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In Wheat Flour Dough and Bread Evaluation

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Nancy Cady Stachiw

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USE OF THE TEXTUREPRESS
IN WHEAT FLOUR DOUGH AND BREAD EVALUATION

By

Nancy Cady Stachiw

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ABSTRACT

USE OF THE TEXTUREPRESS IN WHEAT FLOUR DOUGH AND BREAD EVALUATION

By

Nancy Cady Stachiw

The Food Technology Corporation's texturepress was employed to assess physical dough properties, in order to predict bread quality. These measures were compared to standard extensigrams. Extensigraph and texturepress measurements were recorded for doughs from homogeneous batches of hard and soft flours in five treatment combinations consisting of sodium stearoyl-2-lactylate (SSL), potassium bromate, 1% and 2% NaCl and SSL and bromate. The thin slice tensile test cell, which consists of a horizontal work table embedded with staggered pins was used for texturepress readings. Yeasted bread doughs were prepared and evaluated for volume, compressibility, tenderness and tensile strength. The texturepress was sensitive to dough treatment interactions during the 45, 90 and 135 minute relaxation times. The texturepress showed a strong predictive relationship to extensigraph measures and to bread volume. R^2 values for bread volume predicted from texturepress measures ranged from .86 to .92 .

To Mike and my parents

for their love and support.

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INTRODUCTION

Wheat has long been cultivated as a source of food in the human diet. Evidence of cultivation by early man dates back to antiquity. It is generally believed that modern wheat evolved from a wild grassy type wheat found in the dry pasturelands of the Southern Mediterranean and Middle East. Cultivation most probably began in Syria - Palestine and spread to Greece and Persia. Carbon 14 dating shows that primitive wheat, einkorn and emmer was cultivated in Europe from 2000 B.C. on. (Matz, 1959.) By the Greco - Roman period, wheat production had advanced to a sophisticated level of agriculture. Wheat crossed many frontiers, including that to the new world as wheat cultivation was unknown in North and South America until it arrived with European explorers. Now, wheat is widely grown throughout the entire continent and has become a major food source.

Botanical classification places wheat into the grass family of Gramineae and genus Triticum. Of 18 species, several have economic and agricultural significance. Notably, T. vulgare is the species used for common bread flour.

Once wheat is milled, it is beneficial to the baker to be able to determine the quality of the protein and also its functionality. Upon hydration and manipulation, flour and water are converted to dough. This activity causes the gliadin and glutenin proteins, two of the four flour protein fractions to form a cohesive, elastic three dimensional structure called gluten. This stable gluten matrix is capable of expanding and entrapping air.

To determine how well a given flour will function in a certain food system, it is necessary to perform tests to evaluate its performance. Tests that subject dough to various stresses encountered in the bakery will facilitate evaluation. These so-called physical dough tests are invaluable tools in assessing quality.

The extensigraph, manufactured by the C.W. Brabender Company is often used to assess physical dough properties. It measures extensibility or the ability to stretch and resistance to extension. These values indicate the machinability and gas retention properties of the dough.

The Food Technology Corporation's Texturecorder or Allo-Kramer Shear Press, as it was formerly called, is an instrument used to determine a number of textural properties of food systems. The texturepress is commonly used in the food industry due to its adaptability to many products.

This investigation proposed to determine if ingredient effect on bread quality could be predicted from texturepress measurements of bread dough or if these measurements could be used to predict flour quality. In addition, it was determined whether these values could be related to extensigraph trends, which are well known to millers and bakers.

The mixing profile and water absorption capacity of untreated soft and hard wheat flours were measured by the Brabender farinograph. These flours, with combinations of oxidant (potassium bromate $KBrO_3$), conditioner (sodium stearoyl -2- lactylate SSL) and salt were uniformly mixed, forming doughs of varying strengths. Doughs were assessed by both the extensigraph and texturepress. Yeasted bread doughs were prepared on a limited number of samples, which were selected to give a broad range of rheological quality characteristics. The doughs were baked and evaluated for volume and tenderness, compressibility and tensile strength. These data were then analyzed to determine if a correlation between extensigraph and texturepress measurements existed and to ascertain whether texturepress values could be used to predict ingredient behavior on bread quality.

REVIEW OF LITERATURE

Significance of Wheat Production

Wheat as a food source is cultivated on every continent excluding Anartica in the world. Wheat production exceeds that of rice which is the second most grown crop. From Table 1. (FAO, 1984), wheat ranks first in the production of all cereal grains.

Table 1. 1983 World Cereal Production.

Cereal	10^6 tons
Wheat	499.8
Rice	449.8
Maize	344.4
Barley	168.2
Sorghum	63.6
Oats	43.3
Rye	32.2
Millet	29.9

FAO, 1984.

Wheat is a highly adaptable crop suitable for cultivation at different elevations, temperatures and soil conditions. Optimal growth occurs at about 23 ^{o}C with warm days, cool evenings and approximate yearly rainfalls of 23 - 75 cm. (Bushuk, 1986).

Table 2. (USDA FAS, 1984) shows the major world wheat producers from 1984 to 1985. United States production ranks third in the world behind China and the Soviet Union. The United States currently exports 37% of world wheat and wheat flour. Of this, about 12% is in the form of flour, the remainder as unmilled grain. Flour exports are shipped to Africa, Saudi Arabia and the Soviet Union (Kent, 1983).

Table 2. World Wheat Producers.

Country	10^6 tons
China	84
Soviet Union	75
EEC	74.2
United States	70
India	44.6
East Europe	38
Canada	21
Australia	17.3

USDA FAS, 1984.

Domestic consumption of wheat in the United States for 1978 totaled 22,834 thousand tons. Sixty-nine percent of the total went for human food.(Kent, 1983). Most wheat and wheat flour in the domestic industry are utilized in the human food sector in the form of bread, while 20% of domestic wheat is used for animal feed. Wheat for feed has steadily declined since the 1940's. This could possibly be due to government subsidy programs which increased the price of wheat, making use as feed an unattractive economic alternative to sale as human food.(Matz, 1969.) Roughly 10% of the total domestic wheat is used for seed.

In the United States, a program of enrichment was started for flour to increase the nutrient content of some nutrients that are decreased during processing. The Great Depression and subsequently World War II wreaked havoc on the nutritional as well as economic status of the country. The National Research Council (NRC), recommended that niacin, riboflavin, thiamin and iron be added to bread flour (Kent, 1983). Upon processing of white flour, the bran and germ which contain minerals and vitamins are removed which cause a reduction in nutrient density. Enrichment of flour was part of a program to maintain specific standard levels of these nutrients. The U.S. Food and Drug Administration determines the levels of enrichment which are monitored regularly. Usually premixed vitamin and mineral preparations are used (Schiller, 1984).

Botanical and Chemical Composition of Wheat

A wheat germ is generally oval shaped with light hairs (beard) at one end. The approximate size of a kernel varies, but is usually 5 - 8 mm in width and 5 - 15 mm in length. The wheat kernel is a naked caryopses which means that the pericarp or fruit coat which provides protection and the husk are removed during processing. In addition to the pericarp which is high in cellulose, there is the testa or seed coat which inhibits water movement in the kernel. These fractions are components of the bran which is high in fiber and the minerals phosphorus, calcium and magnesium. The aleurone layer overlaps as part of the bran and endosperm. It has high alpha amylase activity, high lipid content and contains phytic acid which binds minerals. The starchy endosperm is a source of energy reserve and is the largest constituent of the kernel. The starch is embedded in a protein matrix. The germ or embryo is the smallest component in the kernel. It is high in lipid and tocopherol which gives stability to the germ (Bushuk, 1986; Kent, 1983).

According to Matz (1959), "It is a general rule throughout the world that wherever wheat can be grown, it will be". Due to wheats extreme versatility, it can be grown in both temperate and harsh climates. The two types of wheat are therefore differentiated as winter or spring depending upon the season in which they are sown. Winter wheat is planted in late fall and remains in the ground over winter. This is the predominant wheat in moderate climates. Winter wheat is harvested in midsummer.

Spring wheat is planted in the spring and is common in Canada and the Soviet Union where extreme winter temperatures would damage young seedlings. Spring wheat varieties grow and mature rapidly yielding grain with high protein and a vitreous endosperm - desirable characteristics in bread flour (Kent, 1983).

Wheat can further be classified based on the strength of the flour it yields. The milling term "hard or soft wheat" is used to describe flours. Hard wheat flour has 11 - 13% protein, is free-flowing and of uniform endosperm particles. This flour is suitable for breadmaking. Soft wheat flour contains less protein, in the range of 7 - 9%, and is very fine with nonuniform starch granules. Crackers and cakes are produced from soft wheat (Kent, 1983).

If the whole wheat kernel is milled, this is a 100% extraction flour. It is slightly colored and has more ash, fiber and thiamin than typical white flour. White flour is based on a 72% extraction of the kernel and is 100% straight flour.

In order to understand how flour functions in a bread system, it is necessary to examine the constituents of the endosperm in detail. It is composed of 74.5% carbohydrate (predominantly starch), 12% water, 11.8% protein, 1.2% fat and 0.46% ash (Campbell, 1972).

Carbohydrate

Of several components that make up the carbohydrate fraction of the endosperm, the starch fraction is the most important. The physical structure of the starch granules consists of two distinct shapes. According to Stamberg (1939), the smaller granules have diameters averaging less than 15 u and constitute 88% of the total number of granules, but only 7% of the weight. The larger granules are lens-shaped, 15 - 30 u, account for 12% of the total number and 93% of the weight. Disbursed throughout these granules are polymers of D-glucose. Amylose, the linear alpha (1-4) polymer composes 25% of the starch and the remainder is amylopectin, the branched polymer with alpha (1-4) and alpha (1-6) links.

While insoluble in cold water, a starch granule will swell in the presence of heat, absorbing water and expanding until it bursts. This phenomenum is known as gelatinization. During bread baking the starch granules are partially gelatinized and interact with lipids and proteins (Campbell, 1972). Starch acts as a 'water sink' and through gelatinization, sets the bread system (Hoseney et al., 1978).

Other components in the endosperm include 0.4% cellulose, 2% pentosans and 2% sugars (Bushuk, 1986).

Although the cellulose is a major constituent in the bran of the wheat, most is removed from flour during processing. The pentosans are classified as hemicellulose and are present in greater levels in the bran. As reported by Campbell (1972) there are both water soluble and insoluble pentosans and the water soluble are important to rheological dough properties. In 1969, Hoseney et al. theorized that the hydrophillic pentosans immobilized free water and had an 'improving effect' on loaf quality.

Maltose is the predominant sugar in the endosperm. Glucose, fructose and sucrose are also present in small amounts (Campbell, 1972).

Lipid

Wheat flour lipids are composed of both nonpolar and polar elements in approximately equal amounts. Cherry (1982) reported that triglycerides (20.8%) are the major constituents in the nonpolar fraction. Glycolipids (26.4%) and phospholipids (22.7%) form the polar fraction. These lipids are essential to bread quality (Bushuk, 1986). The glycolipids apparently interact with gelatinized starch during baking.

Minerals and Vitamins

Greater processing and refining result in decreased ash content of flour. The chief minerals in unenriched flour are phosphate and potassium followed by magnesium and calcium, with trace amounts of iron, aluminum and sulfur. The B-vitamin complex present in whole wheat flour is lost during processing to white flour. Levels of selected B-vitamins and iron are raised to whole wheat standards by enrichment (Kent, 1983).

Protein

For a particular wheat cultivar, the protein content of the grain will be determined by environmental and agricultural elements. From Bushuk (1984), these controlling factors are soil nitrogen, soil moisture and seasonal growth temperatures. Furthermore, when subjected to a certain growth environment, some cultivars yield more protein than others. It appears though, that protein quality is genotypic and thus inherited.

Fractionation of wheat protein by their respective solubilities was first performed by Osborne in 1907. The flour proteins were classified into two broad categories. The first group is the soluble, non gluten proteins; the albumins and globulins. The second category is the insoluble, gluten forming proteins; prolamines and glutelins.

The albumins are water soluble, have molecular weights that range from 17,000 - 28,000 and account for 6 - 12% of the total protein. The globulins are soluble in dilute salt solutions, have a similar molecular weight and make up 5% of the total (Bushuk, 1986; Campbell, 1972).

These soluble proteins are composed of similar amino acid composition. They contain twice the amount of cystine than the insoluble proteins and also have greater asparagine. The globulins and albumins have less glutamine and proline versus the gluten proteins.

There is a discrepancy in the literature as to the importance of albumin and globulin to bread baking performance. Pomeranz (1980) stated "neither the globulins nor the albumins are essential to produce a normal loaf of bread". Campbell (1972) and Kent (1983) gave evidence that the albumins may contribute to baking flour quality and the globulins may be necessary to ensure optimal baking performance.

In 1745, the earliest isolation of gluten was performed by Beccari, an Italian chemist. Gluten is composed of prolamines, which are termed gliadin in wheat, and glutelins, which are called glutenin. The gliadin protein is soluble in dilute alcohol and possesses molecular weights ranging from 20,000 to 50,000. The glutenin proteins are soluble in dilute acid and base and have molecular weights from 50,000 to several millions (Campbell, 1972.; Kent, 1983).

The amino acid composition of the gluten forming proteins is characterized by high concentrations of glutamine, asparagine and proline. The free amide groups of glutamine and asparagine contribute to hydrogen bonding in the dough system (Holme, 1966).

The gliadin proteins are typed as extensible, with low elasticity and having intramolecular disulfide bonds. The glutenin proteins are described as elastic, with low extensibility and possessing both intra and intermolecular disulfide links (Holme, 1966; Campbell, 1972).

Gluten formation upon hydration and mixing of wheat flour is a unique phenomena. The flour particles are wetted, hydrate and form a continuous dough. Gluten proteins double their weight with water during hydration.

The exact role of the individual gluten protein remains as yet unclear. Pomeranz (1980) showed from reconstitution investigations that the gliadin protein dictated loaf volume and that glutenin was the fraction responsible for mixing time and dough development time. This has been challenged by Bushuk (1984), whose research has indicated that gliadin not glutenin controls loaf volume.

The gliadin and glutenin fractions in any case do contribute to functionality, even though the exact mechanism may not be understood. Wall (1979) reported that functional properties of cereal foods were established by the molecular structure of their proteins, interactions of the proteins with each other and with other components in the system. Functionality can be defined as properities of a food system that impart certain characteristics and functions other than nutrition.

Bread Dough System

Upon hydration and manipulation, flour and water are converted to dough. This activity causes the gliadin and glutenin proteins to form the cohesive and elastic structure gluten. Starch granules become embedded in the gluten framework during mixing and lend support to the gluten structural foundation. This stable gluten matrix is capable of expanding and entrapping air. Therefore it is essential that adequate dough development occur to ensure ideal performance in breadmaking. Measuring rheological parameters in a dough is necessary to determine this. Rheology is the study of flow and deformation of matter. It is comprised of elasticity, viscosity and plasticity.

Elasticity or the ability to stretch directly relates to desirable attributes in yeasted breads. Bohn and Bailey (1936b) described elasticity as the tendency to resume the original condition upon elimination of the applied force. Whereas matter exhibits plasticity when it does not recover its original shape upon discontinuation of the applied force. Doughs demonstrate both elastic and viscous properties. Doughs made from hard wheat flours are more elastic than soft flour doughs (Ewart, 1972). Viscosity is also determined by the protein present in the flour. This is why the protein content in wheat will establish its functional uses in food systems.

Protein content directly influences bread attributes. Pomeranz (1980) reported the correlation between wheat protein and loaf volume was r = 0.901. Therefore sufficient mixing is necessary for proper gluten development.

The unique molecular structure of gluten allows several types of bonding between the polypeptide chains. Reviewing chemical models of breadmaking, Cherry (1982) suggested, " that gluten consists of folded polypeptide chains in the alpha-helix conformation with their polar groups at the surface surrounding a hydrophobic center".

The chemical bonds of gluten protein may be summarized into four models which are covalent, ionic, hydrogen and

Van der Waals. Bloksma (1975) investigated the disulfide interchange which accounts for the covalent links between proteins.

Disulfide linkages in gliadin are predominantly intramolecular and those in glutenin are both intra and intermolecular. Thiol or SH groups are present primarily in the albumin protein fraction. Cystine and cysteine, which contain S-S groups, account for 1.4% of the amino acids in gluten. The ratio of disulfide to thiol in flour is approximately 7 - 15:1 (Campbell, 1972; Wehrli and Pomeranz, 1969).

During mixing, dough development is enhanced by thiol groups which stimulate the disulfide interchange reaction by reducing disulfide groups. Existing S-S bonds are broken and new links formed. Reactions between thiol and disulfide bonds result in the shifting and 'moving about' of the S-S links in the dough (Kent, 1983).

The presence of reducing or oxidizing agents affects dough rigidity. Cleavage and reformation of bonds is thought to occur when thiol groups are oxidized. This renders them unavailable to participate in the exchange reaction with the S-S groups, a stress releasing action (Bloksma, 1975; Wehrli and Pomeranz, 1969).

Wall (1979) concluded that high molecular weight glutenin and residual insoluble proteins with extensive intermolecular disulfide crosslinks were the significant elements contributing to the rigorous mixing stability necessary in bread making. However, a balance of all proteins was essential for optimal texture and volume.

Ionic bonds, which result from the attraction between opposite charges, also play an important role in gluten strength even though basic and acid moities on the amino acids are not as numerous as hydrophobic or amide side chains (Belitz et al., 1986). Approximately 7.3% of the gliadin amino acid residues and 9.3 of those in glutenin contain charges. The incorporation of sodiom chloride into most breads contributes ions (Wehrli and Pomeranz, 1969).

Belitz et al. theorized that the charged amino acids act as 'spacers' by forming ionic bonds and firming the gluten matrix from these additional cross-links. Charges on the amino acids in dough have also been postulated to complex with ionic side chains of lipids and pentosans (Wehrli and Pomeranz, 1969).

Hydrogen bonding in bread dough results from the high percentage of glutamine and asparagine. Their free amide side groups participate in hydrogen bonding. Although much weaker than covalent or ionic bonds, hydrogen bonds are so numerous in dough as to have a substantial impact on dough stability (Campbell, 1972). Wehrli and Pomeranz (1969) reported that most hydroxyl groups capable of hydrogen bonding are in starch. However, the starch granules are so tightly packed, that only the surface hydroxyls are capable of bonding.

Van der Waals forces originate from the balance of nonspecific attractions between two atoms as they near each other and the counter repulsion at close proximity. These bonds are not effective at distances greater than 4 angstrom. It is postulated that these bonds are significant in stabilizing the starch complex of dough (Acker and Schmitz, 1967).

Hydrophobic bonding between gluten protein and lipids is theorized to affect plasticity and elasticity of bread dough by stabilizing conformation. These type bonds may also play a role in baking when other chemical bonds are thermally weakened. Hydrophobic bonds endure until 60^{o} C thus influencing structure, especially oven spring (Wall, 1979; Wehrli and Pomeranz, 1969).

The fundamental requirement for 'good mixing'in dough formation is adequate and uniform distribution of ingredients. Bushuk (1966) recognized that mixing speed was dependent on size and hardness of the flour particles, and presence of sufficient liquid (based upon water absorption of the flour).

Tsen (1967) concluded that different flours responded to mixing differently and as a result, protein extractability changed. High speed mixing allowed greater extraction of glutenin proteins because mixing caused aggregates of gluten to develop which the author theorized made protein more accessible for extraction.

Soft wheat flours with less protein favor a rapid development as compared to harder flours. Bohn and Bailey (1936a) perceived that slack doughs resulted from excessive mixing, but that they tightened upon resting. Their research showed that overmixing a dough produced a poor quality loaf of bread and that high speed mixing tended to develop doughs with greater stress readings. The baking performance of doughs mixed at higher speeds was better than performance of doughs at lower speeds.

Bread System

Fermentation

After mixing and gluten formation, dough is allowed to repose. During this rest period called fermentation, yeast becomes quite active. Fermentation time is the function of the strength of the flour, quality of the protein and addition of ingredients.

Sufficient air incorporation by mixing is essential as no new air cells are formed by yeast production of CO_2. Rather, existing gas cells formed during mixing expand (Hoseney and Seib, 1978). Carbon dioxide diffuses into the air cells causing increased pressure. Due to the visco-elastic nature of dough, the cells swell, equalizing pressure (Hoseney, 1984).

Hoseney (1984) explained that mixing allows only one half an air cell's potential air incorporation. Punching of dough allows the subdivision of expanded bubbles to form the nuclei for more cells. Punching and dividing yields more cells that give bread its characteristic fine texture.

The strain of yeast involved in breadmaking is Saccharomyces cerevisiae. It ferments the sugars in dough to carbon dioxide and small amounts of ethanol. Magoffin and Hoseney (1974) explained that the fermentable sugars in dough are derived from three sources: 1) sugar native in the flour, 2) sugars from amylase enzymatic activity and 3) sugars added to the dough formulation.

When dough is baked, it expands and increases in size. It mushrooms to nearly its final volume during the first stages of baking. This rapid increase in volume from gas expansion is called oven spring (Hoseney and Seib, 1978). The capacity of gluten to entrap gas and expand is responsible for the increase in loaf volume.

Water is converted to steam upon elevation of temperature. Gluten stretches to accomodate this expanse. Enzymatic and yeast activity cease at 60° C. Gluten is denatured and forms the structure of the bread. Starch is partially gelatinized and as cited by Pomeranz (1969), contributes to the coherence of bread crumb.

Salt

The inclusion of salt into dough formulae has several beneficial effects. Salt exerts an osmotic effect on yeast, thus regulating fermentation (Campbell, 1972). It strengthens gluten, possibly through facilitating hydrophobic bonding, although the exact process is not fully understood (Magoffin and Hoseney, 1974; Wehrli and Pomeranz, 1969). Bushuk (1966) reported that salt does not effect hydration of starch but does influence hydration in gluten. Salt also enhances bread flavor and omission from the formulation causes a quick fermentation and tough crumb.

Sodium Stearoyl -2 - Lactylate

Sodium stearoyl-2-lactylate (SSL) is the salt produced from the reaction between the naturally occurring lactic and stearic acids. SSL is classified as a high activity dough conditioner.

Its beneficial action is thought to result from binding with flour protein fractions and or emulsifying the starch fraction (Tenney, 1978). Some of the improving effects of SSL are increased gas retention, greater dough strength and mixing tolerance, shorter proof time, higher volume, softer crumb and retarded staling (Kent, 1983; Knightly, 1973). SSL is more soluble than other types of similar commercial conditioners such as calcium stearoyl-2-lactylate (CSL) and more functional due to its superior dispersibility in water (Stutz et al., 1973).

Tenney (1978) conducted a baking study to test the effect of several dough conditioners. SSL incorporation resulted in superior response, producing the greatest loaf volume.

Potassium Bromate

Potassium bromate ($KBrO_3$) is a bread improver or oxidizing agent. It is generally used from 10 - 45 ppm of the flour weight and counters structural relaxation responses in bread dough (Kaufman et al., 1986).

Bromate is a slow acting oxidizer which enhances dough handling properties and increases dough elasticity. This causes increased gas retention, which improves volume and crumb texture. Oxidizers also impart a whitening effect to the bread crumb (Kent, 1983).

Treatment with bromate reduces the number of available thiol groups by oxidation. These SH groups are no longer accessible for interruption of the disulfide interchange which causes dough relaxation. Consequently, the dough is strengthened and is less extensible (Kent, 1983). Ewart (1972) reported that when an excess of oxidizer is added, the thiol level will become deleteriously low. The result is a dough that is too strong and tough and in jeopardy of being overworked.

A study by Tsen in 1968, observed that most thiol groups were oxidized by bromate in the initial stages of baking. Bloksma (1975) verified that improvers such as bromate do affect the removal of thiol groups by oxidizing the sulphydryls of cysteine.

Ascorbic Acid

Ascorbic acid also functions as an improver in wheat flour dough, although the mechanism of action is not fully understood. In the United States, no maximum level of use has been set for ascorbic acid due to its recognized safety as a vitamin (Kent, 1983).

Gluten is strengthened which improves loaf volume by the addition of small amounts of ascorbic acid in the ppm range. Kuninori and Matsumoto (1963) found that ascorbic acid (AA), a reducing compound was oxidized to dehydroascorbic acid (DHA) and in this form oxidized thiol groups in the wheat flour. This effect is similar to action by bromate (Tsen, 1965).

Kaufman et al. (1986) theorized that two enzymes present in wheat could be responsible for oxidizing ascorbic acid to DHA. L-ascorbate oxidase and glutathione dehydrogenase both catalyze the reaction, although the dehydrogenase is specific for glutathione only. Tsen (1965), reported that air will also cause the oxidation of AA to DHA during mixing thus increasing the improving effect.

Wheat Flour Dough/Bread Evaluation

Since inherent components in flour will determine its eventual functionality and effectiveness in a bread system, it is imperative to adequately measure and predict quality. Chemical tests such as ash, protein and moisture denote chemical composition but are not indicative of potential baking quality. Faubion and Faridi (1986) stated that two flours with the same protein and ash contents could perform entirely different when prepared and baked in a similar environment. Evaluation of rheological dough properties is more predictive of behavior. Rheological dough characteristics influence quality. Physical dough tests have been developed which mimic various stresses and conditions encountered in bread production. These type of tests are used to evaluate a flours potential performance.

Protein quality is fundamental to producing an optimal loaf of bread. According to Matz (1959), gluten quality measurement is composed of four principles, 1) expansion by heat, 2) recovery from compression, 3) gluten extension and 4) gluten relaxation. Hibbard and Parker (1975) reported that the purpose of rheological investigations of wheat doughs was, 1) to give a description of mechanical behavior, 2) relate rheological characteristics to structure and composition and 3) relate rheological parameters to performance. In order to characterize a flour these objectives must be addressed.

Farinograph

The Brabender farinograph is frequently employed as an indicator of mixing tolerance and water absorption capacity of a flour. Plasticity and mobility are measured as the dough is mixed under controlled conditions - constant rpm and temperature (Shuey, 1975). Information from the farinograph helps the baker determine how much water to add to the dough formulation and provides a mixing profile of the dough.

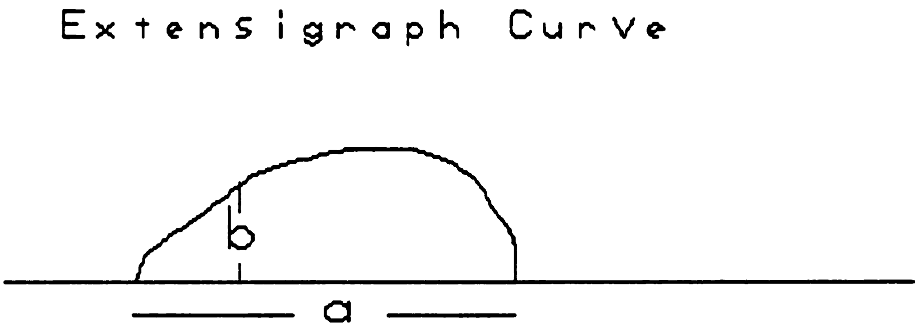
Near and Sullivan (1935) found that the water absorption of a flour depended upon the quantity and quality of gluten. Their research showed that ordinarily high protein flours had higher water requirements, but that flour streams with identical ash and protein could differ by as much as 5% in water absorption. Hylnka (1962) reported that there was a linear relationship between temperature and farinograph absorption. As temperature increased, dough mobility increased and the percent absorption of the experimental flours decreased. The addition of salt caused a decrease in absorption.

Geddes et al. (1940) investigated the relationship between normal farinograms and baking strength of Canadian hard wheat flour. Correlation coefficients between protein content and loaf volume were found the be $r = +.903$. Farinograph measurements were modified slightly and the researchers found the correlation between protein content and the dough development angle to be $r = -.735$. Protein content and departure which is an index to breakdown of the dough were correlated at $r = -.652$. The authors concluded that inclusion of farinograph measurements into regression equations already containing protein content did not enhance prediction of loaf volume.

Johnson et al. (1946) conducted a comparative study between the farinograph and the mixograph. They noted that protein content constituted the major influence on farinograph and mixograph curves. The area of the farinogram was found to be correlated to protein content which in turn could serve to aid in flour classification, or placing a flour into an appropriate food system.

Extensigraph

The extensigraph is an instrument which is also used to assess physical dough properties. It is designed to measure extensibility and the resistance to extension of a dough. A constant directional force is applied to a piece of dough which is extended until breakage (Shuey, 1975). An example of an extensigraph curve and the measurements that are recorded from it are found in Figure 1 which is adapted from Campbell, 1972. The ability of the dough to stretch 'a' is measured in mm and termed extensibility. The height of the curve 50 mm beyond the origin 'b' is the force counteracting the extension. This is the resistance to extension. The proportional number or ratio relates to the shortness of the dough. The smaller the ratio the greater the tendency of the dough to flow. To fully characterize the extensigram, the area is also recorded. Measurements from the extensigraph signify the machineability of the dough and gas retention potential during fermentation.



a = extensibility (mm)

b = resistance to extension (BU)

b/a = proportional number

Figure 1. Measurements recorded from an extensigraph curve. (Campbell, 1972.)

Grogg and Melms (1956) studied the effect of different salt levels and water absorption on physical characteristics of wheat flour doughs. It was found that by increasing the salt level, dough became more resistant to extension and as absorption increased, tension (resistance to extension) decreased. Also at any level of absorption, the addition of salt brought about an increased tension.

In 1949, Fisher et al. investigated the effects of mixing methods and varying salt content on extensigrams. Their research demonstrated that if the same amount of mixing is performed on a dough, the method of mix is unimportant. It was also found that rheological properties were influenced by mixing. Doughs from three different wheat types produced similar extensigrams even though mixed by different mixers.

Using extensigrams as a means for predicting baking performance, Munz and Brabender (1940) found that the ratio of resistance to extension to extensibility increased with the addition of potassium bromate. These workers theorized that since the area under the extensigraph curve was related to gluten content, the area could possibly be used to predict loaf volume. Merritt and Bailey (1945) added bromate to flour of various strengths. Extensibility for all flours, at all levels of bromate decreased over time, and resistance to extension increased. Maximal loaf volumes for the weaker flours were obtained at lower fermentation times. The higher protein flours required greater fermentations to achieve their highest volumes when baked into breads.

Munz and Brabender (1941) used the extensigraph as a means of characterizing flours from wheat cultivars with varying protein contents. The low protein pastry flour exhibited extensigraph curves that were low and long, these showing little resistance to extension and greater extensibility. Results from tests with hard wheat flour doughs were successfully correlated to baking performance.

Figure 2 illustrates typical curves a baker might encounter. Curve A shows a tight dough with the highest

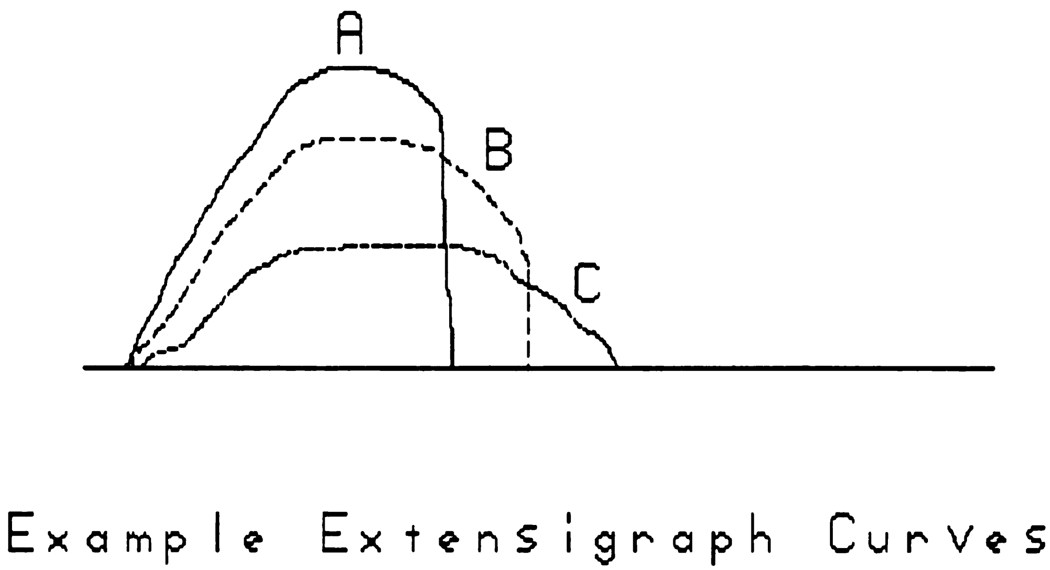


Figure 2. Extensigraph curves from three different dough types.

B.U. of resistance and the shortest mm of extension This dough is too elastic and unable to properly expand. It would have poor volume if baked into bread. Curve B is more ideal and if baked could expand and would have good volume. Curve C represents a soft weak dough with the least resistance to extension and greatest extensibility. It would produce a low volume bread if baked due to collapsed cells. The structure would be too weak to support expansion from fermentation.

Aitken et al. (1944) concluded that there appeared to be a relation between the area under the extensigraph curve and protein content. Increased protein content caused a large increase in extensibility and a slight increase in resistance to extension. The authors found a very significant correlation of r = .96 between extensibility and protein content. There was a significant correlation r = .77 between resistance to extension and protein content.

Halton (1949) concluded that "bread quality is a function of tensile strength and of the relaxation time of the dough". The extensigraph is a tensile testing instrument, but there is difficulty in interpreting the units of measure. Brabender Units (BU) for the extensigraph are not the same as those for the farinograph and other instruments. Levine (1987) expounded on this problem, and explained that the BU was not listed on any standard table as a measure of torque or force.

The extensigraph does not evaluate elasticity and viscosity. A hook is passed through a piece of dough at a constant force and the resistance to extension and extensibility are recorded. Fisher et al. (1949) stated that these measurements from the extensigraph are dependent upon elasticity and viscosity even though they are not direct measures of these properties. Extensibility and resistance to extension possess no independent meaning and are determined by the calibration and adjustments of the extensigraph, and the technique of the person performing the tests. In spite of these limitations, due to ease of operation and reliable results, the extensigraph is used widely in the milling and baking industry.

Texturecorder and Press TR5

The Food Technology Corporation's texturepress or shear press, is a texture measuring instrument which can be fitted with numerous test cells. Due to the ease of changing cells and the variety of determinations which can be performed, this instrument is commonly employed in the food industry. Cells are availiable such as the single blade shear cell which measures food properties such as tenderness and crispness. The texturepress can be equipped with the single blade meat shear cell for testing tenderness and bind in poultry and meats, the succulometer cell can be used to measure free fluids in vegetables which it extracts by compression. The multi-purpose universal cell can be utilized for extrusion of solid and fluid, back extrusion and as a viscosity measure. In cereal research the compression cell is often used as a compressibility index for cakes, and the standard shear/compression cell is used on a variety of baked foods to evaluate tenderness (Food Technology Corporation, 1983).

The texturepress has been used successfully in numerous studies to determine textural characteristics in several types of cookies, muffins and quickbreads (Cady et al., 1987; Dryer et al., 1982; Gorczyca and Zabik, 1979; Hoojjat and Zabik, 1984 and Vratanina and Zabik, 1978). Huffman et al. (1984) evaluated shear force and tensile strength of restructured beef steaks with the shear press. The multiple blade cell of the texturepress was also used in a study by Mast and MacNeil (1983) to determine the effects of kosher versus conventional processing of broiler chickens.

Gruber and Zabik (1966) utilized the shear press to determine compressibility, tensile strength and tenderness of butter cakes of varying standards prepared from commercial yellow cake mixes which were then compared to sensory evaluations. Strength of gels produced from frozen, spray dried and freeze dried eggs were evaluated using the fixed blade cell of the texturepress (Zabik and Figa, 1968). Schadle et al. (1983) investigated the quality of freeze dried carrot bars. Texture of the carrots was measured with the thin blade shear compression cell. The shear compression cell was also employed by Abou-Fadel and Miller (1983) in their research which studied the effects of thermally processed green beans and cherries in pouches versus processing in cans.

The thin slice tensile test cell (Model ST) of the texturepress was designed for tensile measurements of foods such as comminuted meats and cheeses (Food Technology Corportion, 1983). Thus far it has not been used as a physical dough evaluator. Tensile strength is recorded in pounds force (or kilograms force), and if shown to be practical could have potential in quality assessment.

EXPERIMENTAL DESIGN

This study proposed to determine if the effect of ingredient behavior on dough rheolgical properties could be measured with the texturepress, which heretofore had not been used for quality evaluations of flour doughs. Also it was investigated whether texturepress dough values related to extensigraph trends and had potential to measure optimal bread quality and be indicators of these factors.

For dough rheology testing, controlled sources of wheat flour were prepared into homogenous batches. The dough was divided in half, and each half was evaluated on a different instrument, the texturepress and the extensigraph. The extensigraph is being used as the current standard for fixing optimal dough properties in industry and research.

To obtain a wide range of measures, hard red wheat flour and soft white wheat flour were used. Doughs from these flours incorporating 1% salt were evaluated. The action of flour improvers: bromate at 20 ppm and sodium stearoyl-2-lactylate at 0.5% were tested as both single and double additives for both flour systems. The effects of salt at 2% in both dough systems also were determined. There a was total of 10 treatments or rather, five treatments for each flour type.

Eight treatment combinations were arranged in a 2^3 factorial design. The main effect of flour type, bromate and SSL were evaluated, as well as the interaction of these factors. Testing of each dough was executed following 45, 90 and 135 minute rest periods. To determine the effect of time and any interaction time might have with treatments, a split-plot design was demanded. Treatments served as the whole plot factor and time as the split of a randomized complete block split-plot design. The linear additive model for this design in which the factorial arrangement has been partitioned out of the treatment total would be:

$$Y_{i,j,k,l,m,} = u + R_i + A_j + B_k + (AB)_{j,k} + C_l + (AC)_{j,l} + (BC)_{k,l} + (ABC)_{j,k,l} + E_{i,j,k,l} + T_m + (AT)_{j,m} + (BT)_{k,m} + (ABT)_{j,k,m} + (CT)_{l,m} + (ACT)_{j,l,m} + (BCT)_{k,l,m} + (ABCT)_{j,k,l,m} + S_{i,j,k,l,m}$$

u = population mean

R_i = replication effect

A_j, B_k and C_l = main effect of factors A, B and C
A = flour type
B = addition of SSL
C = addition of bromate

$(AB)_{j,k}$ $(AC)_{j,l}$ $(BC)_{k,l}$ and $(ABC)_{j,k,l}$ = interaction of factors.

T_n = main effect of time.

$(AT)_{j,n}$, $(BT)_{k,n}$ $(ABT)_{j,k,n}$ $(CT)_{l,n}$ $(ACT)_{j,l,n}$ $(BCT)_{k,l,n}$, and $(ABCT)_{j,k,l,n}$ = interactions of treatment main effects and time.

$E_{i,j,k,l,}$ = $Error_a$

$S_{i,j,k,l,m,}$ = $Error_b$

Additional analyses included linear regression to test whether texturepress values alone or in combination could be used to predict extensigraph measures. The dependent variables Y being extensigraph values, were regressed on the X variables, or texturepress numbers. These type of analyses tested whether the characterization of extensigrams by texturepress readings was possible.

The population correlation coefficient rho was used to measure the strength of the association between texturepress measurements and extensigraph dough readings. The co-relation between values from these instruments was tested.

Four treatments from the initial 10 treatments were selected and baked into bread. These treatments were chosen to provide a broad range of bread volumes. The soft wheat flour dough as well as the hard red flour dough with 2% salt, the hard flour with SSL and the hard flour with SSL and bromate were prepared in three replications of a randomized complete block design. Three observations per treatment per block were performed. The pup loaves were evaluated for volume, specific volume, crumb tenderness, compressibility and tensile strength. Linear regression was used to examine the ability of the extensigraph and texturepress to predict the aforementioned bread properties. Correlations between measures from both these instruments and bread properties were also examined.

MATERIALS AND METHODS

To meet the objectives of this study, research was performed in four phases. These phases were: preliminary flour functionality and quality check, physical dough evaluation, baking tests and statistical analyses.

In the first phase, percentage protein was measured which serves as an index to potential bread quality and loaf volume. Prior to farinograph testing, moisture content of the flour was determined to adjust farinograph water absorption to the standard 14% basis. Two types of flours from controlled sources were employed. These were a soft white wheat flour and a hard red wheat four. Absorption and mixing stability were recorded which indicates the amount of water needed for dough formualtion and the mixing tolerance of each flour.

Based upon farinograph results, a homogeneous batch of dough was prepared and divided in half for the second phase of research. Dough properties were tested on the texturepress and simultaneously on the extensigraph.

Selected treatments were prepared as yeasted doughs and baked for phase three. Mix time, optimal fermentation and proof time were determined based upon farinograph and extensigraph results. Phase four consisted of statistical analyses including multiple linear regression to establish whether dough quality measures can predict bread quality.

Materials

Untreated hard red wheat flour was procured from The Pillsbury Company, Minneapolis, Minnesota. The flour was milled in Minneapolis on December 3, 1984. Product specifications as provided by Pillsbury listed: 14.00 $\pm$ .25% moisture, 0.49 $\pm$ .02% ash and 12.60 $\pm$ .25% protein. The hard flour was specially pulled from the milling process prior to normal commercial treatment of any kind.

Soft white wheat flour was purchased from the King Milling Company in Lowell, Michigan. The flour was milled from Michigan soft white wheat and trade-named "King Krust Flour". The flour was untreated and specifications provided by King Milling Company listed: 13.40% moisture, 0.43% ash and 8.67% protein. The pH of this flour was listed as 6.10.

Sodium stearoyl-2-lactylate, a dough conditioner with the trade name Emplex, was supplied by Patco Products, Kansas City, Missouri. Potassium bromate in the form of Bromette oxidation tablets was obtained from Cain Food Industries, Inc., Dallas Texas. Diastatic malt blend 33-1 was supplied by Sandoz Nutrition, Minneapolis, Minnesota.

L-ascorbic acid was purchased from Fisher Scientific Company, Fairlawn, New Jersey.

Iodized salt, sugar, Fleischmann's[R] active dry yeast, Carnation[R] nonfat dry milk and Crisco[R] vegetable shortening were all procured from Michigan State University Food Stores.

Chemical Analyses

Moisture

Moisture analyses were performed for both the soft white wheat flour and hard red flour. Triplicate 2.0000 gram samples were dried to a constant weight in a Hotpack Vacuum Oven, Model 633 (Hotpack Corp., Philadelphia, Pa.) at 100 ^{o}C in a partial vacuum of 27 mm of Hg for 6 hours according to AACC Method 44-40 (1983).

The dried samples were transferred to a desiccator until cooled (25 ^{o}C) and then weighed to the closest .0001 gram with a Mettler AE 166 Balance (Mettler Instruments Corp., Hightstown, N.Y.). Moisture was calculated from weight loss and expressed as percentage moisture of the original sample weight.

Protein

Analyses of protein in the soft and hard wheat flours were performed by the microkjeldahl method for total nitrogen determination. Duplicate 0.5 g samples were digested in sulfuric acid, sodium sulfate and copper sulfate at 400 - 500 ^{o}C until completion. Samples were transferred to a distillation apparatus (Buchii Kjeldahl Machine, Brinkman Instruments) and distilled according to AOAC Methods 2.057, 14.026 and 14.068. (1980.) Total protein was calculated based on percent nitrogen in the sample multiplied by a factor of 5.7 .

Farinograph Evaluation

Flours were evaluated for absorption and stability using a Farinograph, manufactured by C.W. Brabender Instruments, Inc. (Model PL-2H, Dynameter number 2092). A Thermobath (Type P 60-B) maintained at 30 $\pm$ .1 ^{o}C was used to regulate temperature of the mixing bowl.

AACC Method 54 - 21 A (1983) for constant flour weight procedure was followed. Moisture content of the hard and soft wheat flours were determined. Weight of the flour for testing was adjusted to 14% moisture content (based on moisture content of the flour) according to Table 82-23. The small 50 gram farinograph bowl was used. Upon addition of the flour to the bowl, the flour was mixed at high speed for 1 minute. Titrations were attempted until dough developments centering on the 500 B.U. line were achieved. All water was delivered within 25 seconds of mixing. The sides of the bowl were scraped using a plastic spatula. To prevent evaporation from occurring, the glass plate was lowered to cover the bowl. The fast speed setting (63 rpm) was used for mixing the hard flour. The speed was set at slow (45 rpm) for mixing the soft white flour. Farinograph evaluations were performed in triplicate.

Water absorption values were calculated on a 14% moisture basis by the following:

$$\text{Absorption } \% = 2(x + y - 50)$$

x = ml water
y = g flour used, equivalent to 14% mb.

The following values were recorded from farinograph curves:

Dough development time or peak time is an indication of dough consistency. It is the time required from the first addition of water to the point where the flour dough reaches its maximun peak before stabilizing along the 500 B.U. line.

Arrival time is indicative of flour strength. It is the time measured from the beginning of mixing until the curve reaches the 500 B.U. line recorded in minutes.

Stability is the difference in minutes between the the point where the curve first reaches the 500 B.U. line (arrival) and the point where the curve leaves the 500 B.U. line (departure time).

Extensigraph Testing

Water absorption from farinograph estimates were used in dough formulation. The procedure for extensigraph testing was adapted from AACC 54-10 (1983), modified for this study. An Extensograph Type E-1, number 762, manufactured by C.W. Brabender Instruments Inc. was employed for physical dough assessment. Temperature of the fermentation cabinet and homogenizers was regulated by the thermobath maintained at 30 $\pm$ 0.1 ^{o}C. Temperature and relative humidity of the laboratory were determined daily with a Meteorgraph Model M701 (Weather Measure Corp. Sacramento California).

Six-hundred grams of sifted flour were mixed in a Kitchen Aid K-5A mixer. NaCl was dissolved in the water, and if used, the bromate was prepared in a 20 ppm solution. When included, the SSL was sifted into the flour. Water used for making solutions was subtracted from the total water determined from farinograph absorption. Formulations for the 10 treatments are given in Table 3.

Table 3. Dough formulations for extensigraph and texturepress evaluation.

Treatments	Ingredients[a]					
	Water		Flour	Salt	Potassium Bromate	SSL
	SWF	HRF				
1, 6	56.8	65.2	100	1.0	-	-
2, 7	56.8	65.2	100	2.0	-	-
3, 8	56.8	65.2	100	1.0	20 ppm	-
4, 9	56.8	65.2	100	1.0	-	0.5
5, 10	56.8	65.2	100	1.0	20 ppm	0.5

[a] All ingredients listed on a % flour weight basis; ingredient weights were constant for the two types of flour except for the amount of water which varied as listed.

All liquid was added to the flour and mixed with the paddle attachment at speed 1 (142 rpm) for 30 seconds. The sides of the bowl were scraped and the dough was blended for 1 minute at speed 1 with the dough hook attachment. Mixing was stopped for 5 minutes and the bowl was covered during this rest period. Mixing was resumed for 2 minutes and 15 seconds at speed 2 for the hard flour and 2 minutes at speed 2 for the soft flour. The dough was divided in two, and one half the dough was scaled into three 150 gram pieces for extensigraph evaluation. The remaining dough was used for texturepress testing.

For extensigraph evaluation, the 150 gram pieces were rounded in the ball homogenizer for 20 rotations. Next, the dough ball was placed into the slot of the shaped homogenizer forming a cylinder of dough. Sticky doughs were dusted with rice flour. The cylinders were clamped into holders and placed into the extensigraph fermentation cabinets. The doughs were left to repose and then tested at 45, 90 and 135 minute intervals.

Testing was accomplished by measuring the ability of the dough to stretch and the amount of force it took to pull a hook through the dough at different stages of fermentaion. Following testing, doughs were remolded, rerolled and placed back into the fermentaion cabinet. The extensigrams were assessed for extensibility measured in millimeters, resistance to extension in B.U. (50 mm beyond the origin), peak height and area. Area (cm^2) was measured by means of a planimeter. The ratio or proportional number which is resistance to extension divided by extensibilty was calculated.

Texturepress Testing

Following mixing and division of dough for extensigraph evaluation, the remaining dough was partitioned into 3 pieces of approximate equal weight, 100 to 120 grams. These pieces were placed in holders and put into the extensigraph fermentation cabinet for 45 minute time intervals. After 45 minutes repose, the dough was sheeted to 3.5 mm and cut into 13 cm by 14 cm rectangles.

The three sample rectangles were placed on the thin slice tensile test cell (Model ST) of the Food Technology Corporation Model TR5 Texturepress (Rockville, MD.) for testing. This attachment is a horizontal work table embedded with staggered pins. The dough was stretched until breakage. The test cell has a 50 lb maximum pull and readings are measured as a percentage of the maximun pull and recorded as lbs force. The range for texturepress measurement was set at 1/10 for all treatments. Upon completion of testing, the stretched dough was weighed, reformed and put back into the fermentation cabinet.

Maximum height of the curve was used to calculate lbs force. Since all samples were weighed, a lbs force/g value was also determined. The point where the dough sample began to tear after the initial stretch was recorded, or if a tear was not evident, the point 50 mm from the origin was measured. Slope of the curve was computed and area of the curve calculated by the following linear regression equation:

$$cm^2 = -.22884 + 178.7803(wt)$$

wt = weight in grams of the texturepress curve

Evaluations were performed after the 45, 90 and 135 minute rest periods.

Baking Study: Preparation and Testing

Four selected treatments that represented a broad range of extensigraph and texturepress readings, were baked into bread from both hard and soft flours according to AACC Method 10-10A, the basic straight dough method. (1983). The formula used for this method, which involves the addition of all ingredients during the intial mixing action is given in Table 4.

Ascorbic acid and potassium bromate were prepared into solutions. Since neither the hard nor soft flours were malted at milling, a malt concentrate stock was prepared by centrifugation. All liquid added from solutions were deducted from the total water requirement. Yeast was hydrated with the sugar and one half the water for 5 minutes before incorporation. The salt was dissolved in the remaining water and solutions. The SSL was sifted in

Table 4. Bread formulations.

Ingredients[a]	Trt.2	Trt.7	Trt.9	Trt.10
	SWF	HRF	HRF	HRF
Flour	100.0	100.0	100.0	100.0
Salt	2.0	2.0	1.0	1.0
Sugar	6.0	6.0	6.0	6.0
Non-fat dry milk	4.0	4.0	4.0	4.0
Active dry yeast	4.0	4.0	4.0	4.0
Shortening	3.0	3.0	3.0	3.0
Water	47.0	55.3	55.3	55.3
Ascorbic acid[b]	40 ppm	40 ppm	40 ppm	40 ppm
Malt[b]	0.3	0.3	0.3	0.3
Potassium bromate[b]	-	-	-	20 ppm
Sodium Stearoyl - 2 lactylate	-	-	0.5	0.5

[a] All ingredients listed on a % flour weight basis.

[b] Contained in 5 ml of solution.

with the flour. Shortening and NFDM were also blended with the flour and SSL.

All ingredients were first blended with the paddle attachment of the KitchenAid K5A mixer for 10 seconds. The bowl was scraped with a spatula and mixing was continued with a dough hook attachment. The hard flour dough was mixed for 5 minutes 15 seconds and the soft white flour dough for 4 minutes and 30 seconds. Mix times were approximations based on farinograph results.

Following mixing, the temperature of the dough was recorded. Three 100 gram pieces of dough were scaled, shaped by hand and placed into a free-standing fermentation cabinet (National Mfg. Co. Lincoln, Nebraska) maintained at 30 ± 1 ^{o} C and 85% relative humidity.

The first knock-down occurred after 50 minutes from the initiation of mixing for the hard flour dough and 45 minutes for the soft flour dough. The doughs were degassed with a sheeter, folded into thirds and fermented again. The second punch was performed after 25 minutes for the hard dough and 30 minutes for the soft. Again the doughs were sheeted. Following a 10 minute repose, the doughs were sheeted, molded and panned. Hard flour doughs were proofed for 38 minutes and soft for 28 minutes. The proofed pup loaves were baked at 193. ^{o} C for 18 minutes in an Etco forced convection oven (Harvic Mfg. Corp. New York, N.Y.). The test loaves were cooled on wire racks for 1 hour. All evaluations were determined within 24 hours of baking.

Each pup loaf was weighed and volume was measured by rapeseed displacement with a loaf volumeter. Specific volume (cc/g) was also computed.

After volume testing, the loaves were uniformly sliced to 14 mm (setting 44) with a Hobart Slicer (The Hobart Mfg. Co., Troy Ohio). The crust was removed from the crumb and crumb samples were evaluated by three different cells of the texturepress.

Compressibility was measured with the compression test cell (Model CW-2) equipped with the 3000 lb transducer at a range of 1/30. The plunger of the cell is 5.5 cm in diameter. Crumb tenderness was assessed by the multiple blade standard shear - compression cell (CS-1), set at range 1/10. The thin slice tensile test cell (Model ST), the same cell used to evaluate dough samples, was also utilized for tensile measurements of bread crumb. For tensile readings, the range was set at 1/30.

Statistical Testing

All statistical analyses were performed on a Zenith 241 AT computer utilizing either SAS (1985), or SPSS (1986) statistical packages. The randomized complete block, split plot and the partitioning of the 2^3 factorial anovas for data from both the extensigraph and texturepress were computed using SAS ANOVA procedures. Multiple linear regression and calculation of the simple correlation coefficient were performed by SPSS. The randomized complete block design employed for the bread baking experiment was analyzed using the SPSS ANOVA procedures (Nie et al., 1975). Differences between means were determined significant by using the Least Significance Difference (LSD) method (Steele and Torrie, 1980).

RESULTS AND DISCUSSION

Proximate chemical analyses of the two flours revealed that the soft white wheat flour had a moisture content of 11.10 ±.05 percent and 8.65 ±.04 percent dry weight protein. The hard red wheat flour had 11.25 ±.03 percent moisture and 12.82 ±.04 percent dry weight protein. Moisture levels in flour are generally in the range of 12 to 14 percent which maintain flour integrity though it may not surpass 15 percent in the United States (Campbell, 1972). The protein levels measured for each flour type are well within normal limits for that particular variety (Campbell 1972; Kent 1983 and Munz and Brabender, 1941).

Farinograph

Means and standard deviations of farinograph measurements are given in Table 5. Arrival time measured the rate at which water was taken up by the flour and is an indicator of strength. The hard flour with a higher protein content had longer arrival times than the soft wheat flour. Flour absorption is recorded as the amount of water necessary to cause the farinograph to center on the

500 BU line. The hard flour had an absorption of 61.4% and the soft flour had 53.9%. These two flours were chosen to obtain a wide range of dough performance. As early as 1935, Near and Sullivan recognized that high protein flours had greater water requirements and that absorption and arrival time increased as protein content increased. In 1976, Volpe incorporated yeast protein isolate (YPI) into flour. She found increased hydration and absorption with increased substitution of YPI for flour.

Table 5. Means and standard deviations of farinograph measurements performed on hard red (HRF) and soft white (SWF) flours.

Farinograph Measure	SWF	HRF
Arrival Time (min)	0.66 ±.08	2.88 ±.13
Peak Time (min)	0.96 ±.15	5.39 ±.12
Departure Time (min)	2.33 ±.38	11.11 ±.35
Stability (min)	1.50 ±.25	8.43 ±.47
Absorption[a] (%)	53.90 ±.10	61.40 ±.15

n=3

[a] absorption expressed on a 14% moisture basis.

Peak time or maximum resistance was much greater for the hard flour than the soft wheat flour as was departure time, which is recorded when the curve leaves the 500 BU line. A long departure time shows how tolerant the flour will be to mixing; departure time also signals the beginning of the breakdown of the dough. The stability is the difference between the arrival and departure times. The hard flour had a stability of 8.43 min compared to 1.50 min for the soft flour. This indicated good mixability for the hard wheat flour. Long stabilty is vital in bread making where flour must stand up to intense mixing without deteriorating. Munz and Brabender (1941) tested several American wheat varieties with the farinograph. In this early study, they found that the soft white wheat flour from Michigan had an absorption of 52% and was characterized by a quick arrival and short stability. The hard flours with greater protein contents than the soft wheat flours demonstrated high absorbance, long stability, high peak times and long departures. They concluded that by examining farinograph data, one could obtain information on water absorption capacity, general strength and mixing sensitivity of flours. These factors are very important to bakers when making practical decisions in the bakeshop dealing with recipe formulation, mixing times and when selecting a flour for an appropriate food system.

Extensigraph and Texturepress Testing

A homogeneous batch of dough for each of the ten treatments was divided in two. One half of the dough was tested on the extensigraph and the other half evaluated on the texturepress. The ten treatments are described in the Materials and Methods, Table 3. Testing occurred at three time intervals of 45, 90 and 135 minutes. Absorption for each flour was kept constant.

The extensigraph measured the stretching capability of dough in millimeters of extensibility. The force counteracting the extension was recorded as resistance to extension (BU) and the maximum resistance was recorded as peak resistance (BU). The ratio of these values characterized the shortness of the dough and, the area or energy (cm^2) represented the total force required for dislocating the dough.

Values that were recorded from texturepress readings are illustrated by Figure 3. The highest point or maximum height of the curve was used to calculate a lbs force reading which represented the maximum pull to stretch the dough until breakage. Due to the nature of the worktable, tearing occurred following the intitial stretch of dough. The tear was identified by a slight dip in the curve from the reduction in force. If a tear (lbs force) was not distinguishable, then the value 50 mm beyond the origin was measured. The slope of the curve and area (cm^2) were also determined. The weight in grams of the dough test pieces were measured and a lbs force/g value was calculated.

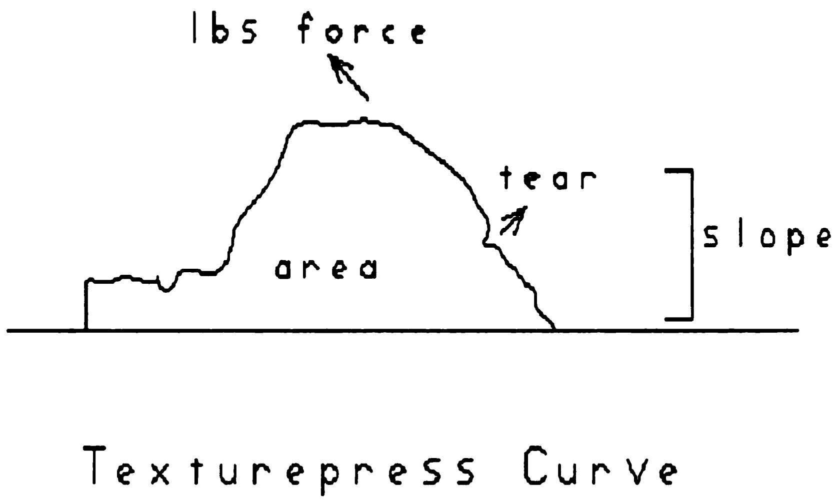


Figure 3. Example curve and measurements recorded from the texturepress.

Maximum Resistance and LBS Force

Figures 4 and 5 graphically show the means for extensigraph maximum resistance measurements performed on doughs from the hard red (HRF) and soft white (SWF) flours. There was a general increase in maximum resistance over time for most treatments. Research by Halton (1949) showed that the height of the curve or maximum resistance increased with increased age of the dough. The hard flour doughs exhibited much greater resistance for all treatments when compared to the soft flour doughs. Aitken et al. (1944) found that increased protein content caused an increase in the height of the extensigraph curve in doughs prepared from flours with 11.1 to 14.4% protein. The addition of 2% NaCl resulted in doughs producing the highest resistance in soft wheat doughs and the second highest in hard wheat flour doughs. Fisher et al. (1949) studied the effects of salt on extensograms and concluded that increased salt content increased maximum resistance and that weak and strong flours responded differently to salt. The double additive effect of bromate and sodium stearoyl-2-lactylate caused doughs to demonstrate the greatest maximum resistance in hard wheat flour doughs and second greatest in soft wheat flour doughs. For both flour types, the 1% NaCl treatments produced the weakest doughs having the least resistance to stretching by the extensigraph dough hook. The soft flour doughs plus 1% NaCl showed little change over time and slightly decreased in maximum resistance which could signify a breakdown in the dough's cohesive forces.

The lbs force readings from the texturepress represented the maximum force required to stretch doughs on that instrument. The means are illustrated by Figures 6

Figure 4. Influence of treatment on maximum resistance of soft white flour (SWF) doughs measured by the extensigraph.

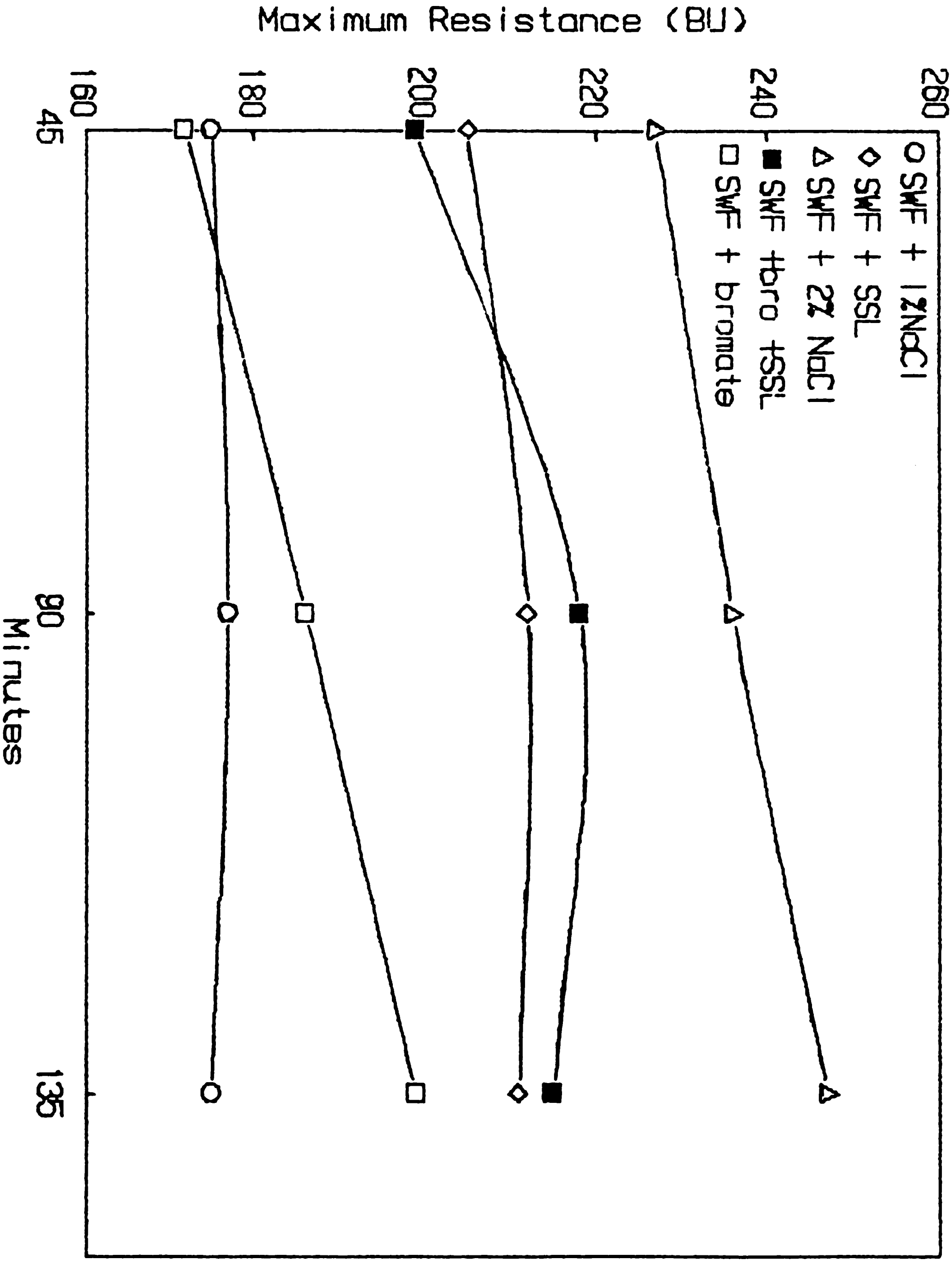
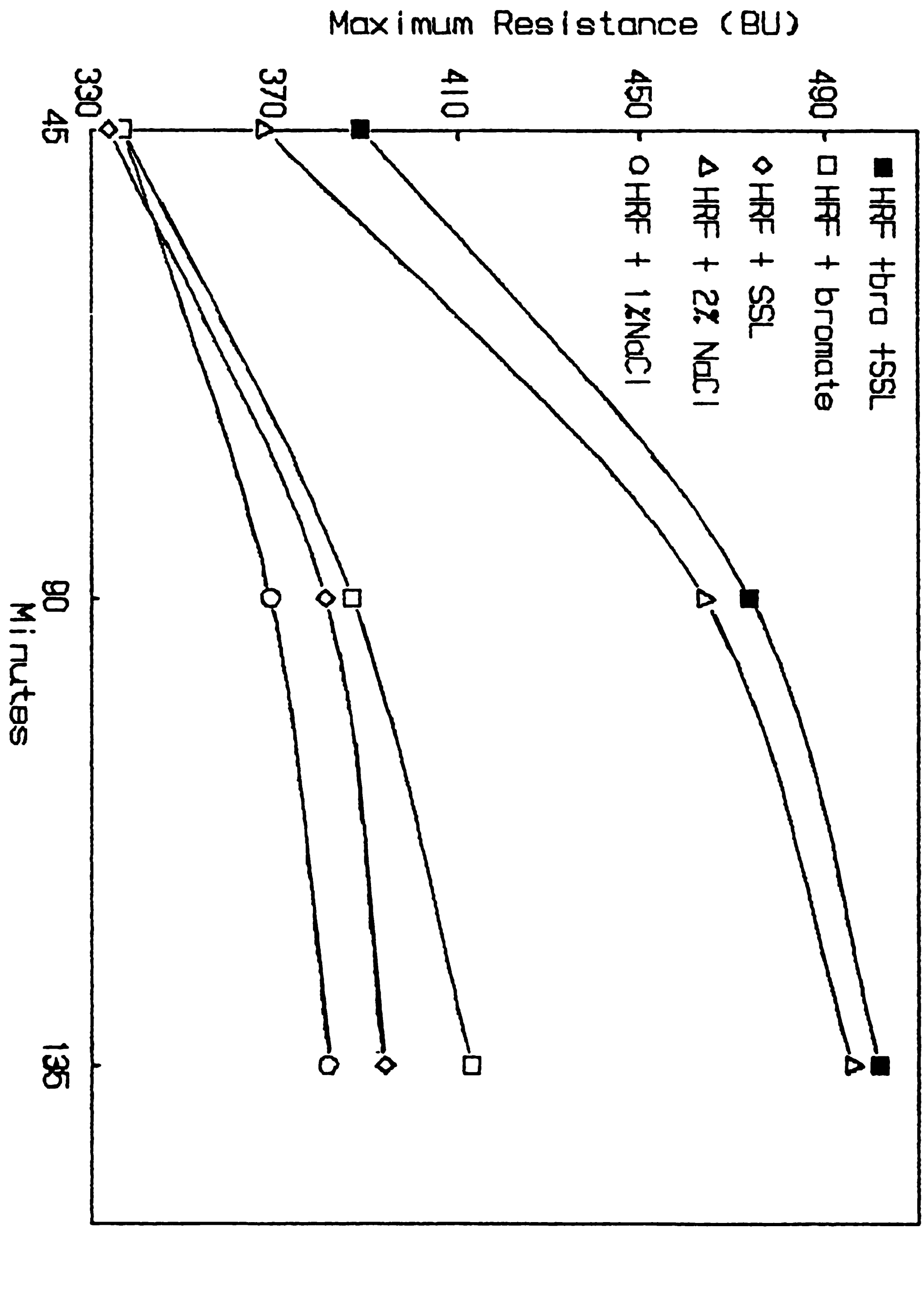

Maximum Resistance (BU)
260
240
220
200
180
160
45
90
135
Minutes
○ SWF + 1%NaCl
◇ SWF + SSL
△ SWF + 2% NaCl
■ SWF +bro +SSL
□ SWF + bromate

Figure 5. Influence of treatment on maximum resistance of hard red flour (HRF) doughs measured by the extensigraph.


Maximum Resistance (BU)
Minutes
330
370
410
450
490
45
80
135
HRF +bro +SSL
HRF + bromate
HRF + SSL
HRF + 2% NaCl
HRF + 1%NaCl

and 7. As also had been seen on the extensigrams of these two dough systems there was an overall trend of increased force with increased time. Fisher et al. (1949) described the stretching process as a breakdown in a doughs bonding forces. A stress is applied and as stretching commences, there is a rise in the curve. At random places in the dough, the stress becomes too great and cohesive forces between molecules are broken. The curve falls and the dough tears as tensile strength is surpassed. The hard and soft flours treated with the double additives bromate and SSL recorded the largest lbs force values at 90 and 135 minutes. The doughs with 2% NaCl exhibited intermediate lbs force readings for both flours. The soft flour plus 1% NaCl and the hard flour plus bromate demonstrated the lowest measurements in their flour type group. The lbs force readings from the texturepress, particularly from the hard flour doughs were spread over a much narrower range of values at a given time when compared to the extensigraph maximum resistance numbers. This could mean the texturepress was less sensitive to treatment differences. However the texturepress appeared more sensitive to measuring differences in individual treatments over time.

A dough is expected to demonstrate an increase in resistance upon repose (Munz and Brabender, 1940; Merrit and Bailey, 1945). Increases in resistance indicate how

Figure 6. Influence of treatment on lbs force readings of soft white flour (SWF) doughs measured by the texturepress.

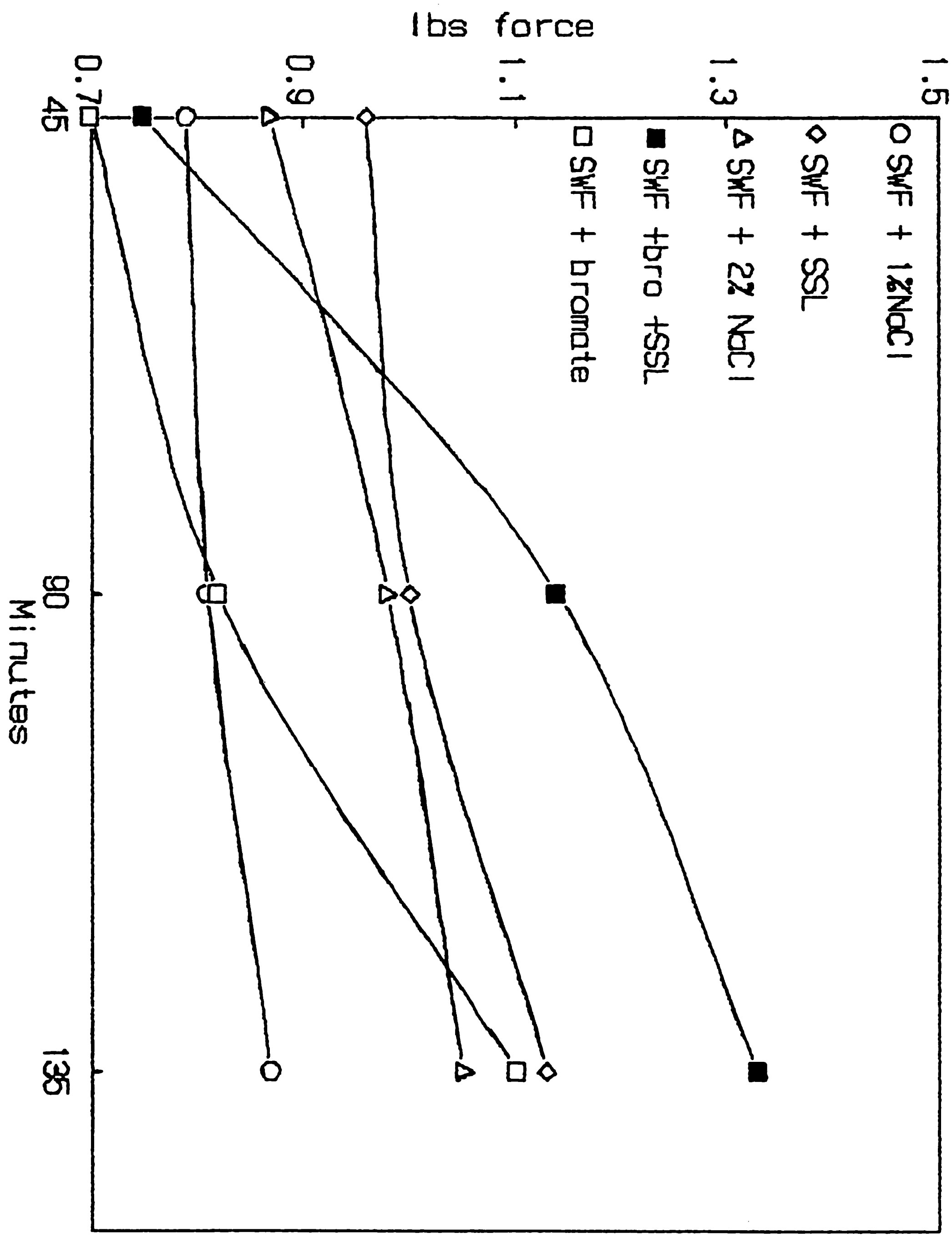
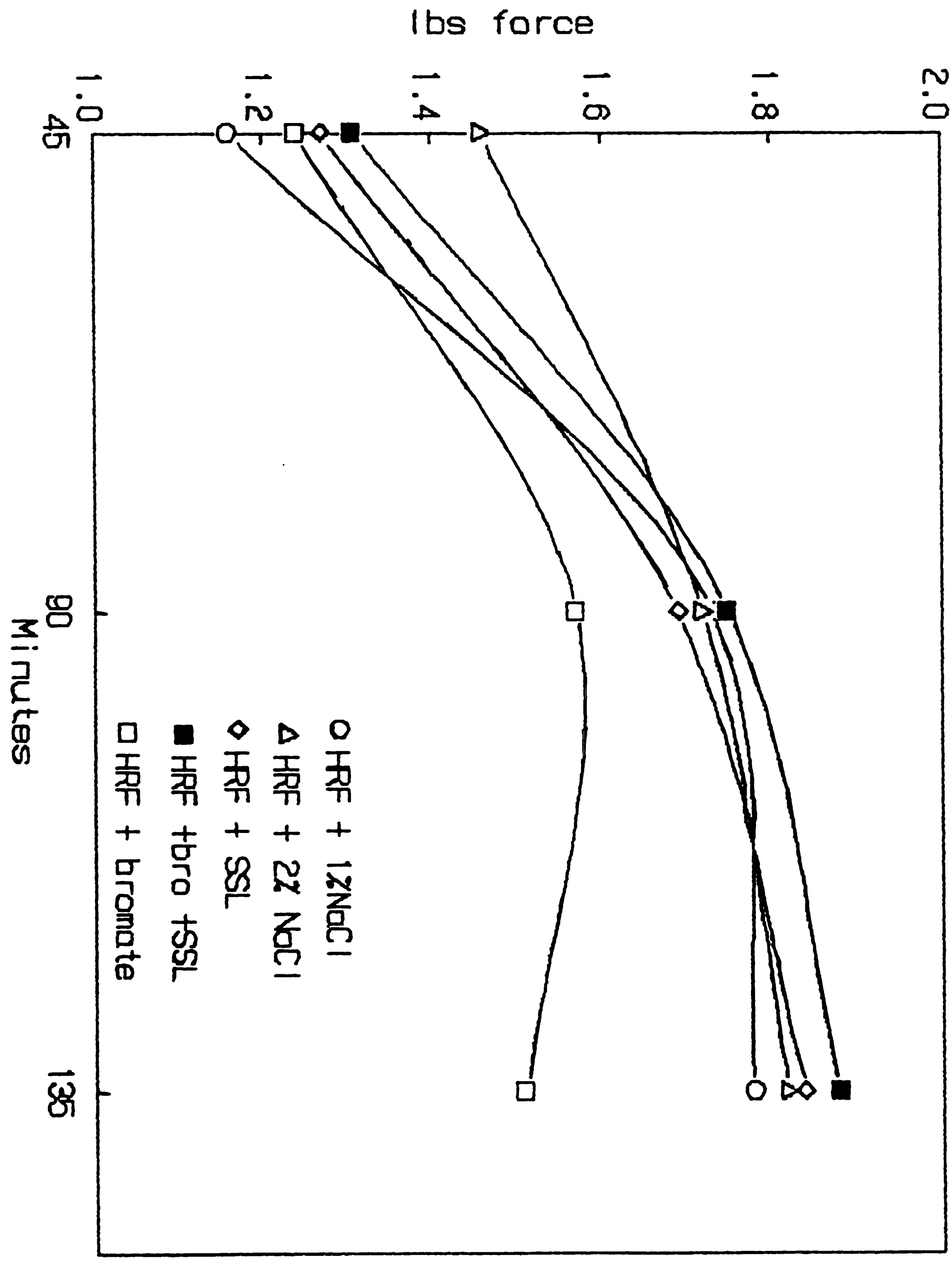

lbs force
1.5
1.3
1.1
0.9
0.7
45
90
135
Minutes
○ SWF + 1%NaCl
◇ SWF + SSL
△ SWF + 2% NaCl
■ SWF +bro +SSL
□ SWF + bromate

Figure 7. Influence of treatment on lbs force readings of hard red flour (HRF) doughs measured by the texturepress.


lbs force
1.0
1.2
1.4
1.6
1.8
2.0
45
90
135
Minutes
HRF + 1%NaCl
HRF + 2% NaCl
HRF + SSL
HRF +bro +SSL
HRF + bromate

the dough will react during fermentation, moulding and final proofing. Just as the extensigraph was sensitive to changes occurring in the dough during the rest intervals, the texturepress was also capable of detecting change.

Resistance to Extension and Tear

Figures 8 and 9 show the effect of treatment on resistance to extension values for doughs prepared from the hard and soft flours. The range of measurements for the soft flour treatments which exhibited only a slight increase in resistance over time was narrow when compared to the range for the hard flours. The incorporation of 2% NaCl and additives slightly increased resistance in these soft flour doughs, but due to the weakness of these doughs from their low gluten content the curves were basically flat.

The hard flour doughs increased their resistance to stretching over time as they became stronger and the gluten developed. The dough with bromate and SSL exhibited excellent tolerance to resistane (stand-up) as did the 2% salted dough. Grogg and Melms (1956) demonstrated that at any flour absorption, addition of NaCl resulted in increased resistance to extension. The range of values from the low resistance readings in the soft wheat doughs

Figure 8. Influence of treatment on resistance to extension of soft white flour (SWF) doughs measured by the extensigraph.

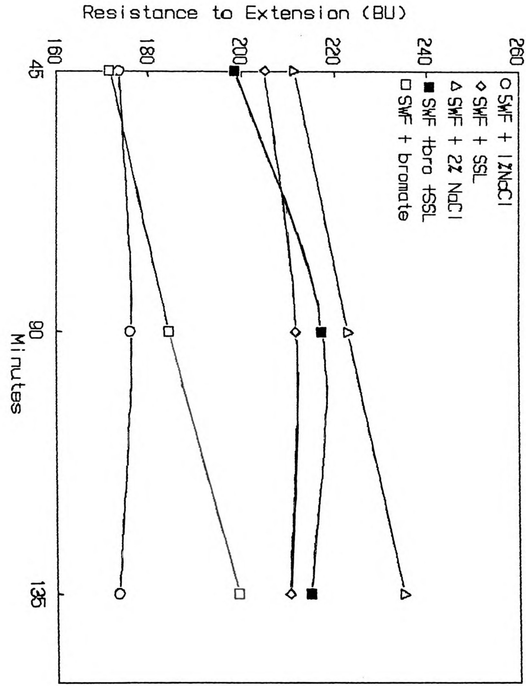
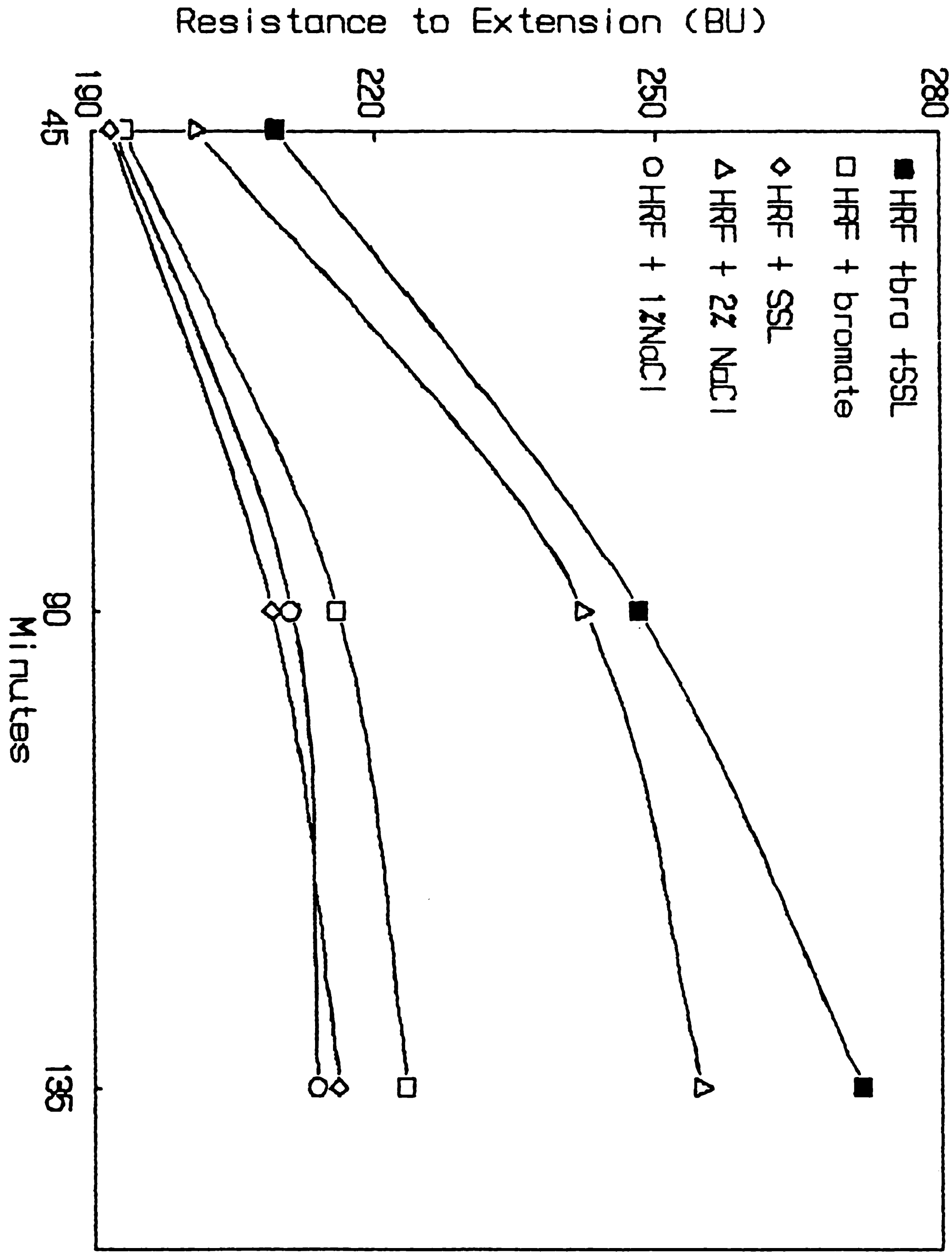

Resistance to Extension (BU)
260
240
220
200
180
160
45
90
135
Minutes
○ SWF + 1%NaCl
◇ SWF + SSL
△ SWF + 2% NaCl
■ SWF +bro +SSL
□ SWF + bromate

Figure 9. Influence of treatment on resistance to extension of hard red flour (HRF) doughs measured by the extensigraph.


Resistance to Extension (BU)
Minutes
280
250
220
190
45
90
135
HRF +bro +SSL
HRF + bromate
HRF + SSL
HRF + 2% NaCl
HRF + 1%NaCl

to the high resistance values in the hard wheat doughs was desired in this study.

Tear readings (lbs force) from the texturepress are shown graphically by Figures 10 and 11. The range of measures was not flat for the soft doughs as seen when the doughs were tested by the extensigraph. The strongest doughs resulted from treatment with double additives and 2% NaCl for the soft flour doughs. The hard flour treatments exhibited varied effects with the greatest force required to tear doughs with double additives followed by doughs treated with SSL. SSL is a surface active compound which strengthens gluten and results in superior gas retention in bread (Knightly, 1973).

The addition of NaCl strengthened the gluten and thereby caused an increase in resistance to extension and lbs force readings. NaCl solubilizes protein and also enhances hydrophobic bonding in dough (Wehrli and Pomeranz, 1969). Research by Volpe (1976) and Siluala (1985) demonstrated the strengthening effect of salt on resistance to extension in composite doughs containing either YPI or navy and pinto bean concentrate flour.

Bromate is a slow acting oxidizer (Tsen, 1968) which explains why its effects were often not observed until the 135 minute repose time. SSL emulsified the starch fraction

Figure 10. The effect of treatment on tear values of soft white flour (SWF) doughs measured by the texturepress.

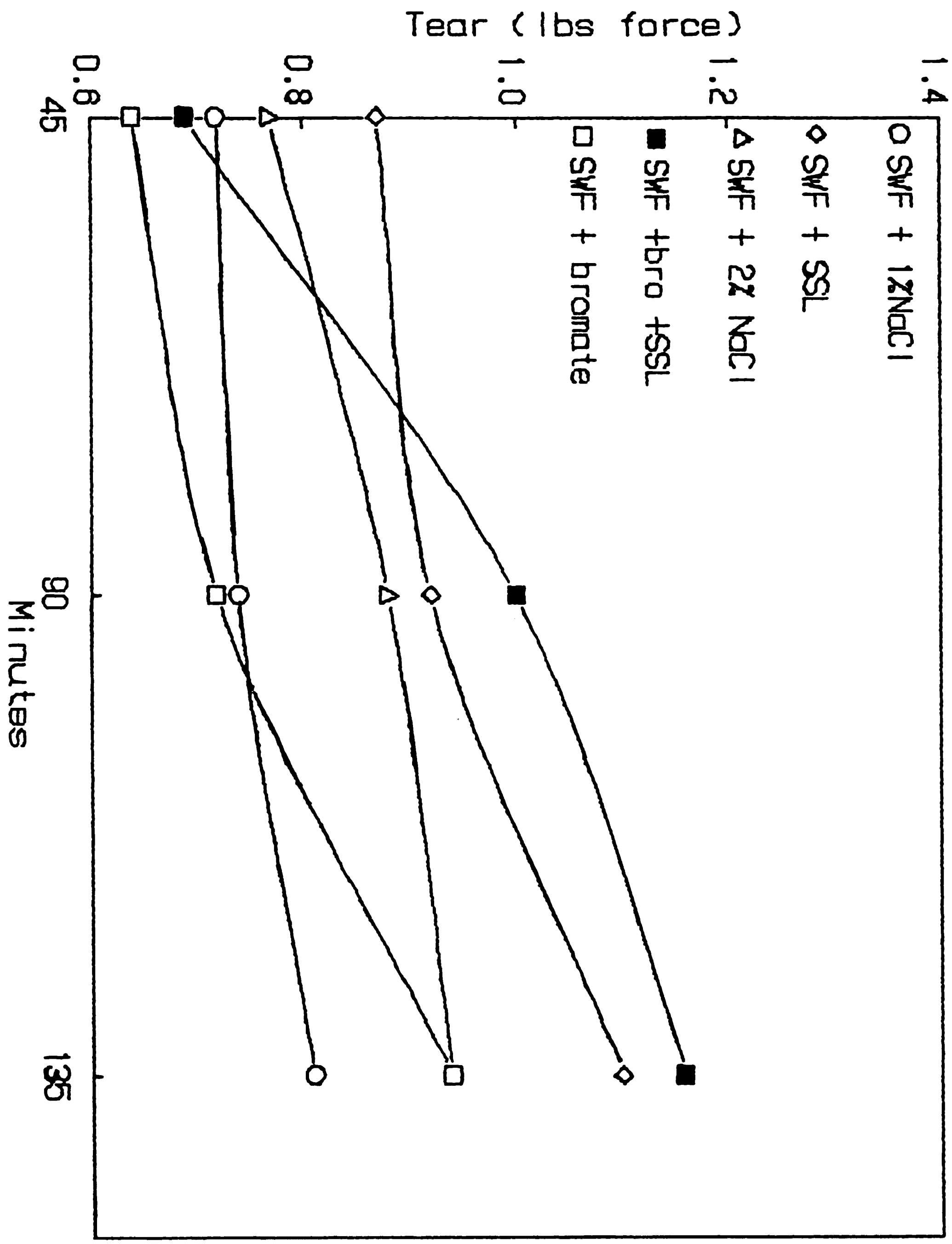
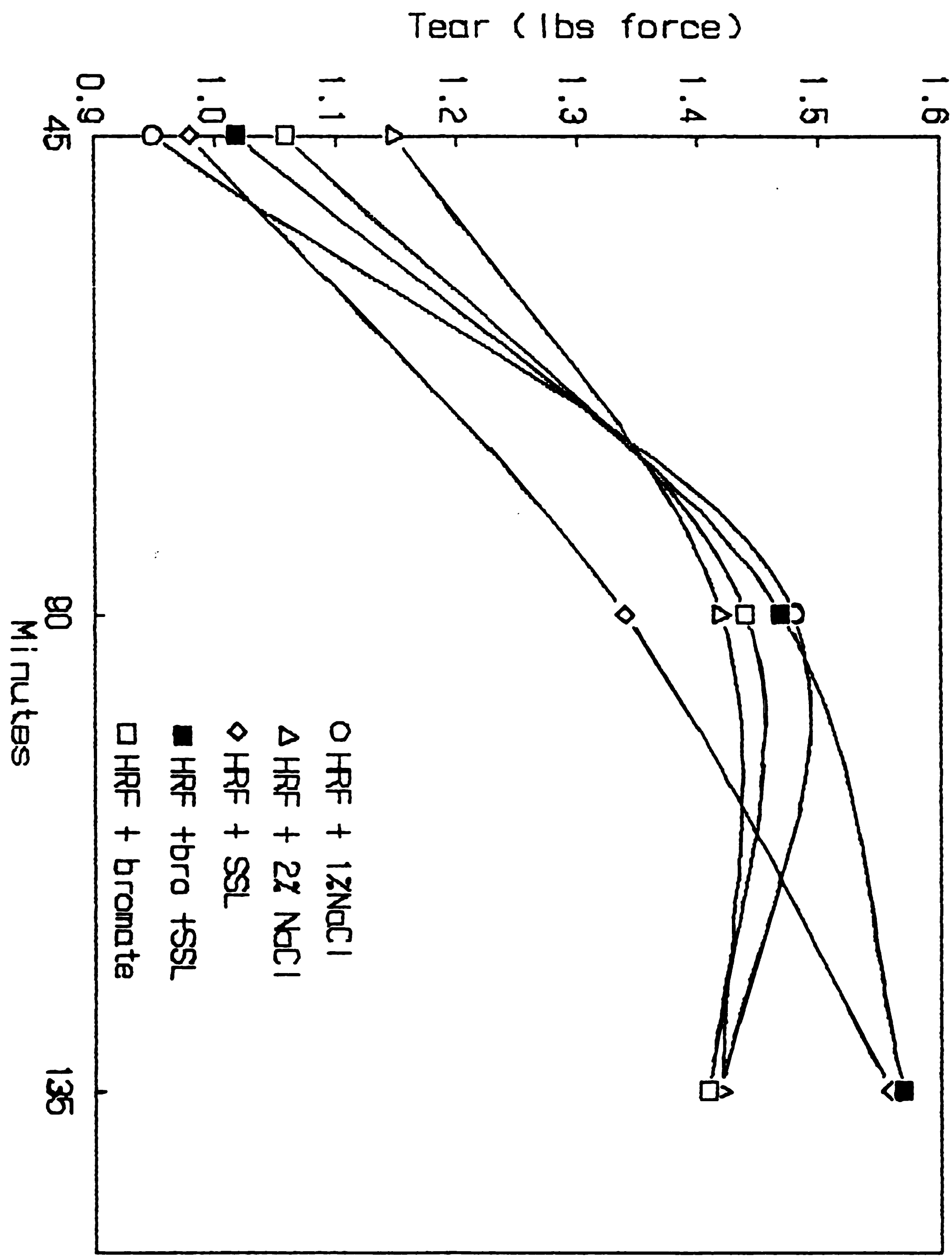

Tear (lbs force)
0.6
0.8
1.0
1.2
1.4
45
90
135
Minutes
○ SWF + 1%NaCl
◇ SWF + SSL
△ SWF + 2% NaCl
■ SWF +bro +SSL
□ SWF + bromate

Figure 11. The effect of treatment on tear values of hard red flour (HRF) doughs measured by the texturepress.


Tear (lbs force)
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
45
90
135
Minutes
○ HRF + 1%NaCl
△ HRF + 2% NaCl
◇ HRF + SSL
■ HRF +bro +SSL
□ HRF + bromate

and worked synergistically with bromate resulting in superior response from the test doughs. Tenney (1978) explained that improvers interact with flour proteins resulting in a strengthened protein complex and or bind with starch causing a softening of the grain. Knightly (1973) concluded that although SSL and bromate reacted by a different mechanism, their improving effects were similar.

Extensibility

Extensibility measurements for soft flour doughs are shown in Figure 12 and for hard wheat doughs in Figure 13. There was an overall decrease in the ease of stretching the dough for all treatments as the dough tightened and became more elastic. Extensibility measures for soft and hard wheat doughs generally decreased over time. The range in extensibility readings was 127.7 mm for soft wheat doughs to 258.3 mm for hard wheat doughs. Merritt and Bailey (1945) also found decreased extensibilities with increased rest time and reworking of dough.

Addition of 2% NaCl to the doughs had more effect than addition of improvers in both flour types. The hard wheat flour doughs had greater extensibilities due to higher protein. Aitken et al. (1944) demonstrated that increased protein caused an increase in the length of the extensigram. Increased salt concentration also caused an

Figure 12. Influence of treatment on extensibility of soft white flour (SWF) doughs measured by the extensigraph.

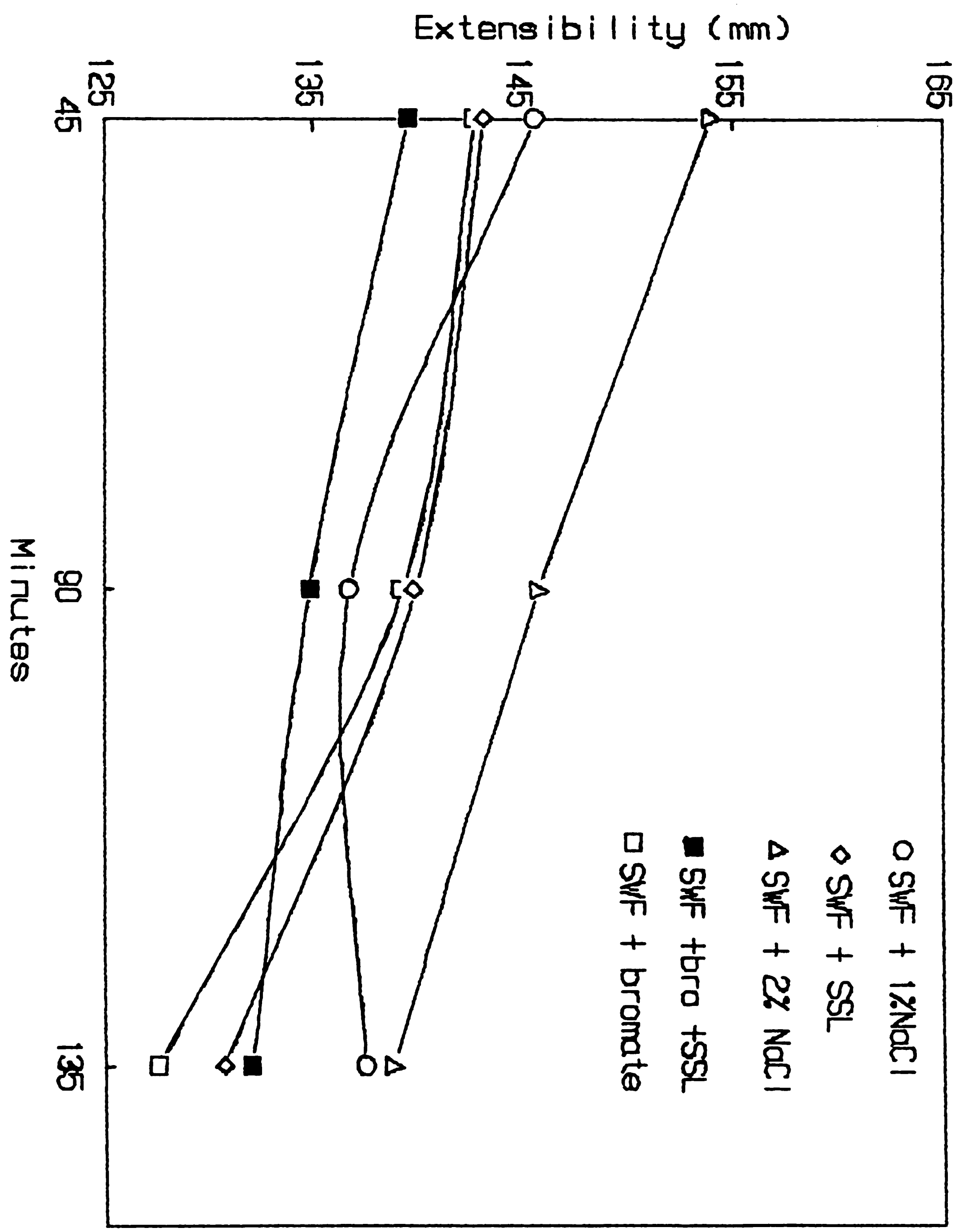
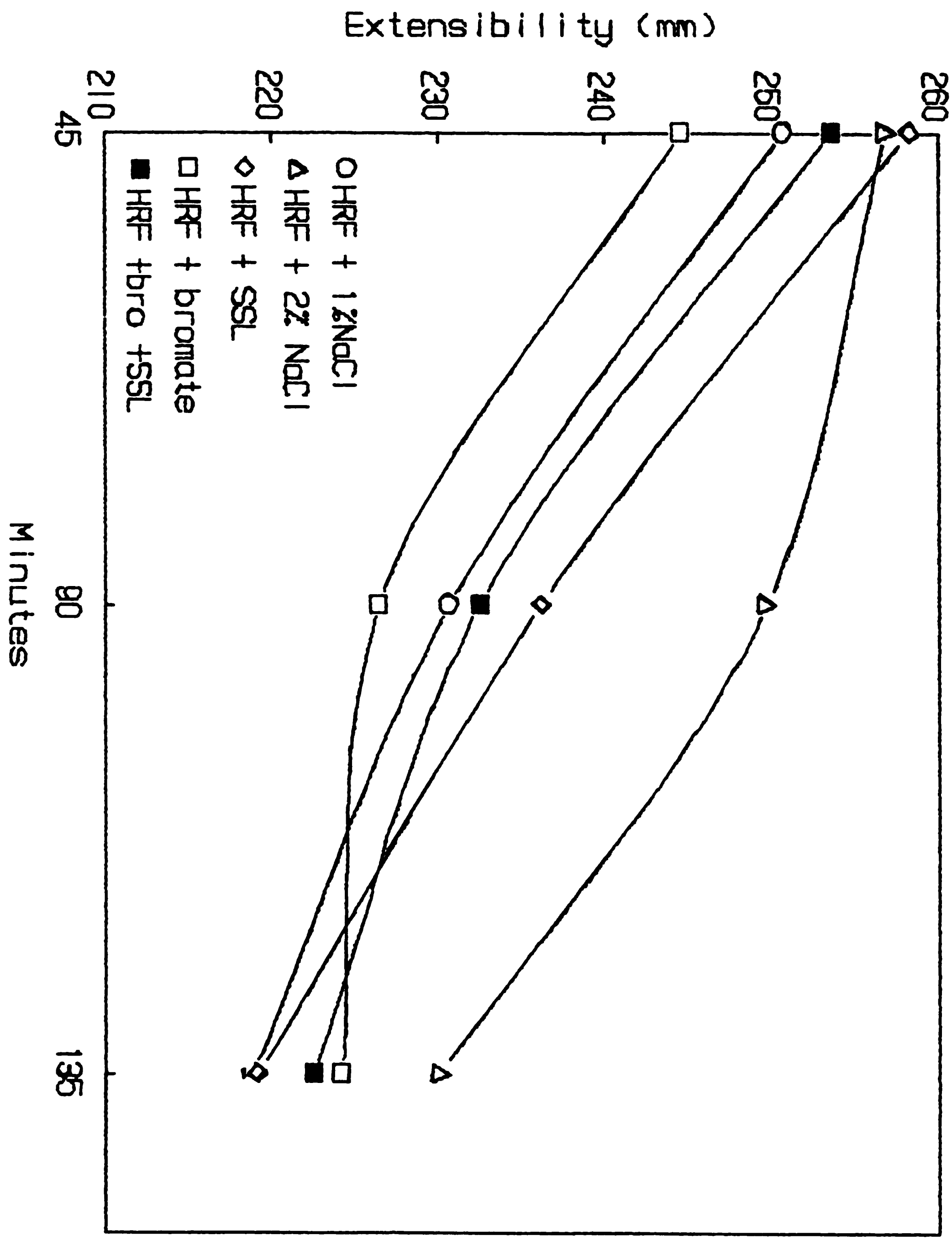

Extensibility (mm)
125
135
145
155
165
45
90
135
Minutes
SWF + 1%NaCl
SWF + SSL
SWF + 2% NaCl
SWF +bro +SSL
SWF + bromate

Figure 13. Influence of treatment on extensibility of hard red flour (HRF) doughs measured by the extensigraph.


Extensibility (mm)
210
220
230
240
250
260
45
80
135
Minutes
HRF + 1%NaCl
HRF + 2% NaCl
HRF + SSL
HRF + bromate
HRF +bro +SSL

increase in extensibility (Fisher et al., 1949). When examining exstensigraph curves, it is desirable to attain a balance between extensibility readings and resistance. Doughs which are too extensible such as all the soft flour doughs in this study, do not machine well and yield poor bread. Gas retention is a function of the flour protein and the dough must be extensible enough to permit leavening yet not too weak as these soft wheat doughs to allow gas to escape (Shuey, 1975). The overall decrease in extensibility from test doughs was attributable to an increase in elasticity of the doughs as the gluten bonding system strengthened. Aitken et al. (1944) found dough extensibility and flour protein content very highly associated with a correlation of r=.96. Extensibility has also been shown to have a strong relationship with loaf volume (Moss, 1980).

Area

Area (cm^2) or energy values measured from extensigrams are illustrated in Figures 14 and 15. The area represents the total force required for stretching the doughs. The results from the soft flour doughs were inconclusive as no discernible trend was evident other than the area of these curves was quite small when compared to the areas of the hard flour doughs. Addition of 2% NaCl caused the greatest

Figure 14. The effect of treatment on area of extensigrams as measured during 45, 90 and 135 minute test times of soft white flour (SWF) doughs.

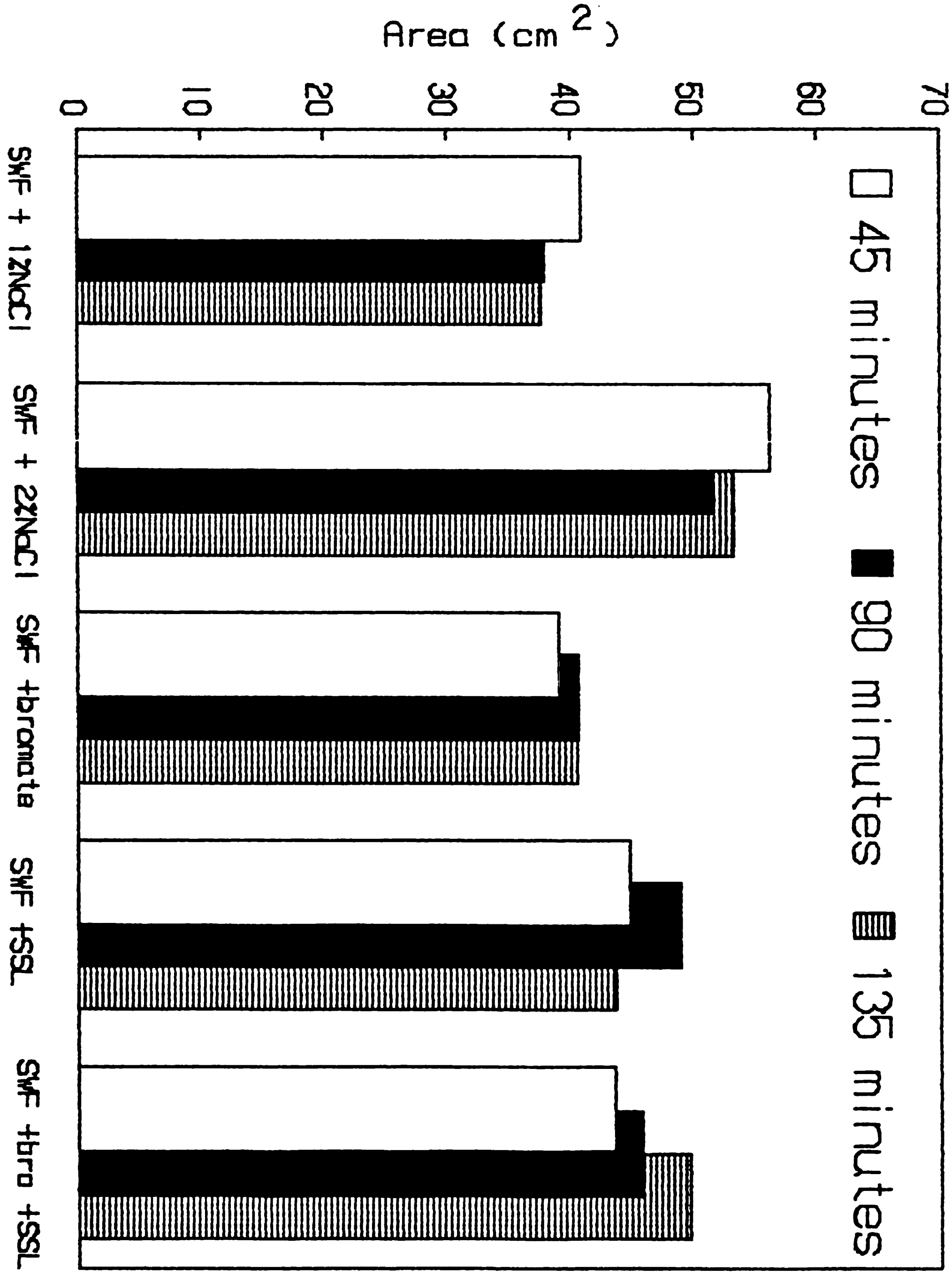
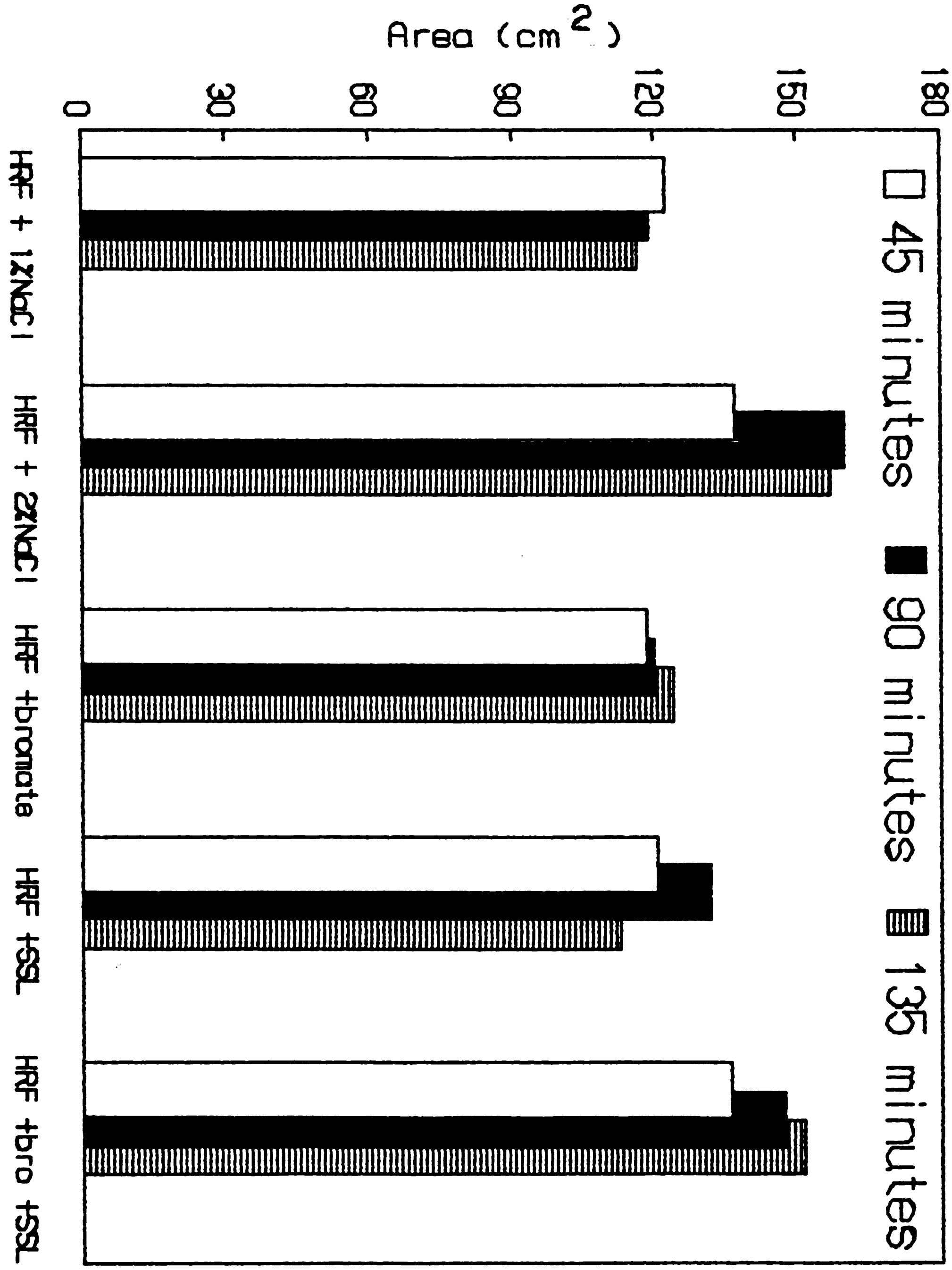

Area (cm 2)
0
10
20
30
40
50
60
70
45 minutes
90 minutes
135 minutes
SWF + 1%NaCl
SWF + 2%NaCl
SWF +bromate
SWF +SSL
SWF +bro +SSL

Figure 15. The effect of treatment on area of extensigrams as measured during 45, 90 and 135 minute test times of hard red flour (HRF) doughs.


Area (cm2)
0
30
60
90
120
150
180
45 minutes
90 minutes
135 minutes
HRF + 1%NaCl
HRF + 2%NaCl
HRF +bromate
HRF +SSL
HRF +bro +SSL

increase in area for both flour types. The slow action oxidizing effect of bromate caused an increase in area over time in both flours, and when used as a double additive with SSL. The improving effects of SSL appeared most effective as a single additive. Merritt and Bailey (1945) concluded that the strongest flours yielded curves with the greatest areas; these strong flours also had the highest volumes when baked into bread.

The behavior of the soft flour doughs was unpredictable due to their weak and floury nature. Some treatments decreased in area over time and others increased. However, the total extensigram areas of the soft flour doughs were much smaller compared to the hard wheat doughs. Aitken et al. (1944) reported that extensigram area increased as flour protein content increased. The areas of the soft flours represented slack doughs which would require a quick processing time. For both flours, addition of bromate strengthened the respective doughs. Research by Munz and Brabender (1941) showed that dough extensigraph areas increased upon addition of bromate to the dough. High energy values indicate good tolerance to fermentation and that a long dough process should be used. The energy measure characterized dough behavior, stability and potential baking volume. Nevertheless, Shuey (1975)

Figure 16. The effect of treatment on area of texturegrams as measured during 45, 90 and 135 minute test times of soft white flour (SWF) doughs.

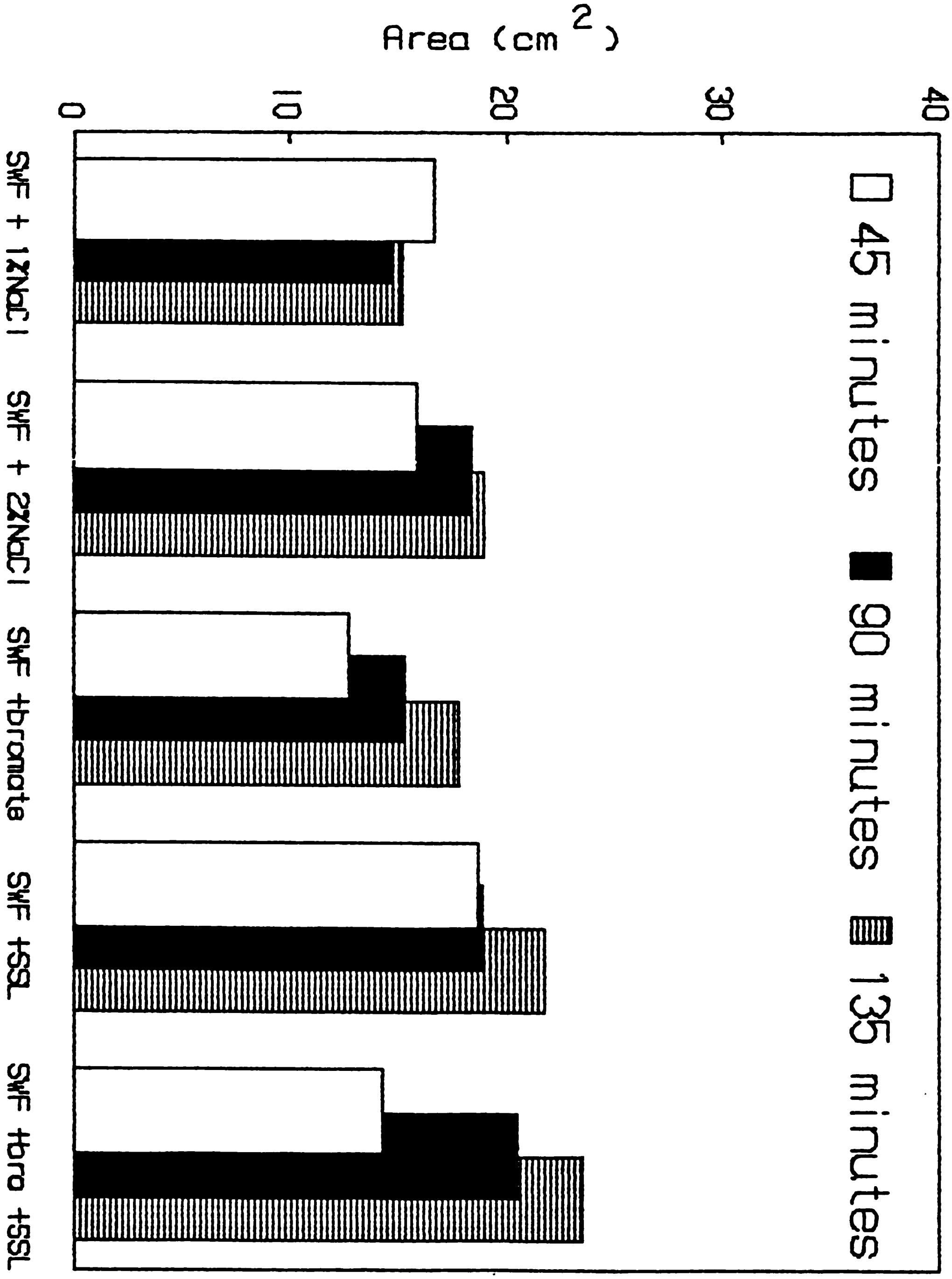
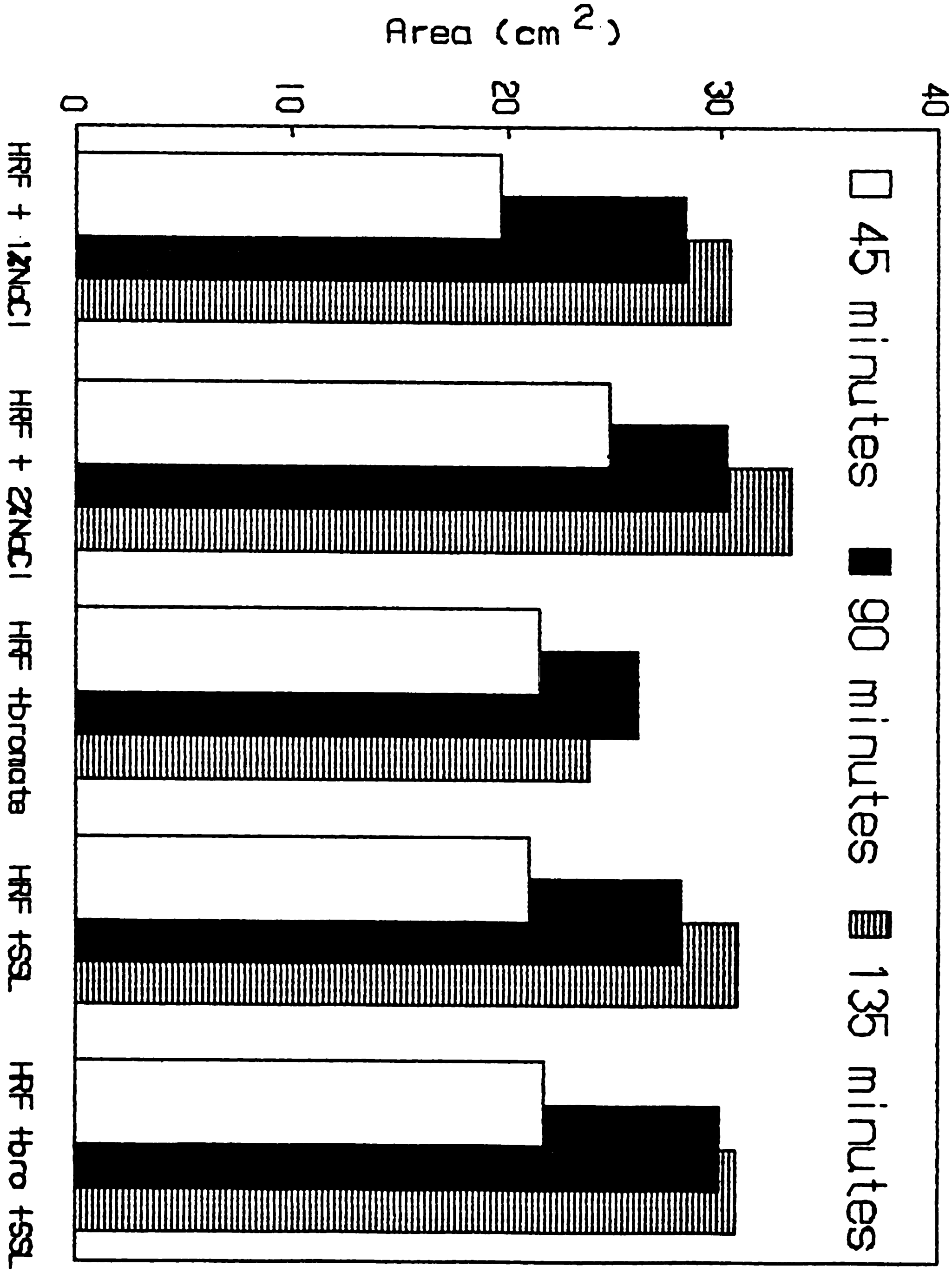

45 minutes
90 minutes
135 minutes
Area (cm 2)
0
10
20
30
40
SWF + 1%NaCl
SWF + 2%NaCl
SWF +bromate
SWF +SSL
SWF +bro +SSL

Figure 17. The effect of treatment on area of texturegrams as measured during 45, 90 and 135 minute test times of hard red flour (HRF) doughs.



Area (cm 2)
0
10
20
30
40
45 minutes
90 minutes
135 minutes
HRF + 1%NaCl
HRF + 2%NaCl
HRF +bromate
HRF +SSL
HRF +bro +SSL

cautioned that area measurements can be misleading as it is possible for two very different doughs to have the same area.

The effect of treatment on area of texturepress curves are shown in Figures 16 and 17. For most all treatments there was an increase in energy over time. This increase was more dramatic in the hard flour doughs due to their greater gluten contents. The bromate and SSL double action appeared to have the most improving effect on the soft flour doughs and the addition of 2% salt resulted in the greatest areas for the hard flour. Except in the hard flour when employed singularly, bromate increased energy over time as also seen by area of the extensigrams. The texturepress areas demonstrated similar trends as were seen for extensigram areas. Total work for soft flour doughs was much less than for hard flour doughs which signified how weak and slack the soft doughs were. The greater areas for the hard flour doughs represented doughs that would stand up during fermentation and be strong and elastic.

Means and standard deviations for maximum resistance, resistance to extension, extensibility, area, force and tear are found in the Appendix. Means and standard deviations for proportional number, slope, lbs force/g and weight also are included in the Appendix.

Eight of the ten treatments were arranged in a 2^3 factorial design and the main effects of flour type, SSL and bromate were partitioned out from the analysis. The mean squares from the analyses of variance from these treatments evaluated by the extensigraph are found in Tables 6 and 7. From Table 6, the two-way interactions of bromate and time as well as flour type and time were significant at $p < 0.01$ for maximum resistance measures. The interaction of SSL and time was significant at $p < 0.05$ for these same maximum resistance measures from the extensigraph. The three-way interaction of all factors (ABC) was also highly significant ($p < 0.01$). These interactions represented a synergistic effect among the factors which was nonchance. Significant time interactions were expected due to the dynamic nature of the bread dough system which develops and changes over time. However, in spite of significant interactions the magnitude of the main effect of flour type can not be ignored. For maximum resistance the F statistic would be 1546.40 which clearly shows the importance of flour type on maximum resistance measures when averaged over the other factors.

Resistance to extension data analyses from Table 6 revealed highly significant ($p < 0.01$) bromate and time and flour type and time interactions. The three-way interaction of all three factors was also very significant ($p < 0.01$)

Table 6. Mean squares of analyses of variance of flour type and effect of additives on extensigraph measurements performed on wheat flour doughs.

Source of Variation	Degrees of Freedom	Maximum Resistance (BU)	Resistance to Extension (BU)
Rep	3	2189.52	575.70
A	1	923278.05**	11190.96**
B	1	30146.68**	12505.82**
AB	1	896.70	1126.83
C	1	19193.07**	4503.19**
AC	1	12348.81**	1423.73*
BC	1	5554.08**	796.34
ABC	1	9055.93**	2632.37**
Residual Trt.	2	148559.63**	5100.04**
Error 1	27	597.05	283.99
Time	2	25891.18**	7379.53**
AXTime	2	7977.25**	994.04**
BXTime	2	493.33*	121.78
AXBXTime	2	457.98	263.92
CXTime	2	1905.52**	937.67**
AXCXTIme	2	276.76	9.25
BXCXTime	2	62.44	53.21
AXBXCXTime	2	189.23	282.53
TimeXResidual	4	4084.05**	484.47*
Error 2	60	147.43	98.53
Total	119		

* $p < 0.05$
** $p < 0.01$
A flour type
B sodium stearoyl-2-lactylate
C potassium bromate

Table 7. Mean squares of analyses of variance of flour type and effect of additives on extensigraph measurements performed on wheat flour doughs.

Source of Variation	Degrees of Freedom	Extensibility (mm)	Area (cm^2)	Proportional Number
Rep	3	58.14	153.50	0.009
A	1	227253.88**	169396.08**	5.802**
B	1	49.02	2410.61**	0.479**
AB	1	216.00	269.68	0.182**
C	1	129.74	1059.48**	0.175**
AC	1	9.75	809.22**	0.005
BC	1	1.60	673.95**	0.005
ABC	1	1.76	754.43**	0.068
Residual Trt.	2	30545.82**	31756.23**	1.083**
Error 1	27	112.07	64.25	0.017
Time	2	4350.98**	195.65**	0.656**
AXTime	2	868.61**	34.26	0.009
BXTime	2	32.59	132.53**	0.004
AXBXTime	2	57.72	41.59	0.014
CXTime	2	38.56	322.26**	0.026*
AXCXTIme	2	80.68	81.98*	0.002
BXCXTime	2	32.00	81.08*	0.007
AXBXCXTime	2	60.01	11.84	0.030**
TimeXResidual	4	78.04	266.63**	0.006
Error 2	60	46.05	20.66	0.005
Total	119			

* $p < 0.05$
** $p < 0.01$
A flour type
B sodium stearoyl-2-lactylate
C potassium bromate

The response to time was dependent upon flour type and presence of bromate. Bloksma (1975) showed that addition of bromate stiffened and tightened dough. Also response of any factor was dependent upon the level of the other two. Silaula (1985) found significant time-treatments interactions of resistance to extension measures of composite wheat doughs with bean flour concentrate.

From Table 7, the two-way interaction of flour type and time was highly significant ($p < 0.01$) when examining extensibility values. The changes in the dough during the rest times were dependent upon flour type or more specifically, the gluten content. Time had a greater effect than treatment on extensibility. For hard and soft flours, a general reduction in extensibility occurred particularly from the 45 to the 135 minute repose times. Again the magnitude of the main effect of flour type was so highly significant ($F=2027.79$) that the contribution of wheat variety and protein content to extensibility was demonstrated.

Area or energy response to flour type and SSL was dependent on fermentation time and presence or absence of bromate. Bromate which exerts its action over time, oxidizes thiol groups rendering them unavailable for the disulfide reaction which reduces extensibiltiy and increases resistance (Bloksma, 1975). Munz and Brabender

(1940) concluded that an increase in loaf volume in dough fermented for two hours resulted from addition of bromate to the dough formulation. Area response was highly dependent upon the nonchance interdependence of the factors over time. As seen with other extensigraph measures, the main effect of flour type was highly significant ($p < 0.01$) when compared to all other effects and must be considered when generalizing area trends.

The proportional or ratio value (Table 7) is an index to the "boldness" of the dough. A low proportional number is indicative of an extensible, floury dough. A too high ratio signifies a tight, short dough. The proportional number is highly influenced by time, presence of improvers and flour type which affect resistance to extension and extensibility. As this value is derived from other extensigraph values, not surprisingly a four-way interaction of flour type, SSL, bromate and time was very significant ($p < 0.01$). This interaction represented a synergistic effect among all the factors dependent upon the level of each other.

In all extensigraph measures the residual treatment effect was highly significant ($p < 0.01$). Included in this residual were the effects of 2% salt on both flour types and the effect of salt compared to the other factors.

Table 8. Mean squares of analyses of variance of flour type and effect of additives on texturepress measurements performed on wheat flour doughs.

Source of Variation	Degrees of Freedom	Weight (g)	lbs force
Rep	3	171.88	0.112**
A	1	13194.61**	8.998**
B	1	564.20*	0.652**
AB	1	252.49	0.072
C	1	22.24	0.002
AC	1	139.42	0.037
BC	1	0.73	0.041
ABC	1	44.79	0.017
Residual Trt.	2	1790.26**	1.512**
Error 1	27	78.25	0.020
Time	2	602.45**	1.550**
AXTime	2	49.86	0.221**
BXTime	2	44.50	0.061
AXBXTime	2	35.08	0.011
CXTime	2	11.12	0.019
AXCXTIme	2	17.72	0.106*
BXCXTime	2	79.12*	0.060
AXBXCXTime	2	77.62*	0.007
TimeXResidual	4	74.62*	0.027
Error 2	60	22.06	0.028
Total	119		

* $p < 0.05$
** $p < 0.01$
A flour type
B sodium stearoyl-2-lactylate
C potassium bromate

Means squares from the analyses of variance of testurepress measurements weight and lbs force are given in Table 8. A four-way interaction of time, bromate, SSL and flour type was significant ($p < 0.05$) for weight measures. Weight is the weight of the dough test pieces. This four-way interaction is illustrated by Figure 18. The nonparallelness of the lines indicated a significant nonchance interaction and, the simple effects of time were different. Interactions of weight measures were attributed to a difference in the magnitude of response and also from a difference in the direction of the response (Steel and Torrie, 1980). Dough weight was influenced by flour type, bromate, SSL and time working synergistically together. Again a very highly significant main effect of flour type ($p < 0.01$) was noted.

A three-way interaction of flour type, bromate and time was significant ($p <0.05$) for lbs force measures. Response to these factors was apparently not dependent upon the incorporation of SSL. Although SSL action generally improves in combination with bromate, it was not time dependent and appeared to work equally across flour type and time. Figure 19 illustrates the the three-way interaction averaged over SSL. The lines are not parallel and indicate that a difference in level of response to

Figure 18. Interaction of flour type, SSL, bromate and time on weight measures of wheat flour doughs.

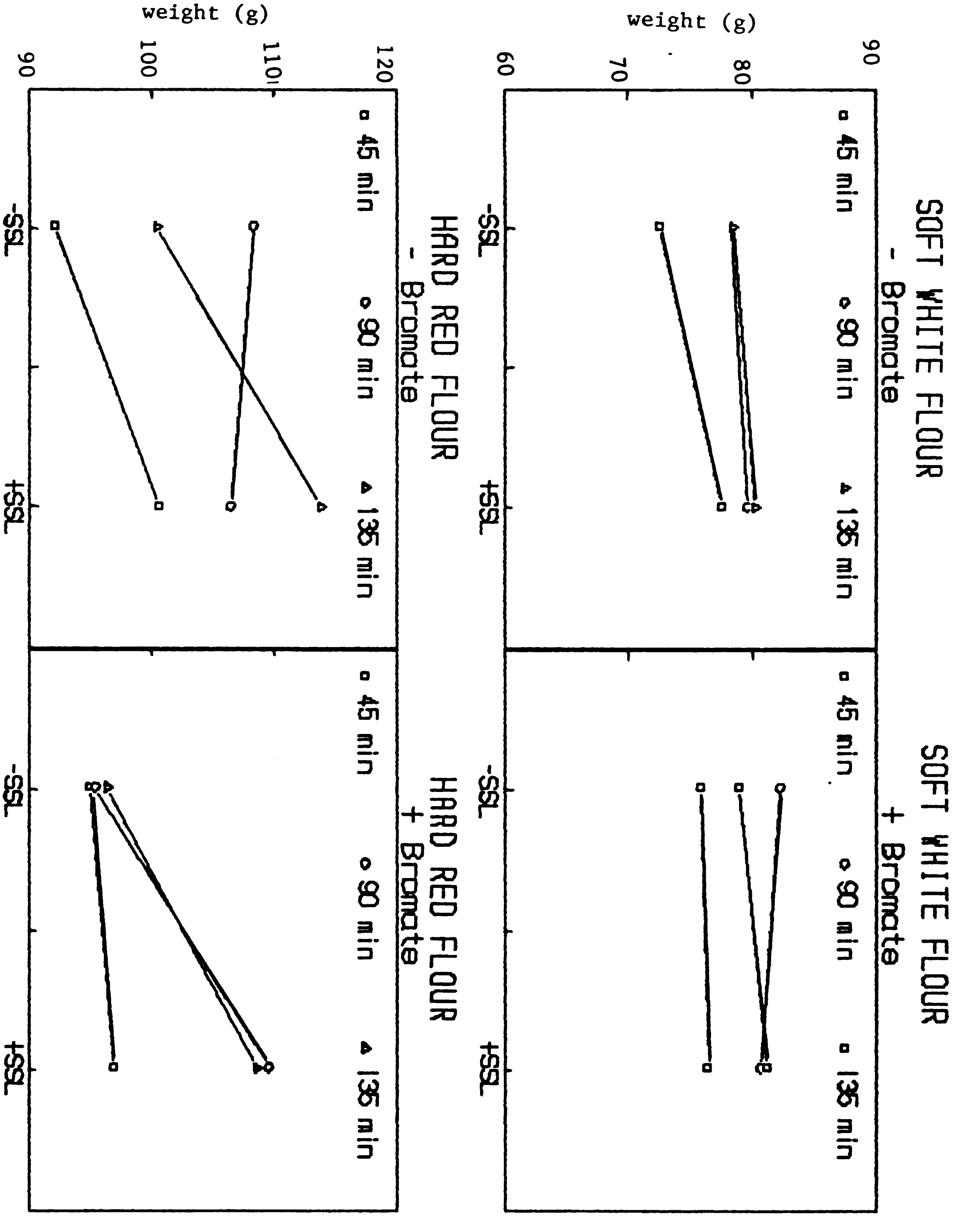
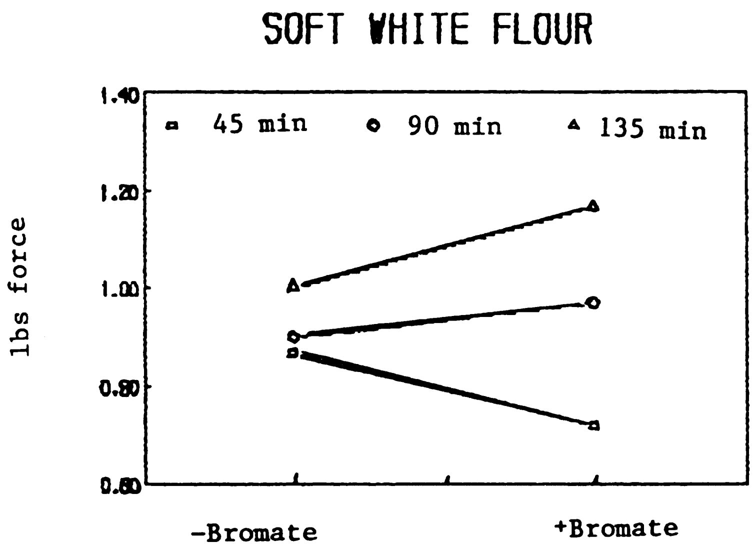
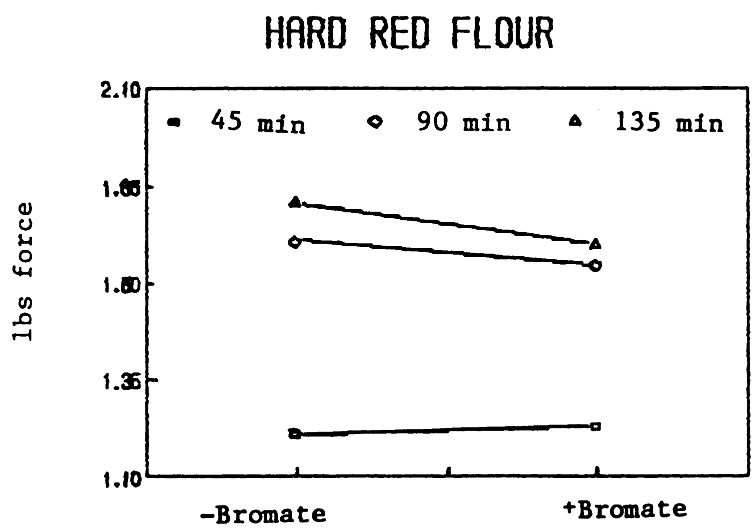

SOFT WHITE FLOUR
- Bromate
SOFT WHITE FLOUR
+ Bromate
HARD RED FLOUR
- Bromate
HARD RED FLOUR
+ Bromate
weight (g)
90
80
70
60
120
110
100
90
45 min
90 min
135 min
-SSL
+SSL

Figure 19. Interaction of flour type, bromate and time on lbs force measures in wheat flour doughs.


SOFT WHITE FLOUR
45 min
90 min
135 min
lbs force
1.40
1.20
1.00
0.80
0.60
-Bromate
+Bromate


HARD RED FLOUR
45 min
90 min
135 min
lbs force
2.10
1.35
1.10
-Bromate
+Bromate

bromate during the three test times was responsible for the significant effect. Apparently in this case the texturepress was more sensitive to treatment interactions than the extensigraph, though these differences may not be meaningful.

Texturepress area and lbs force/g mean squares are shown in Table 9. As observed with lbs force, a three-way interaction between flour type, bromate and time was highly significant ($p < 0.01$) for area. Again area renders an excellent assessment of potential bread character.Response to time was dependent upon hardness or softness of the flour and level of bromate. Flour type main effect as seen in all cases was highly significant ($p < 0.01$).

Time main effects were highly significant as were the two factor interaction of flour type and SSL significant at $p < 0.01$ for lbs force/g measures. It would appear that although the effect of time averaged over all factors was significant, response to time was not dependent on any factors. There was a synergistic, nonchange effect among flour type and SSL on lbs force/g response.

Table 10 contains the mean squares from the analyses of variance of texturepress measures slope and tear. The interaction between time and flour type was highly significant ($p < 0.01$) for both slope and tear. Neither measure was sensitive enough to differences in treatments over time other than the effect of protein content. When recording slope measurements, a high number indicated a steeper slope. The texturepress pulls at a constant rate and the force per unit of time would be greater for steeper or higher slope values.

Table 9. Mean squares of analyses of variance of flour type and effect of additives on texturepress measurements performed on wheat flour doughs.

Source of Variation	Degrees of Freedom	Area (cm^2)	lbs force/ g
Rep	3	15.02	0.195**
A	1	1711.71**	1.952**
B	1	228.32**	0.247**
AB	1	23.77	0.551**
C	1	7.96	0.000
AC	1	1.01	0.003
BC	1	14.52	0.048
ABC	1	15.22	0.024
Residual Trt.	2	445.78**	0.515**
Error 1	27	7.80	0.028
Time	2	379.27**	1.026**
AXTime	2	61.95**	0.116
BXTime	2	26.05*	0.073
AXBXTime	2	1.79	0.024
CXTime	2	6.88	0.101
AXCXTIme	2	58.47**	0.066
BXCXTime	2	8.56	0.072
AXBXCXTime	2	7.52	0.021
TimeXResidual	4	7.38	0.054
Error 2	60	6.52	0.038
Total	119		

* $p < 0.05$
** $p < 0.01$
A flour type
B sodium stearoyl-2-lactylate
C potassium bromate

Table 10. Mean squares of analyses of variance of flour type and effect of additives on texturepress measurements performed on wheat flour doughs.

Source of Variation	Degrees of Freedom	Slope	Tear (lbs force)
Rep	3	128.14	0.087**
A	1	2879.85**	4.948**
B	1	27.10	0.287**
AB	1	101.27	0.145**
C	1	92.43	0.013
AC	1	2.60	0.009
BC	1	16.50	0.001
ABC	1	54.90	0.003
Residual Trt.	2	307.44**	0.656**
Error 1	27	29.74	0.018
Time	2	1362.84**	1.291**
AXTime	2	182.31**	0.213**
BXTime	2	48.52	0.046
AXBXTime	2	22.38	0.024
CXTime	2	2.77	0.019
AXCXTIme	2	38.17	0.056
BXCXTime	2	31.07	0.028
AXBXCXTime	2	7.10	0 000
TimeXResidual	4	14.83	0.025
Error 2	60	19.68	0.020
Total	119		

* $p < 0.05$
** $p < 0.01$
A flour type
B sodium stearoyl-2-lactylate
C potassium bromate

There was a highly significant interaction effect ($p < 0.01$) between SSL and flour type for tear measures. The response to SSL was dependent on flour strength when measuring tear. Again the main effect for flour type was very significant for tear and, this effect should be noted due to the magnitude of the F statistic.

Both the extensigraph and texturepress consistently measured residual treatment effects as highly significant ($p < 0.01$) and ascertained the tremendous importance of flour type in determining dough behavior. Treatments were chosen to obtain a wide variablity in results to compare the sensitivity of the texturepress to the extensigraph. From this analysis, it has been demonstrated that data were behaving as expected. It would appear that the extensigraph measured more significant interactions with time and synergism amongst factors. However the texturepress did pick up three-way and four-way interdependencies. In general the texturepress was more stable over time than the extensigraph. In the case of dough this would be undesirable as bread dough changes over time. Even though overall sensitivity was not as great, the texturepress was still capable of detecting major trends and seemed to give a good indication of potential bread quality.

Baking Study

The means and standard deviations of bread weight, volume and specific volume of the four treatments that were used in the baking study are shown in Table 11. The weights of soft flour pup loaves with 2% NaCl were significantly greater at alpha=0.05 than those of all other treatments. The two hard flour breads plus improvers were not significantly different from each other. The hard flour with 2% NaCl and the hard flour bread with double additives were not significantly different at alpha = 0.05. From an initial 100 gram piece of dough, weight loss ranged from 16.1 to 19.4 percent. The soft flour bread which weighed the most had coarse thick crumb cells and was quite compact as compared to the other loaves.

Volume and specific volume measures illustrated that the range of treatments was broad enough that each was significantly different at alpha = 0.05 from the other treatments. The lowest volume and specific volume occurred in bread baked from soft wheat. The low volume was attributable to a collapsed crumb as the soft flour doughs were too weak to support the expansion during fermentation and baking. Volume increased by using hard flour and also from addition of SSL and bromate. The improving action of

Table 11. Means for weight, volume and specific volume of pup loaves prepared from hard red and soft white wheat flour treatments.

Treatment	Weight (g)	Volume (cc)	Specific Volume (cc/g)
Trt. 2 SWF + 2% NaCl	83.88[a]	327.33[a]	3.87[a]
Trt. 7 HRF + 2% NaCl	82.50[b]	438.23[b]	5.30[b]
Trt. 9 HRF + SSL	80.60[c]	471.67[c]	5.85[c]
Trt. 10 HRF + bromate + SSL	81.36[bc]	503.80[d]	6.20[d]
LSD critical value	1.36	15.55	0.30

n=3

Means in the same column with the same letter are not significantly different by LSD method at alpha = 0.05.

SSL and bromate was quite dramatic particularly when employed in tandem. Merritt and Bailey (1945) found that incorporation of potassium bromate into dough formulation caused an increase in bread volume. SSL has been shown to increase dough stability and gas production in flour and water doughs (Tsen and Weber, 1981) and result in increased loaf volume (Finney and Shogren, 1971; Tenney, 1978). A specific volume around 6 is generally desirable in bread. Tsen and Hoover (1971) investigated the effects of SSL on bread baking and found increased specific volume with incorporation of SSL.

Table 12 contains means and standard deviations for tenderness, compressibility and tensile strength measurements performed on pup loaves. Tenderness was recorded using the multiple blade cell of the texturepress. The soft wheat bread was significantly different at alpha = 0.05 from each of the three other treatments. As expected, based on extensigraph curves showing that the soft wheat doughs were weak and unable to expand, the soft wheat breads required the highest lbs force/g to shear. This means that they were the least tender. The air cells of the bread had collasped. Even though not statistically different, the hard flour breads especially those treated with SSL and bromate had the most tender crumbs with fine uniform air cells. Tsen and Hoover (1971) found enhanced

Table 12. Means for tenderness, compressibility and tensile strength of pup loaves prepared from hard red and soft white wheat flours.

Treatment	Tenderness (lbs force/g)	Compressibility (lbs force)	Tensile Strength (lbs force)
Trt. 2 SWF + 2% NaCl	13.08[a]	14.87[a]	0.593[a]
Trt. 7 HRF + 2% NaCl	9.66[b]	11.19[b]	0.540[ab]
Trt. 9 HRF + SSL	9.40[b]	7.51[c]	0.467[b]
Trt. 10 HRF + bromate + SSL	9.37[b]	5.71[c]	0.497[b]
LSD critical value	2.03	2.55	0.077

n=3

Means in the same column with the same letter are not significantly different by LSD method at alpha = 0.05.

crumb softness and retention of softness in bread baked with SSL. Incorporation of SSL at .5% resulted in superior response of crumb grain and texture over controls in bread baked by Finney and Shogren (1971).

Compressibility readings indicated the amount of force necessary to compress the bread sample. The soft wheat bread samples with their tough crumbs, required the most force to compress and were statistically different from the other three treatments at alpha = 0.05. The hard flour bread without benefit of additives other than salt, which tightened the gluten, required the second most force to compress and was significantly different at alpha = 0.05 from the other three treatments. SSL and bromate activity in the bread dough significantly at alpha = 0.05 improved crumb softness. Tenney (1978) tested compressibility in bread and found that addition of SSL resulted in the softest bread crumb over controls and when compared to other surfactants.

Bread samples were also evaluated using the thin slice tensile test cell (which was the same cell that dough samples were stretched upon). Breads with 2% salt were not statistically different from each other at alpha = 0.05 and all hard flour breads were not significantly different at alpha = 0.05. The soft wheat bread required the greatest lbs force to tear. The breads incorporating improvers had the most tender crumb and required the least lbs force. This indicates an inverse relationship from dough to bread. The soft wheat doughs were weak and had the lowest force readings, but when baked required more lbs force to tear.

Extensigraph and Texturepress Correlation

Tables 13, 14 and 15 show the correlation coefficients between extensigraph and texturepress dough measurements at 45, 90 and 135 minutes, respectively. The correlation coefficient shows the strength of the linear relationship between variables. A positive correlation indicates that low measures for one variable will also be low for the second variable or high values from one will be high for the other. A negative correlation would mean that the variables had an opposite tendency (Steel and Torrie, 1980).

Most correlations comparing variables from the two instruments and also when comparing different measures from the same instrument were significant. At all three test times, weight for the texturepress measurements was very highly associated to maximum resistance and extensibility of the extensigraph. At 90 minutes weight and maximum resistance were correlated at $r = .86$ and weight and extensibility at $r = .88$. These variables were positively

Table 13. Pearson correlation coefficients between texturepress and extensigraph dough measurements at 45 minutes.

Variables	Weight	lbs force	lbs force/g	Area1
Weight	1.00			
lbs force	0.70***	1.00		
lbs force/g	0.28	0.81***	1.00	
Area1	0.59***	0.93***	0.77***	1.00
Slope	0.40*	0.80***	0.73***	0.66***
Tear	0.58***	0.97***	0.86***	0.92***
Max. Res.	0.84***	0.82***	0.46**	0.72***
R.E.	0.33*	0.28	0.13	0.24
Extensi.	0.85***	0.81***	0.45**	0.70***
Pro. No.	0.76***	0.73***	0.42**	0.63***
Area2	-0.52***	-0.46**	-0.32	-0.36*

	Slope	Tear	Maximum Resistance	Resistance to Extension
Slope	1.00			
Tear	0.83***	1.00		
Max. Res.	0.59***	0.75***	1.00	
R.E.	0.25	0.29	0.43**	1.00
Extensi.	0.53***	0.72***	0.95***	0.21
Pro. No.	0.47**	0.64***	0.83***	-0.10
Area2	-0.33*	-0.41**	-0.51***	0.35*

	Extensibility	Proportional Number	Area2
Extensi.	1.00		
Pro. No.	0.95***	1.00	
Area2	-0.65***	0.75***	1.00

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
Texturepress variables: weight, lbs force, lbs force/g area1, slope and tear.
Extensigraph variables: max. res., R.E., extensi., pro. no. and area2.

Table 14. Pearson correlation coefficients between texturepress and extensigraph dough measurements at 90 minutes.

Variables	Weight	lbs force	lbs force/g	Area1
Weight	1.00			
lbs force	0.91***	1.00		
lbsforce/g	0.59***	0.85***	1.00	
Area1	0.90***	0.98***	0.82***	1.00
Slope	0.74***	0.87***	0.78***	0.81***
Tear	0.83***	0.97***	0.88***	0.94***
Max. Res.	0.86***	0.89***	0.72***	0.91***
R.E.	0.50**	0.61***	0.61***	0.66***
Extensi.	0.88***	0.89***	0.67***	0.88***
Pro. No.	0.77***	0.72***	0.45**	0.68***
Area2	-0.19	-0.22	-0.18	-0.11

	Slope	Tear	Maximum Resistance	Resistance to Extension
Slope	1.00			
Tear	0.90***	1.00		
Max. Res.	0.74***	0.87***	1.00	
R.E.	0.44**	0.61***	0.72***	1.00
Extensi.	0.76***	0.86***	0.95***	0.53***
Pro. No.	0.66***	0.68***	0.75***	0.11
Area2	-0.43**	-0.29	-0.03	-0.40*

	Extensibility	Proportional Number	Area2
Extensi.	1.00		
Pro. No.	0.90***	1.00	
Area2	-0.21	0.44***	1.00

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
Texturepress variables: weight, lbs force, lbs force/g area1, slope and tear.
Extensigraph variables: max. res., R.E., extensi., pro. no. and area2.

Table 15. Pearson correlation coefficients between texturepress and extensigraph dough measurements at 135 minutes.

Variables	Weight	lbs force	lbs force/g	Area1
Weight	1.00			
lbs force	0.89***	1.00		
lbsforce/g	0.50**	0.78***	1.00	
Area1	0.89***	0.97***	0.73***	1.00
Slope	0.69***	0.89***	0.76***	0.83***
Tear	0.81***	0.96***	0.78***	0.90***
Max. Res.	0.88***	0.87***	0.55***	0.85***
R.E.	0.59***	0.63***	0.45**	0.65***
Extensi.	0.84***	0.83***	0.51**	0.79***
Pro. No.	0.62***	0.56***	0.29	0.51**
Area2	0.01	-0.05	-0.05	0.00

	Slope	Tear	Maximum Resistance	Resistance to Extension
Slope	1.00			
Tear	0.93***	1.00		
Max. Res.	0.78***	0.82***	1.00	
R.E.	0.57***	0.58***	0.75***	1.00
Extensi.	0.74***	0.80***	0.94***	0.51***
Pro. No.	0.49**	0.54***	0.64***	-0.02
Area2	-0.06	-0.12	0.00	0.33*

	Extensibility	Proportional Number	Area2
Extensi.	1.00		
Pro. No.	0.85***	1.00	
Area2	-0.19	0.38*	1.00

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
Texturepress variables: weight, lbs force, lbs force/g area1, slope and tear.
Extensigraph variables: max. res., R.E., extensi., pro. no. and area2.

correlated. The correlation between lbs force readings from the texturepress and maximum resistance and extensibility were also very significant at $p < 0.001$ for every test time. The correlation coefficients for lbs force and maximum resistance ranged from .82 to .89 . Coefficients for lbs force and extensigraph extensibility ranged from .81 to .89 . Although the association between resistance to extension (RE) and texturepress measures was rather weak at 45 minutes, a highly significant relationship was shown during the 90 and 135 minute test times between several variables and RE. A strong positive association existed between the proportional number and weight and lbs force values.

It would appear that dough weight and lbs force readings exhibited the greatest association with extensigraph values. Since the lbs force measured the maximum force to stretch the dough it would seem likely to demonstrate a strong relation to maximum resistance from the extensigraph. However,the weight of the test dough depended upon the elasticity of the dough and the ability of the researcher to uniformly sheet the dough. A heavier more elastic dough would tend to have greater resistance.

Correlations Between Extensigraph and Bread Measurements

The correlation coefficients between extensigraph dough measurements at 45, 90 and 135 minutes and bread assessment values are shown in Tables 16, 17 and 18 respectively. Volume which is the principal quality element of bread was very highly correlated to several extensigraph measures. At all three test times bread volume was highly associated with maximum resistance, extensibility, proportional number and area. At 45 minutes, the correlations were .90 or higher. Research by Moss (1980) showed a very significant correlation between extensibility and loaf volume in conventional bread doughs, and also between maximum resistance and loaf volume in sheeted doughs for 161 Australian wheats. Aitken et al. (1944) found extensibility and loaf volume correlated at r=.94. Specific volume of bread as expected, followed the same trends as volume and had the greatest relationship with the same extensigraph variables.

Except for resistance to extension (RE), all other extensigraph numbers were significantly correlated with shear or tenderness and compressibility of the bread crumb. From the high degree of association between extensigraph and bread quality readings, most notably volume, it is easy to understand why the extensigraph has been widely employed

Table 16. Pearson correlation coefficients between extensigraph dough measurements at 45 minutes and bread values.

Variables	Volume	Specific Volume	Shear	Compressibility	Tensile Strength
Volume	1.00				
Sp. Vol.	0.99***	1.00			
Shear	-0.76**	-0.74**	1.00		
Compress.	-0.94***	-0.94***	0.68*	1.00	
Tensile	-0.76**	-0.77**	0.57	0.76**	1.00
Max. Res.	0.90***	0.88***	-0.84***	-0.79**	-0.56
R.E.	-0.40	-0.40	0.27	0.34	0.45
Extensi.	0.90***	0.90***	-0.79**	-0.71**	-0.67*
Pro. No.	0.91***	0.90***	-0.78**	-0.75**	-0.68*
Area	0.90***	0.88***	-0.82**	-0.72**	-0.60

	Maximum Resistance	Resistance to Extension	Extensibility	Proportional Number	Area
Max.Res.	1.00				
R.E.	-0.20	1.00			
Extensi.	0.88***	-0.47	1.00		
Pro. No.	0.87***	-0.57	0.99***	1.00	
Area	0.96***	-0.37	0.96***	-0.95***	1.00

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
Bread variables: volume, specific volume, shear, compressibility and tensile strength.
Extensigraph variables: max. res., R.E., extensi., pro. no. and area.

Table 17. Pearson correlation coefficients between extensigraph dough measurements at 90 minutes and bread values.

Variables	Volume	Specific Volume	Shear	Compressi-bility	Tensile Strength
Volume	1.00				
Sp. Vol.	0.99***	1.00			
Shear	-0.76**	-0.74**	1.00		
Compress.	-0.94***	-0.94***	0.67*	1.00	
Tensile	-0.76**	-0.77**	0.57	0.76**	1.00
Max. Res.	0.84***	0.81***	-0.82**	-0.69*	-0.49
R.E.	0.14	0.09	-0.14	-0.07	0.11
Extensi.	0.84***	0.83***	-0.85***	-0.67*	-0.60*
Pro. No.	0.83***	0.83***	-0.80**	-0.69*	-0.63
Area	0.85***	0.83***	-0.86***	-0.68*	-0.57

	Maximum Resistance	Resistance to Extension	Extensi-bility	Proportional Number	Area
Max.Res.	1.00				
R.E.	0.51	1.00			
Extensi.	0.90***	0.13	1.00		
Pro. No.	0.75**	-0.16	0.95***	1.00	
Area	0.96***	0.29	0.98***	-0.89***	1.00

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
Bread variables: volume, specific volume, shear, compressibility and tensile strength.
Extensigraph variables: max. res., R.E., extensi., pro. no. and area.

Table 18. Pearson correlation coefficients between extensigraph dough measurements at 135 minutes and bread values.

Variables	Volume	Specific Volume	Shear	Compressi- bility	Tensile Strength
Volume	1.00				
Sp. Vol.	0.99***	1.00			
Shear	-0.76**	-0.74**	1.00		
Compress.	-0.94***	-0.94***	0.67*	1.00	
Tensile	-0.76**	-0.77**	0.57	0.76**	1.00
Max. Res.	0.80***	0.77**	-0.81**	-0.66*	-0.42
R.E.	0.14	0.09	-0.27	-0.08	0.24
Extensi.	0.81**	0.87***	-0.86***	-0.73**	-0.63*
Pro. No.	0.85***	0.86***	-0.75**	-0.73**	-0.73**
Area	0.79**	0.76**	-0.81**	-0.63*	-0.44

	Maximum Resistance	Resistance to Extension	Extensi- bility	Proportional Number	Area
Max.Res.	1.00				
R.E.	0.60*	1.00			
Extensi.	0.90***	0.22	1.00		
Pro. No.	0.66*	-0.17	0.91***	1.00	
Area	0.99***	0.56	0.92***	-0.70*	1.00

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
Bread variables: volume, specific volume, shear, compressibility and tensile strength.
Extensigraph variables: max. res., R.E., extensi., pro. no. and area.

in practical and scientific research. The extensigraph is clearly capable of characterizing a flours potential baking performance.

Correlations Between Texturepress and Bread Measurements

The correlation coefficients between bread values and texturepress dough measurements at 45, 90 and 135 minutes are given in Tables 19, 20 and 21. From Table 19 at 45 minutes, only weight and lbs force were significantly correlated to volume and specific volume. A greater association between texturepress measures and volume was exhibited at both 90 and 135 minutes. At these times, all texturepress values were significantly related to volume and specific volume. A very high degree of association was shown at the 135 minute time (Table 21) between tear and volume of $r=.94$. Both slope and lbs force were correlated at $p < 0.001$ with volume at 135 minutes with $r = .88$.

The relationship between bread shear and texturepress numbers was more evident from dough evaluated at 90 and 135 minutes. At longer fermentation times the gluten was more developed and the association between readings from the texturepress was greater with bread values at these times. Crumb compressibility also tended to be related to texturepress readings at the longer rest times. From Table 21 which presents correlations between bread quality and

Table 19. Pearson correlation coefficients between texturepress dough measurements at 45 minutes and bread values.

Variables	Volume	Specific Volume	Shear	Compressibilty
Volume	1.00			
Spec. Vol.	0.99***	1.00		
Shear	-0.76**	-0.74**	1.00	
Compress.	-0.94***	-0.94***	0.67*	1.00
Tensile	-0.76**	-0.77**	0.57	-0.76**
Weight	0.69*	0.68*	-0.79**	-0.54
lbs force	0.60*	0.60*	-0.46	-0.44
lbs force/g	0.15	0.15	-0.03	-0.07
area	0.50	0.49	-0.40	-0.33
slope	0.37	0.36	-0.20	-0.33
tear	0.56	0.56	-0.34	-0.44
	Tensile	**Weight**	**lbs force**	**lbs force/g**
Tensile	1.00			
Weight	-0.65*	1.00		
lbs force	-0.31	0.43	1.00	
lbs force/g	0.06	0.11	0.77**	1.00
Area	-0.20	0.30	0.93***	0.69*
Slope	-0.09	0.02	0.72**	0.66*
Tear	-0.22	0.26	0.97***	0.83***
	Area	**Slope**	**Tear**	
Are	1.00			
Slope	0.54	1.00		
Tear	0.91***	0.78**	1.00	

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
Bread variables: volume, specific volume, shear, compressibility and tensile strength.
Texturepress variables: weight, lbs force, lbs force/g, area, slope and tear.

Table 20. Pearson correlation coefficients between texturepress dough measurements at 90 minutes and bread values.

Variables	Volume	Specific Volume	Shear	Compressibilty
Volume	1.00			
Spec. Vol.	0.99***	1.00		
Shear	-0.76**	-0.74**	1.00	
Compress.	-0.94***	-0.94***	0.67*	1.00
Tensile	-0.76**	-0.77**	0.57	0.76**
Weight	0.75**	0.73**	-0.80**	-0.67*
lbs force	0.79**	0.77**	-0.72**	-0.65*
lbs force/g	0.79**	0.79**	-0.53	-0.65*
area	0.76**	0.74**	0.75**	-0.58*
slope	0.58*	0.58*	-0.37	-0.54
tear	0.76**	0.75**	-0.57	-0.63*
	Tensile	**Weight**	**lbs force**	**lbs force/g**
Tensile	1.00			
Weight	-0.60*	1.00		
lbs force	-0.51	0.92***	1.00	
lbs force/g	-0.44	0.66*	0.88***	1.00
Area	-0.43	0.89***	0.97***	0.84***
Slope	-0.27	0.58*	0.72**	0.83***
Tear	-0.44	0.77**	0.94***	0.96***
	Area	**Slope**	**Tear**	
Area	1.00			
Slope	0.62*	1.00		
Tear	0.89***	0.85***	1.00	

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
Bread variables: volume, specific volume, shear, compressibility and tensile strength.
Texturepress variables: weight, lbs force, lbs force/g, area, slope and tear.

Table 21. Pearson correlation coefficients between texturepress dough measurements at 135 minutes and bread values.

Variables	Volume	Specific Volume	Shear	Compressibilty
Volume	1.00			
Spec. Vol.	0.99***	1.00		
Shear	-0.76**	-0.74**	1.00	
Compress.	-0.94***	-0.94***	0.67*	1.00
Tensile	-0.76**	-0.77**	0.57	0.76**
Weight	0.68*	0.66**	-0.77**	-0.52
lbs force	0.88***	0.86***	-0.81**	-0.76**
lbs force/g	0.75**	0.72**	-0.68*	-0.62*
area	0.79**	0.77**	-0.80**	-0.65*
slope	0.88***	0.86***	-0.64*	-0.82**
tear	0.94***	0.92***	-0.76**	-0.88***
	Tensile	**Weight**	**lbs force**	**lbs force/g**
Tensile	1.00			
Weight	-0.57	1.00		
lbs force	-0.68*	0.90***	1.00	
lbs force/g	-0.48	0.79**	0.92***	1.00
Area	-0.59*	0.94***	0.94***	0.86***
Slope	-0.55	0.57	0.85***	0.83***
Tear	-0.74**	0.76**	0.95***	0.84***
	Area	**Slope**	**Tear**	
Area	1.00			
Slope	0.77**	1.00		
Tear	0.88***	0.93***	1.00	

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
Bread variables: volume, specific volume, shear, compressibility and tensile strength.
Texturepress variables: weight, lbs force, lbs force/g, area, slope and tear.

texturepress measures at 135 minutes, tear was very highly correlated to compressibility (r=-.88). Tensile strength of the bread was measured with the same cell upon which texturepress dough readings were recorded. Tensile strength was associated with dough weight at 45 and 90 minutes testing. Tensile strength and tear exhibited a strong relationship at 135 minutes with a correlation of r=-.74 .

The texturepress clearly demonstrated a relationship between dough properties and bread quality factors. The association was stronger at longer dough rest times. Since bread dough is traditionally fermented from 1 hour to 3 hours (Merritt and Bailey, 1945; Hoseney and Seib, 1978) depending upon its requirements, the texturepress could be a viable tool of assessment.

Regression Equations

Prediction equations of extensigraph variables from texturepress independent variables are given in Tables 22, 23, 24 and 25. Tables 22, 23 and 24 contain the estimates of the true regression lines at 45, 90 and 135 minutes. In Table 25, time was included as an independent variable. Maximum resistance and extensibiltiy at each dough test time had the greatest R^2 numbers. The R^2 indicates the strength of the relationship between dependent and independent variables. It is the percent of variability in Y (extensigraph variables) explained by association with X (texturepress variables). Here, the maximum resistance R^2 ranged from .84 to .83 at each time. Extensibility R^2 ranged from .83 for 45 and 90 minutes to .77 for 135 minutes. These clearly indicated an important association and illustrated that texturepress measures could characterize extensigrams.

When regression equations were examined with time included as an independent variable presented in Table 25, maximum resistance and extensibility again have the

Table 22. Estimate of parameters[a] in the multiple regression equations for the extensigraph at 45 minutes testing by the texturepress.

Variable	Constant	Weight	lbs force	lbs force/g	Slope	Tear	Area1	R^2
Maximum Resistance	-29.7913	2.0169	310.6973	-1183.0266			-3.2745	.84
Resistance to Extension	136.0984	0.5629	-51.4226			72.1777		.14
Extensi-bility	-53.5870	1.0537	134.5078	-4750.9615				.83
Proportional Number	2.1720	-0.0086	-1.1181			0.8945		.67
Area2	93.2604	-0.5793		-1735.3922			0.7131	.32

Area1 = texturepress area, Area2 = extensigraph area

[a] Under each texturepress variable column heading weight through area, fb coefficients are listed for extensigraph dependent variables in the general form $y = b_0 + b_1X_1 + b_2X_2 + \ldots$.

Table 23. Estimate of parameters[a] in the multiple regression equations for the extensigraph at 90 minutes testing by the texturepress.

Variable	Constant	Weight	lbs force	lbs force/ g	Slope	Tear	Area1	R^2
Maximum Resistance	-156.2975	2.6123			-281.1819	186.5595	4.8572	.84
Resistance to Extension	202.5942	-0.7053			-116.8967	30.7461	3.6078	.51
Extensi-bility	-24.3864	1.3465		-2186.9319		67.9570	1.7553	.83
Proportional Number	2.1959	-0.0094		35.1182		-0.5378		.62
Area2	80.2083	-0.5504			-81.8019	-44.2009	3.9311	.43

Area1 = texturepress area, Area2 = extensigraph area

[a] Under each texturepress variable column heading weight through area, b coefficients are listed for extensigraph dependent variables in the general form $y = b_0 + b_1X_1 + b_2X_2 + \ldots$.

Table 24. Estimate of parameters[a] in the multiple regression equations for the extensigraph at 135 minutes testing by the texturepress.

Variable	Constant	Weight	lbs force	lbs force/ g	Slope	Tear	Area1	R^2
Maximum Resistance	-312.2173	5.1479		-4260.3573	582.0510			.83
Resistance to Extension	124.6276	0.3508			137.0721	-39.4819	2.4784	.44
Extensi- bility	-64.9792	2.2154	31.8979		173.8554		-3.0187	.77
Proportional Number	2.7699	-0.0182			-1.3580		0.0303	.44
Area2	34.1157	0.2010			94.6967	-60.7066	1.1163	.10

Area1 = texturepress area, Area2 = extensigraph area

[a] Under each texturepress variable column heading weight through area, b coefficients are listed for extensigraph dependent variables in the general form $y = b_0 + b_1X_1 + b_2X_2 + \ldots$.

Table 25. Estimate of parameters[a] in the multiple regression equations for the extensigraph from texturepress independent variables including time.

Variable	Constant	Time	Weight	lbs force	lbs force/ g	Slope	Tear	Area1	R^2
Maximum Resistance	-123.7992	-15.8518	3.1468	114.9866	-4555.1335		82.5161		.82
Resistance to Extension	124.3430	5.8422	0.3079	-32.9339			26.3879	2.6627	.46
Extensi- bility	14.1558	-26.0442	1.9271	91.2238				-2.8921	.76
Proportional Number	1.9304	0.1887	-0.0116	-0.5706				0.0297	.57
Area2	53.0956	4.3812	-0.2850					2.2477	.16

Area1 = texturepress area, Area2 = extensigraph area

[a] Under each texturepress variable column heading weight through area, b coefficients are listed for extensigraph dependent variables in the general form $y = b_o + b_1X_1 + b_2X_2 + \ldots$.

greatest accounted variability. Coefficients for time were included in all equations. Weight and lbs force were employed in maximum resistance and extensibility equations. The R^2 for extensibility was slightly less compared to examination at individual fermentation times. The texturepress aptly predicted maximum resistance using these expansive equations.

One of the basic goals of this experiment was to derive regression equations that would be meaningful for predicting bread quality from dough measurements. Tables 26, 27 and 28 show the prediction equations for bread variables from texturepress independent variables at 45, 90 and 135 minute dough evaluation times. Table 29 contains the estimate of bread variables when time is included as an independent variable.

A strong predictive relationship existed for all bread variables, particularly volume and specific volume. It appears that the texturepress was quite capable in explaining a high degree of variability in all bread measures. R^2 for volume ranged from .92 at 45 minutes to .89 at 90 and 135 minutes relaxation time. This could mean that the texturepress in its own right could be of value in characterizing a flour and its future baking performance. From Table 29, when time was included in the equation there was a decrease in R^2 for all variables. No gain was

Table 26. Estimate of parameters[a] in the multiple regression equations for bread measurements at 45 minutes testing on the texturepress.

Variable	Constant	Weight1	lbs force	lbs force/g	Slope	Tear	Area	R^2
Weight2	83.2064		-7.1402	404.5927	24.0988	-18.7312	0.6639	.77
Volume	-223.7003	5.5680	-503.6130	-18470.5432		999.5812		.92
Specific Volume	-2.9656	0.0695	-5.5421	-257.3662		13.1813	-0.0573	.92
Shear	29.0861	-0.1736	6.5873	237.0534	-18.0944		-0.3980	.79
Tensile	0.4629		-0.3996	18.3127	1.3732	-0.7613	0.0319	.87
Compressi-bility	45.0687	-0.3129	38.7603	1032.4970		-76.1797		.77

Weight1 = texturepress weight, Weight2 = bread loaf weight

[a] Under each texturepress variable column heading weight through area, b coefficients are listed for bread dependent variables in the general form $y = b_0 + b_1X_1 + b_2X_2 + \dots$.

Table 27. Estimate of parameters[a] in the multiple regression equations for bread measurements at 90 minutes testing on the texturepress.

Variable	Constant	Weight1	lbs force	lbs force/ g	Slope	Tear	Area	R^2
Weight2	102.5409	-0.1903		-1859.1876	7.0084	9.6859	0.4581	.75
Volume	-442.8049	7.6569		65199.2711	-441.5947	-287.1963	-13.5799	.89
Specific Volume	-6.8718	0.1061		939.9880	-5.8831	-4.2791	-0.1973	.89
Shear	28.9968	-0.1748		-812.1540	4.8201	7.5301		.72
Compress- bility	62.1441	-0.5466		-3769.3261	18.9291	17.2281	1.1720	.79
Tensile	1.3179	-0.0108		-61.3618	0.8659	0.1402	0.0269	.80

Weight1 = texturepress weight, Weight2 = bread loaf weight

[a] Under each texturepress variable column heading weight through area, b coefficients are listed for bread dependent variables in the general form $y = b_o + b_1X_1 + b_2X_2 + \ldots$.

Table 28. Estimate of parameters[a] in the multiple regression equations for bread measurements at 135 minutes testing on the texturepress.

Variable	Constant	Weight1	lbs force	lbs force/ g	Slope	Tear	Area	R^2
Weight2	83.8170	-0.0507		441.2790		-7.0279	0.1676	.71
Volume	179.3294	0.5614		-8717.6503	233.5605	166.6177		.89
Specific Volume	0.8058	0.0412		-181.4484	6.4276	2.0984	-0.0956	.89
Shear	22.1545	-0.1455		334.1045	-13.5733		0.1509	.70
Compress-bility	21.2564	-0.0250		449.0254		-17.9298	0.3237	.87
Tensile	0.6442			5.8536	0.6509	-0.4148	0.0033	.74

Weight1 = texturepress weight, Weight2 = bread loaf weight

[a] Under each texturepress variable column heading weight through area, b coefficients are listed for bread dependent variables in the general form $y = b_o + b_1X_1 + b_2X_2 + \ldots$.

Table 29. Estimate of parameters[a] in the multiple regression equations for bread measurements from texturepress independent variables including time.

Variable	Constant	Time	Weight1	lbs force	lbs force/ g	Slope	Tear	Area	R^2
Weight2	85.5687	0.5655	-0.0378		121.1827	5.2293	-7.3674	0.1766	.46
Volume	204.2151	-40.8166	2.1896		-8488.4694		251.0998	-3.5585	.69
Specific Volume	2.2514	-0.5411	0.0294		-113.1831		3.4798	-0.0556	.68
Shear	17.2264	0.8826	-0.0779	17.2265	233.5293				.65
Compressibility	0.6934	0.0171	-0.0027		7.0665	0.4726	0.6935	0.0091	.56
Tensile	85.5687	0.5656	-0.0378		121.1827	5.2293	-7.3674	0.1766	.46

Weight1 = texturepress weight, Weight2 = bread loaf weight

[a] Under each texturepress variable column heading weight through area, b coefficients are listed for bread dependent variables in the general form $y = b_0 + b_1X_1 + b_2X_2 + \ldots$.

evident for using one equation which spanned over all test times. The texturepress exhibited greater predictive ability when employed over a range of test times.

The estimates of the true regression lines for bread variables from extensigraph independent variables are shown in Tables 30, 31 and 32. R^2 values for volume and specific volume ranged from .86 to .92 demonstrating a highly important association between extensigraph measures and bread quality. The R^2 values for the extensigraph were comparable to the range from the texturepress. All other variables showed a strong relationship except for tensile strength with R^2 values from .42 to .59. Maximum resistance was important in all regression equations.

Table 33 presents the estimate of bread measurements from extensigraph independent variables when time was included as an independent variable. R^2 for all variables decreased in these expansive equations when compared to examination at individual test times. However the magnitude in reduction of the R^2 was not as great as seen with the texturepress. Volume as predicted by texturepress measures including time possessed an R^2 of .69 . Volume predicted by the extensigraph with time included as a variable had an R^2 of .84, which suggested that the extensigraph was more capable of explaining variability in bread volume with one equation than the texturepress.

Table 30. Estimate of parameters[a] in the multiple regression equations for bread measurements at 45 minutes testing on the extensigraph.

Variable	Constant	Maximum Resistance	Resistance to Extension	Extensibility	Proportional Number	Area	R^2
Weight	88.4193	-0.0429	0.0369	-0.0788		0.1640	.78
Volume	165.4362	1.7910	-1.3013	1.7103		-4.0086	.92
Specific Volume	1.0913	0.0150	-0.0167	0.0275		-0.0618	.92
Shear	22.0250	-0.0345		-0.0292		0.0564	.73
Compressibility	20.4002	-0.1770	0.1349	-0.1206		0.4262	.86
Tensile	0.6351	-0.0013	0.0015	-0.0020		0.0043	.55

[a] Under each extensigraph variable column heading maximum resistance through area, b coefficients are listed for bread dependent variables in the general form $y = b_o + b_1X_1 + b_2X_2 + \ldots$.

Table 31. Estimate of parameters[a] in the multiple regression equations for bread measurements at 90 minutes testing on the extensigraph.

Variable	Constant	Maximum Resistance	Resistance to Extension	Extensibility	Proportional Number	Area	R^2
Weight	64.1163	-0.0164		0.0331	64.1163	0.0438	.65
Volume	1334.4496	1.2476	-0.9839	-3.4582	-368.1038		.89
Specific Volume	18.6438	0.0137		-0.0517	-6.7941		.88
Shear	9.0603	-0.0257	0.1004		-6.9183	-0.0327	.79
Compressi-bility	-55.4645	-0.0976	0.1487	0.2360	16.2330		.74
Tensile	0.2926	-0.0006	0.0024		-0.0591		.42

[a] Under each extensigraph variable column heading maximum resistance through area, b coefficients are listed for bread dependent variables in the general form $y = b_0 + b_1X_1 + b_2X_2 + \ldots$.

Table 32. Estimate of parameters[a] in the multiple regression equations for bread measurements at 135 minutes testing on the extensigraph.

Variable	Constant	Maximum Resistance	Resistance to Extension	Extensibility	Proportional Number	Area	R^2
Weight	75.5548	-0.0319	0.0319		2.9530	0.0694	.81
Volume	422.3673	1.3177			-158.8923	-2.7714	.86
Specific Volume	5.6172	0.0175			-2.3460	-0.0383	.86
Shear	11.9913	-0.0208			2.7956	0.0286	.74
Compressi-bility	11.5466	-0.1060			9.3962	0.2527	.70
Tensile	0.3050	-0.0012	0.0021			0.0065	.59

[a] Under each extensigraph variable column heading maximum resistance through area, b coefficients are listed for bread dependent variables in the general form $y = b_o + b_1X_1 + b_2X_2 + \ldots$.

Table 33. Estimate of parameters[a] in the multiple regression equations for bread measurements from extensigraph independent variables including time.

Variable	Constant	Time	Maximum Resistance	Resistance to Extension	Extensibility	Proportional Number	Area	R^2
Weight	75.7094	-0.616	-0.0116			6.2413	0.0432	.67
Volume	441.4591	-1.7512	1.0256	-0.9239	0.4022	-74.5921	-1.5637	.84
Specific Volume	5.8620	0.2913	0.0129	-0.0085	0.0051	-0.6380	-0.0228	.84
Shear	16.1474	0.0881	-0.0210	0.0290	-0.0249	-1.4096	0.0197	.73
Compressi-bility	0.3328	0.5907	-0.0796	0.0663		6.1208	0.1400	.67
Tensile	0.3338	-0.0154	-0.0005	0.0018				.47

[a] Under each extensigraph variable column heading maximum resistance through area, b coefficients are listed for bread dependent variables in the general form $y = b_o + b_1X_1 + b_2X_2 + \ldots$.

When comparing the ability of the two different instruments to predict bread characteristics, it seemed that each machine was capable of characterizing bread quality to a high degree. In this research the extensigraph demonstrated expected trends by exhibited a strong predictive relationship to bread variables. Because of this association long known to bakers and researchers, the extensigraph was used as a standard by which to compare the texturepress. Volume R^2 was near identical for both extensigraph and texturepress at all test times. While perhaps not a replacement for the extensigraph, the texturepress warrants serious attention. From this research, it appears that the texturepress has potential in physical dough assessment . Although the extensigraph gives highly reproducible and accurate results, its use is limited to physical dough evaluation. The texturepress is adaptable to many baked food products besides bread. This research indicated that the texturepress was successful in effectively evaluating dough characteristics and characterizing potential bread volume.

SUMMARY AND CONCLUSIONS

The Food Technology Corporation's Texturepress enjoys wide use in the food industry and research due to its adaptability to many food products as a texture measurement. It has successfully been employed testing baked bread, but has never been used to assess physical dough properties. The objectives of this study were to determine if ingredient effect on bread dough prepared from hard and soft flours, could be predicted from texturepress measurements and whether these measurements could be related to extensigraph trends established from these same doughs. The extensigraph has been widely used by the baking industry, and thus, was used as a standard by which to measure texturepress performance.

Soft white wheat flour (SWF) and hard red wheat flour (HRF) were used to give a wide range of treatments. Farinograph evaluation determined that the hard flour with 12.8% protein had a higher absorption, greater stability and a longer arrival time than the soft white wheat flour with 8.7% protein.

To further broaden the range of treatments, sodium stearoyl-2-lactylate (SSL), a dough conditioner, and potassium bromate, an oxidant, were employed. SSL was used at 0.5% of flour weight and bromate at 20 ppm of flour weight. NaCl at either 1 or 2% of flour weight was also incorporated into the dough formulation. A homogeneous dough was mixed and divided in half. Half of the dough was evaluated on each of the two machines, the texturepress and the extensigraph, at 45, 90 and 135 minute relaxation times. In the second phase of study, four selected treatments were baked into pup loaves and evaluated for volume, specific volume, crumb compressibility, crumb tenderness and tensile strength.

For maximum resistance (BU) readings from the extensigraph, the hard flour doughs exhibited much greater resistance for all treatments when compared to the soft flour doughs. The incorporation of 2% NaCl resulted in doughs demonstrating the highest resistance in soft wheat doughs and second highest in hard wheat doughs. The double additive effect of bromate and SSL caused doughs to exhibit the greatest maximum resistance in hard wheat doughs and the second greatest in soft wheat doughs. The weakest doughs for both flour types were those doughs incorporating only 1% NaCl.

The lbs force readings from the texturepress represented the maximum force required to stretch doughs with that instrument. Trends established by use of the extensigraph were also shown by the texturepress. There was an overall trend of increased force with increased time. The hard and soft flour doughs treated with the bromate and SSL recorded the greatest lbs force values at 90 and 135 minutes. The soft flour dough with 1% NaCl and the hard flour dough with bromate demonstrated the lowest lbs force measurements for their respective flour type group. Both the extensigraph and the texturepress were sensitive to changes in the dough which occurred over time.

Eight of the ten treatments were statistically analyzed in a factorial arrangement of a split-plot design. Treatments in the whole plot were split over time. The three factors in the whole plot were flour type, presence of SSL and presence of bromate.

The two-way interactions of bromate and time as well as flour type and time were significant at $p < 0.01$ for maximum resistance measures from the extensigraph. The interaction of SSL and time was significant at $p < 0.05$ for maximum resistance. The three-way interaction of all factors in the whole plot was also highly significant at $p < 0.01$. These interactions represented a synergistic effect of factors which was expected due to the dynamism of the dough system. Extensibility from the extensigraph exhibited a highly significant ($p < 0.01$) two-way interaction of flour type and time. The magnitude of change in extensibility of the test doughs during rest times depended upon their protein content.

Mean squares from the analyses of variance for lbs force measures from the texturepress indicated a significant ($p < 0.05$) three-way interaction of time, presence of bromate and flour type. SSL action improved when employed in tandem with bromate, but it appeared to work equally well across flour type and time in this experiment. The response to bromate was dependent upon flour type and time of measurements. For texturepress tear and slope measures, a highly significant interaction ($p < 0.01$) between time and flour type was evident. Neither measure was sensitive to differences in treatments from presence of improvers over time. These texturepress measures were only sensitive to the effect of protein content.

The range of treatments was broad enough that each of the four treatments baked into bread were significantly different from the others at alpha = 0.05 for volume and specific volume measures. The lowest volume resulted in bread baked from the soft wheat flour. This was attributable to a collapsed crumb as the soft flour dough was too weak to support expansion. The highest volume resulted in bread baked from hard flour containing double additives; SSL and bromate. These results were expected from examination of extensigraph curves and possibly from inspection of texturepress curves.

The bread baked from soft wheat flour was the least tender, it required the greatest lbs force to compress the crumb and possessed the greatest tensile strength. The soft wheat bread was significantly less tender at alpha = 0.05 than the other three hard wheat breads.

Examination of correlation coefficients indicated the strength of the linear relationship between variables. Most correlations between the texturepress and the extensigraph were significant. At the 45, 90 and 135 minute test times, the relationships between lbs force readings and maximum resistance values were very significant at $p < 0.01$. The correlation coefficients ranged from .82 to .89 . Pounds force also demonstrated a strong association with extensibility. Correlation coefficients for these measures ranged from .81 to .89 . The lbs force readings were measured from the maximum pull required to stretch the dough. Thus, it was not surprising that this measure tended to be strongly associated with extensigraph maximum resistance values.

Correlations between extensigraph and bread measures showed that at all test times bread volume was highly associated with maximum resistance, extensibility, proportional number and area. Correlations for these variables and bread volume were .90 or higher at 45 minutes. These same extensigraph measures also exhibited a strong relationship to crumb tenderness and compressibility. This strong association between the extensigraph and bread quality was expected and has been known to exist for some time.

When examining correlation coefficients between the texturepress and bread measurements at 45 minutes, only weight and lbs force were highly correlated to volume. At 90 and 135 minute test times, all texturepress values were significantly related to volume and specific volume at $p < 0.05$. Texturepress tear and bread volume demonstrated a strong relationship at 135 minutes with the correlation coefficient equal to .94 . Tear and crumb compressibility were also highly related at longer rest times. The texturepress exhibited a clear association with bread quality factors. The relationship was more evident at longer fermentation times when the gluten was more developed. Bread dough is traditionally fermented for times much longer than 45 minutes to allow adequate development.

Multiple linear regression was used to derive meaningful prediction equations amongst variables. When the variability in extensigraph variables was examined by association with texturepress variables an important predictive relationship emerged. Maximum resistance R^2 predicted by texturepress variables ranged from .83 to .84 at all test times. Extensibility R^2 varied from .83 at 45 and 90 minutes to .77 at 135 minutes. The texturepress appeared quite capable of characterizing extensigrams to a high degree.

A strong predictive relationship existed when texturepress measures were used to predict bread quality parameters. The texturepress explained a high degree of variability in volume and specific volume. R^2 for volume ranged from .89 at 90 and 135 minutes to .92 at 45 minutes. When time was included in the prediction equations as an independent variable, there was a decrease in R^2 for all bread quality characteristics.

The extensigraph also demonstrated a strong predictive relationship to bread variables. R^2 for volume and specific volume ranged from .86 to .92 for all extensigraph measures. This range was comparable to the range shown by the texturepress. Although texturepress measures explained a greater percent of variability in bread volume measures than did the extensigraph at 135 minutes. When time was included as an independent variable for predicting bread characteristics, R^2 from extensigraph measures were greater, especially when predicting volume and specific volume. Coefficients for maximum resistance were necessary in all multiple linear regression equations for bread values predicted from extensigraph measures.

The texturepress was sensitive to dough treatment interactions although not as sensitive as the extensigraph. Maximum resistance from the extensigraph and lbs force from the texturepress were highly correlated to each other. Several texturepress measures were highly associated to bread volume which indicated the potential usefulness of this instrument in physical dough evaluation. The texturepress showed a strong predictive relationship to extensigraph measures and to bread volume signifying its ability to successfully characterize bread quality. Since proper quality assessment is the key to ensuring functional reliability in the bread dough system, this data suggested that the texturepress was adept in estimating dough performance.

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RECOMMENDATIONS FOR FUTURE RESEARCH

Evaluation of a flour is necessary to determine how it will perform in a certain food system and to ensure functional reliability. The texturepress appears capable of assessing a flour's characteristics and providing an index to potential bread volume. Therefore, further research with this instrument is warranted.

This study demonstrated that the texturepress was sensitive to ingredient behavior (the action of improvers) in a dough system. Research dealing with a wide range of flour types of varying protein contents would yield useful information. Studies such as this have been successfully performed with the extensigraph and are used as comparative guides for different cultivars. Since protein content is an excellent indicator to performance, incorporation of protein content could be included into prediction equations.

Modification of the test cell itself would be beneficial. The work table should be lengthened even further as several of the slack, extensibile doughs did not completely break upon stretching.

In this research, dough test weight was variable. This was due to the requirement that doughs be of uniform thickness prior to testing. Procedure modifications to allow for consistent sample weight could result in better dough characterization. Perhaps preweighed sample doughs could be fermented in special holders the same size as the test area. The use of variable sample size dependent upon the nature of the dough would also be possible.

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APPENDIX

Appendix A. Means and standard deviations for texturepress measurements performed on doughs prepared from hard red (HRF) and soft white (SWF) flours.

Treatment	Time (min)	Weight (g)	Force (lbs)	LBS Force/ g
SWF 1	45	72.6 ± 1.9	0.790 ±.098	.0108 ±.0009
+ 1% NaCl	90	78.3 ± 1.3	0.808 ±.049	.0103 ±.0005
	135	78.4 ± 1.5	0.870 ±.130	.0124 ±.0035
SWF 2	45	78.5 ± 1.4	0.872 ±.093	.0110 ±.0012
+ 2% NaCl	90	82.2 ± 3.3	0.980 ±.106	.0120 ±.0013
	135	83.4 ± 1.4	1.053 ±.167	.0125 ±.0020
SWF 3	45	75.9 ± 4.9	0.698 ±.066	.0092 ±.0006
+ bromate	90	82.2 ± 3.3	0.805 ±.144	.0098 ±.0014
	135	79.0 ± 5.0	1.010 ±.096	.0128 ±.0010
SWF 4	45	77.7 ± 1.9	0.955 ±.221	.0124 ±.0028
+ SSL	90	79.6 ± 2.0	0.998 ±.123	.0125 ±.0013
	135	80.3 ± 2.5	1.130 ±.174	.0140 ±.0019
SWF 5	45	76.5 ± 3.2	0.745 ±.106	.0097 ±.0012
+ bromate	90	80.7 ± 3.7	1.142 ±.105	.0156 ±.0039
+ SSL	135	81.2 ± 2.2	1.327 ±.037	.0164 ±.0006
HRF 6	45	92.2 ±14.3	1.160 ±.259	.0127 ±.0034
+ 1% NaCl	90	108.6 ± 5.4	1.733 ±.278	.0159 ±.0018
	135	100.4 ±12.0	1.776 ±.425	.0175 ±.0026
HRF 7	45	97.9 ± 9.7	1.457 ±.199	.0153 ±.0036
+ 2% NaCl	90	103.3 ± 5.8	1.722 ±.269	.0166 ±.0017
	135	114.4 ± 3.8	1.820 ±.118	.0160 ±.0010
HRF 8	45	95.0 ± 5.0	1.238 ±.115	.0131 ±.0016
+ bromate	90	95.2 ± 7.5	1.565 ±.139	.0165 ±.0015
	135	96.2 ± 8.5	1.513 ±.127	.0159 ±.0019
HRF 9	45	100.8 ± 5.0	1.265 ±.145	.0127 ±.0012
+ SSL	90	106.2 ± 5.4	1.688 ±.173	.0160 ±.0014
	135	113.9 ± 5.9	1.840 ±.140	.0155 ±.0013
HRF 10	45	97.0 ± 8.8	1.228 ±.112	.0116 ±.0030
+ bromate	90	109.8 ±13.5	1.748 ±.189	.0166 ±.0019
+ SSL	135	108.6 ±13.1	1.875 ±.177	.0162 ±.0013

n=4

Appendix B. Means and standard deviations for texturepress measurements performed on doughs prepared from hard red (HRF) and soft white (SWF) flours.

Treatment	Time (min)	Area (cm^2)	Slope	Tear (lbs force)
SWF 1	45	16.69±2.53	.216±.025	.719±.113
+ 1% NaCl	90	14.80±1.00	.247±.028	.741±.043
	135	15.52±2.29	.270±.046	.806±.151
SWF 2	45	15.88±1.42	.243±.061	.766±.078
+ 2% NaCl	90	18.35±2.26	.313±.054	.881±.102
	135	18.98±2.57	.311±.086	.944±.177
SWF 3	45	12.83±0.79	.234±.021	.639±.067
+ bromate	90	15.37±2.10	.284±.084	.715±.104
	135	17.78±2.08	.304±.014	.938±.065
SWF 4	45	18.65±4.12	.252±.071	.874±.222
+ SSL	90	18.86±2.75	.278±.018	.915±.088
	135	21.80±2.51	.317±.051	1.051±.166
SWF 5	45	14.27±1.65	.224±.015	.689±.075
+ bromate	90	20.45±2.42	.319±.026	1.000±.083
+ SSL	135	23.46±1.07	.351±.027	1.163±.048
HRF 6	45	19.67±4.11	.275±.065	.946±.169
+ 1% NaCl	90	28.32±3.02	.467±.039	1.475±.238
	135	30.38±4.62	.436±.077	1.418±.334
HRF 7	45	24.84±5.10	.327±.063	1.148±.207
+ 2% NaCl	90	30.28±3.04	.395±.061	1.424±.206
	135	33.30±1.25	.444±.023	1.420±.046
HRF 8	45	21.48±1.69	.315±.032	1.059±.090
+ bromate	90	26.05±2.99	.440±.038	1.441±.109
	135	23.75±1.87	.402±.071	1.410±.136
HRF 9	45	20.99±2.32	.264±.037	.979±.114
+ SSL	90	28.13±2.60	.399±.039	1.339±.120
	135	30.80±1.80	.415±.017	1.560±.099
HRF 10	45	21.68±1.57	.297±.052	1.018±.105
+ bromate	90	29.88±3.19	.416±.074	1.473±.141
+ SSL	135	30.70±3.43	.485±.074	1.571±.151

n=4

Appendix C. Means and standard deviations for extensigraph measurements performed on doughs prepared from hard red (HRF) and soft white (SWF) flours.

Treatment	Time (min)	Maximum Resistance (BU)	Resistance to Extension (BU)
SWF 1	45	174.9 ±12.5	173.7 ±12.7
+ 1% NaCl	90	176.9 ± 7.8	176.4 ± 7.5
	135	175.1 ± 9.4	173.6 ±13.0
SWF 2	45	227.1 ±18.6	211.4 ±11.6
+ 2% NaCl	90	235.8 ±10.0	223.0 ± 8.9
	135	247.4 ± 4.2	235.1 ± 3.2
SWF 3	45	171.7 ± 7.1	171.8 ± 7.0
+ bromate	90	185.5 ±13.2	184.6 ±12.0
	135	199.1 ±16.2	199.5 ±16.7
SWF 4	45	205.3 ±12.1	205.0 ±11.9
+ SSL	90	211.8 ±17.8	211.8 ±17.8
	135	210.5 ±19.2	210.1 ±19.4
SWF 5	45	199.0 ± 5.8	198.6 ± 6.1
+ bromate	90	217.9 ± 8.4	217.4 ± 8.7
+ SSL	135	214.8 ±24.6	214.8 ±24.6
HRF 6	45	336.6 ± 9.6	192.6 ± 9.3
+ 1% NaCl	90	369.0 ±21.4	211.1 ±10.3
	135	381.6 ±26.8	213.7 ± 7.8
HRF 7	45	368.4 ±22.1	201.2 ±15.3
+ 2% NaCl	90	464.3 ±15.4	242.3 ± 9.8
	135	496.4 ±17.3	254.8 ±10.8
HRF 8	45	336.8 ±17.6	193.5 ±11.5
+ bromate	90	386.8 ± 9.6	216.0 ±12.8
	135	412.6 ±17.8	223.3 ± 9.4
HRF 9	45	333.5 ±26.0	192.1 ±11.0
+ SSL	90	380.8 ±32.3	208.6 ± 9.5
	135	393.7 ±32.9	215.8 ±12.3
HRF 10	45	388.7 ±18.1	209.4 ± 4.4
+ bromate	90	474.3 ±21.0	248.2 ±10.9
+ SSL	135	501.8 ±34.2	271.9 ±29.7

n=4

Appendix D. Means and standard deviations for extensigraph measurements performed on doughs prepared with hard red (HRF) and soft white (SWF) flours.

Treatment	Time (min)	Extensibility (mm)	Area (cm^2)	Proportional Number
SWF 1	45	145.8 ± 5.0	40.9 ± 3.4	1.23 ±.10
+ 1% NaCl	90	136.8 ± 4.1	38.0 ± 2.7	1.29 ±.04
	135	137.5 ± 5.6	37.8 ± 3.8	1.28 ±.09
SWF 2	45	154.0 ±13.9	56.3 ± 8.0	1.47 ±.10
+ 2% NaCl	90	145.8 ± 6.7	51.7 ± 6.5	1.62 ±.10
	135	138.8 ± 9.8	53.4 ± 4.1	1.78 ±.12
SWF 3	45	142.8 ± 2.1	39.1 ± 2.4	1.21 ±.06
+ bromate	90	139.3 ± 3.0	40.7 ± 3.9	1.33 ±.06
	135	127.7 ± 2.7	40.6 ± 3.5	1.56 ±.13
SWF 4	45	143.2 ± 6.3	44.8 ± 3.9	1.43 ±.06
+ SSL	90	139.9 ± 7.7	49.0 ± 2.7	1.52 ±.17
	135	130.8 ±10.0	43.7 ± 3.5	1.63 ±.22
SWF 5	45	139.6 ± 5.6	43.6 ± 1.5	1.43 ±.06
+ bromate	90	134.9 ± 1.3	45.8 ± 1.5	1.61 ±.08
+ SSL	135	132.1 ± 4.7	49.7 ± 2.2	1.63 ±.14
HRF 6	45	250.8 ± 7.0	122.6 ± 6.8	1.34 ±.12
+ 1% NaCl	90	230.7 ±10.2	119.1 ± 8.9	1.60 ±.08
	135	218.9 ± 5.1	116.4 ± 9.8	1.74 ±.09
HRF 7	45	256.9 ±18.0	137.2 ± 7.3	1.43 ±.14
+ 2% NaCl	90	249.8 ± 7.0	160 2 ± 6.2	1.84 ±.10
	135	230.1 ± 8.7	157.3 ±10.9	2.16 ±.11
HRF 8	45	244.7 ± 6.2	118.5 ± 6.1	1.38 ±.07
+ bromate	90	226.5 ± 7.7	120.0 ± 3.6	1.61 ±.08
	135	224.2 ± 7.6	124.1 ± 4.4	1.84 ±.10
HRF 9	45	258.3 ±11.1	120.7 ± 5.4	1.30 ±.06
+ SSL	90	236.2 ±12.3	131.9 ± 9.3	1.61 ±.09
	135	219.2 ± 9.9	112.8 ±13.0	1.80 ±.15
HRF 10	45	253.7 ± 7.5	136.2 ± 5.7	1.53 ±.08
+ bromate	90	232.5 ± 7.0	147.5 ± 6.6	2.00 ±.08
+ SSL	135	222.5 ± 6.7	151.7 ± 7.0	2.27 ±.18

n=4