flaky than those baked from the other varietal flours. No differences were seen among the other flours.

Crust Shrinkage

Significant differences in the crust shrinkage of pastry wafers were found among varietal flours and reconstitution types at α=0.01. Also significant at α=0.01 was the interaction between main effects.

Table 11. Flakiness, crust shrinkage, surface blistering score and breaking strength means for varietal flours.[1]

Varietal Flour	Height of a Stack[2] of 4 Wafers (cm)	Crust Shrinkage[3] (%)	Surface[4,5] Blistering Score	Breaking Strength[6] (lb force/ cm^2 broken)
Tecumseh	2.8^{a}	8.5^{a}	2.9^{a}	1.7^{b}
Frankenmuth	2.6^{b}	8.1^{a}	2.9^{a}	2.2^{a}
Hillsdale	2.6^{b}	$7.2^{a,b}$	3.1^{a}	$2.0^{a,b}$
Augusta	2.5^{b}	5.8^{b}	3.1^{a}	1.9^{b}

[1]Means having the same superscript are not significantly different at $\alpha=0.01$.

[2]n=21; Standard error=0.04; LSD=0.16.

[3]n=21; Standard error=0.46; LSD=1.74.

[4]n=21; Standard error=0.12; LSD=0.33.

[5]1=very slight; 5=very high.

[6]n=21; Standard error=0.08; LSD=0.32.

Means for crust shrinkage of pastry wafers baked from varietal parent and reconstituted flours (interaction) are provided in Table 12. In Figure 10, they are presented in the form of a bar graph. Tecumseh whole flour exhibited the most crust shrinkage, and was significantly different from Augusta, Hillsdale and Frankenmuth A.F.R. flours, Augusta whole gluten, Augusta pH 6.1-insoluble, Hillsdale pH 5.8/6.1-insoluble, and all varietal pH 4.7-insoluble and pH 5.6-insoluble reconst. flours. All varietal pH 4.7-insoluble and pH 5.6-insoluble reconst. flours yielded less shrunken pastry than all other flours, with the exception of Augusta A.F.R., Augusta pH 6.1-soluble and Hillsdale pH 5.8/6.1-insoluble reconst. flours. Of these, Augusta pH 4.7-insoluble pastry wafers were the least shrunken.

These crust shrinkage means ranged from 0.8 to 14.3%. Miller and Trimbo (1970), by varying dough formulations and treatments, observed 0-35% crust shrinkage in pastry. With a 10.6% flour protein content and 40% vegetable shortening (based on flour wt.) in the formula, a crust shrinkage of 8% was found by these workers. Miller and Trimbo (1970) noted that thickening of pastry strips accompanied crust shrinkage; this occurrence was also observed by the author.

Crust shrinkage means for each reconstitution type are given in Table 10, and illustrated in Figure 11. Overall, pastry wafers baked from parent flours displayed the most crust shrinkage; they were significantly different from all

Table 12. Crust shrinkage of pastry wafers baked from varietal parent and reconstituted flours.[1]

Reconstitution Type	Crust Shrinkage (%)			
	Augusta	Hillsdale	Frank.	Tecumseh
Parent Flour	11.4	10.3	9.2	14.3
Whole crude gluten	7.2	9.3	11.5	12.0
A.F.R.[2]	3.1	7.5	8.1	9.9
pH 4.7-insoluble	0.8	3.7	3.2	1.8
pH 5.6-insoluble	4.5	3.9	2.4	1.8
pH 5.8/6.1-insoluble	9.1	5.4	9.3	9.9
pH 6.1-soluble	4.1	10.1	12.8	10.2

[1] n=3; Standard error=1.22; LSD=4.59 at α=0.01.

[2] All fractions reconstituted in original proportions.

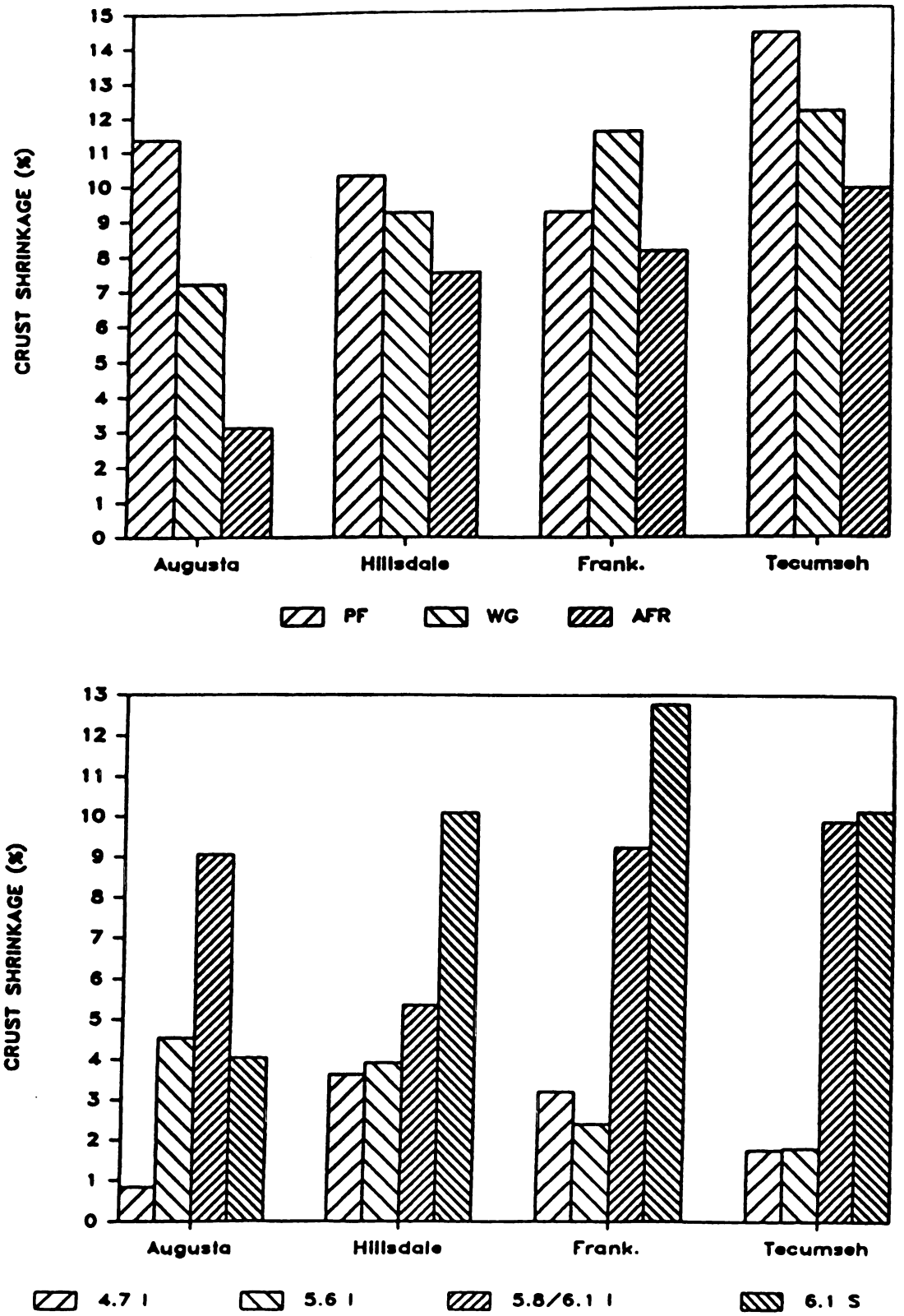


Figure 10. Crust shrinkage of pastry wafers baked from varietal parent and reconstituted flours. Above: PF=parent flour; WG=whole crude gluten, AFR=all fract. reconst. Below: I=insol., S=sol.

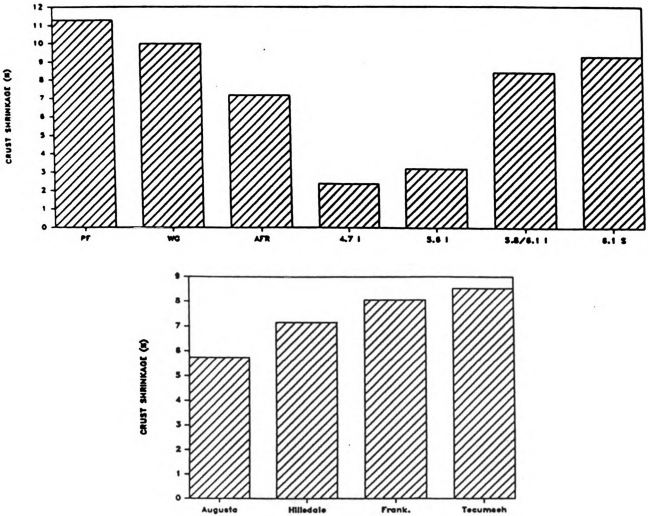


Figure 11. Crust shrinkage of pastry wafers. Above: Means for reconstitution types. PF= parent flour, WG=whole crude gluten, AFR=all fract. reconst., I=insol., S= sol. Below: Means for varietal flours.

others, except those baked from whole crude gluten and pH 6.1-soluble reconst. flours. Pastry baked from pH 4.7-insoluble reconst. flours had significantly less shrinkage than other types.

Crust shrinkage of pastry wafers progressively decreased as the pH of the fraction decreased among the single fraction reconst. flours. Consistent with flakiness results, this also seems to indicate that less gluten strength or development was present in the lower pH fractions of probable higher glutenin content. These results suggest that a higher gliadin ratio in flour could contribute to greater crust shrinkage in pastry.

Crust shrinkage means for varietal flours are shown in Table 11. Pastry wafers baked from Augusta flours exhibited significantly less shrinkage than Frankenmuth and Tecumseh flours. Hillsdale flours were not significantly different from those of the other varieties.

Surface Blistering Scores

Significant differences were found among the reconstitution types at α=0.01. No significant differences were found among varietal flours. Interaction between main effects was not significant.

Surface blistering score means of pastry wafers baked from varietal parent and reconstituted flours (interaction) are provided in Table 13, and in the form of bar graphs in

Table 13. Surface blistering scores of pastry wafers baked from varietal parent and reconstituted flours.[1]

Reconstitution type	Surface Blistering Score[2]			
	Augusta	Hillsdale	Frank.	Tecumseh
Parent Flour	2.0	2.7	2.0	2.0
Whole crude gluten	2.8	3.2	2.7	2.2
A.F.R.[3]	4.0	4.7	4.2	4.7
pH 4.7-insoluble	1.7	2.0	2.0	2.0
pH 5.6-insoluble	2.5	2.2	2.0	1.7
pH 5.8/6.1-insoluble	4.0	2.7	2.7	3.3
pH 6.1-soluble	4.7	4.3	4.7	4.3

[1] n=3, Standard error=0.31, LSD=0.87 at α=0.05.

[2] 1=very slight, 5=very high

[3] All fractions reconstituted in original proportions.

Figure 12. The pastry wafers with the highest surface blistering score means were those baked from Augusta and Frankenmuth pH 6.1-soluble reconst. flours, and those baked from Tecumseh and Hillsdale A.F.R. flours. Pastry wafers from Tecumseh pH 5.6-insoluble and Augusta pH 4.7-insoluble reconst. flours had the lowest surface blistering scores. The range for means was 1.7 to 4.7.

Among the surface blistering score means for reconstitution type (Table 10; Figure 13), pastry wafers from the pH 6.1-soluble reconst. and A.F.R. flours were significantly more blistered than all other types. Again, for the single fraction reconst. flours, as the pH increased, the surface blistering score similarly increased. With surface blistering as an indicator of gluten strength, these results are consistent with those for flakiness and crust shrinkage. Thus, the probable higher gliadin ratio of the higher pH gluten fractions is once more indicated as contributing more gluten strength.

Surface blistering score means for varietal flours are given in Table 11 and displayed in Figure 13. Overall, Augusta and Hillsdale had higher mean scores than Frankenmuth and Tecumseh. However, the difference is insignificant.

Breaking Strength

Significant differences in the breaking strength of pastry wafers were observed among varietal flours and

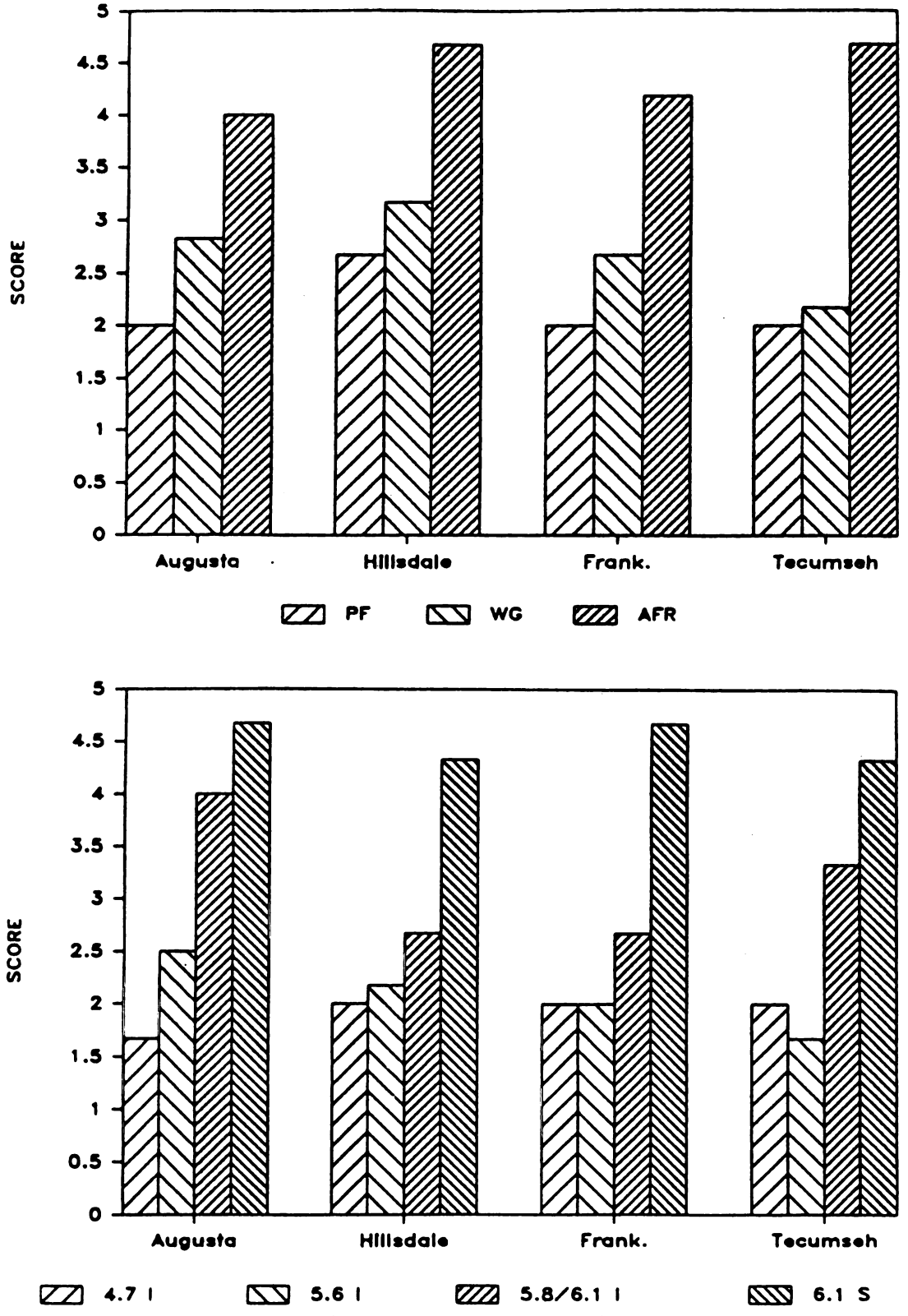


Figure 12. Surface blistering scores of pastry wafers baked from varietal parent and reconstituted flours. Above: PF=parent flour, WG=whole crude gluten, AFR=all fract. reconst. Below: I=insol., S=sol.

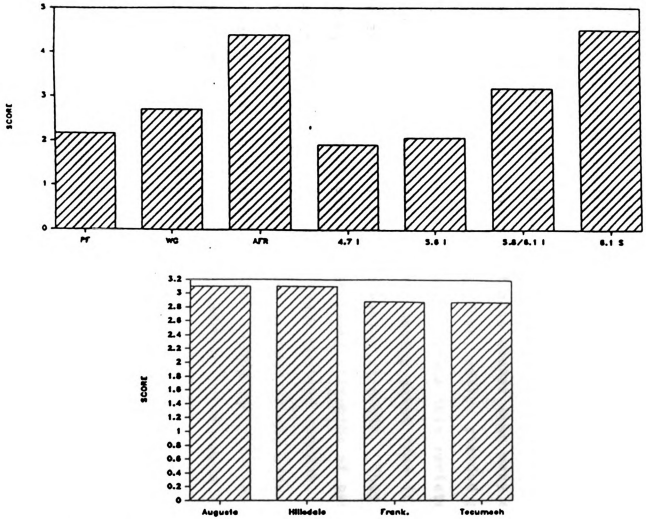


Figure 13. Surface blistering scores of pastry wafers. Above: Means for reconstitution types. PF=parent flour, WG=whole crude gluten, AFR=all fract. reconst., I= insol., S=sol. Below: Means for varietal flours.

reconstitution types at α=0.01. A significant interaction between main effects was found at α=0.05.

Means for breaking strength of pastry wafers baked from varietal parent and reconstituted flours (interaction) are provided in Table 14 and illustrated as bar graphs in Figure 14. Frankenmuth pH 6.1-soluble reconst. flour yielded pastry wafers with the highest breaking strength, significantly higher than all varietal parent and pH 5.8/6.1-insoluble reconst. flours, and also higher than many other pastry types. Tecumseh parent flour, oddly, yielded pastry with the lowest breaking strength. Since this varietal flour had the highest protein content, pastry baked from it would be expected to have a higher breaking strength. Thus, among the parent flours, the breaking strengths of pastry wafers were not determined by flour protein content. Of these parent flours, Frankenmuth yielded pastry with the highest breaking strength. Other researchers (Denton et al., 1933; Miller and Trimbo, 1970) reported an increase in breaking strength with increased flour protein content.

The range of means was between 1.1 to 2.9 lbs force/cm^2 broken. Miller and Trimbo (1970) reported a Kramer Shear Press value of 240 lbs force for pastry baked from a dough containing 40% shortening (based on flour wt.) and an all-purpose flour having a protein content of 10.6%. This shear value seems comparatively high. A pastry containing 50% shortening and all-purpose flour was reported by Stinson and

Table 14. Breaking strength of pastry wafers baked from varietal parent and reconstituted flours.[1]

Flour type	Breaking Strength (lb force/cm^2 broken)			
	Augusta	Hillsdale	Frank.	Tecumseh
Parent Flour	1.4	1.3	1.8	1.1
Whole crude gluten	1.4	1.6	2.3	1.8
A.F.R.[2]	2.2	2.7	2.0	1.9
pH 4.7-insoluble	2.4	2.6	2.3	1.5
pH 5.6-insoluble	1.3	1.8	2.2	1.4
pH 5.8/6.1-insoluble	1.6	1.5	1.9	1.7
pH 6.1-soluble	2.8	2.3	2.9	2.3

[1] n=3; Standard error=0.22; LSD=0.63 at 0.05.

[2] All fractions reconstituted in original proportions.

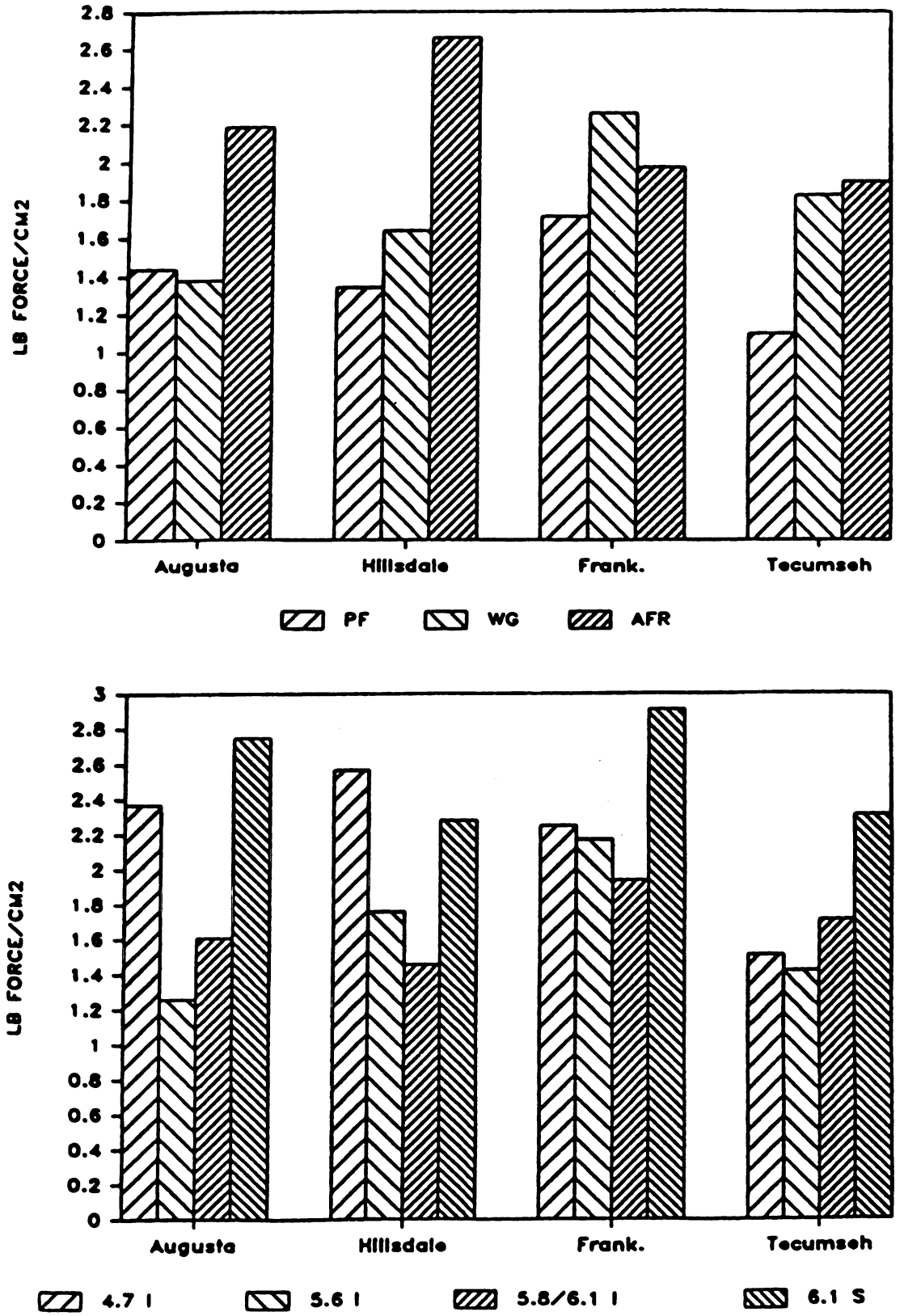


Figure 14. Breaking strength of pastry wafers baked from varietal parent and reconstituted flours. Above: PF=parent flour, WG=whole crude gluten, AFR=all fract. reconst. Below: I=insol., S=sol.

Huck (1969) as having a shear press value of 20.7 lb/g. The use of multiple blade test cells, and differences in the areas of pastry samples sheared could account for the discrepancy between literature values and those of the present study.

Breaking strength means for each reconstitution type are given in Table 10 and depicted as a bar graph in Figure 15. Pastry baked from pH 6.1-soluble reconst. flour had a significantly higher breaking strength than the other types, with the exception of A.F.R., and pH 4.7-insoluble reconst. flours. Though not significantly different from the pH 5.6-insoluble, pH 5.8/6.1-insoluble or whole crude gluten reconst. flours, the pastry baked from parent flours had the lowest breaking strength of all reconstitution types. The relationship between breaking strength and pH of the fraction used in the single fraction reconst. flours was not linear as for crust shrinkage and surface blistering scores. The flours with extremes of pH, that is 4.7 and 6.1, yielded the toughest pastry wafers. If the pH 4.7-insoluble reconst. flour is excluded, breaking strength does decrease with decreasing pH. The pH 4.7-insoluble fraction contained noticeable amounts of bran particles and starch not removed during gluten washing, thus more of the fraction was required in reconstituting to the original protein content of the flour. A larger amount of weaker gluten could possibly have contributed to greater gluten strength or development, quantitatively. However, flakiness, crust shrinkage, and surface blistering of pastry

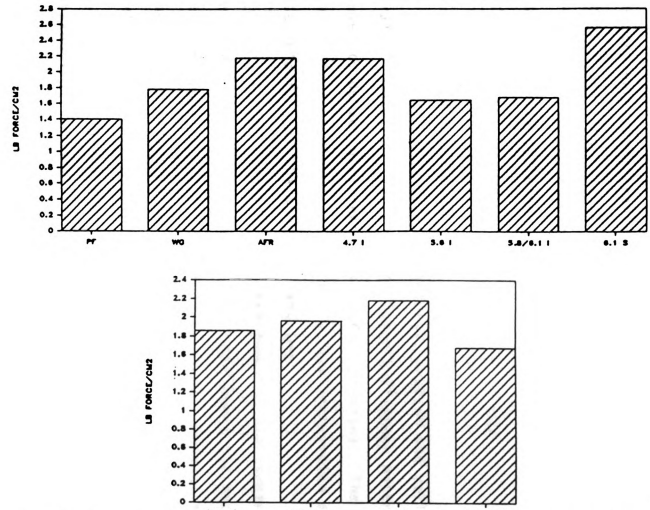


Figure 15. Breaking strength of pastry wafers. Above: Means for reconstitution types. PF=parent flour, WG=whole crude gluten, AFR=all fract. reconst., I=insol., S=sol. Below: Means for varietal flours.

from the pH 4.7-insoluble reconst. flour indicated less gluten strength within this fraction.

Breaking strength means for the different varietal flours are provided in Table 11, and illustrated in Figure 15. Pastry baked from Frankenmuth flours had a significantly higher breaking strength than those from Augusta and Tecumseh flours. Breaking strength means for Hillsdale flours were not significantly different from those of the other varietal flours.

Crust Surface Browning

As previously stated, lightness, redness and yellowness values, obtained from a Hunter Color Difference meter, were used to detect differences in surface browning. The values will first be discussed separately, the interpreted as descriptions of the browning reaction.

Lightness. Significant differences in the lightness mean values of pastry wafers were found among the reconstitution types at α=0.01. Differences among varietal flour means were insignificant. Interaction between main effects was significant at α=0.01.

Table 15 gives the lightness value means of pastry wafers baked from varietal parent and reconstituted flours; these are also shown in Figure 16. Pastry baked from Augusta parent flour had the lightest surface; it was significantly lighter than all varietal pH 4.7-insoluble and pH

Table 15. Lightness values of pastry wafers baked from varietal parent and reconstituted flours.[1]

Reconstitution type	Lightness[2]			
	Augusta	Hillsdale	Frank.	Tecumseh
Parent Flour	71.7	69.2	68.7	69.3
Whole crude gluten	57.9	60.4	60.4	64.7
A.F.R.[3]	60.8	66.1	63.9	65.5
pH 4.7-insoluble	55.5	59.4	58.1	54.6
pH 5.6-insoluble	46.8	56.2	53.7	49.2
pH 5.8/6.1-insoluble	66.5	62.7	60.3	65.5
pH 6.1-soluble	69.8	61.0	65.6	65.9

[1] n=3, Standard error=1.91, LSD=7.20 at α=0.01.

[2] As determined by Hunter Color Difference ("L" value, 0 (black) to 100 (white)).

[3] All fractions reconstituted in original proportions.

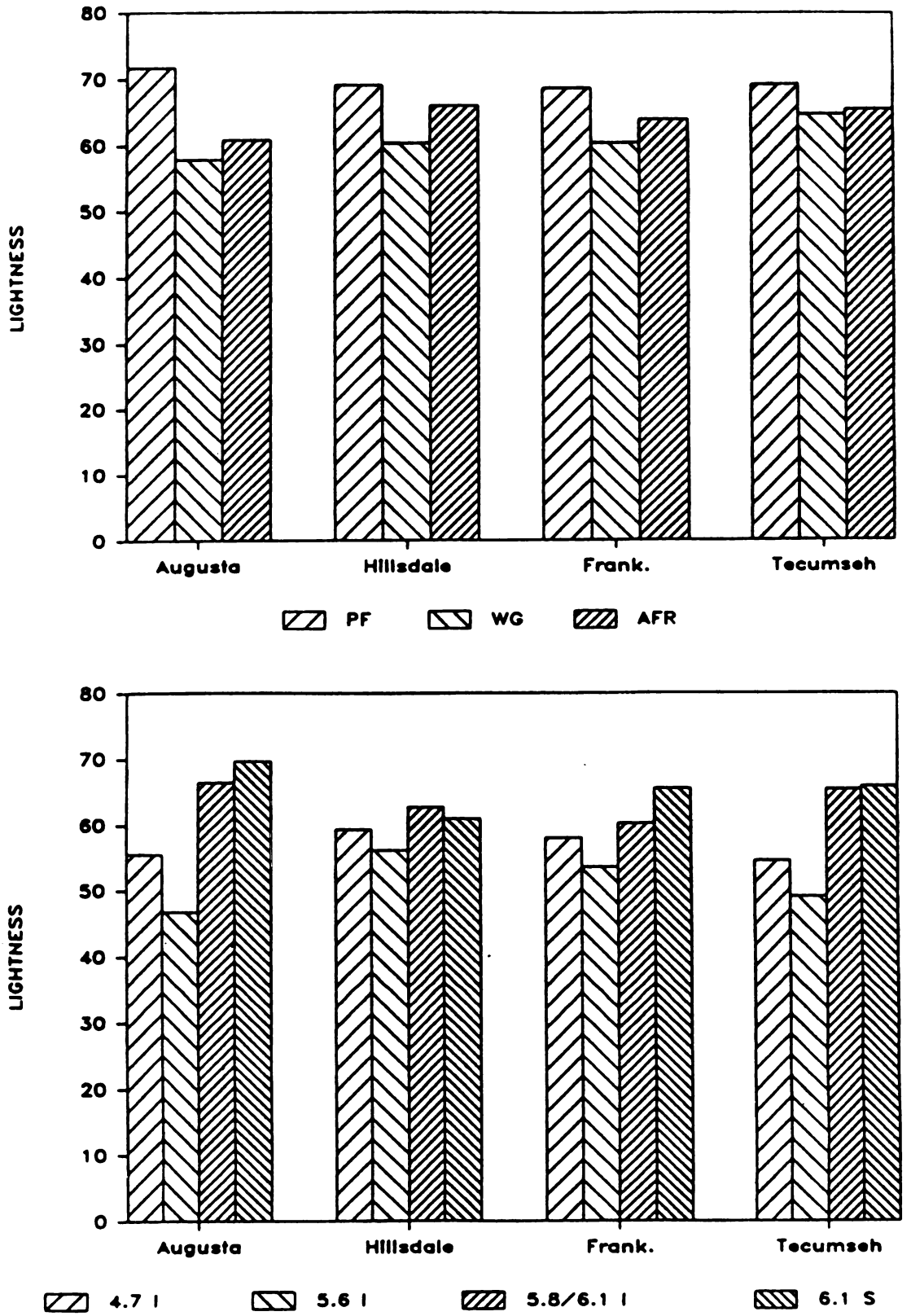


Figure 16. Lightness ("L") of pastry wafers baked from varietal parent and reconstituted flours. Above: PF=parent flour, WG=whole crude gluten, AFR= all fract. reconst. Below: I=insol., S=sol.

5.6-insoluble reconst. flours, all varietal whole crude gluten reconst. flours (except Tecumseh), Augusta A.F.R., Hillsdale pH 6.1-soluble, plus Hillsdale and Frankenmuth pH 5.8/6.1-insoluble reconst. flours. Augusta pH 5.6-insoluble reconst. flour yielded the darkest pastry; it was significantly darker than all others, except those baked from Frankenmuth and Tecumseh pH 5.6-insoluble reconst. flours. Means ranged from 46.8 to 71.7.

Lightness mean values for reconstitution types are provided in Table 16, and illustrated in Figure 17. Pastry wafers baked from parent flours were significantly lighter than those baked from all other flour types. The pH 5.6-insoluble reconst. flours yielded the darkest pastry wafers; they were significantly darker than those from all other reconstitution types. With the exception of the pH 5.6-insoluble reconst. flours, as pH decreased among the single fraction reconst. flours, the pastry wafers yielded were darker. Lightness value means for varietal flours are given in Table 17 and depicted as a bar graph in Figure 17. Pastries from Hillsdale flours were lightest, and those from Augusta were darkest. However, the slight differences were insignificant.

Redness. Reconstitution type means for redness were significantly different at $\alpha=0.01$. Varietal flour means were not significantly different. A significant interaction between main effects was found at $\alpha=0.01$.

Table 16. Lightness, redness and yellowness value means for reconstitution types.[1,2]

Reconstitution type	Lightness[3,4]	Redness[5,6]	Yellowness[7,8]
Parent flours	69.7[a]	-0.6[d]	20.2[b]
Whole crude gluten	60.8[c]	2.8[b,c]	21.5[a]
A.F.R.[9]	64.1[b,c]	2.4[c]	21.6[a]
pH 4.7-insoluble	56.9[d]	3.8[b]	21.0[a]
pH 5.6-insoluble	51.4[e]	6.2[a]	20.9[a,b]
pH 5.8/6.1-insoluble	63.8[b,c]	2.1[c]	21.7[a]
pH 6.1-soluble	65.6[b]	1.9[c]	21.7[a]

[1]Means having the same superscript are not significantly different at α=0.01.

[2]As determined by Hunter Color Difference.

[3]"L" values = 0 (black) to 100 (white).

[4]n=12; Standard error=0.95; LSD=3.60.

[5]"a" values; negative values indicate greenness.

[6]n=12; Standard error=0.30; LSD=1.15.

[7]"b" values.

[8]n=12; Standard error=0.21; LSD=0.79.

[9]All fractions reconstituted in original proportions.

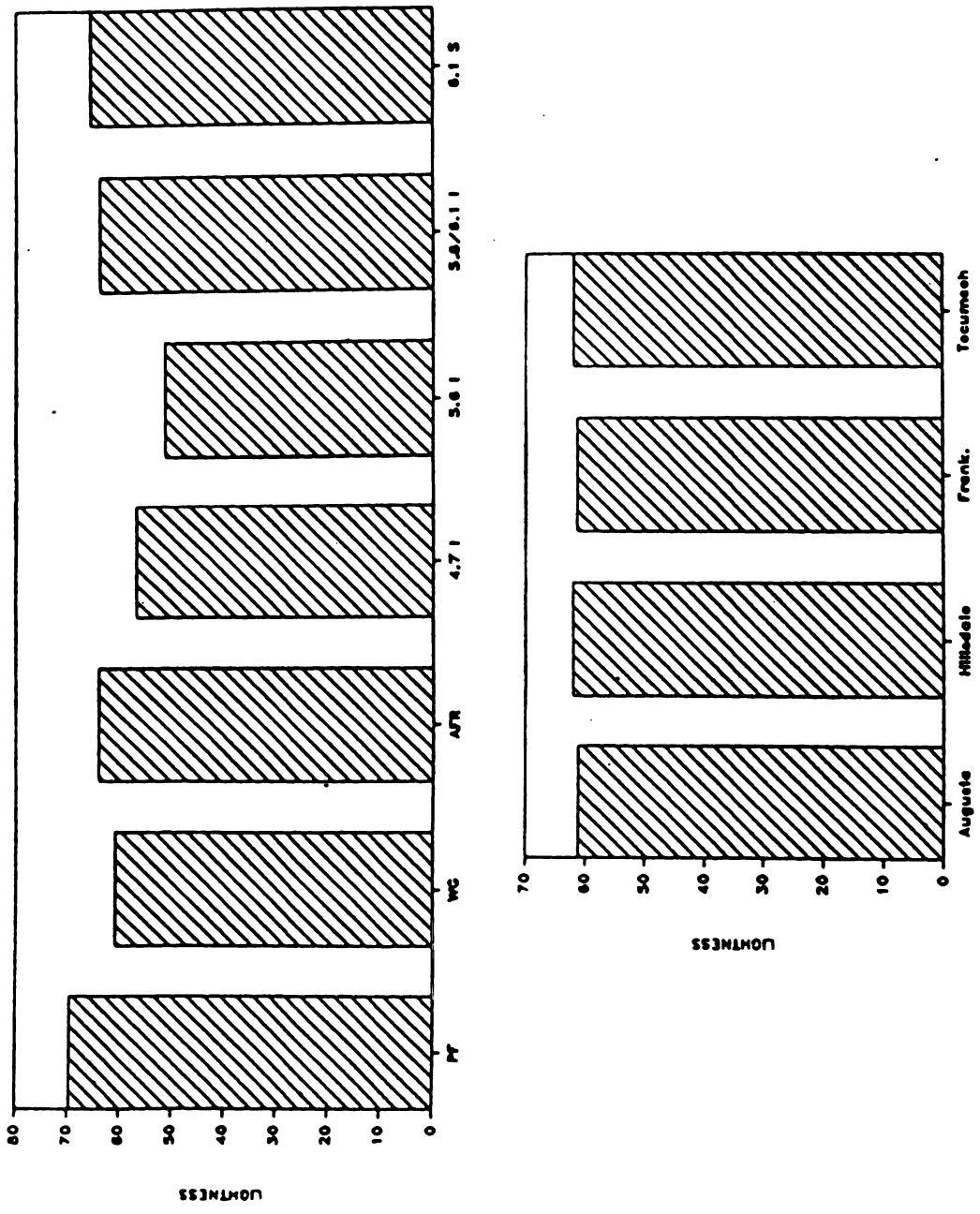


Figure 17. Lightness ("L") of pastry wafers. Above: Means for reconstitution types. PF= parent flour, WG=whole crude gluten, AFR=all fract. reconst., I=insol., S= sol. Below: Means for varietal flours.

Table 17. Lightness, redness and yellowness value means for varietal flours.[1,2]

Varietal flour	Lightness[3,4]	Redness[5,6]	Yellowness[7,8]
Tecumseh	62.1[a]	2.6[a]	21.0[b,c]
Frankenmuth	61.5[a]	2.8[a]	21.9[a]
Hillsdale	62.1[a]	2.3[a]	21.4[a,b]
Augusta	61.3[a]	3.0[a]	20.7[c]

[1]Means having the same superscript are not significantly different at α=0.01.

[2]As determined by Hunter Color Difference.

[3]"L" values=0 (black) to 100 (white).

[4]n=21; Standard error=0.72; LSD=2.04.

[5]"a" values.

[6]n=21; Standard error=0.23; LSD=0.65.

[7]"b" values.

[8]n=21; Standard error=0.16; LSD=0.59.

Redness value means of pastry wafers baked from varietal parent and reconstituted flours are shown in Table 18, and as a bar graph in Figure 18. Augusta pH 5.6-insoluble reconst. flour yielded pastry with the highest redness value; pastry from this flour had a significantly redder surface than pastry samples from all other flour types, except Augusta pH 4.7-insoluble, Augusta whole crude gluten, and pH 5.6-insoluble reconst. flours from the other wheat varieties. Pastry baked from Augusta parent flour was the least red; in fact, the negative value indicates a greenish hue to this pastry type. Augusta parent flour pastry was significantly less red (and more green) than pastry from all other types, except Augusta pH 5.8-insoluble, Augusta pH 6.1-soluble, Tecumseh whole crude gluten reconst., and all varietal parent flours. Mean values ranged from -1.2 to 6.9 (+).

In Table 16 and Figure 19, redness value means for each reconstitution type are shown. The pastry wafers baked from the pH 5.6-insoluble reconst. flours had significantly redder crust surfaces than those baked from other reconstitution types. As with lightness values, when the pH 5.6-insoluble reconst. flours were excluded, pastry wafers were increasingly red as pH of the single fraction reconst. flours decreased. Pastry baked from the parent flours was significantly less red and more green than that from other types.

Table 18. Redness values of pastry wafers baked from varietal parent and reconstituted flours.[1]

Reconstitution type	Redness[2]			
	Augusta	Hillsdale	Frank.	Tecumseh
Parent Flour	-1.2	-0.7	-0.4	-0.1
Whole Crude gluten	4.6	3.0	2.2	1.4
A.F.R.[3]	3.4	1.5	2.2	2.5
pH 4.7-insoluble	5.3	2.0	3.6	4.2
pH 5.6-insoluble	6.9	5.2	6.1	6.7
pH 5.8/6.1-insoluble	1.4	1.8	3.6	1.7
pH 6.1-soluble	0.2	3.3	2.4	1.6

[1] n=3, Standard error=0.61, LSD=2.29 at α=0.01.

[2] As determined by Hunter Color Difference ("a" values); negative values indicate greenness.

[3] All fractions reconstituted in original proportions.

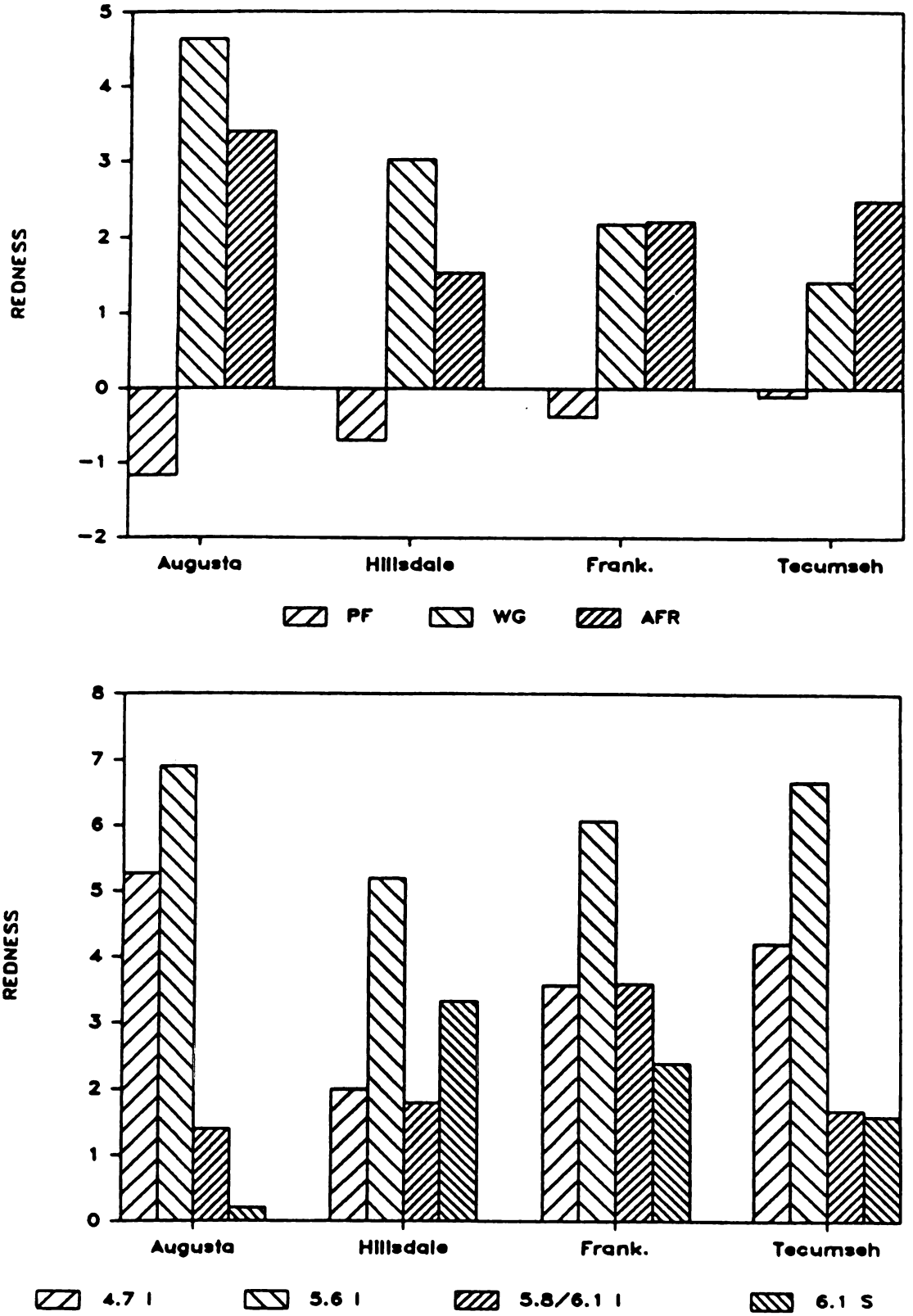


Figure 18. Redness ("a") of pastry wafers baked from varietal parent and reconstituted flours. Above: PF=parent flour, WG=whole crude gluten, AFR=all fract. reconst. Below: I=insol., S=sol.

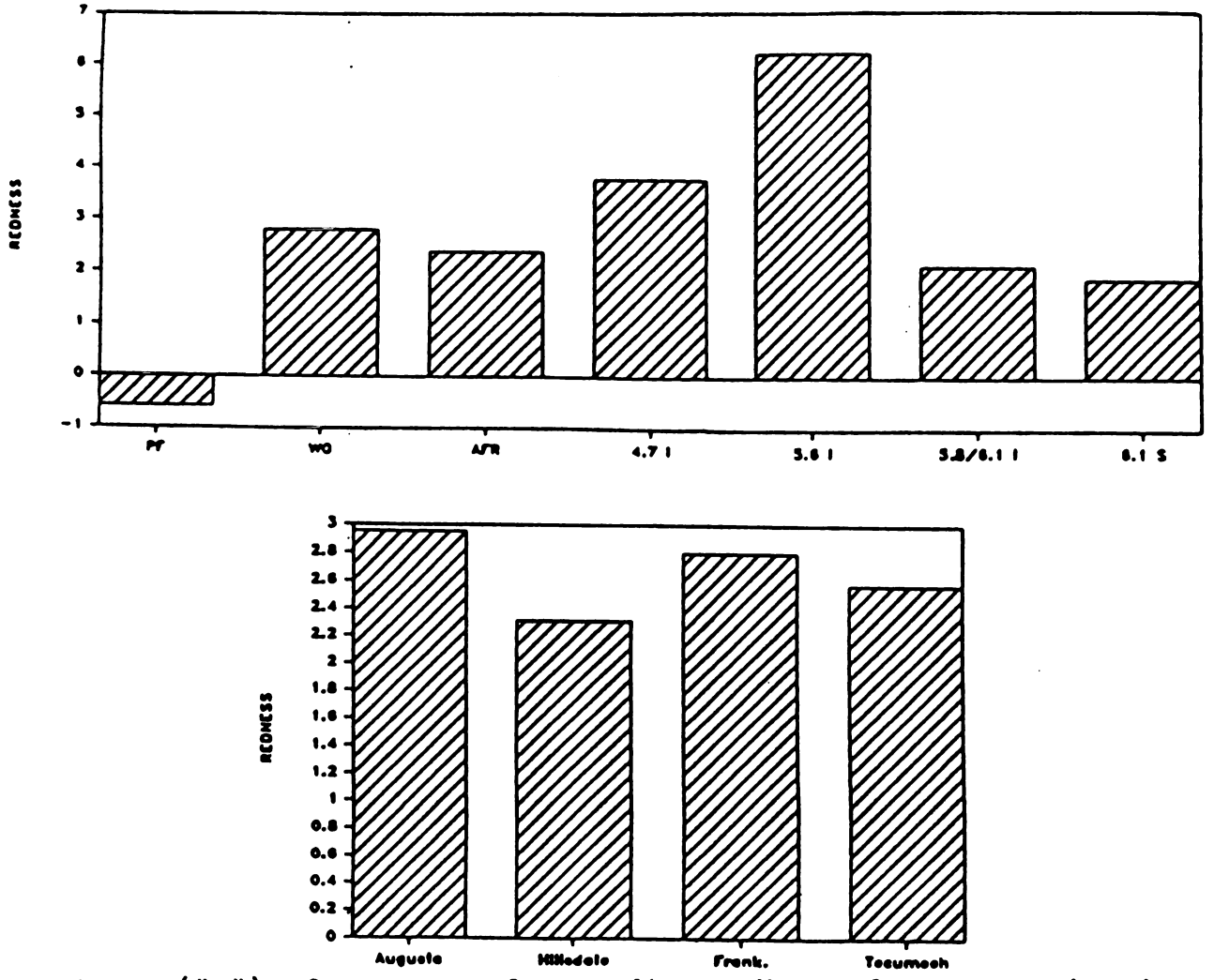


Figure 19. Redness ("a") of pastry wafers. Above: Means for reconstitution types. PF= parent flour, WG=whole crude gluten, AFR=all fract. reconst., I=insol., S= sol. Below: Means for varietal flours.

Varietal flour redness value means are provided in Table 17 and depicted as a bar graph in Figure 19. Pastries from Augusta flours were the most red; those from Hillsdale were the least red. These differences were insignificant, however.

Yellowness. Significant differences in the yellowness value means of pastry wafers were found among both reconstitution types and varietal flours at α=0.01. A significant interaction between main effects was found at α=0.01.

Yellowness value means of pastry wafers baked from varietal parent and reconstituted flours are shown in Table 19, and as a bar graph in Figure 20. Frankenmuth pH 6.1-soluble reconst. flour yielded pastry wafers that had the most yellow surface color; pastry baked from this flour was significantly more yellow than Hillsdale and Tecumseh pH 4.7-insoluble reconst., Augusta and Tecumseh pH 5.6-insoluble reconst., Augusta pH 5.8-insoluble reconst., Augusta pH 6.1-soluble reconst., and all varietal parent flours. Pastry baked from Augusta pH 5.6-insoluble reconst. flour had the least yellow surface color, and was significantly different from pastries baked from all other flours, except those from Hillsdale and Tecumseh pH 4.7-insoluble reconst., Augusta and Tecumseh pH 5.6-insoluble reconst., Augusta pH 6.1-soluble reconst., and all varietal parent flours. Mean values ranged from 19.0 to 23.1.

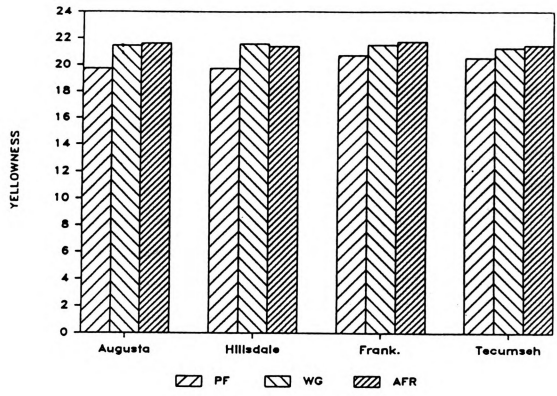
Table 19. Yellowness values of pastry wafers baked from varietal parent and reconstituted flours.[1]

Reconstitution Type	Yellowness[2]			
	Augusta	Hillsdale	Frank.	Tecumseh
Parent Flour	19.7	19.7	20.7	20.5
Whole Crude gluten	21.5	21.6	21.5	21.3
A.F.R.[3]	21.6	21.4	21.7	21.5
pH 4.7-insoluble	21.6	20.5	22.1	20.0
pH 5.6-insoluble	19.0	22.4	21.4	20.8
pH 5.8/6.1-insoluble	20.9	22.3	22.4	21.3
pH 6.1-soluble	20.6	21.6	23.1	21.4

[1] n=3, Standard error=0.42, LSD=1.57 at α=0.01.

[2] As determined by Hunter Color Difference ("b" values).

[3] All fractions reconstituted in original proportions.



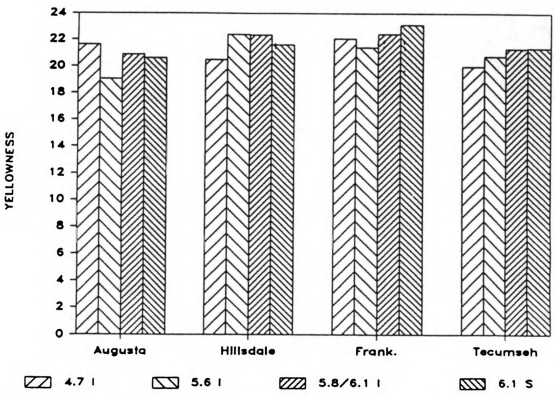


Figure 20. Yellowness ("b") of pastry wafers baked from varietal parent and reconstituted flours. Above: PF=parent flour, WG=whole crude gluten, AFR=all fract. reconst. Below: I=insol., S=sol.

Yellowness mean values for each reconstitution type are provided in Table 16, and illustrated in Figure 21. The parent flours yielded pastries that were significantly less yellow than those baked from all other reconstitution types, except the pH 5.6-insoluble reconst. flours. Pastries baked from the pH 5.8/6.1-insoluble reconst. flours were the most yellow; however, these were only significantly different from pastries baked from the parent flours. Among the single pH fraction reconst. flours, no relationship was seen between pH and resulting yellowness of the pastry crust surface.

Yellowness mean values for varietal flours are shown in Table 17, and as a bar graph in Figure 21. Pastry wafers baked from Frankenmuth flours had significantly more yellow crust surfaces than those from Tecumseh and Augusta flours. Augusta flours yielded pastry wafers having the least yellow crust surface; these wafers were significantly less yellow than those from Hillsdale and Frankenmuth flours.

Differences in Browning Reaction. Among the reconstitution types, the lightness and redness values, especially the latter, differentiated most consistently between browning reactions on the various pastry crust surfaces. Although highly significant differences were found among the yellowness values, all pastry types had yellowish surfaces, and the range of values was not as wide as for the redness and lightness values. Redness and lightness values followed the

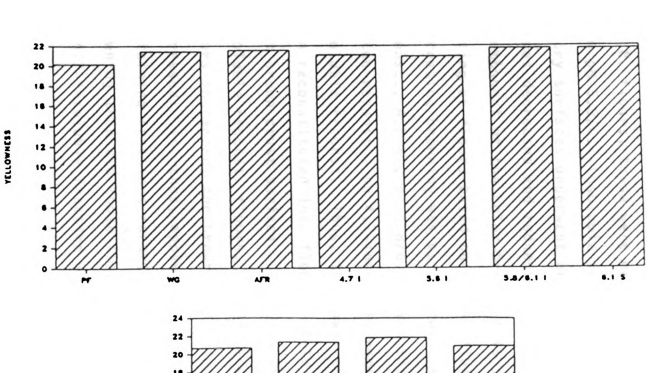


Figure 21. Yellowness ("b") of pastry wafers. Above: Means for reconstitution types. PF= parent flour, WG=whole crude gluten, AFR=all fract. reconst., I=insol., S=sol. Below: Means for varietal flours.

same pattern, and the relationship was linear, with the exception of two values. That is, as lightness decreased, redness increased, with the exception of pastries from A.F.R. flours; these were more red, but not as dark as those from pH 5.8/6.1-insoluble reconst. flours. Thus, as the pastry surfaces underwent browning during baking, lightness values decreased and redness values increased. Since red is a component of the color brown, this seems logical. The ranking of flours based on reconstitution type in order of increasing browning was as follows: parent, pH 6.1-soluble reconst., A.F.R., pH 5.8/6.1-insoluble reconst., whole crude gluten reconst., pH 4.7-insoluble reconst., and pH 5.6-insoluble reconst. Thus, the lower pH gluten fractions, when reconstituted into flours, yielded the pastry with the most brown crust surface. With the exception of the pH 5.6-insoluble reconst. flours, as the pH of the singly reconst. flours increased, the browning reaction of these flours decreased. It, thus, appears that the higher glutenin-containing fractions contributed to greater crust surface browning than did those fractions higher in gliadins. The pH 4.7-insoluble fraction may have produced less browning in pastry due to the presence of some starch + water-solubles material. Water-soluble protein would have accounted for part of the protein used in reconstitution; the water-soluble proteins possibly contribute less browning than the gluten proteins. The pH 5.6-insoluble gluten fraction had

a more greasy feel; additional flour lipid in this fraction could possibly have enhanced the browning reaction in pastry.

No significant differences were seen in lightness and redness values among the varietal flour means. Although significant differences were found among yellowness varietal flour means, it appears that crust browning differences among varietal flours were insignificant. Since the varietal flours used in this study differed in protein content, these results are in agreement with Smak (1972); this author stated that positive correlations between browning and protein content were variety-dependent.

Correlations Among Dependent Variables

Correlations among the textural characteristics of pastry wafers are shown in Table 20. Flakiness was positively correlated with both crust shrinkage and surface blistering scores; crust shrinkage, however, was not significantly correlated with surface blistering scores. Miller and Trimbo (1970) stated that the pie crusts that exhibited the most flakiness had also exhibited the most crust shrinkage and thickening during baking.

Breaking strength was not significantly correlated with flakiness or crust shrinkage, but was positively correlated with surface blistering scores. Matthews and Dawson (1963) found negative correlations between flakiness scores and

Table 20. Correlation coefficients among textural characteristics of pastry wafers.[1]

Source	Flakiness	Crust Shrinkage	Surface Blistering Score	Breaking Strength	Lightness	Redness	Yellowness
Flakiness	--						
Crust shrinkage	0.74	--					
Surface blistering score	0.47	n.s.	--				
Breaking strength	n.s.	n.s.	0.48	--			
Lightness	0.82	0.69	0.42[2]	n.s.	--		
Redness	-0.75	-0.65	n.s.	n.s.	-0.95	--	
Yellowness	n.s.	n.s.	n.s.	0.46[2]	n.s.	n.s.	--

[1] n=28; n.s. = not significant at α=0.01.

[2] Significant at α=0.05.

breaking strength values ($r=-0.83$ to -0.99 at $\alpha=0.01$). Miller and Trimbo (1970) found all combinations of flakiness and tenderness in pie crusts and concluded that "flakiness is not a requisite for tenderness."

Lightness values were positively correlated with flakiness, crust shrinkage and surface blistering scores; lightness values were negatively correlated with those for redness. Redness values were negatively correlated with flakiness and crust shrinkage. Yellowness values were positively correlated with breaking strength.

The pastry wafers having greater flakiness and crust shrinkage and, thus, probably more gluten development, appear to have undergone less browning, as indicated by lightness and redness values. Overall, flakiness, crust shrinkage, surface blistering and browning reaction were reliable indicators of gluten strength and development in pastry wafers. Breaking strength was inconsistent.

Correlations Between Dependent Variables and Flour Protein Content

Table 21 shows correlations between the textural characteristics of pastry and flour protein content. An extremely high correlation was found between flakiness and flour protein content ($r=0.96$ at $\alpha=0.01$). A pie crust baked from a high protein flour was found by Miller and Trimbo (1970) to be very flaky as compared with pie crust baked

Table 21. Correlations coefficients of flour protein content and percentage of gluten fractions with textural characteristics of pastry wafers.

Source	Flour Protein Content[1]	Percentage of Gluten Fractions Obtained[2]
Flakiness	0.96	n.s.
Crust shrinkage	0.81	n.s.
Surface blistering score	-0.82	n.s.
Breaking strength	-0.50[3]	0.58
Lightness	0.44[3]	n.s.
Redness	n.s.	n.s.
Yellowness	n.s.	n.s.

[1] n=4; n.s.=not significant at α=0.01.

[2] n=16 (compared with all single fraction reconstituted flour values); n.s.=not significant at α=0.05.

[3] Significant at α=0.05

from starch, but no protein. Crust shrinkage was positively correlated with flour protein content; this is also in agreement with Miller and Trimbo (1970).

Both surface blistering score and breaking strength were negatively correlated with flour protein content. Surface blistering would be expected to be greater in flours of higher protein content, since it indicates gluten strength. Also, pastry wafers baked from the higher protein flours would be expected to have higher breaking strengths, due to the potential for greater gluten development. Denton et al. (1933) and Miller and Trimbo (1970) found an inverse relationship between tenderness and flour protein content (a positive correlation between breaking strength and flour protein content). The breaking strength means for varietal flours had a pattern similar to that of the values for the parent flour, that is, Frankenmuth pastry was the toughest, and Tecumseh pastry, the most tender. Thus, Tecumseh flour was particularly anomalous with regard to breaking strength. When Tecumseh is excluded from the varietal flour mean data, the relationship between flour protein content and breaking strength is a positive correlation. That the negative correlation found among all four varieties is only significant at $\alpha=0.05$, reflects this. Therefore, it appears that the correlation between flour protein content and breaking strength of pastry wafers is variety dependent.

Lightness values were positively correlated with flour protein content, indicating that increased protein quantity did not increase crust surface browning, but rather the contrary. This finding is consistent with the positive correlations found between lightness and the flakiness, crust shrinkage and surface blistering scores of pastry wafers; these positive correlations suggested that greater gluten development concurred with less crust surface browning. Redness and yellowness values were not significantly correlated with flour protein content.

Correlations Between Pastry Textural Characteristics and Flour Fractionation Patterns

Among the single fraction reconst. flours, only breaking strength of pastry wafers was positively correlated ($r = 0.58$ at $\alpha = 0.05$) with the percentage of each gluten fraction obtained during fractionation. This means that an increase in the yield of a gluten fraction coincided with increased breaking strengths of pastry wafers baked from flour reconstituted from that gluten fraction alone. For example, the pastry wafers baked from pH 6.1-soluble reconst. flours had higher breaking strengths as compared with those wafers baked from pH 5.6-insoluble reconst. flours; among all varietal flours, a much greater percentage of pH 6.1-soluble material was yielded as compared with pH 5.6-insoluble material. The pH 4.7-insoluble reconst. flours

baked into pastries having higher breaking strengths; significantly larger amounts of pH 4.7-insoluble material were yielded from each varietal flour. Thus, the amount of gluten having gliadin-to-glutenin ratios that resulted in more tender pastry wafers, was small.

Effect of Fractionation/Reconstitution Procedures on Pastry Textural Characteristics

Finney (1943) stated that "for a wheat-flour fractionating technique to be of value, each of the fractions must retain its original characteristics to the extent that when a flour is reconstituted and the usual baking ingredients added it will yield a dough and loaf of bread identical (within experimental error) with that obtained from the original flour." In this case, textural characteristics of pie pastry baked from the whole crude gluten and A.F.R. flours should approximate those of the corresponding parent flour. By comparing the whole crude gluten and A.F.R. flours with the parent flours, the effect each fractionation procedure (gluten washing vs. isoelectric precipitation) has on textural characteristics of pastry can be seen.

From Figures 8 and 9, it can be seen that the flakiness of pastry wafers baked from A.F.R. flours more closely resembled those of the parent flours. Neither the whole crude gluten nor the A.F.R. flours yielded pastry wafers as flaky as those baked from the parent flours. However, the

isoelectric precipitation process appears to have partially restored the gluten functionality as defined by flakiness.

Crust shrinkage in pie pastry baked from the whole crude gluten and A.F.R. flours was lower than in pastry baked from the parent flours (Figures 10 and 11). The isoelectric precipitation process in this case caused a far greater deviation from crust shrinkage values of the parent flour. This seems inconsistent with the flakiness results.

Surface blistering scores, shown in Figure 12 and 13, were higher in the two reconstituted flours, as compared with the parent flour. The A.F.R. flours received much higher surface blistering scores than either the whole crude gluten or parent flours, however. This is inconsistent with the crust shrinkage results when both are viewed as measures of gluten strength.

Breaking strength values (Figures 14 and 15) were higher in both reconstitution types as compared with the parent flours. The A.F.R. flours deviated the most with regards to this variable.

Lightness values were significantly lower in both reconstitution types as compared with the parent flours (Figures 16 and 17), the greater difference being between the whole crude gluten and parent flours.

Redness values were greatly affected by both fractionation processes (Figures 18 and 19). Pastry baked from the parent flours had a greenish hue (-a values). A reddish

hue was detected on the surfaces of the pastry wafers baked from the whole crude gluten and A.F.R. flours. The whole crude gluten flours yielded pastry wafers with higher redness (+a) values, thus differing more from the pastry baked from the parent flours.

Yellowness values were significantly higher in pastry baked from both reconstitution types as compared with that baked from the parent flours (Figures 20 and 21); these values were just slightly, and not significantly, higher in the A.F.R. flours, when compared to the values from whole crude gluten flours.

These lightness, redness and yellowness results indicate that both fractionation processes resulted in greater crust surface browning in pie pastry. As compared with the parent flours, the whole crude gluten flours differed more in this respect. The isoelectric precipitation procedure appears to have reduced the surface browning potential somewhat.

Overall, the whole crude gluten flours provided a better model of the parent flour. The crust shrinkage, surface blistering score, and breaking strength results were more similar to those of the parent flours. The A.F.R. flours served as a better model with regards to flakiness and crust surface browning results.

The fractionation and reconstitution procedures did have an effect on the textural characteristics of pie pastry. Using a doughing step in the reconstitution procedure

(followed by lyophilization and grinding) could possibly restore the properties of the parent flour. Then again, the deleterious effect of a doughing step on cake structure, when combined with lyophilization and grinding (Donelson et al., 1960a), suggests that differences in pastry baked from reconstituted flours so treated could be greater.

Implications of the Data

The quantity and quality of protein in pastry flours have a tangible effect on the textural characteristics of pie pastry. From the correlation data, it can be seen that the quantity of protein influences the flakiness, crust shrinkage, surface blistering score, breaking strength and lightness of pastry wafers. The reconstitution type data shows that the quality of protein, as varies by gliadin-to-glutenin ratio, also influences these factors, plus the redness values of pastry wafers. The influence that the gluten fraction type used in the single fraction reconst. flours had on these textural characteristics, especially flakiness and crust shrinkage, indicates that gluten development does occur in pie pastry. The amount and type of gluten, as determined by both flour variety and reconstitution type, were probably largely responsible for the statistical differences found among types of pastry. The higher glutenin-containing flours (lower pH) yielded pastry that was less flaky, less shrunken, less blistered, with a

darker crust color. However, the pH 5.6-insoluble reconst. flour pastry was more tender than pH 4.7-insoluble reconst. flour pastry. Since the flour lipid was not extracted prior to fractionation this, too, could have influenced textural characteristics. The pH 5.6-insoluble gluten fraction had a noticeable greasy feel. Frazier et al. (1981) stated that the bound flour lipid was located with the high molecular weight glutenin. Possibly the flour lipid precluded the full extent of gluten development that might otherwise have occurred in the pH 5.6-insoluble reconst. flour dough.

Fractionation and reconstitution procedures themselves affect the textural properties of pie pastry. In this study, the properties of the parent flour were not restored within experimental error upon reconstitution. The additional fractionation by pH (isoelectric precipitation) step, in many cases, further changed the resultant textural properties of pie pastry.

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the functionality of soft wheat flour, particularly gluten quantity and quality, in pie pastry, using fractionation/reconstitution techniques. In fractionating the soft wheat flours, gluten was first washed out, and subsequently fractionated by pH (isoelectrically precipitated). Fractionation patterns of four varietal flours were compared. Flours were reconstituted to their original protein contents from whole crude gluten, and from the gluten fractions singly and all in their original proportions for the four varietal flours. Pie pastry was baked from these reconstituted, plus their parent, flours, and the textural characteristics - flakiness, crust shrinkage, surface blistering, breaking strength and crust surface browning (as lightness, redness and yellowness) were measured. The effects of both flour variety and reconstitution type on these textural characteristics were reported.

As the protein content of the flours increased, so did the percentage of gluten yielded and its corresponding protein content. Fractionation of gluten by pH revealed different patterns among the four varieties; Augusta was

particularly anomalous in this regard. For the other three varietal flours, as the flour protein content increased, the percentage by weight of each gluten fraction obtained, the percentage of total gluten protein and total flour protein contributed by each gluten fraction increased for the pH 4.7-insoluble material, and decreased for the other gluten fractions. Observations on the appearance of gluten fractions revealed that the lower pH fractions had the characteristic appearance of glutenin, whereas the higher pH fractions had an appearance characteristic of gliadin.

Results of the baking test for pastry indicated that reconstitution did not restore the original properties of the parent flours. Flakiness, crust shrinkage, surface blistering, breaking strength and crust surface browning were affected by both fractionation procedures. The isoelectric precipitation procedure generally contributed greater loss of the original flour properties.

Among the single pH fraction reconstituted flours, as pH increased, flakiness, crust shrinkage and surface blistering scores in pastry increased, whereas crust surface browning decreased. Breaking strengths were higher in the pastries baked from the pH 4.7-insoluble and pH 6.1-soluble reconst. flours (the extremes of pH), and highest in the latter.

Flakiness was found to be positively correlated with flour protein content, crust shrinkage and surface blistering scores. Both flakiness and crust shrinkage were

negatively correlated with crust surface browning.

Significant differences among varietal flours for flakiness and crust shrinkage could be attributed to differences in flour protein content. Breaking strength was found to be truly flour variety-dependent, since the highest protein flour yielded pastry having the lowest breaking strength. Among the other varietal flours, breaking strength could be positively correlated with flour protein content.

Overall, these data suggest that flour selection may be an important determinant of the textural characteristics of pastry. Additionally, higher protein flours may be used in pie doughs without undesirable toughness in pastry.

In the opinion of the author, among the parent flours, Tecumseh yielded pastry with the most desirable characteristics. Pastry wafers baked from Tecumseh parent flour were the most flaky, which is a favorable attribute. However, crust shrinkage was appreciably higher in this pastry type which is undesirable.

Surface blistering scores were more desirable in pastry from the reconstituted flours as compared with any parent flour; an intermediate score of ~3.0 would be ideal. With higher scores the surface blisters were burst. Among the parent flours, Hillsdale had the surface blistering score closest to the ideal. The score for Tecumseh was acceptable.

Strangely, the Tecumseh parent flours yielded the pastry with the lowest breaking strength. This pastry was not too fragile to make handling or serving a problem.

Crust surface browning was most desirable in the A.F.R. flours. Lightness values varied little among the parent flours. The Tecumseh parent flours yielded the most red wafers. Thus, even with the higher crust shrinkage the other desirable attributes of Tecumseh parent flour pastry made this type the most desirable.

In future investigations in the fractionation/reconstitution of soft wheat pastry flours, electron microscopy of pie doughs and pie pastry could possibly reveal additional information on the functionality of flour components. That pastry is a low moisture product would be advantageous for this type of work. Also, it remains to be determined what conditions are necessary for full restoration of the original flour properties, as determined by functionality in pastry, upon flour fractionation/reconstitution.

Agronomic studies, such as varying the level of nitrogen fertilization in order to alter protein contents within a variety, followed by pastry baking of the flours, could reveal much to the wheat growers. The effect on pastry of flours milled from wheats grown on different plots may also be of interest.

APPENDIX

Table 22. Agronomic and compositional data of varietal soft wheats.

Wheat Variety	1983 Yield[1] (Bu/acre)	Test Wt.[2] (lbs/bu)	Total Wheat Protein[2,3] (%)	Total Wheat Ash[2,3] (%)
Augusta	69.3	58.3	9.05	1.53
Hillsdale	68.9	60.7	9.50	1.57
Frankenmuth	67.0	60.6	10.17	1.68
Tecumseh	54.3	62.4	11.55	1.72

[1]Dr. E. Everson, Dept. Crop and Soil Science, Michigan State University, East Lansing, MI

[2]Soft Wheat Quality Laboratory, Wooster, OH.

[3]Reported on a 14% moisture basis.

Table 23. Experimental milling data for varietal soft wheats.[1,2]

Wheat Variety	Break Yield %	Straight Grade %	Flour Protein[3] %	Flour Ash[3] %
Augusta	34.1	76.7	7.9	0.40
Hillsdale	29.4	76.0	8.1	0.36
Frankenmuth	31.5	76.1	9.0	0.41
Tecumseh	27.6	77.7	10.6	0.40

[1]Soft Wheat Quality Laboratory, Wooster, OH.

[2]Allis-Chalmer milled flours.

[3]Reported on a 14% moisture basis.

Table 24. Experimental milling and baking data for varietal soft wheats and their flours.[1]

Wheat Variety	ESI[2] (%)	Friability[3] (%)	Cookie Diameter (cm)
Augusta	10.5	27.9	17.8
Hillsdale	11.6	27.0	17.8
Frankenmuth	10.6	26.5	18.1
Tecumseh	9.2	27.1	18.2

[1]Soft Wheat Quality Laboratory, Wooster, OH.

[2]Endosperm separation index (Yamazaki and Andrews, 1982).

[3]Percentage of flour obtained from break and reduction rolls as compared with total amount of stock fed into rolls (Andrews, 1986).

Table 25. Standard pie dough formulations used in the baking test for pastry.

Flour Types	Standard (g)		
	Flour	Shortening	Salt solution[1]
Augusta and Tecumseh 5.6-insoluble	20	8.2	5.2
Frankenmuth 5.6-insoluble	44	18.0	11.4
All varieties - whole crude gluten	60	24.6	15.5
Augusta 5.8-insoluble	70	28.7	18.1
All others	100	41.0	25.8

[1]6.98% salt

Table 26. Final moisture contents of humidified reconstituted flours.[1]

Reconstitution type	Moisture (%)			
	Augusta	Hillsdale	Frank.	Tecumseh
Whole Crude gluten	11.19	11.76	10.13	10.73
All Fractions Reconst.	11.18	12.02	10.23	11.19
pH 4.7-insoluble	11.82	10.41	10.15	10.66
pH 5.6-insoluble	10.38	10.09	12.78	10.86
pH 5.8/6.1-insoluble	11.33	10.14	10.78	11.72
pH 6.1-soluble	12.56	11.51	10.55	10.62

[1] n=2.

Table 27. Protein contents of reconstituted flours.[1]

Flour Type	Protein (%)		Error[2] (%)
	Experimental	Calculated	
Hillsdale pH 6.1 soluble	7.85	8.08	2.85
Frankenmuth pH 4.7-insoluble	9.25	9.01	2.66
Frankenmuth whole crude gluten	9.27	9.01	2.89
Tecumseh pH 4.7-insoluble	10.97	10.83	1.29
Tecumseh All Fractions Reconst.	10.51	10.83	2.95

[1] n=2; 20% random sampling.

[2] $\text{Error (\%)} = \frac{\text{Calculated - Experimental}}{\text{Calculated}} \times 100$

Table 28. Analysis of variance for flakiness.[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
V	3	0.77	0.258	6.59	.000
R	6	5.91	0.985	25.14	.000
VxR	18	1.40	0.078	1.99	.026
Error	56	2.19	0.039		

[1]V=flour variety, R=reconstitution type.

Table 29. Analysis of variance for crust shrinkage.[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F value	Probability
V	3	95.20	31.732	7.13	.000
R	6	836.31	139.384	31.30	.000
VxR	18	254.73	14.152	3.18	.000
Error	56	249.35	4.453		

[1]V=flour variety, R=reconstitution type.

Table 30. Analysis of variance for surface blistering scores.[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
V	3	0.96	0.321	1.13	.346
R	6	83.53	13.922	48.73	.000
VxR	18	7.99	0.444	1.55	.105
Error	56	16.00	0.286		

[1]V=flour variety, R=reconstitution type.

Table 31. Analysis of variance for breaking strength.[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
V	3	2.67	0.890	6.00	.001
R	6	11.53	1.921	12.95	.000
VxR	18	4.85	0.270	1.82	.045
Error	56	8.31	0.148		

[1]V=flour variety, R=reconstitution type.

Table 32. Analysis of variance for lightness ("L").[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
V	3	11.21	3.737	0.34	
R	6	2618.19	436.364	39.88	.000
VxR	18	517.20	28.733	2.63	.003
Error	56	612.73	10.942		

[1]V=flour variety, R=reconstitution type.

Table 33. Analysis of variance for redness ("a").[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
V	3	4.87	1.622	1.46	.235
R	6	303.75	50.626	45.57	.000
VxR	18	66.63	3.702	3.33	.000
Error	56	62.21	1.111		

[1]V=flour variety, R=reconstitution type.

Table 34. Analysis of variance for yellowness ("b").[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
V	3	15.79	5.264	10.09	.000
R	6	22.13	3.689	7.07	.000
VxR	18	28.36	1.575	3.02	.000
Error	56	29.22	0.522		

[1]V=flour variety, R=reconstitution type.

REFERENCES

REFERENCES

A.A.C.C. 1983. Approved Methods of the A.A.C.C. 8th ed. The Association, St. Paul, MN.

Abboud, A.M., Rubenthaler, G.L., and Hoseney, R.C. 1985. Effect of fat and sugar in sugar-snap cookie and evaluation of tests to measure cookie flour quality. Cereal Chem. 62:124.

Adams, C.F. 1975. Nutritive Value of American Foods In Common Units. Agriculture Handbook No. 456. U.S.D.A., Washington, D.C.

Alexander, G.L. 1939. Soft-wheat testing problems. Cereal Chem. 16:197.

Alsberg, C.L., and Griffing, E.P. 1927. The heat coagulation of gluten. Cereal Chem. 4:411.

Amendola, J. 1972. Pies. In: "The Bakers' Manual for Quantity Baking and Pastry Making". J. Amendola, ed. p. 91. Ahrens Publishing Co., New York, NY.

Andrews, L.C. 1986. Private communication. Soft Wheat Quality Laboratory, Wooster, OH.

Axford, D.W.E., and Elton, G.A.H. 1960. The mechanical development of bread doughs. Chem. Ind. (London) 1960: 1257.

Axford, D.W.E., McDermott, E.E., and Redman, D.G. 1978. Small-scale tests of breadmaking quality. Milling Feed Fert. 161(5):18.

Baker, J.C., Mize, M.D., and Parker, H.K. 1943. Measurement and significance of gluten quality. Cereal Chem. 20:506.

Beckwith, A.C., Nielsen, H.C., Wall, J.S., and Huebner, F.R. 1966. Isolation and characterization of a high-molecular-weight protein from wheat gliadin. Cereal Chem. 43:14.

Beckwith, A.C., Wall, J.S., and Dimler, R.J. 1963. Amide groups as interaction sites in wheat gluten proteins: Effects of amide-ester conversion. Arch. Biochem. Biophys. 103:319.

Békés, F., Zawistowska, U., and Bushuk, W. 1983. Lipid-mediated aggregation of gliadin. Cereal Chem. 60:379.

Bennet, R., and Ewart, J.A.D. 1965. The effect of certain salts on doughs. J. Sci. Food Agr. 16:199.

Bennion, M. 1980. Batters and doughs. In: "Introductory Foods", M. Bennion, ed., 7th ed., p. 400. MacMillan Publ. Co., New York, NY.

Berger, K.G. 1970. Fats as structural components of foods. Food Manufacture 45(5):60.

Bernardin, J.E., Kasarda, D.D., and Mecham, D.K. 1967. Preparation and characterization of α-gliadin. J. Biol. Chem. 242:445.

Bietz, J.A., Burnouf, T., Cobb, L.A., and Wall, J.S. 1984. Wheat varietal identification and genetic analysis by reversed-phase high-performance liquid chromatography. Cereal Chem. 61:129.

Bietz, J.A., and Wall, J.S. 1972. Wheat gliadin subunits: Molecular weights determined by sodium dodecyl sulfate-polyacrylamide gel electrophoresis. Cereal Chem. 49:416.

Bietz, J.A., and Wall, J.S. 1980. Identity of high molecular weight gliadin and ethanol-soluble glutenin subunits of wheat: Relation to gluten structure. Cereal Chem. 57:415.

Brenneis, L.S. 1965. Qualitative factors in the evaluation of cookie flours. Baker's Dig. 39(1):65.

Briant, A.M., and Snow, P.R. 1957. Freezer storage of pie shells. J. Am. Dietetic Assoc. 33:796.

Bushuk, W. 1985. Flour proteins. Structure and functionality in dough and bread. Cereal Foods World 30:447.

Bushuk, W., Tsen, C.C., and Hlynka, I. 1968. The function of mixing in breadmaking. Baker's Dig. 42(4):36.

Bushuk, W. and Zillman, R.R. 1978. Wheat cultivar identification by gliadin electrophoregrams. I. Apparatus, method and nomenclature. Can. J. Plant Sci. 58:505.

Butaki, R.C. and Dronzek, B. 1979. Comparison of gluten properties of four wheat varieties. Cereal Chem. 56:159.

Campbell, A.M. 1972. Flour. In: "Food Theory and Applications", P.C. Paul, and H.H. Palmer, eds. p. 616. John Wiley and Sons, New York, NY.

Cluskey, J.E., Taylor, N.W., Charley, H., and Senti, F.R. 1961. Electrophoretic composition and intrinsic viscosity of glutens from different varieties of wheat. Cereal Chem. 38:325.

Cole, E.W., Torres, J.V., and Kasarda, D.D. 1983. Aggregation of A-gliadin: Gel permeation chromatography. Cereal Chem. 60:306.

Davis, A.B. and Eustace, W.D. 1984. Scanning electron microscope views of material from various stages in the milling of hard red winter, soft red winter, and durum wheat. Cereal Chem. 61:182.

Denton, M.C., Gordon, B. and Sperry, R. 1933. Studies of tenderness in pastries made from flours of varying strengths. Cereal Chem. 10:156.

Dietrich, F.B. 1967. Relationship between pie dough formulation and crust quality. Baker's Dig. 41(2):83ab.

Dill, D.B. and Alsberg, C.L. 1924. Some critical considerations of the gluten washing problem. Cereal Chem. 1:222.

Dimler, R.J. 1963. Gluten - the key to wheat's utility. Baker's Dig. 37(1):52.

Doekes, G.J. and Wennekes, L.M.J. 1982. Effect of nitrogen fertilization on quantity and composition of wheat flour protein. Cereal Chem. 59:276.

Doguchi, M. and Hlynka, I. 1967. Some rheological properties of crude gluten mixed in the farinograph. Cereal Chem. 44:561.

Donelson, D.H. and Wilson, J.T. 1960a. Effect of the relative quantity of flour fractions on cake quality. Cereal Chem. 37:241.

Donelson, D.H. and Wilson, J.T. 1960b. Studies on the effect of flour-fraction interchange upon cake quality. Cereal Chem. 37:683.

Donelson, J.R., Yamazaki, W.T. and Kissell, L.T. 1984. Functionality in white layer cake of lipids from untreated and chlorinated patent flours. II. Flour fraction interchange studies. Cereal Chem. 61:88.

Dunn, J.A. 1930. Testing soft wheat flours for uses other than cake mixing. Cereal Chem. 7:372.

Eliasson, A.-C. and Hegg, P.-O. 1980. Thermal stability of wheat gluten. Cereal Chem. 57:436.

Everson, E. 1985. Private communication. Michigan State University, East Lansing, MI.

Everson, E.H., Wiess, M.V., Ellingboe, A.H., Trupp, C.R., Olien, C.R., Gallun, R. and Yamazaki, W.T. 1974. Registration of Tecumseh wheat. Crop Sci. 14:908.

Ewart, J.A.D. 1968. A hypothesis for the structure and rheology of glutenin. J. Sci. Food Agr. 19:617.

Ewart, J.A.D. 1973. Sodium dodecyl sulfate electrophoresis of wheat gliadins. J. Sci. Food Agr. 24:685.

Ewart, J.A.D. 1979. Glutenin structure. J. Sci. Food Agric. 30:482.

Finney, K.F. 1943. Fractionating and reconstituting techniques as tools in wheat flour research. Cereal Chem. 20:381.

Finney, K.F., Jones, B.L., and Shogren, M.D. 1982. Functional (bread-making) properties of wheat protein fractions obtained by ultracentrifugation. Cereal Chem. 59:449.

Fisher, E.A. and Halton, P. 1936. Observations on gluten washing. Cereal Chem. 13:575.

Frater, R., Hird, J.F.R., Moss, H.J. and Yates, J.R. 1960. A role for thiol and disulphide groups in determining the rheological properties of dough made from wheaten flour. Nature 186:451.

Frazier, P.J., Daniels, N.W.R. and Eggitt, P.W.R. 1981. Lipid-protein interactions during dough development. J. Sci. Food Agric. 32:877.

Funk, K., Zabik, M.E. and Downs, D.M. 1965. Comparison of shear press measurements and sensory evaluation of angel cakes. J. Food Sci. 30:729.

Gaines, C.S. 1985. Associations among soft wheat flour particle size, protein content, chlorine response, kernel hardness, milling quality, white layer cake volume, and sugar-snap cookie spread. Cereal Chem. 62: 290.

Gaines, C.S. and Donelson, J.R. 1985a. Effect of varying flour protein content on angel food and high-ratio white layer cake size and tenderness. Cereal Chem. 62:63.

Gaines, C.S. and Donelson, J.R. 1985b. Evaluating cookie spread potential of whole wheat flours from soft wheat cultivars. Cereal Chem. 62:134.

Gates, J.C. 1976. Pastry and pies. In: "Basic Foods", R. Gilbert, ed., p. 268-270. Holt, Rinehart and Winston, New York, NY.

Gortner, R.A. 1924. Viscosity as a measure of gluten quality. Cereal Chem. 1:75.

Graham, J.S.D. 1963. Starch-gel electrophoresis of wheat flour proteins. Australian J. Biol. Sci. 16:342.

Graham, J.S.D., Morton, R.K. and Raison, J.K. 1963. Isolation and characterization of protein bodies from developing wheat endosperm. Australian J. Biol. Sci. 16: 375.

Graveland, A., Bosveld, P., Lichtendonk, W.J., Moonen, H.H.E. and Scheepstra, A. 1982. Extraction and fractionation of wheat flour proteins. J. Sci. Food Agric. 33:1117.

Greenaway, W.T. and Watson, C.A. 1975. The Gluto-matic for semiautomatic determination of wet and dry gluten content of wheat flour. Cereal Chem. 52:367.

Greene, F.C. and Kasarda, D.D. 1971. Apolar interactions of α-gliadin: Binding of 2-p-toluidinylnaphthalene-6-sulfonate. Cereal Chem. 48:601.

Griffith, T. and Johnson, J.A. 1957. Relation of the browning reaction to storage stability of sugar cookies. Cereal Chem. 34:159.

Griswold, R.M. 1962. "The Experimental Study of Foods." p. 450. Houghton Mifflin Co., New York, NY.

Gruber, S.M. and Zabik, M.E. 1966. Comparison of sensory evaluation and shear-press measurements of butter cakes. Food Technol. 20(7):118.

Hamauzu, Z., Arakawa, T. and Yonezawa, D. 1972. Molecular weights of glutenin- and gliadin-polypeptides estimated by SDS-polyacrylamide gel electrophoresis. Agr. Biol. Chem. 36:1829.

Hänsel, H. and Seibert, L. 1978. The effect of breeding for baking quality on protein content and protein yield in winter wheat (IAEA-RC-5718). In: "Seed Protein Improvement By Nuclear Techniques". International Atomic Energy Agency, Vienna, Austria.

Hepburn, F.N. and Bradley, W.B. 1965. The amino acid composition of hard wheat varieties as a function of nitrogen content. Cereal Chem. 42:140.

Hirahara, S. and Simpson, J.I. 1961. Microscopic appearance of gluten in pastry dough and its relation to the tenderness of baked pastry. J. Home Econ. 53:681.

Hlynka, I. and Anderson, J.A. 1951. Further studies on the reaction of wheat proteins with reducing carbohydrates. Cereal Chem. 28:136.

Holme, J. and Briggs, D.R. 1959. Studies on the physical nature of gliadin. Cereal Chem. 36:321.

Hornstein, L.F., King, F.B. and Benedict, F. 1943. Comparative shortening value of some commercial fats. Food Research 8:1.

Hoseney, R.C., Finney, K.F., Shogren, M.D. and Pomeranz, Y. 1969a. Functional (breadmaking) and biochemical properties of wheat flour components. II. Role of water-solubles. Cereal Chem. 46:117.

Hoseney, R.C., Finney, K.F., Shogren, M.D. and Pomeranz, Y. 1969b. Functional (breadmaking) and biochemical properties of wheat flour components. III. Characterization of gluten protein fractions obtained by ultracentrifugation. Cereal Chem. 46:126.

Howard, B.D. and Morse, E.H. 1973. Muffins and pastry made with medium-chain triglyceride oil. J. Am. Dietetic Assoc. 62:51.

Huebner, F.R. and Wall, J.S. 1974. Wheat glutenin subunits. I. Preparative separation by gel filtration and ion-exchange chromatography. Cereal Chem. 51:228.

Huebner, F.R. and Wall, J.S. 1976. Fractionation and quantitative differences of glutenin from wheat varieties varying in baking quality. Cereal Chem. 53:258.

James, T.R. and Huber, L.X. 1927. A study of the physical properties of washed gluten. Cereal Chem. 4:449.

Jeanjean, M.F., Damidaux, R. and Feillet, P. 1980. Effect of heat treatment on protein solubility and visco-elastic properties of wheat gluten. Cereal Chem. 57:325.

Johnson, A.C. and Hoseney, R.C. 1979. Chlorine treatment of cake flours. III. Fractionation and reconstitution techniques for Cl_2-treated and untreated flours. Cereal Chem. 56:443.

Jones, R.W., Babcock, G.E., Taylor, N.W. and Senti, F.R. 1961. Molecular weights of wheat gluten fractions. Arch. Biochem. Biophys. 94:483.

Jones, R.W., Taylor, N.W. and Senti, F.R. 1959. Electrophoresis and fractionation of wheat gluten. Arch. Biochem. Biophys. 84:363.

Kasarda, D.D., Bernardin, J.E. and Gaffield, W. 1968. Circular dichroism and optical rotatory dispersion of α-gliadin. Biochemistry 7:3950.

Kasarda, D.D., Bernardin, J.E. and Nimmo, C.C. 1976. Wheat proteins. In: "Advances in Cereal Science and Technology", Y. Pomeranz, ed., Monograph Series, Vol. I. A.A.C.C., St. Paul, MN.

Kasarda, D.D., Nimmo, C.C. and Kohler, G.O. 1971. Proteins and the amino acid composition of wheat fractions. In: "Wheat: Chemistry and Technology", Y. Pomeranz, ed., 2nd ed., p. 227. A.A.C.C., St. Paul, MN.

Kasarda, D.D., Nimmo, C.C. and Kohler, G.O. 1978. Proteins and the amino acid composition of wheat fractions. In: "Wheat Chemistry and Technology", Y. Pomeranz, ed., 2nd ed. (Revised), A.A.C.C., St. Paul, MN.

Kent-Jones, D.W. and Amos, A.J. 1967. "Modern Cereal Chemistry", 6th ed. Food Trade Press, London.

Khan, K. and Bushuk, W. 1979. Studies of glutenin. XII. Comparison by sodium dodecyl sulfate-polyacrylamide gel electrophoresis of unreduced and reduced glutenin from various isolation and purification procedures. Cereal Chem. 56:63.

Khan, K., Hamada, A.S. and Patek, J. 1985. Polyacrylamide gel electrophoresis for wheat variety identification: Effect of variables on gel properties. Cereal Chem. 62: 310.

Khan, K., McDonald, C.E. and Banasik, O.J. 1983. Polyacrylamide gel electrophoresis of gliadin proteins for wheat variety identification - procedural modifications and observations. Cereal Chem. 60:178.

Kissell, L.T. 1959. A lean-formula cake method for varietal evaluation and research. Cereal Chem. 36:168.

Kissell, L.T. and Yamazaki, W.T. 1975. Protein enrichment of cookie flours with wheat gluten and soy flour derivatives. Cereal Chem. 52:638.

Knuepfer, W.H. 1960. Pie crusts and fillings. Proc. Am. Soc. of Bakery Engineers, p. 292-296.

Koenig, V.L., Ogrins, A., Trimbo, H.B. and Miller, B.S. 1964. The electrophoretic analysis of flour from several varieties of hard red winter wheat grown at several locations. J. Sci. Food Agr. 15:492.

Kramer, A. 1972. Texture - Its definition, measurement and relation to other attributes of food quality. Food Technol. 26(1):34.

Kress, C.B. (Chairman). 1932. Report of the subcommittee on pie-flour tests. Cereal Chem. 9:411.

Kress, C.B. (Chairman). 1936. Report of the 1935-36 committee on testing pie flours. Cereal Chem. 13:731.

Lawrence, J.M., Day, K.M., Huey, E. and Lee, B. 1958. Lysine content of wheat varieties, species, and related genera. Cereal Chem. 35:169.

Lawrence, J.M., Herrick, H.E. and Grant, D.R. 1970. Analysis of wheat flour proteins by polyacrylamide gel electrophoresis. Cereal Chem. 47:98.

Lookhart, G.L., Cooper, D.B. and Jones, B.L. 1985. Effect of temperature and alternate lactate buffer systems on resolution of wheat gliadin proteins by polyacrylamide gel electrophoresis. Cereal Chem. 62:19.

Lookhart, G.L., Finney, K.F. and Bruinsma, B.L. 1984. Polyacrylamide gel electrophoresis of wheat gliadins: the effect of environment and germination. Cereal Chem. 61:496.

Lookhart, G.L., Jones, B.L., Hall, S.B. and Finney, K.F. 1982. An improved method for standardizing polyacrylamide gel electrophoresis of wheat gliadin proteins. Cereal Chem. 59:178.

Lookhart, G.L., Jones, B.L., Walker, D.E., Hall, S.B. and Cooper, D.B. 1983. Computer-assisted method for identifying wheat cultivars from their gliadin electrophoregrams. Cereal Chem. 60:111.

Loving, H.J. and Brenneis, L.J. 1981. Soft wheat uses in the United States. In: "Soft Wheat: Production, Breeding, Milling, and Uses." W.T. Yamazaki and C.T. Greenwood, eds. A.A.C.C., St. Paul, MN.

Lowe, B. 1943. "Experimental Cookery", 3rd ed. John Wiley and Sons, New York, NY.

Maes, E.E.A. 1966. Protein solubility and baking quality. Cereal Sci. Today 11:200.

Maleki, M., Hoseney, R.C. and Mattern, P.J. 1980. Effects of loaf volume, moisture content, and protein quality on the softness and staling rate of bread. Cereal Chem. 57: 138.

Marais, G.F. and D'Appolonia, B.L. 1981. Factors contributing to baking quality differences in hard red spring wheat. I. Bases for different loaf volume potentials. Cereal Chem. 58:444.

Matthews, R.H. and Dawson, E.H. 1963. Performance of fats and oils in pastry and biscuits. Cereal Chem. 40:291.

Matz, S.A. 1972. Air-, steam-, and unleavened products. In: "Bakery Technology and Engineering", S.A. Matz, ed., 2nd ed., p. 174-177. AVI Publ. Co., Westport, CT.

McDermott, E.E. and Pace, J. 1960. Comparison of the amino-acid composition of the protein in flour and endosperm from different types of wheat, with particular reference to variation in lysine content. J. Sci. Food Agric. 11:109.

McDermott, E.E., Stevens, D.J. and Pace, J. 1969. Modification of flour proteins by disulfide interchange reactions. J. Sci. Food Agr. 20:213.

Mecham, D.K. 1968. The sulfhydryl and disulfide contents of wheat flours, doughs, and proteins. Baker's Dig. 42(1):26.

Meredith, O.B. and Wren, J.J. 1966. Determination of molecular-weight distribution in wheat-flour proteins by extraction and gel filtration in a dissociating medium. Cereal Chem. 43:169.

Mesdag, J. 1979. Genetic variation in grain yield and protein content of spring wheat (Triticum aestivum L.) In: "Crop Physiology and Cereal Breeding". J.H.J. Spietz and T.L. Kramer, eds. p. 166-167. Centre for Agricultural Publishing and Documentation, Wageningen, Holland.

Michigan State University. 1982. Mstat. A microcomputer program for the design, management and analysis of agronomic research experiments. Michigan State University, East Lansing, MI.

Miller, B.S. and Johnson, J.A. 1954. A review of methods for determining the quality of wheat and flour for breadmaking. Kansas Agr. Exp. Sta., Bull. No. 7.

Miller, B.S., Koenig, V.L., Trimbo, H.B. and Ogrins, A. 1964. Effects of cobalt-60 γ-irradiation and mechanical damage on soft wheat flour. J. Sci. Food Agr. 15:701.

Miller, B.S., Pomeranz, Y. and Afework, S. 1984. Hardness (texture) of hard red winter wheat grown in a soft wheat area and of soft red winter wheat grown in a hard wheat area. Cereal Chem. 61:201.

Miller, B.S. and Trimbo, H.B. 1970. Factors affecting the quality of pie dough and pie crust. Baker's Dig. 44(2): 46.

Miller, D., Nordin, P. and Johnson, J.A. 1957. Effect of pH on cake volume and crumb browning. Cereal Chem. 34:179.

Mitra, R.K., Bhatia, C.R. and Rabson, R. 1979. Bioenergetic cost of altering the amino acid composition of cereal grains. Cereal Chem. 56:249.

Nielsen, H.C., Babcock, G.E. and Senti, F.R. 1962. Molecular weight studies on glutenin before and after disulfide-bond splitting. Arch. Biochem. Biophys. 96:252.

Noble, I.T., McLaughlin, H. and Halliday, E.G. 1934. Factors influencing the apparent shortening value of a fat. Cereal Chem. 11:343.

Olewnik, M.C. and Kulp, K. 1984. The effect of mixing time and ingredient variation on farinograms of cookie doughs. Cereal Chem. 61:532.

Orth, R.A. and Bushuk, W. 1972. A comparative study of the proteins of wheats of diverse baking qualities. Cereal Chem. 49:268.

Orth, R.A. and Bushuk, W. 1973. Studies of glutenin. I. Comparison of preparative methods. Cereal Chem. 50: 106.

Osborne, T.B. 1907. The proteins of the wheat kernel. Carnegie Inst. Wash., Publ. 84, Washington, D.C.

Osborne, T.B. 1924. "The Vegetable Proteins." 2nd ed. Longmans, Green, and Co., London.

Ostrander, A.J., Abbott, J.K. and Campbell, A.M. 1971. Shortening power and related properties of fat as affected by substitution of elaidinized lipid. Baker's Dig. 45(2):28.

Peleg, M. 1983. The semantics of rheology and texture. Food Technol. 37(11):54.

Pence, J.W., Elder, A.H. and Mecham, D.K. 1951. Some effects of soluble flour components on baking behavior. Cereal Chem. 28:94.

Pence, J.W., Mohammad, A. and Mecham, D.K. 1953. Heat denaturation of gluten. Cereal Chem. 30:115.

Pence, J.W. and Olcott, H.S. 1952. Effect of reducing agents on gluten proteins. Cereal Chem. 29:292.

Platt, S.G. and Kasarda, D.D. 1971. Separation and characterization of α-gliadin fractions. Biochim. Biophys. Acta 243:407.

Pomeranz, Y. 1978. Composition and functionality of wheat-flour components. In: "Wheat Chemistry and Technology", Y. Pomeranz, ed. 2nd ed. (Revised), A.A.C.C., St. Paul, MN.

Pratt, D.B., Jr. 1963. Soft wheat flour. Air classification as a building block approach. Baker's Dig. 37(4): 40.

Pratt, D.B., Jr. 1978. Criteria of flour quality. In: "Wheat Chemistry and Technology", Y. Pomeranz, ed., 2nd ed. (Revised), p. 202. A.A.C.C., St. Paul, MN.

Preonas, D.L., Nelson, A.I. and Steinberg, M.P. 1967. Continuous production of pie dough. Baker's Dig. 41(6): 34.

Preston, K.R. and Tipples, K.H. 1980. Effects of acid-soluble and acid-insoluble gluten proteins on the rheological and baking properties of wheat flours. Cereal Chem. 57:314.

Pyler, E.J. 1973. Miscellaneous bakery products. In: "Baking Science and Technology." Vol. II. E.J. Pyler, ed., p. 1017-1022. Siebel Publ. Co., Chicago, IL.

Redman, D.G., Axford, D.W.E. and Elton, G.A.H. 1966. Mechanically produced radicals in flour. Chem. Ind. (London) 1966:1298.

Ronalds, J.A. and Winzor, D.J. 1969. Partial characterization of interactions in aqueous gluten extracts. Arch. Biochem. Biophys. 129:456.

Rose, T.S., Dresslar, M.E. and Johnston, K.A. 1952. The effect of the method of fat and water incorporation on the average shortness and the uniformity of tenderness of pastry. J. Home Econ. 44:707.

Rubenthaler, G., Pomeranz, Y and Finney, K.F. 1963. Effects of sugars and certain free amino acids on bread characteristics. Cereal Chem. 40:658.

Sandstedt, R.M., Jolitz, C.E. and Blish, M.J. 1939. Starch in relation to some baking properties of flour. Cereal Chem. 16:780.

Sapirstein, H.D. and Bushuk, W. 1985. Computer-aided analysis of gliadin electrophoregrams. I. Improvement of precision of relative mobility determination by using a three reference band standardization. Cereal Chem. 62: 372.

Schofield, J.D. and Baianu, I.C. 1982. Solid-state, cross-polarization magic-angle spinning carbon-13 nuclear magnetic resonance and biochemical characterization of wheat proteins. Cereal Chem. 59:240.

Shellenberger, J.A. 1982. Processing and utilization: Wheat. In: "C.R.C. Handbook of Processing and Utilization in Agriculture", Vol. II. I.A. Wolff, ed., p. 91-93. C.R.C. Press, Boca Raton, FL.

Shogren, M.D., Finney, K.F. and Hoseney, R.C. 1969. Functional (breadmaking) and biochemical properties of wheat flour components. I. Solubilizing gluten and flour protein. Cereal Chem. 46:93.

Simmonds, D.H. 1972. Wheat grain morphology and its relationship to dough structure. Cereal Chem. 49:324.

Smak, C. 1972. New approach to determine the brownness of bread crust. Correlation between crust color and protein content. Cereal Chem. 49:554.

Smith, E.E. 1925. Viscosity and baking quality. Cereal Chem. 2:177.

Sollars, W.F. 1956. A new method of fractionating wheat flour. Cereal Chem. 33:111.

Sollars, W.F. 1958a. Fractionation and reconstitution procedures for cake flours. Cereal Chem. 35:85.

Sollars, W.F. 1958b. Cake and cookie flour fractions affected by chlorine bleaching. Cereal Chem. 35:100.

Sollars, W.F. 1973a. Fractionation and reconstitution techniques for studying water-retention properties of wheat flours. Cereal Chem. 50:708.

Sollars, W.F. 1973b. Water-retention properties of wheat flour fractions. Cereal Chem. 50:717.

Sollars, W.F. and Rubenthaler, G.L. 1975. Flour fractions affecting farinograph absorption. Cereal Chem. 52:420.

Steel, I. 1977. The search for consistency in biscuit doughs. Baking Ind. J. 9:21.

Stenvert, N.L. and Kingswood, K. 1977. The influence of the physical structure of the protein matrix on wheat hardness. J. Sci. Food Agric. 28:11.

Stinson, C.G. and Huck, M.B. 1969. A comparison of four methods for pastry tenderness evaluation. J. Food Sci. 34:537.

Strbac, V.D., Ayers, G.S. and Ries, S.K. 1974. The protein fractions in chemically induced high-protein wheat seed. Cereal Chem. 51:316.

Swanson, C.O. 1924. Factors which influence the quantity of protein in wheat. Cereal Chem. 1:279.

Swartz, V. 1943. Effect of certain variables in technique on the breaking strength of lard pastry wafers. Cereal Chem. 20:120.

Szczesniak, A.S., Humbaugh, P.R. and Block, H.W. 1970. Behavior of different foods in the standard shear compression cell of the shear press and the effect of sample weight on peak area and maximum force. J. Texture Studies 1:356.

Tanaka, K. and Bushuk, W. 1972. Effect of protein content and wheat variety on solubility and electrophoretic properties of flour proteins. Cereal Chem. 49:247.

Tatham, A.S., Miflin, B.J. and Shewry, P.R. 1985. The beta-turn conformation in wheat gluten proteins: Relationship to gluten elasticity. Cereal Chem. 62:405.

Tsen, C.C. and Anderson, J.A. 1963. Determination of sulfhydryl and disulfide groups in flour and their relation to wheat quality. Cereal Chem. 40:314.

Tsen, C.C., Bauck, L.J. and Hoover, W.J. 1975. Using surfactants to improve the quality of cookies made from hard wheat flours. Cereal Chem. 52:629.

Tsourides, K.N. 1968. Quality control for the pie baker. 1. Ingredient specifications. Baker's Dig. 42(1):32.

Voisey, P.W. 1977a. Interpretation of force-deformation curves from the shear-compression cell. J. Texture Studies 8:19.

Voisey, P.W. 1977b. Effect of blade thickness on readings from the F.T.C. shear compression cell. J. Texture Studies 7:433.

Waggle, D.H., Lambert, M.A., Miller, G.D., Farrell, E.P. and Deyoe, C.W. 1967. Extensive analyses of flours and millfeeds made from nine different wheat mixes. II. Amino acids, minerals, vitamins, and gross energy. Cereal Chem. 44:48.

Walden, C.C. and McConnell, W.B. 1955. Studies on technics for reconstituting flours. Cereal Chem. 32:227.

Wasik, R.J. and Bushuk, W. 1974. Studies of glutenin. V. Note on additional preparative methods. Cereal Chem. 51:112.

Wehrli, H.P. and Pomeranz, Y. 1970. A note on the interaction between glycolipids and wheat flour macromolecules. Cereal Chem. 47:160.

Woychik, J.H., Boundy, J.A. and Dimler, R.J. 1961a. Starch gel electrophoresis of wheat gluten proteins with concentrated urea. Arch. Biochem. Biophys. 94:477.

Woychik, J.H., Boundy, J.A. and Dimler, R.J. 1961b. Amino acid composition of proteins in wheat flour. J. Agr. Food Chem. 9:307.

Wrigley, C.W. 1970. Protein mapping by combined gel electrofocusing and electrophoresis: Application to the study of genotypic variations in wheat gliadins. Biochemical Genetics 4:509.

Wrigley, C.W. 1980. The genetic and chemical significance of varietal differences in gluten composition. Ann. Technol. Agric. 29:213.

Wrigley, C.W., Autran, J.C. and Bushuk, W. 1982. Identification of cereal varieties by gel electrophoresis of grain proteins. In: "Advances in Cereal Science and Technology", Vol. V. A.A.C.C., St. Paul, MN.

Wrigley, C.W. and Shepherd, K.W. 1973. Electrofocusing of grain proteins from wheat genotypes. Ann. N.Y. Acad. Sci. 209:154.

Wu, K.-Y. and McDonald, C.E. 1976. Effect of nitrogen fertilizer on nitrogen fractions of wheat and flour. Cereal Chem. 53:242.

Wu, Y.V., Cluskey, J.E. and Sexson, K.R. 1967. Effect of ionic strength on the molecular weight and conformation of wheat gluten proteins in 3M urea solutions. Biochim. Biophys. Acta 133:83.

Yamazaki, W.T. 1950. The fractionation and reconstitution of soft winter wheat flours. Ph.D. Dissertation, Ohio State University, Columbus, OH.

Yamazaki, W.T. 1969. Soft wheat flour evaluation. Baker's Dig. 43:30.

Yamazaki, W.T. and Andrews, L.C. 1982. Small-scale milling to estimate the milling quality of soft wheat cultivars and breeding lines. Cereal Chem. 59:270.

Yamazaki, W.T. and Donelson, J.R. 1976. Effects of interactions among flour lipids, other flour fractions, and water on cookie quality. Cereal Chem. 53:998.

Zaehringer, M.V., Briant, A.M. and Personius, C.J. 1956. Effects on baking powder biscuits of four flour components used in two proportions. Cereal Chem. 33:170.

Zeleny, L. 1978. Criteria of wheat quality. In: "Wheat Chemistry and Technology", Y. Pomeranz, ed., 2nd ed. (Revised), p. 24-25. A.A.C.C., St. Paul, MN.

Zillman, R.R. and Bushuk, W. 1979. Wheat cultivar identification by gliadin electrophoregrams. III. Catalogue of electrophoregram formulas of Canadian wheat cultivars. Can. J. Plant Sci. 59:287.