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Functional Performance of Thual Barley Grown in Two Locations as Affected by Salt in Model and Food Systems

Ruthann Burroughs Swanson
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by Ruthann Burroughs Swanson entitled "Functional Performance of Thual Barley Grown in Two Locations as Affected by Salt in Model and Food Systems." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Human Ecology.

Marjorie P. Penfield, Major Professor

We have read this dissertation and recommend its acceptance:

Mary Nelle Traylor, Nina L. Marable, Sharon L. Melton, Vernon H. Reich

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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FUNCTIONAL PERFORMANCE OF THUAL BARLEY GROWN IN TWO LOCATIONS AS AFFECTED BY SALT IN MODEL AND FOOD SYSTEMS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Ruthann Burroughs Swanson

June 1986

DEDICATION

This dissertation is dedicated to the memory of James Gordon Fowler and in honor of Carrie Cordelia Powell Fowler, grandparents of the author.

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ABSTRACT

Functional properties of Thual hull-less whole-grain barley flours milled from barley grown in two locations were studied. Proximate composition of Tennessee-produced barley flour approximated that of whole-wheat flour; flour milled from Alaska-produced barley had reduced protein and increased carbohydrate plus ash levels. Alaska barley flour had higher levels of the amino acids detrimental to loaf volume, whereas higher levels of amino acids related to increased loaf volume were present in the Tennessee barley flour. Photomicrographs of flour components revealed a bimodal starch distribution. Starch granule shapes approximated those of wheat. Adhering matter was present.

Composite flours that were 50% bread and varying levels of whole-wheat to whole-grain barley (50:0, 40:10, 30:20 and 20:30) were studied in apparent viscosity, dough development and dough expansion systems. Mixogram parameters reflected slow hydration of the barley flour and the quality and quantity of protein present. Salt (1.5, 2.0, 2.5 or 3.0%) increased dough strength at all barley flour levels; salt effect was greater when the composite flours contained the Alaska barley. The positive effect of salt on dough strength was reduced in complete dough systems. Differences in apparent viscosity and dough expansion had no practical importance in breadmaking functionality.

Response surfaces from the complete dough development study that depicted barley flour and salt levels within barley source were used to identify an optimal formula for each barley source. Breads containing

composite flours were 20% barley flour from grain produced in each location. A 50:50 bread:whole-wheat composite flour was the control. Salt level in all breads was 2.0%. Specific loaf volume was reduced by 5-6% with barley incorporation. Appearance of the crumb and shape of the Tennessee barley and control breads did not differ; Alaska barley bread exhibited tunnels. Instron Texture Profile Analysis revealed no differences among the three breads in hardness, cohesiveness, springiness and chewiness; Alaska barley breads were more gummy. Generally, consumer acceptability of appearance, texture and flavor of the two whole-grain barley breads did not differ from the whole-wheat control.

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CHAPTER I

INTRODUCTION

Grain and cereal consumption in the United States has become a cause of concern among nutritionists. As important contributors to the diet of B vitamins, iron and both digestible and nondigestible carbohydrates, grains and cereals and their bakery products are important components of an adequate and balanced diet (Gustafson, 1983; Ranhotra, 1981). The Dietary Guidelines for Americans (USDA and US DHHS, 1980) recommend an increase in the consumption of foods containing starch and fiber and a decrease in the consumption of sugar. Increased consumption of whole-grains also has been encouraged (USDA and US DHHS, 1980). The recommendation to decrease the consumption of red meat (USDA and US DHHS, 1980), an important source of trace minerals, also has implications for the importance of the nutrient contribution of grains and cereals in the diet. Conversely, a reduction in grain and cereal consumption among Americans of 6-19% has occurred since 1965 (USDA, 1980). More recently an increase in the sales of variety breads, which are breads other than white pan bread, has been reported (Raskin, 1980). Whole-wheat, raisin, and multigrain breads are examples.

Barley has been found in consumer surveys to have a positive nutritional and healthful image (Moore, 1980). This image has been utilized in the marketing of a barley-based snack food with better nutritive value than other grain-based snack foods. This product appealed to consumers who did not usually purchase snack foods (Moore, 1980). A

rice-barley malt flour has been suggested for substitution at the 10% level in speciality breads (Moore, 1978). In addition, variety breads containing various forms of milled hulled barley--barley flour, barley grits or barley flakes--are currently being test-marketed in the United States (Nelson, 1984).

In spite of its positive image among consumers (Moore, 1980), barley as a component of the United States food supply generally has been overlooked. In other countries barley plays a prominent role in the diet with the hull-less varieties being preferred (Pomeranz, 1974a; Whitehouse, 1970). Prentice and coworkers (1979) indicate that hulled varieties also are suitable for human consumption if the hulls are removed or are finely milled. In the United States, hulled varieties usually are used for human food (Pomeranz, 1974a). However, only 5 million bushels are used annually with the primary uses being in infant foods, soups, dressings and breakfast cereals. Barley flour is produced chiefly as a by-product of the pearling process. High-grade patent flour can be produced by conventional roller milling (Dickson, 1979). More recently barley as the major component of high fiber brewer's spent grains (BSG) has been investigated as a partial replacement for wheat flour in bakery products (Dreese and Hoseney, 1982).

Functionality of barley in food products is influenced by variety and type (covered versus hull-less); climatic conditions under which it is grown also may be influential (Goering et al., 1970; Whitehouse, 1970). Barley is grown primarily in the north central states with the hulled varieties of malting quality being produced in the largest

quantity. However, its production as a spring crop in Tennessee is being investigated (Reich, 1984), while its production in Alaska is the cornerstone of the new in-state grain industry (Pollock, 1981). Thual, a hull-less variety, is currently being investigated in both areas (Lewis, 1984; Reich, 1984).

Protein, starch and fat contents of barley approximate those of wheat; production at northern latitudes results in an increase in protein, a decrease in starch and maintenance of fat content (Oohara, 1978; Whitehouse, 1970; Wooding and Husby, 1980). Dietary fiber content of hulled barley flour (70% extraction) has been reported to be higher than whole-wheat flour (Frolich and Hestangen, 1983), although hull-less barley flour has been found to have a fiber content that approximates wheat (Bhatty, 1986). However, climatic growing conditions also influence fiber content with a reduction occurring at northern latitudes (Oohara, 1978). Whole-grain barley has been found to be an excellent source of thiamin, riboflavin, folic acid, pyridoxine and tocopherols (Pomeranz, 1974a). Mineral content of whole-grain barley is greater than is that of barley flour due to the decortication operation necessary to produce patent barley flour (Liu et al., 1974; Pomeranz, 1974a; Weaver et al., 1981). Reductions in mineral content during milling are not as great for barley as for wheat (Weaver et al., 1981), and the use of whole-grain barley flour will further minimize mineral loss, making whole-grain barley flour a good source of iron, zinc, manganese, copper, chromium and nickel (Weaver et al., 1981). The mineral content of the

hull-less barley kernel has been reported to be higher than the mineral content of hulled barley (Liu et al., 1974).

Although barley has been used for centuries in breadmaking, its use decreased as wheat production increased (Pomeranz, 1974a) and wheat bread became a staple in the western diet. Despite the overall decrease in grain consumption among Americans, the recent increase in sales of variety breads and the positive image of barley among consumers, barley flour has been the subject of few research studies. Information on its functional properties and performance in baked products could be used as a basis for the development of products containing whole-grain barley flour. Availability of these barley products would encourage increased consumption of whole-grain products among Americans as recommended in the Dietary Guidelines (USDA and US DHHS, 1980). This study has the following objectives:

1. to evaluate and compare the functional properties of the whole-grain flour milled from hull-less Thual barley grown in two diverse climates;
2. to evaluate the effect of salt at varying levels on the functional properties of two barley flours;
3. to evaluate the functional performance of the two barley flours in a whole-grain yeast bread using objective and sensory techniques.

CHAPTER II

REVIEW OF LITERATURE

I. FUNCTIONAL CHARACTERISTICS OF BARLEY FLOUR COMPONENTS

The functional properties of a variety flour are important, as the use of a variety flour in food formulations depends on its ability to contribute desirable structure, texture, flavor and color characteristics to the product. Functionality has been defined as "any property of a substance besides nutritional ones that affects its utilization" (Pour-El, 1981). Grain components important in flour functionality are protein, starch, lipids and pentosans. Presently, the functional characteristics of wheat flour (FDA, 1983) are the basis for the development of standards for baked products as well as the formulas for their production. Wheat is milled to enhance its functional characteristics for specific end-product uses. The Code of Federal Regulations (FDA, 1983) further specifies some physical characteristics of the flour including type of wheat, particle size and amount of bran present; the chemical properties, moisture content and enzyme levels, also are specified. These characteristics influence the functional performance of a flour in a food system.

Interest in the production of variety breads has resulted in the use of a whole-wheat bread as a standard (Prentice et al., 1979; Prentice and D'Appolonia, 1977). The physical properties of whole wheat flour differ from those of wheat flour (FDA, 1983). The presence

of the bran, germ and aleurone is responsible for alterations in the functional performance of the flour (Bohn and Machon, 1933; Grewe and LeClerc, 1943; Pomeranz et al., 1970a, 1970b; Shetlar and Lyman, 1944; Sibbett and Harris, 1945). Whole-grain variety flours from nonwheat cereal sources would further alter the characteristics of the food system as the characteristics of the grain's functional components would differ from wheat. Several functional characteristics of the flour will be the subject of this review.

Starch

Characteristics of starch important in baked products include the surface characteristics of the granules, crystalline organization of the granule (Kulp and Lorenz, 1981), amylose-amylopectin ratio (Hoseney et al., 1978) and gelatinization characteristics (Sandstedt, 1961). Sandstedt (1961) postulated that starch has five important roles in the structure of bread dough: (1) acts to dilute the gluten to the desired consistency, (2) is a source of sugar through the action of amylase, (3) has a surface capable of interacting to form a strong union with gluten, (4) permits stretching of the gas-cell film as a result of gelatinization and (5) competes with gluten for water resulting in the setting and rigidity of the gluten film. More recently, Hoseney et al. (1978) suggested that starch acts as a "water sink," making water available for protein hydration during breadmaking.

Studies on the role of starch in baked products have shown that wheat starch is not unique in its ability to fulfill these functions. Starches from rye and barley produced experimental bread loaves nearly

equal in volume to those produced from wheat starch (Hoseney et al., 1971). Lean formula cakes and experimental cookies made with barley starch produced acceptable experimental products (Sollars and Rubenthaler, 1971). Although starch is regarded by some investigators to be of lesser importance in white pan bread (Bechtel et al., 1978; Pomeranz, 1969), its role in rye bread is not as a reinforcer but rather as the major structural component (Pomeranz et al., 1984), indicating the increased importance of starch in some variety breads. Characteristics of barley starch important in baked products will be reviewed.

Starch Granule Structure

Starch is present in cereals as discrete granules that vary in size and shape depending on their botanical source. Wheat starch granules are diverse in size and bimodal in distribution. The smaller granules are round whereas the large granules are disc-shaped. Some granules exhibit pitting and grooves. Barley starch granules also are diverse in size and bimodal in distribution with an oval shape and smooth surface. Some granules exhibit grooves and depressions (Hall and Sayre, 1970). However, starch granules from some waxy barley sources have been described as polygonal (DeHaas et al., 1983). The surface and size of the granule are important as gluten must adhere to the surface of the starch granules during bread production (Sandstedt, 1961).

The ratio of small to large granules has been found to vary depending on barley variety, with an increase in the size range occurring in hull-less varieties (Goering et al., 1973; Kim and Kim, 1974). When

properties of mature large and small barley starch granules from a single variety were compared, no substantial differences were found (Goering and DeHaas, 1974).

Barley starch granules (Pomeranz, 1974b) like wheat starch granules (Hoseney et al., 1978) are embedded in the protein matrix of the grain. The protein matrix influences the susceptibility of the wheat starch granules to water absorption and subsequent gelatinization (Derby et al., 1975).

Amylose-Amylopectin Ratio

The starch granule contains both amylose and amylopectin. Amylose comprises approximately 24% of the total starch in nonwaxy barley varieties (Pomeranz, 1974a). Kim and Kim (1974) noted little difference in amylose content between hulled and hull-less varieties; however, Goering et al. (1970) found hull-less varieties to have a lower iodine affinity, indicating a reduction in amylose content. Unlike wheat in which the amylose-amylopectin ratio differs little in different varieties, barley varieties that are high in either amylose or amylopectin are found (Hoseney et al., 1978).

Hoseney et al. (1978) attributed the success of a breadmaking starch to properties associated with the amylose-amylopectin ratio within a starch granule. Substituting waxy barley starch for wheat starch in reconstitution studies produced loaves of bread that collapsed upon removal from the oven. Therefore, the setting of the crumb structure was attributed to the amylose fraction. Ghiasi et al. (1984) produced

an altered amylose-amylopectin ratio bread using waxy barley starch that did not differ in volume from the control, although the bread shrank after removal from the oven. Rather than containing a 25.0:75.0 amylose-amylopectin ratio, this bread had a amylose-amylopectin ratio of 16.6 to 83.4; the bread crumb was soft and sticky (Ghiasi et al., 1984).

Characteristics of the amylose and amylopectin starch components have been found to differ among barley varieties that exhibit variation in amylograph viscosity curves (DeHaas and Goering, 1972). Amylose is more tightly coiled in some varieties although it occupies the same space. In the same varieties, amylopectin also appears to be larger. Differences in the susceptibility to α-amylase attack also have been reported. The starches with the largest amylose and amylopectin molecules and the least susceptibility to α-amylase attack exhibited the greatest viscosity on heating (DeHaas and Goering, 1972).

Gelatinization

Gelatinization of starch occurs during the baking process with water absorption, temperature and time influencing the gelatinization process (Yasunaga et al., 1968). Absorption of water, which is facilitated by heat, results in the swelling of the starch granule. If adequate water is absorbed, the crystalline organization of the starch granule is disrupted and an exudate may be released (Derby et al., 1975). If the ratio of amylopectin to amylose is increased, absorption of water is easier as the starch granule has a less crystalline structure (Ghiasi et al., 1984). Finally, the starch granule may implode

(Derby et al., 1975). Gelatinization is limited primarily by the amount of moisture present (Yasunaga et al., 1968). Water availability is determined by the presence of other components that compete with starch for water as well as the amount of water in the formula (Derby et al., 1975). Sandstedt (1961) proposed that the starch absorbs water from the gluten, producing a semirigid protein film necessary for bread crumb structure.

In amylograph studies, barley gelatinizes at temperatures slightly above those of wheat starch (Goering and Brelsford, 1965; Hoseney et al., 1971), and exhibits a two-stage gelatinization curve similar to wheat starch (Goering and Brelsford, 1965). Barley starches exhibit a wide variation in swelling power, solubility and viscosity. Differences in the temperature required for the initial viscosity increase also have been found, with the wheat starch viscosity increasing at 64°C whereas hull-less barley starch viscosity increased at 68.5-79°C depending on variety. Hull-less barley starch maximum viscosity was reached at higher temperatures than was wheat starch maximum viscosity. This temperature difference could not be attributed to altered amylose-amylopectin ratios (Goering et al., 1974). When hull-less and hulled barleys were compared, the hull-less gene was associated with an increased initial, holding and cooling viscosities (Goering et al., 1970).

Susceptibility to Enzymatic Attack

Amylases split the starch into sugar and dextrins, both of which have a role in bread production. Intact starch granules are susceptible

to enzymatic attack although they are less susceptible than are damaged starch or gelatinized starch. Further, susceptibility of nonwaxy starch to enzymatic attack during the gelatinization process varies with barley starch granule size (MacGregor and Ballance, 1980). MacGregor and Ballance (1980) reported that at 35°C the small granules were hydrolyzed more rapidly by barley malt α-amylase than were the large granules. At 65°C, large granules, which gelatinized first, were hydrolyzed more rapidly (MacGregor and Ballance, 1980). Due to the differences in susceptibility of different size starch granules to attack by α-amylase, an alteration in the ratio of large to small starch granules may influence baking potential of the barley starch.

Naturally occurring α-amylases that remain in close contact with the wheat starch granules throughout the dough preparation process are found in the adhering matter surrounding the starch granule. Adhering matter composition studies revealed the presence of both gluten and water-soluble proteins, starch fragments and pentosans. The presence of the adhering matter is necessary in a starch-gluten model dough system to produce a farinograph curve similar to flour dough (Kulp and Lorenz, 1981). Barley starch also contains α-amylases in close proximity to the starch granules (MacGregor, 1979). Wheat flours usually contain adequate β-amylase for bread making but may be deficient in α-amylase (Pratt, 1978). Whole-wheat flours also have been reported to have lower than optimal levels of diastatic enzymes (Bohn and Machon, 1933). Alpha-amylase is supplemented during milling to produce a flour that is suitable for use in yeast products (FDA, 1983). Supplementation also

may be done during production (Himmelstein, 1985). The desirable level of α-amylase varies with end-product use (Pratt, 1978). Because barley has a lower amylase activity level than does wheat (Rubenthaler et al., 1965), amylase supplementation of barley flour during milling or product production may be necessary. Added amylases differ in the extent and temperature of activity depending on their source (Rubenthaler et al., 1965); the temperature range of activity must be compatible with the gelatinization temperature of the starch. Generally, fungal amylases have the lowest heat stability and temperature range of activity, whereas bacterial amylases exhibit the greatest heat stability and highest temperature of activity. Malt amylase is intermediate in heat stability and is compatible with wheat flour (Himmelstein, 1985). Malt amylase also should be compatible with barley flour because barley starch exhibits an amylograph gelatinization curve similar to wheat starch although varietal differences have been found (Goering et al., 1974).

Protein

Suitability of wheat for breadmaking has been attributed to the functional nature of its protein. Protein functional properties important in breadmaking are hydration and cohesive binding (Wall, 1979). Both protein quality and protein content, which are reflected in loaf volume values, influence these functional characteristics. Protein quality is primarily a variety trait that may be altered by environmental conditions. Conversely, protein content is primarily influenced

by agronomic and environmental conditions with variety having less effect (Bushuk, 1984).

Characterization of grain proteins differing in breadmaking potential has been the focus of most investigations. Although most studies have been on wheat proteins, other grains including barley have received limited study.

Protein Composition

The protein classes present in wheat and barley are albumin, globulin, prolamin, soluble glutelin and residue protein or insoluble glutelin. The prolamin fraction is designated gliadin and hordein in wheat and barley respectively (Wall, 1979; Pomeranz, 1974a), whereas the glutelin fraction in wheat is designated glutenin (Ewart, 1972). This classification of the grain protein fractions is based on their solubility (Bushuk, 1985; Wall, 1979). These proteins vary widely in amino acid composition resulting in differences in molecular weight, secondary, tertiary and quarternary structure as well as solubility. The glutelin and prolamin fractions are the primary contributors to structural support in baked yeast products. However, the ratio of glutelin to prolamin does not differ appreciably from wheat (Landenberger and Morse, 1918).

Protein Quality

After hydration and mechanical manipulation, the wheat glutelin and prolamin fractions associate to form gluten, the protein complex responsible for structural support in yeast-leavened baked products (Bietz

et al., 1973). Gluten-like protein complexes may be formed from the proteins present in other grains including barley (Cunningham and Anderson, 1950; Cunningham et al., 1955). However, the viscoelastic properties of the wheat gluten and barley "gluten" have been found to differ. Barley "gluten" is tougher, less elastic, cohesive and sticky, than is wheat gluten, and it will disintegrate with continued mechanical manipulation. However, barley gluten is more cohesive and elastic than is rye "gluten"(Cunningham and Anderson, 1950). Barley "gluten" unlike the gluten of wheat cannot be precipitated from flour with water, but must be precipitated from acid extracts (Cunningham and Anderson, 1950; Cunningham et al., 1955).

The "gluten" forming potential of barley varies with barley variety and within varieties depending on the cultivation practices used. The differences in "gluten" forming potential could not be attributed to differences in the hordein or glutelin composition by Shestakova and Vakar (1979). Flours produced from hull-less barley varieties exhibited greater stability, greater elasticity and less weakening in farinograph tests than did flour from hulled barley varieties (Cheigh et al., 1975). When compared to a wheat standard, hull-less barley-wheat composite flours exhibited a reduction in dough stability, but not in extensibility (Kim et al., 1978).

Role of glutelin. Functionality of gluten in yeast breads has been related to the structure of the glutelin. Glutenin from a good quality wheat baking flour is an intertwined fibrous structure with both thick

and thin round strands (Orth et al., 1973). This component is responsible for the strength and cohesion of the gluten complex. Glutenin has poor solubility and a tendency to associate as a result of the presence of the amide glutamine, which promotes hydrogen bonding. Hydrophobic bonding between protein chains occurs due to the presence of the nonpolar amino acids (Bietz et al., 1973). Glutenin content has been found to vary with wheat cultivar (Doekes and Wennekes, 1982); the ratio of acetic acid soluble glutenin to acetic acid insoluble glutenin or residue protein differs among wheats that vary in breadmaking quality. An increase in the insoluble fraction is associated with improved breadmaking quality as indicated by loaf volume (Bushuk, 1985).

Although polypeptide subunits of glutenin are similar to gliadin, their molecular weights (MW) differ, ranging from 11,000 to 133,000 MW, whereas gliadin contains subunits with MW ranging from 36,000 to 44,000. A major subunit of glutenin is intermediate in weight (44,000) and is similar in MW to high MW gliadin (Bietz et al., 1973). Wrigley (1972) indicated that this fraction of glutenin is responsible for the baking quality of flours and that it appears in the grain as maturity is reached. Some workers consider this intermediate fraction to be a high molecular weight gliadin, which the molecular weight approximates, and therefore attribute the improved baking performance of the flour to the gliadin fraction (Bushuk, 1984).

Barley glutelins also are composed of numerous subunits ranging in molecular weight from a low of 12,000-25,000 to a high of more than 100,000. Glutelin subunits with a molecular weight ranging from 40,000

to 50,000 predominate (Shestakova and Vakar, 1979). This fraction corresponds in molecular weight to the intermediate glutenin fraction of wheat that may be responsible for differences in flour quality (Wrigley, 1972). As with wheat, differences in glutenin subunits occurred among barley varieties (Shestakova and Vakar, 1979).

Role of prolamin. Although glutelin is the "gluten" constituent that contributes strength and cohesion, the prolamin fraction is necessary to provide elasticity, allowing the gluten film to stretch. This protein fraction varies with different cereal sources and may be used to identify specific varieties (Huebner and Rothfus, 1968; Shestakova and Vakar, 1979).

Like gliadin, hordein also is high in proline and glutamine with low levels of basic and sulfur-containing amino acids (Baxter, 1981). Barley hordein is composed of two fractions. One hordein fraction is soluble in hot 70% alcohol as is gliadin; the remaining hordein is soluble in hot 70% ethanol and 2 mM mercaptoethanol. The MW ranges from 15,000-100,000. This higher molecular weight fraction, is cross-linked by interchain disulfide bonds (Baxter, 1981). The subunits range in MW from 38,000 to 77,000 (Shestakova and Vakar, 1979). The proportion of high MW hordein increases as barley protein increases (Baxter, 1981).

Protein Content

Protein content is positively and linearly related to loaf volume within a wheat variety (Bushuk, 1984). Wheat protein content increases also are associated with an increase in glutamic acid and proline, the

predominant amino acids in gluten (McDonald and Gilles, 1967). Glutamic acid, proline and phenylalanine also increase with increasing barley protein content (Rhodes and Mathers, 1974). MacRitchie (1979) found a high and positive correlation between loaf volume and gluten amide nitrogen content. Cunningham et al. (1955) reported the amide nitrogen content of wheat and barley cohesive proteins to be 3.2-3.3% and 2.4-2.6%, respectively.

Growing conditions have been shown to alter the protein content of both barley and wheat (Baxter, 1981; Doekes and Wennekes, 1982; Pomeranz et al., 1976; Pomeranz et al., 1977). Nitrogen fertilization increases the overall protein content of both grains (Doekes and Wennekes, 1982; Pomeranz et al., 1977), although the protein increase is less for hull-less than for hulled barleys and was found to differ with barley cultivar (Pomeranz et al., 1977). In wheat, this protein increase is associated with an increase in loaf volume (Doekes and Wennekes, 1982).

Environmental conditions also have been found to affect the protein content of barley. Both the availability of soil nitrogen and the initial content of nitrogen are implicated as factors influencing the nitrogen uptake (Pomeranz et al., 1977). Further uptake of nitrogen is facilitated by long photoperiods (Wooding and Husby, 1980). Whitehouse (1970) indicated that grain protein content increased as the latitude of cultivation approached the Arctic Circle. Hordein content of barley has been found to increase with an increase in barley nitrogen (Baxter, 1981).

Water Absorption

Water absorption capacity or hydration is of critical importance in imparting functional properties to protein. The presence of polar amino acid sites on the protein molecules allows the protein to be hydrated. Environmental factors affect hydration potential of the protein through an effect on polarity (Hutton and Campbell, 1981). Barley "gluten" absorbed less water and the absorption rate was slower than was that of wheat gluten. Water content of rehydrated formic acid extracted gluten was 55.2% and 65.0% for barley and wheat, respectively (Cunningham et al., 1955).

II. INTERACTIONS OF BREAD COMPONENTS

Baked products are dependent upon the successful interaction of flour functional components as well as the interaction of the flour with added ingredients. Flour functionality may be enhanced by careful selection of additional ingredients at appropriate levels. The addition of water facilitates interactions as the flour components and added ingredients become hydrated. Mixing and heating influence interactions through mechanical and chemical effects. Model systems are used to characterize these interactions. The results from model system studies in combination with Response Surface Methodology may be used to determine optimal ingredient levels for use in a food system (Giovanni, 1983).

Using an excess-water model system, D'Appolonia (1972) examined the effect of salt on starch gelatinization. Salt was incorporated in the

model system on a percentage water-weight basis (% per 100 ml water), making the levels present greater than those in a bread system. Sodium chloride increased amylogram peak height significantly at both 1 and 2% levels (% per 100 ml water). Peak temperature also was increased by the addition of NaCl (D'Appolonia, 1972). Similar effects have been found in amylograph studies of wheat and a wheat-barley composite flour when 2% salt was added on a flour-weight basis (Linko et al., 1984).

Ghiasi et al. (1983) studied the effect of salt on starch gelatinization characteristics of experimental wheat doughs. In excess-water systems, adequate water was available to all starch granules, allowing gelatinization to occur over a range of temperatures. In the limited-water systems or experimental doughs, gelatinized starch granules were localized due to uneven heat penetration through the dough; heat facilitated the absorption of water. When salt was added to the limited-water system, changes in starch gelatinization (Ghiasi et al., 1983) as in the excess-water systems (D'Appolonia, 1972; Linko et al., 1984) were found. At the 2% salt level, gelatinization temperatures were increased (Ghiasi et al., 1983).

The presence of salt in wheat dough model systems has been found to alter dough development characteristics through an effect on protein hydration. Salt addition to a flour-water system alters the net positive charge of the flour protein. The presence of the net positive charge is responsible for quick protein hydration. This charge alteration is responsible for a reduction in the rate of hydration. Reduced hydration rates are reflected in an increase in dough development time,

dough stability (Danno and Hoseney, 1982; Galal et al., 1978; Hlynka, 1962) and dough extensibility and resistance (Fisher et al., 1949). Danno and Hoseney (1982) report that mixogram peak height and width also are increased with salt addition. Further, the effects of overmixing can be overcome by the addition of salt.

Linko et al. (1984) examined the effect of NaCl at levels that ranged from 0 to 2.5% (flour-weight-basis) on wheat, barley and a 60:40 wheat-barley flour composite dough. The addition of salt decreased water absorption of all doughs. Although dough development time and stability decreased with the addition of salt to barley flour doughs, both wheat flour and the composite flour doughs exhibited increased dough development time and stability. The wheat and barley composite flour behaved essentially the same as wheat flour except that the composite dough development time continued to be longer (Linko et al., 1984). Unlike wheat doughs in which overmixing effects can be reversed with the addition of salt (Danno and Hoseney, 1982), barley doughs continued to exhibit the effects of overmixing. The effect was not as great when the composite flour rather than the barley flour was evaluated (Linko et al., 1984).

Loaf volume also was related to salt content; wheat bread loaf volume decreased significantly as salt concentration increased from 0.5 to 2.5%, whereas a wheat-barley bread exhibited an increase in loaf volume. A 20% increase in wheat-barley bread loaf volume was acheived as salt concentration increased from 0 to 2.0% (Linko et al., 1984). In a very early study, adjustment of the dough pH to 5 and the addition of

NaCl at the 2% level resulted in the production of an acceptable barley bread (Landenberger and Morse, 1918).

III. BARLEY IN BAKED PRODUCTS

The functionality of barley in baked products has been the focus of few research studies. Studies examining the substitution of barley for wheat in bakery products have reported the following effects on the characteristics of the baked products: decreased loaf volume, increased water absorption time, lack of oven spring, coarse texture, off-flavors, decreased crust color and more rapid staling. Barley as flour, whole-grain flour, barleymeal and brewer's spent grain (BSG) has been used in baked products (Dreese and Hoseney, 1982; Finley and Hanamoto, 1980; Hart et al, 1970; Kim and Lee, 1977; Prentice et al., 1979; Prentice and D'Appolonia, 1977; Swanson and Penfield, 1982).

Research efforts have been directed toward the substitution of barley flour for wheat flour in yeast breads. Landenberger and Morse (1918) described a barley yeast bread containing less than 70% wheat flour as heavy and sour, although maintenance of the pH at 5 and the addition of NaCl at the 2% level produced a barley bread with improved leavening, a good crust and less sourness.

More recently, Kim et al. (1978) prepared a composite flour by substituting hull-less barley flour at the 5% and 10% level for commercial wheat flour. The use of the composite flour in yeast bread altered the specific volume and crumb characteristics. Barley at the 10% level produced a strong characteristic flavor. However, both levels of barley

produced an acceptable bread when evaluated using sensory techniques. Staling rate was increased when composite flours were used (Kim et al., 1978). Bhatty (1986) reports that hull-less barley flour incorporation above 5 to 10% dilutes the gluten, resulting in reduced gas retention and loaf volume. The addition of 1% glycerol mono-stereate (GMS) and 0.5% sodium stearoyl lactylate (SSL) increased the specific loaf volume and produced a 30% hull-less barley bread with the appearance, taste and texture similar to the wheat bread standard (Kim and Lee, 1977).

The use of bread additives to improve the characteristics of barley yeast breads has been examined in detail by Hart and coworkers (1970). Without the use of additives, barley formed a sticky dough that held together well. A moisture content of 50 to 60% was necessary to achieve sufficient proof height. The resulting bread was characterized by a rough, lumpy, coarse-textured crust that was not domed shaped, as oven spring did not occur in the initial stages of baking. The top crust characteristics were improved and a domed shape resulted when Methocel was added to the batter and proofed volume was limited to double that of the initial bread dough. The addition of GMS or shortenings was not found to have a significant effect on the structure of the bread although the loaves were softened (Hart et al., 1970).

A hull-less whole grain barley flour has been used in quick breads. The composite flours contained 50% whole-wheat flour and 20, 30 or 50% barley flour with all-purpose flour constituting the remaining percentage. Sensory panelists judged appearance, texture and flavor of the 30% barley quick bread as most acceptable. At higher barley levels there

was a decrease in moistness and flavor acceptability. These quick breads exhibited a rounded crust, indicating rising during baking, and no significant differences in loaf volume with increasing barley levels. A decrease in tenderness as barley percentage increased was found using physical and sensory techniques. A lack of sourness also was noted by sensory panelists (Swanson and Penfield, 1982).

A high-lysine barleymeal yeast bread has been produced using a straight-dough procedure (Prentice et al., 1979). Barleymeal replaced up to 20% of the white flour. Hydration of the barleymeal was much slower than whole-wheat, necessitating soaking the barleymeal in water prior to incorporation into the product. The 15% barleymeal bread was found to be comparable to the 30% whole-wheat bread in baking behavior and appearance. The consumer could not differeniate between a 30% whole-wheat bread and a 15% barleymeal bread when flavor and texture were evaluated (Prentice et al., 1979).

The utilization of BSG in baked products has become a source of increased interest. BSG is composed of barley hulls and bran and the bran from the adjunct carbohydrate used in the brewing process (Prentice and D'Appolonia, 1977). Whole BSG as well as various mill fractions have been evaluated as partial replacements for white flour in yeast bread formulas (Dreese and Hoseney, 1982; Finley and Hanamoto, 1980; Prentice and D'Appolonia, 1977). BSG incorporation altered the level of water absorption, mixing time, dough stability and other physical properties of the dough, regardless of the mill fraction selected (Finley and Hanamoto, 1980). Good volume has been reported with 15% BSG bran

replacement when dough conditioners and a sponge-and-dough method or the presoaking of the BSG bran prior to incorporation into the dough are used. Improvement of the crumb grain also was found (Dreese and Hoseney, 1982). Laboratory and consumer sensory evaluations of 5% and 10% whole BSG bread indicated acceptance equal to a 30% whole-wheat control (Prentice and D'Appolonia, 1977).

CHAPTER III

PROCEDURES

I. MATERIALS

Thual hull-less six-rowed barley was grown in Alaska and Tennessee during the 1983 and 1984 growing seasons, respectively. The Alaska barley was produced on the State of Alaska Delta Agricultural Project, Delta, Alaska; the Tennessee barley was grown on The University of Tennessee Agricultural Experiment Station Farm, Knoxville, Tennessee. The Alaska grain had a test weight of 59.6 lbs/bu and the test weight for the Tennessee grain was 53.8 lbs/bu. Grain from each source was stored at -20°C in covered metal storage cans until it was ground into whole-grain flour. Storage times ranged from 3 to 9 mo.

After cleaning to remove foreign matter and chaff, the grain was batch ground to meet the industry specifications used by the Minnesota Grain Pearling Co (Cannon Falls, MN) for regular barley flour (Nelson, 1984). Flour particle size distribution (Table 1) was determined using the ro-tap technique described in the Code of Federal Regulations (FDA, 1983) except that a mechanical shaker (approximately 150 cycles/min) was used. After grinding, the flour was stored in covered metal storage cans at -20°C for 12 to 16 mo.

Bread flour milled by Dixie Portland Flour Mills, Inc, Chattanooga, Tennessee, was obtained from Kern's Bakery, Knoxville, Tennessee. Whole-wheat flour, processed by Con-Agra, Inc, Omaha, Nebraska, was

Table 1—Whole-wheat and barley flour particle size distribution

Screen Analysis	Flour Type		
		Barley[b]	
	Whole-wheat[a]	Tennessee	Alaska
	%		
on US #20	0.13	0.07	0.18
on US #40	14.33	9.71	9.44
on US #100	76.03	52.48	51.14
thru US #100	9.50	37.66	39.23

[a]Commercially milled whole-wheat flour.
[b]Laboratory milled whole-grain barley flours.

acquired from The University of Tennessee Food Service Bakery, Knoxville, Tennessee. These flours were stored under conditions identical to the barley flours (8 mo).

Nonfat dried buttermilk solids and Midsol vital wheat gluten were obtained from Kern's Bakery. The nonfat dried buttermilk solids were processed by St. Peter Creamery, Peter, Minnesota, and the vital wheat gluten was manufactured by Midwest Solvent and Co, Inc, Atchison, Kansas. These ingredients were placed in storage containers with lids and stored at -20°C. Cream shortening (Bunge Edible Oil Co, Kankakee, IL), Domino granulated sugar (Amstar Corp, New York, NY) and Morton iodized salt (Morton Thiokol, Inc, Chicago, IL) were obtained from The University of Tennessee Food Service Bakery. Sugar and salt were stored in covered storage bins at room temperature; shortening was stored at 18°C in a covered storage container.

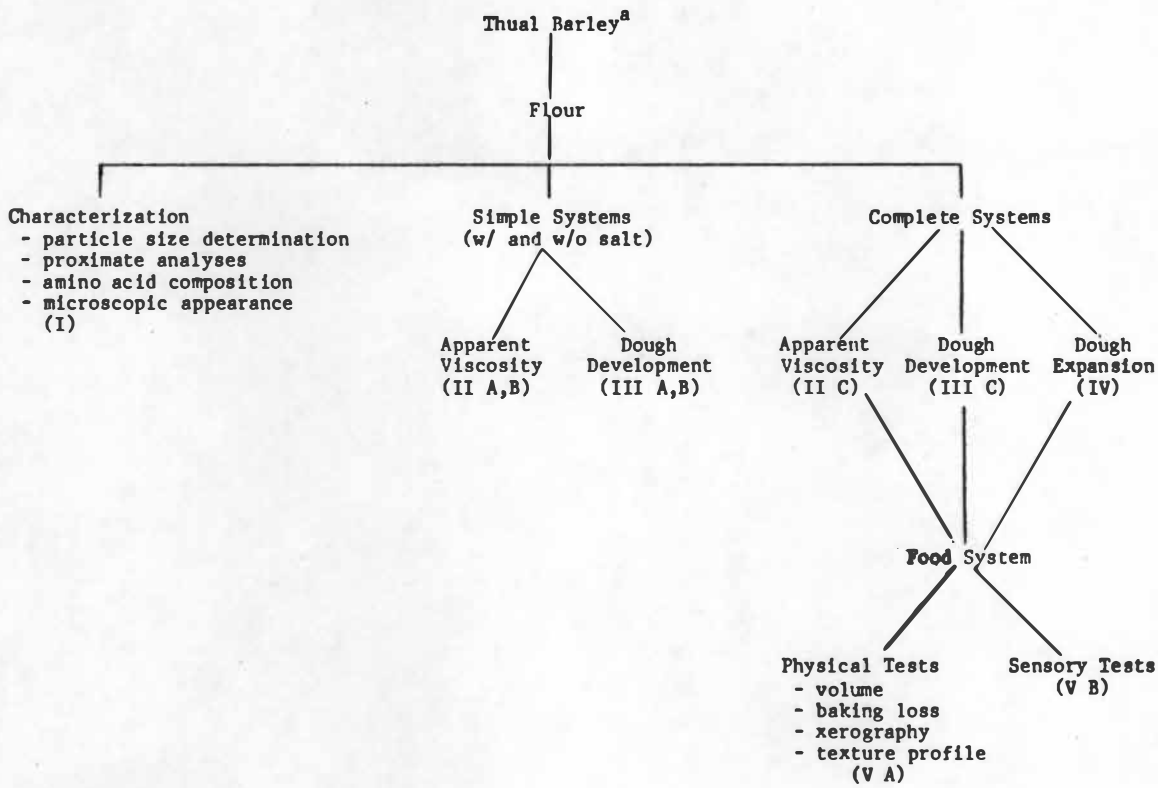
Barley malt flour with an α-amylase activity of 50 units/g was obtained from Minnesota Grain Pearling Co. The barley malt flour was stored under the same conditions as were the other flours. Sodium stearoyl lactylate, manufactured by Wilke International, Inc (Overland Park, KS), was acquired from Food Ingredients Inc, Elk Grove Village, Illinois. Carbrea-Tabs® yeast food and oxidant system that contained potassium bromate, azodicarbonamide, carbamide, ascorbic acid and other excipients was obtained from Cain Food Industries, Inc, Dallas, Texas. Sodium stearoyl lactylate and the yeast food and oxidant system were stored in covered plastic containers at 18°C. All of these ingredients were obtained in adequate amounts for all phases of the study.

Saf-Instant yeast, manufactured by Lesaffre Group, Marcq-en-Baroeul, France, was obtained from The University of Tennessee Food Service Bakery prior to the complete dough model systems and food systems studies. The yeast was stored at -20°C.

II. PLAN OF STUDY AND MEASUREMENTS

The study, which consisted of five parts, is outlined schematically in Figure 1. In part I, flour composition and physical characteristics affecting functional performance were studied. In part II, the apparent viscosity of whole-grain barley flours was studied in excess-water model systems. First, apparent viscosity was studied in simple systems that contained only the composite flours as defined in Table 2 and water (part IIA). In part IIB, the effect of adding various percentages of salt to the simple apparent viscosity systems was examined. In part IIC, apparent viscosity of the composite flours (Table 2) also was studied in complete dough systems as defined in Table 3; salt levels studied were identical to those levels previously used in the simple systems studies (part IIB).

In part III, dough development characteristics of whole-grain barley flours were studied in simple and complete dough model systems. Unlike the apparent viscosity model systems used in part II, the model sytems used in the dough development studies contained limited water. Part IIIA involved the study of whole-grain barley flours (Table 2) in simple systems as previously defined. In part IIIB, the effect of salt on composite flour (Table 2) dough development parameters also was



[a]Thual barley produced in Tennessee and Alaska were studied independently.

Figure 1—Experimental plan.

Table 2—Flour types present in composite flours

Flour type		
Whole-grain barley[a]	Whole-wheat	Bread
	%	
0	50	50
10	40	50
20	30	50
30	20	50

[a]Tennessee and Alaska Thual barley flours were used.

Table 3—Whole-grain variety bread formula

Ingredient	fwb (%)
Bread flour	50.00
Whole-wheat flour	variable[a]
Yeast[d]	3.00
Wheat gluten	2.50
Malt flour	0.25
Sugar	7.00
SSL	0.50
Salt	variable[b]
Shortening[d]	3.00
Non-fat dried mild solids	3.00
Water	variable[c]
	----ppm----
Yeast food + oxidants[e]	66

[a]Whole-wheat flour was 50% for the control; variations were 40, 30, 20% with the remaining percentage whole-grain Thual barley flour.
[b]1.5, 2.0, 2.5 or 3.0% (fwb).
[c]Water level in dough development studies was varied to achieve optimal development as found in Table 12; these levels were used for dough expansion studies. Water level in the apparent viscosity studies was 562.5% (fwb).
[d]Not used in apparent viscosity studies.
[e]Contains potassium bromate, azodicarbonamide, carbamide, ascorbic acid and other excipients.

evaluated in simple systems. Functional performance of the composite flours (Table 2) as affected by various salt levels was evaluated in complete dough systems (Table 3) in part IIIC.

Dough expansion, a study of dough cohesive forces during fermentation, was studied in complete dough systems (Table 3) in part IV. Finally, in part V, the findings from the model systems in parts I through IV were applied to the study of a food system, yeast bread.

Part I: Flour Characterization

The objectives for part I were:

1. to compare proximate analysis values for bread flour, whole-wheat flour and whole-grain barley flour milled from barley grown in Tennessee and Alaska;

2. to compare the amino acid composition of barley grown in Tennessee and Alaska; and

3. to describe the microscopic appearance of whole-wheat flour and Tennessee and Alaska whole-grain barley flour components.

Proximate analyses of the whole-grain barley flour from grain produced in Tennessee and Alaska, bread flour and whole-wheat flour were determined in triplicate using AOAC (1980) methods. Data were analyzed using Analysis of Variance; Tukey's Range Test was used for means separation. Amino acid composition of whole-grain Tennessee and Alaska barley flours was determined in duplicate. Means and standard deviations were determined. These analyses were conducted by an independent laboratory (Anon., 1985).

Structure of flour components was observed using Scanning Electron Microscopy (SEM). Whole-wheat flour and whole-grain barley flours produced from Tennessee and Alaska grain were viewed with an AMR 900 Scanning Electron Microscope at 15 kV accelerating potential. Samples were mounted on SEM stubs with double-sided tape; excess flour was removed by tapping the stubs. Mounted samples were coated with Au to a thickness of 200-300 Å prior to viewing. A Technic sputter coater was used to coat the samples. Representative areas were photographed.

Part II: Apparent Viscosity Studies

The objectives of part II were:

1. to study the effect of barley flour level and barley flour source on the apparent viscosity characteristics in simple systems;
2. to study the effect of salt level, barley flour level and barley flour source on apparent viscosity in simple systems; and
3. to study the effect of salt level, barley flour level and barley flour source on apparent viscosity in complete dough systems.

Apparent viscosity of the composite flour simple system was studied with a 2X4 factorial plan in which composite flour composition was represented by two barley sources (Tennessee and Alaska) and barley percentage (0, 10, 20 and 30%) was represented by four levels (part IIA). A 2X4X4 factorial plan was used to study the effect of salt on apparent viscosity characteristics of simple (part IIB) and complete dough

(part IIC) model systems. Composite flour was represented by two sources (Tennessee and Alaska barley). Barley (0, 10, 20 and 30%) and salt (1.5, 2.0, 2.5 and 3.0%) were present at four levels each. Data were collected according to a randomized complete block design with three replications.

Apparent Viscosity Procedures

In part IIA, apparent viscosity changes of suspensions of the composite flours (Table 2) were studied with a Brabender/visco/Amylograph (C. W. Brabender, Inc., S. Hackensack, NJ) equipped with a 700-cmg cartridge. Three hundred grams distilled water (25°C) were added to a Waring blender container. Eighty grams total flour on a 14% moisture basis were added to the blender container and mixed at low speed for 1.5 min. The slurry was poured into the amylograph bowl. The remaining 150 g water (25°C) were added to the amylograph bowl after rinsing the blender container. The slurry was heated at a temperature increase of 1.5°C/min from a beginning temperature of 25°C to an endpoint temperature of 95°C. The heated slurry was held at 95°C for 14 min and cooled at ambient temperatures for 1 hr (Figure 2). This procedure was modified from D'Appolonia (1972) and Shuey and Tipples (1980). The following amylogram parameters (Figure 2) were determined: temperature and time of initial viscosity increase, maximum viscosity, time and temperature at which maximum viscosity was reached, viscosity after holding at 95°C for 14 min and viscosity of the cooling peak.

In part IIB, the effect of varying percentages of salt on apparent viscosity changes of the composite flours (Table 2) also was studied

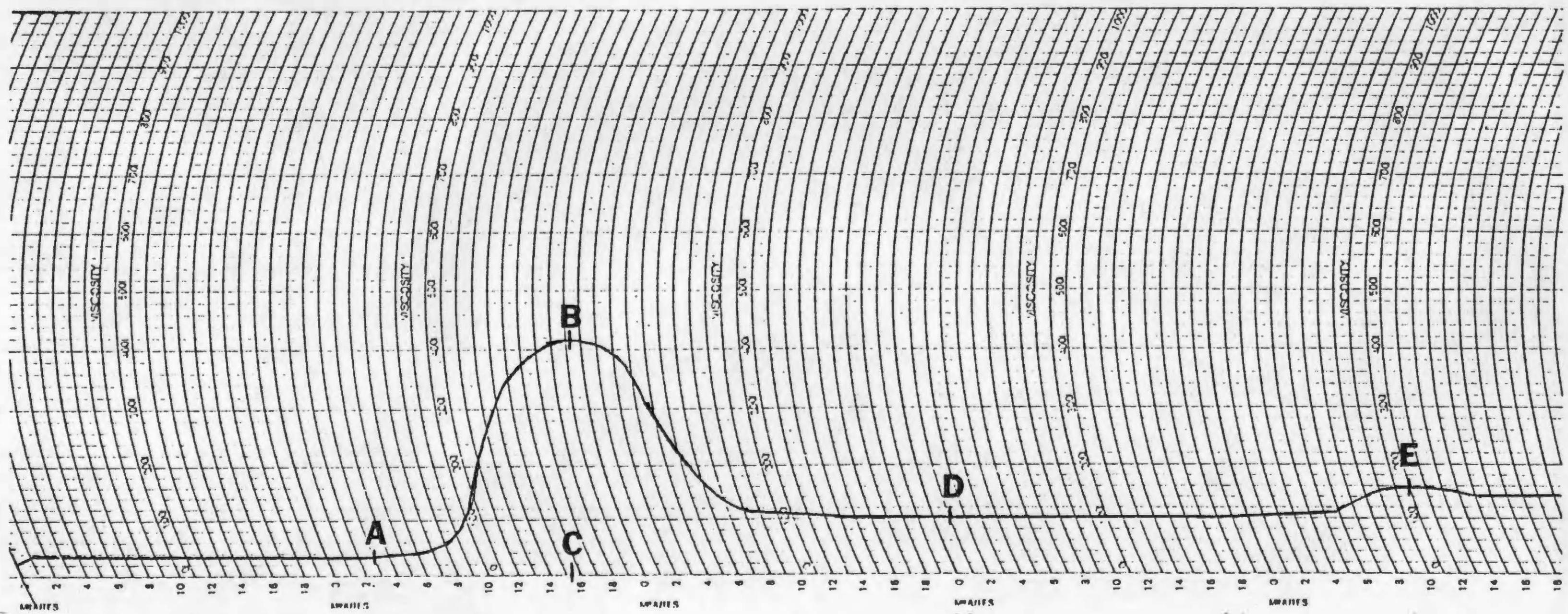


Figure 2—Typical amylogram from the simple system studies (A = time and temperature of initial viscosity increase, B = maximum viscosity, C = time and temperature of maximum viscosity, D = holding viscosity, and E = cooling peak viscosity).

using the Brabender/visco/Amylograph. Salt was added to the 80 g flour (14% moisture basis) at 1.5, 2.0, 2.5 and 3.0% levels (flour-weight basis). The procedure described above was used.

Apparent viscosity changes of suspensions of the dough ingredients listed in Table 3, except as noted, also were studied. Dough ingredients were added at the concentrations indicated; the suspensions contained 80 g composite flour (14% moisture basis) and 450 g distilled water. Three hundred fifty grams distilled water in which the yeast food and oxidant system was dispersed were added to a Waring Blendor container. The remaining dough ingredients (Table 3) were added and mixed at low speed for 30 sec. The apparent pH of each suspension, as measured using an Orion Research (Cambridge, MA) Digital Ionalyzer, model 601A, was adjusted with 0.1 N acetic acid (Table 4). The acetic acid replaced a portion of the water. The remaining water was used to rinse the container prior to addition to the slurry. Water temperature, the heating cycle and parameters evaluated were identical to those used in the simple systems apparent viscosity studies previously described (Figure 2). The cooling cycle was omitted as preliminary work revealed that any effect of cooling on complete dough apparent viscosity was not within the sensitivity range of the instrument.

Adjustment of the acidity of the suspension was necessitated by the absence of acids produced by yeast during fermentation and proofing (Matz, 1972); appropriate acidity levels were determined prior to beginning the apparent viscosity studies. To determine dough acidity levels after fermentation and proofing, dough samples at all flour and

Table 4—Appropriate apparent pH values for complete doughs as a function of barley source and barley and salt levels

	Barley flour (%)						
	0	10		20		30	
Salt (%)		TN[a]	AK[b]	TN	AK	TN	AK
	Apparent pH value						
1.5	5.34	5.45	5.34	5.45	5.34	5.45	5.34
2.0	5.45	5.45	5.45	5.45	5.45	5.45	5.34
2.5	5.45	5.54	5.45	5.45	5.45	5.45	5.34
3.0	5.45	5.54	5.45	5.54	5.45	5.45	5.34

[a]TN = Tennessee.
[b]AK = Alaska.

salt combinations (Table 3, p. 31) were optimally developed as described in the complete dough development study. Fifty grams of the developed dough were rounded and placed in a fermentation cabinet at 34°C and 86-90% relative humidity (rh) for 60 min. After punching down, the dough samples were proofed for an additional 30 min. The proofed dough sample was suspended in 232 g distilled water by mixing in a Waring Blendor container at speed 1 for 1 min. Apparent pH readings were taken immediately. Data were analyzed with Analysis of Variance and Tukey's Range Test, where appropriate. The results of the range test were used to assign apparent pH values to the flour and salt combinations within source of barley (Table 4).

Statistical Analyses

Dependent variable measurements that were obtained from the apparent viscosity studies were analyzed statistically as a function of barley source, barley level and salt level where apporpriate. First, analysis of variance was used to identify significant interactions in the full model. Second, a reduced model that included the main effects and significant interactions was analyzed using analysis of variance. Tukey's Range Test was used for means separation in significant models.

Part III: Dough Development Studies

The objectives for part III were:

1. to study the effect of barley flour level and source on the dough development characteristics of a composite flour system;

2. to study the effect of salt at four levels on the dough development characteristics of composite flour yeast bread systems containing barley flour from two sources and at four levels; and

3. to study the effect of four salt levels on dough development of complete dough systems containing yeast bread ingredients.

The experimental design previously described for the simple and complete dough apparent viscosity studies was used for the dough development studies.

Dough Development Procedures

In part IIIA, mixing characteristics of the composite flours containing varying percentages of barley flour (Table 2, p. 30) were determined with a mixograph (National Mfg Co, Lincoln, NE) equipped with a 35-g bowl. The tension spring setting was 11 and the distilled water temperature was 24-25°C. Mixograms were obtained according to AACC (1980). The amount of water to be added for optimal development was determined by systematically increasing the amount of water added by increments of 0.5 g from 20.0 g to 22.5 g for each flour combination. Optimal development was indicated by the shape of the mixogram and maximum peak height. Three mixograms were obtained using the optimal water level. Maximum peak height, dough development time, angle of development and angle of breakdown were measured from each mixogram (Figure 3). The effect of salt addition at various levels on mixing characteristics also was studied. The previously described procedure

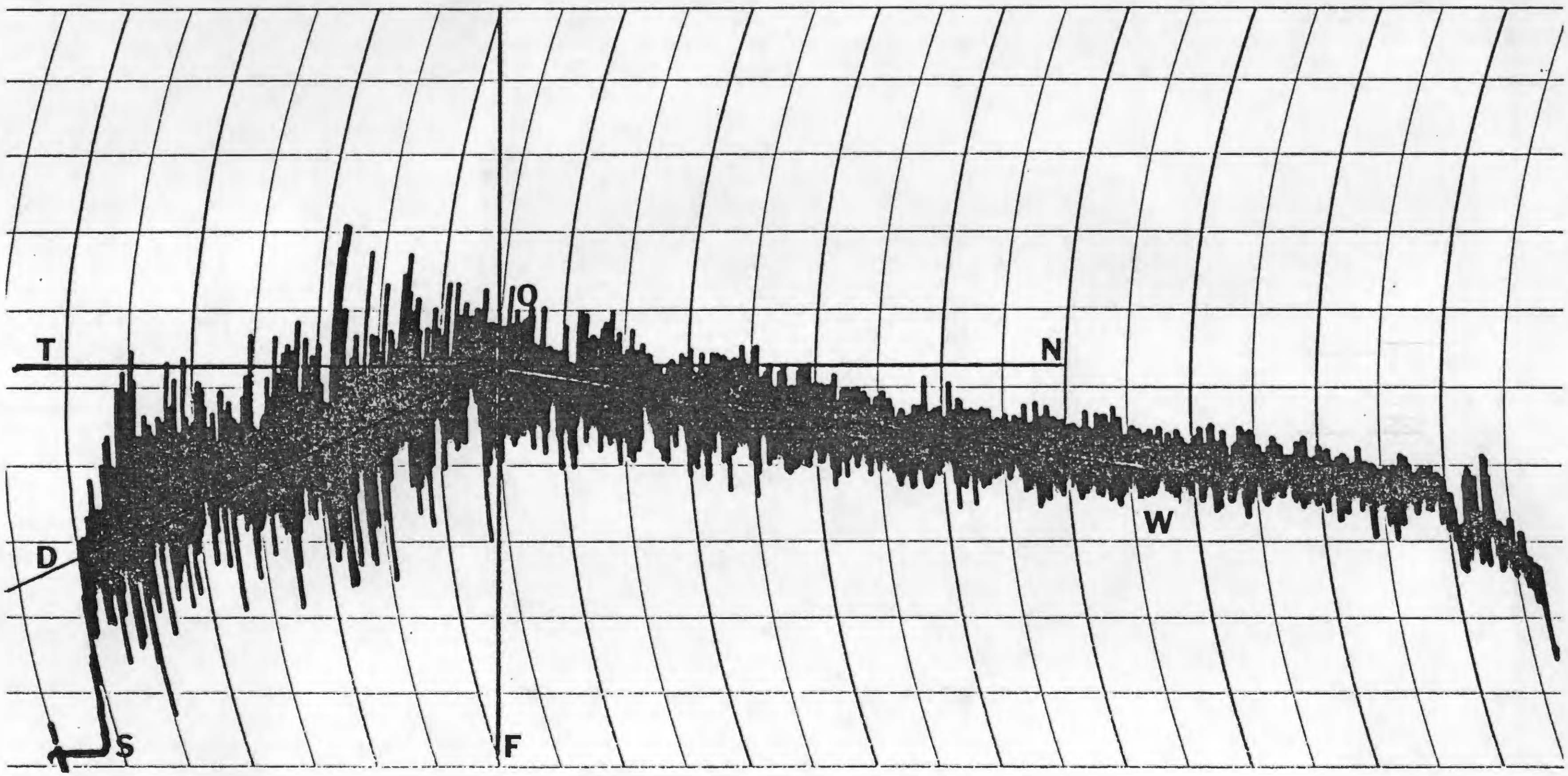


Figure 3—Typical mixogram from the simple system studies (S-F = development time, DOT = development angle, F-O = peak height, WON = breakdown angle).

was used to determine the effect of salt on mixing characteristics in part IIIB.

Mixing characteristics of the composite flours and additional dough ingredients at the concentrations indicated in Table 3 (p. 31) also were determined using a National mixograph (part IIIC) as previously described (part IIIA). The effect of four salt levels on mixing characteristics of the complete dough systems also was evaluated.

The ingredients listed in Table 3, except the yeast and yeast food and oxidant system, were mixed with the flour. A total of 35 g dry material was used for each mixogram. The yeast was suspended in a portion of the water (40°C). The yeast food and oxidant system was dispersed in a portion of the water (24-25°C) prior to addition to the mixograph bowl. The temperature of the remaining water was 24-25°C. The total amount of water added was systematically increased from 16.7 to 20.7 g in increments of 1 g until optimal levels were determined. Each mixogram was run for 20 min. The procedures used to obtain the mixograms and the data from each mixogram were identical to those procedures that were used in the dough development study for the simple system.

Statistical Analyses

Dependent variable measurements that were obtained from the dough development studies, were analyzed statistically as a function of barley source, barley level and salt level. The procedure previously described for the apparent viscosity studies was used.

Part IV: Dough Expansion During Fermentation

The objective for part IV was to study the effect of salt level, barley flour level and source on dough expansion during fermentation. A 2X4X4X4 factorial plan was used. Flour source, the first factor, was represented by barley grown in two locations, Tennessee and Alaska. Whole-grain barley flour and salt were investigated at four levels each. Effect of fermentation time, the fourth factor, was investigated after 15, 30, 45 and 60 min. Data were collected according to a randomized complete block design with two replications.

Dough Expansion Procedure

The method of Hoseney et al. (1979) was used to study dough expansion during fermentation. Straight-doughs were mixed to optimal development as determined in the complete dough development study. Fifty grams of developed dough were used for each sample. The dough ball was placed in the center of a crystallizing dish (170 mm dia) in a fermentation cabinet at 34°C and 86-90% rh. The width and height of the dough were measured at 15 min intervals for 60 min.

Statistical Analyses

Differences in spread ratios (dough width/dough height) were analyzed statistically as a function of barley source, barley level, salt level and fermentation time. Analysis of variance was used to identify significant interactions in the model. Reduced models in which the main effects and significant interactions were present, were analyzed using analysis of variance. Tukey's Range Test was used for means separation.

Part V: Food System

The objectives of part V were:

1. to predict optimal salt and barley flour levels for the production of an acceptable variety bread containing barley flour from each source; and
2. to evaluate the functional performance of the two barley flours in a variety bread using physical and sensory techniques.

Three yeast breads were made using a straight dough procedure. Each batch of dough yielded six loaves. Both Tennessee and Alaska barleys were substituted for the whole-wheat flour at the 20% level. The 0% barley bread served as a control. All three breads contained 2.0% salt. Barley and salt levels that were most appropriate for study in a food system were identified using response surfaces from the complete dough development study. The response surfaces depicted the effect of barley and salt levels within barley source for the dependent variables in the apparent viscosity and dough development studies. To determine the equations used to draw the response surfaces, sums of squares for barley level, salt level and their interactions were partitioned by orthogonal polynomials into linear, quadractic and cubic barley and salt effects within barley source. The equation used to draw the response surfaces for each variable contained all the main effects and the interactions that were significant at $p < 0.1$. The General Linear Models Procedure was used (Freund and Littrell, 1981).

The breads were made according to a straight dough procedure that was adapted from AACC Approved Method 10-10 (AACC, 1976). Dough ingredients were placed in the mixing bowl of a Hobart N-50 mixer (Hobart, Inc, Troy, OH). Yeast was suspended in a portion of the ingredient water (40°C). The yeast food and oxidant system also was incorporated into a portion of the water prior to addition to the mixing bowl. The ingredients were mixed at speed 1 for 2 min. The remaining mixing time required for optimal development as indicated by the complete dough mixograph test was at speed 2. The dough was rounded and placed in calibrated bowls so that height of the dough could be determined after fermentation. Dough fermentation temperature was maintained at 34°C and a relative humidity of 86-90% until the dough doubled in volume, approximately 40 min. The fermented dough was punched and scaled (330 g) and allowed to undergo an intermediate proof for 12-15 min, followed by molding using an Acme Rol-sheeter (D. R. McClain and Son, Pico Rivera, CA). The loaves were panned (19x9.2x5.5 cm) and proofed at 34°C and a relative humidity of 86-90% until the dough height was 7.2 cm. The proofed dough was baked at 220°C in an electric rotary Despatch oven for 25 min. After cooling for 1 hr at room temperature, the bread loaves were placed in plastic freezer bags (0.95 mil thick) and frozen at -20°C.

Physical Tests

Measurements on six intact loaves from each treatment were made approximately 1 hr after removal from the oven but prior to freezing.

Loaf volume was determined by rapeseed displacement using a loaf volumeter. Each loaf of bread was weighed and specific volume and percentage baking loss were calculated.

The remaining physical tests were conducted on bread that had been thawed at room temperature for approximately 2 hr. Frozen storage times ranged from 19 to 40 hr. After removing the end crusts, the bread was sliced in a miter box for physical and sensory evaluation. An end slice and a center slice were designated for the physical tests; the slices were 2.54 cm thick. Each slice was held in a sealed plastic bag until the physical tests were completed. Xerography of slices from each loaf was used to record crumb grain, loaf shape and cell distribution.

Textural quality was determined using a compression cage attachment to an Instron Universal Testing Machine, model 1130 (Canton, MA). Cylindrical samples that were 3.9 cm in diameter and 2.5 cm high, were cut from the center slice with a biscuit cutter. Samples from the end slices were not used because of difficulty in obtaining a uniform slice. Each sample was compressed twice to 40% of its original height. The crosshead speed was 50 mm/min, the chart speed was 100 mm/min and the range setting was 5. A 50-kg load cell was used. Analysis of the curve provided information about the textural quality of the product (Figure 4). Hardness was defined as peak height of the first compression. Cohesiveness was defined as the ratio of the area under the curve of the second compression to the area under the curve of the first compression. Springiness was determined by the distance the sample was compressed during the second compression. The product of hardness and cohesiveness

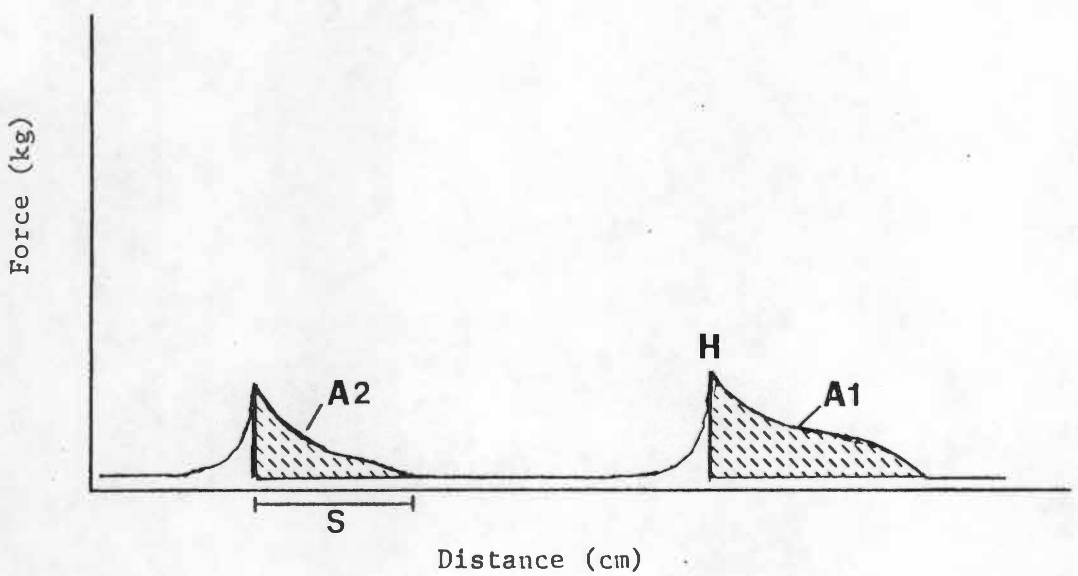


Figure 4—Typical Instron Texture Profile Analysis Curve (H = hardness, A2/A1 = cohesiveness, S = springiness, H x A2/A1 = gumminess, H x A2/A1 x S = chewiness).

was defined as gumminess. Chewiness was defined as the product of gumminess and springiness (Bourne, 1978).

Sensory Evaluation

Sensory evaluation of the bread was conducted by an experienced but untrained 56-member panel in one sensory session. Consumer texture profiles (Szczesniak et al., 1975) modified to include appearance and flavor were used to evaluate the breads. This technique allowed each panelist to describe his/her "ideal" whole-grain bread and the test samples on a 6-point attribute scale where 1 was not at all and 6 was very much so (Appendix A). Bipolar terms were included on the scorecard to verify that the panelists understood the procedure. Evaluations obtained from panelists who did not use these terms consistently were not included in the statistical analysis. Data obtained from 48 panelists were analyzed statistically. Overall acceptability of each bread sample presented was evaluated using a 6-point hedonic scale. Each panelist also answered a short questionnaire regarding bread consumption patterns (Appendix A).

Each panelist received one-half of a 1.25-cm slice of bread from the whole-wheat, Tennessee whole-grain barley and Alaska whole-grain barley breads. Slices designated for sensory tests were placed in individual plastic bags that had been coded with 3-digit random numbers. Coded samples were presented to the panelists individually on a white tray. A balanced order of presentation was used. The samples were evaluated under white light in individual sensory booths. All samples

presented to one panelist were from the same location within the loaf. Samples were served at room temperature; water was provided for rinsing.

Statistical Analyses

Dependent variables in the physical and sensory tests were analyzed statistically as a function of bread type and judge. Analysis of variance was used to determine if the models were significant. Tukey's Range Test was used for means separation, where appropriate. Frequency of response was tabulated from the questionnaires.

CHAPTER IV

RESULTS AND DISCUSSION

I. FLOUR CHARACTERIZATION

Proximate Analyses

Proximate analyses (Table 5) revealed differences in composition attributable to flour type (bread vs. whole-grain) and barley growing conditions. On a 14% mb, bread flour was lower in fat and crude fiber than was whole-wheat flour. These compositional differences are attributed to the removal of the bran, aleurone and germ during milling.

Tennessee whole-grain barley flour composition did not differ from the whole-wheat flour composition except for crude fiber. However, differences were found between the two whole-grain barley flours, although the same barley variety, Thual, was grown in Alaska and Tennessee. Differences in protein and starch plus ash content were found; an inverse relationship was observed. Among the factors affecting protein content of a grain within a variety are temperature and photoperiod (Kolderup, 1975). Whitehouse (1970) reports that grain protein content increases as the latitude of production nears the Arctic Circle. Wooding and Husby (1980) attributed the high protein content typical of Alaska-produced barleys to the long photoperiods. Apparently, the higher Tennessee temperatures overrode the effect of the longer photoperiod in Alaska, resulting in a higher protein content in the Tennessee-produced barley. According to Andersen et al. (1978), there is a correlation

Table 5—Proximate analyses for flour on a 14% moisture basis

	Bread	Whole-wheat	Barley	
			Tennessee	Alaska
	%			
Protein[a]	12.71 ± 0.03a	14.39 ± 0.15b	14.44 ± 0.09b	10.50 ± 0.15c
Fat[a]	0.96 ± 0.03a	2.03 ± 0.01b	2.10 ± 0.07b	2.28 ± 0.76b
Crude fiber[a]	0.25 ± 0.05a	2.11 ± 0.16b	1.47 ± 0.03c	1.32 ± 0.12c
CHO + Ash[b]	72.08a	67.47b	67.99b	71.90a

[a]Mean ± SD where n = 3; means in a row followed by like letters are not significantly different according to Tukey's Range Test ($p > 0.05$).
[b]Determined by difference.

between small kernel size and the increased nitrogen content associated with higher temperatures. Kernel size of the Tennessee-produced barley was smaller than was the kernel size of the Alaska-produced grain (Figure 5).

Amino Acid Compostition

Amino acid compsition, reported as percentage of total flour, differed with barley source (Table 6). When compared to Alaska-produced barley, Tennessee barley contained higher percentages of glutamic acid, proline and phenylalanine, whereas the lysine percentage was lower. This amino acid distribution is characterisitic of grains having an increased protein content. Hepburn and Bradley (1965) and Rhodes and Mathers (1974) reported a similar relationship between protein content and amino acid composition for wheat and barley, respectively. In wheat, glutamic acid and proline are the principle amino acids in gluten (McDonald and Gilles, 1967). Tennessee barley is higher than the Alaska barley in isoleucine, leucine, phenylalanine, serine and valine. These amino acids also are major gluten consituents (McDonald and Gilles, 1967). Hordein, a barley cohesive protein, has been reported to increase with an increase in protein content (Baxter, 1981). Further, Alaska-grown barley is higher than is Tennessee-produced barley in the percentage of lysine and arginine present. In baking tests, wheat bread loaf volume was decreased when histidine, lysine and arginine were increased (Shoup et al., 1966). Therefore, it appears that like wheat, increased barley protein levels are associated with

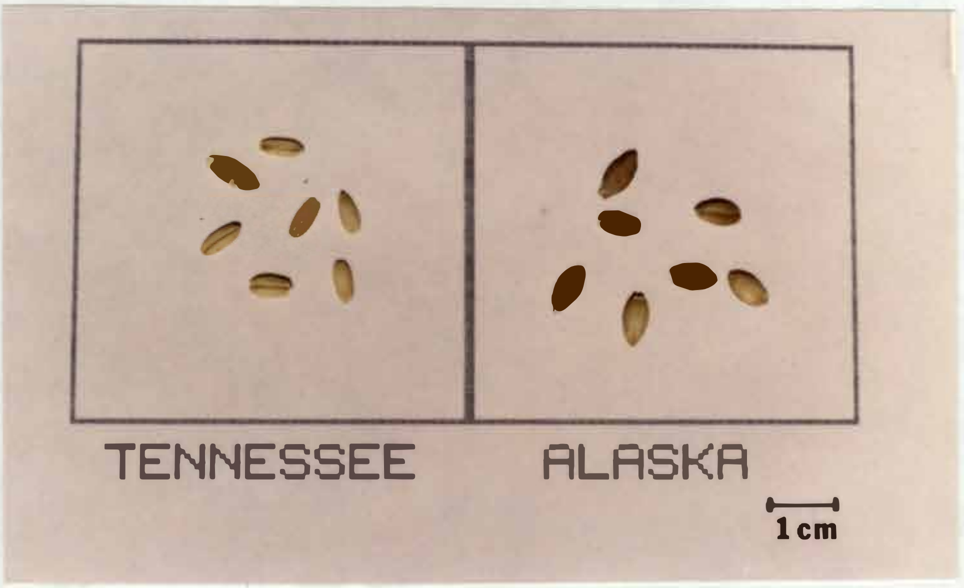


Figure 5—Photograph of Thual hull-less barley kernels grown in Tennessee and Alaska.

Table 6—Amino acid composition of flours from Thual barley grown in two locations[a]

Amino acid	Location: Tennessee	Alaska
	-----------% total flour-----------	
Aspartic acid	0.98 ± 0.02	0.72 ± 0.01
Threonine	0.62 ± 0.04	0.40 ± 0.02
Serine	0.68 ± 0.03	0.46 ± 0.02
Glutamic acid	3.64 ± 0.08	2.50 ± 0.18
Proline	1.41 ± 0.14	0.35 ± 0.00
Glycine	0.66 ± 0.01	0.41 ± 0.03
Alanine	0.65 ± 0.01	0.42 ± 0.02
Cystine	0.33 ± 0.00	0.18 ± 0.03
Valine	0.80 ± 0.09	0.58 ± 0.06
Methionine	0.28 ± 0.00	0.20 ± 0.02
Isoleucine	0.59 ± 0.06	0.48 ± 0.01
Leucine	1.13 ± 0.01	0.83 ± 0.01
Tyrosine	0.34 ± 0.09	0.34 ± 0.03
Phenylalanine	0.96 ± 0.13	0.57 ± 0.03
Histidine	0.55 ± 0.03	0.61 ± 0.16
Lysine, total	0.38 ± 0.04	0.58 ± 0.01
Arginine	0.58 ± 0.02	0.94 ± 0.01

[a]Mean ± SD where n = 2.

increased levels of amino acids important in the formation of a cohesive protein network.

Microscopic Structure

Differences in whole-wheat and barley flour microscopic structure were examined using a scanning electron microscope. The whole-wheat flour (Plate 1) was characterized by the presence of large and small starch granules. The large starch granules were disc-like in shape, whereas the small starch granules were round. Hall and Sayre (1970) reported that wheat starch granules ranged in size from small to medium; the small granules were round and the large granules were disc-shaped.

Little difference in starch granule shape was found when barley starch granules from both sources (Plate 1) were compared to the whole-wheat flour starch granules. No differences attributable to barley source were observed. The granules varied greatly in size; numerous large and small starch granules characteristic of mature barley endosperm (Pomeranz, 1972) are visible. Although Hall and Sayre (1970) reported that barley starch granules were diverse in size and oval in shape with smooth surfaces, DeHaas et al. (1983) reported that polygonal shaped starch granules occurred in some barley varieties. Starch granule shape has implications for starch functionality in bread systems as gluten adheres to the granule surface during breadmaking (Sandstedt, 1961). According to Rasper et al. (1974), a nonwheat starch with granule shapes similar to those of wheat starch can be used successfully in breadmaking. Kulp and Lorenz (1981) also suggested that the starch

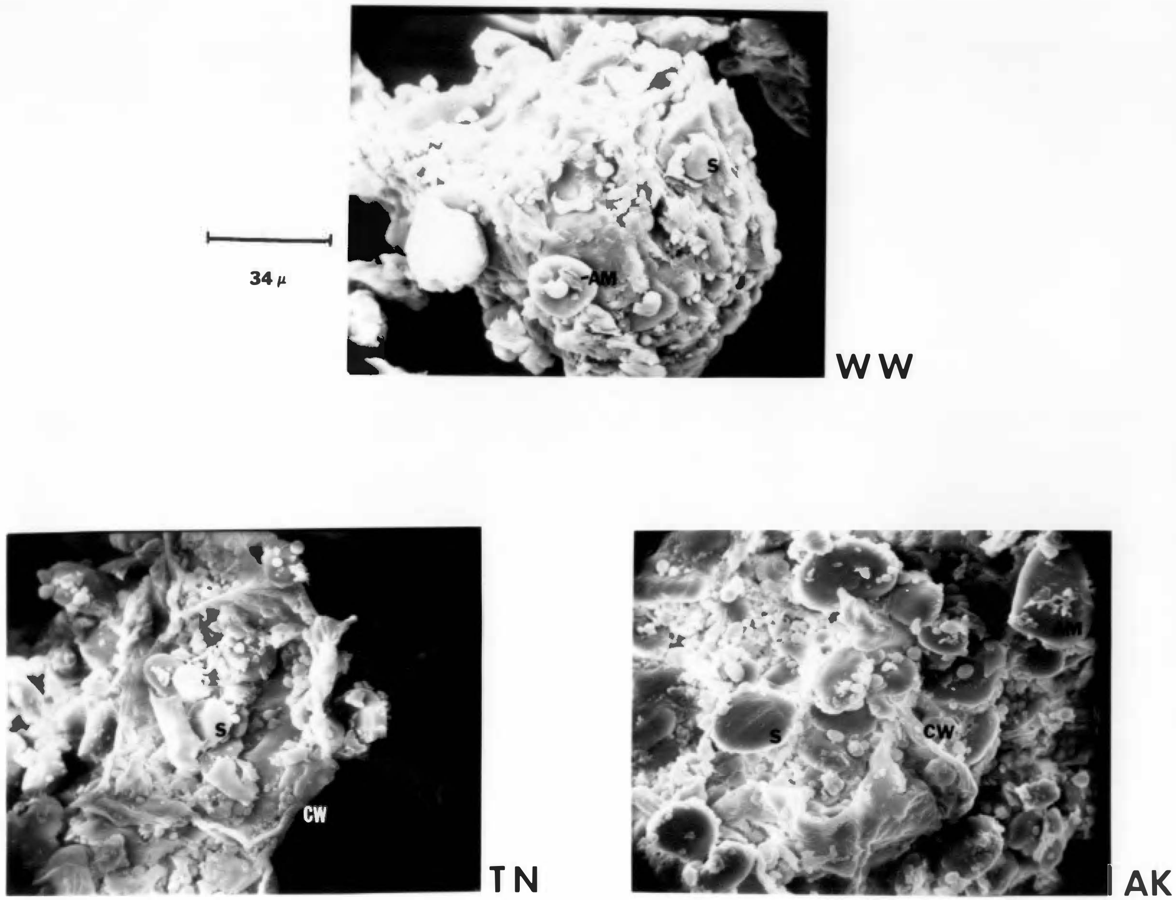


Plate 1—Scanning electron photomicrographs of whole-wheat (WW), Tennessee whole-grain barley (TN) and Alaska whole-grain barley (AK) flours with starch granules (S), adhering matter (AM) and cell walls (CW) identified.

granule shapes rather than starch gelatinization characteristics determine starch functionality in breadmaking.

Adhering matter is visible on the surface of the large barley starch granules as well as on the large whole-wheat starch granule surfaces (Plate 1). In experimental bread systems containing wheat starch, the adhering matter was necessary to produce a successful bread dough. Composition studies reveal that the wheat starch adhering matter contained gluten and water-soluble proteins as well as starch fragments and pentosans (Kulp and Lorenz, 1981). Pomeranz (1972) suggested that the adhering material found on barley starch granules was proteinaceous in nature.

In all three photomicrographs (Plate 1), the starch granules are embedded in a matrix. Both barley (Pomeranz, 1972) and wheat (Hoseney et al., 1978) starch granules have been reported to be embedded in a protein matrix.

The outline of an endosperm cell is clearly visible in the Tennessee whole-grain barley flour sample (Plate 1). Part of an endosperm cell wall is visible in the Alaska whole-grain barley flour sample (Plate 1). Barley endosperm cell walls reportedly consist of 75% β-D-glucan with the remaining percentage of the cell wall material consisting mainly of arabinoxylan. In wheat, the endosperm cell wall consists primarily of pentosans; β-D-glucans constitute the lesser portion (Munck, 1981).

II. APPARENT VISCOSITY STUDIES

Part A: Apparent Viscosity in Simple Systems

Apparent viscosity characteristics of the simple systems (Table 2, p. 30) were evaluated with variation in barley source and barley percentage. A two-stage amylograph apparent viscosity curve was found, regardless of barley source or barley percentage (Figure 2, p. 35). Goering and Brelsford (1965) previously reported that barley starch exhibited a two-stage amylograph gelatinization curve similar to wheat starch. Hoseney et al. (1971), using barley that exhibited amylograph gelatinization curve characteristics similar to the wheat starch control, successfully produced an experimental yeast bread. Because flour components other than starch contributed to the results obtained (Arenson, 1969) in this study, it is difficult to make direct comparisons between the whole-grain composite systems studied and literature studies in which only starch was used.

Effect of Barley Source

Means for the apparent viscosity study as affected by barley source are reported in Table 7; mean squares are reported in Table B1 (Appendix B). Although barley source did not affect time or temperature of intial viscosity increase, maximum viscosity ($p < 0.001$), and the time ($p < 0.0001$) and temperature ($p < 0.0001$) at which maximum viscosity was obtained were significantly affected. The Tennessee barley exhibited a higher maximum viscosity (approximately 30 BU) and a higher temperature

Table 7—Amylogram characteristics of simple systems[a]

Variation	TIBL[b] (min)	TPBL[c] (°C)	MXVIS[d] (BU)	TIMVIS[e] (min)	TPMVIS[f] (°C)	HVIS[g] (BU)	COOL[h] (BU)
Barley source							
Tennessee	24.8a	62.3a	382.5a	40.3a	85.4a	69.2a	137.5a
Alaska	24.4a	61.6a	353.5b	39.3b	83.9b	56.8b	114.6b
Barley level (%)							
0	25.7a	63.5a	435.0a	39.1a	86.0a	80.0a	128.3a
10	24.0a	61.0a	381.2b	40.7c	83.6c	69.0b	127.2a
20	24.7a	62.0a	340.8c	40.0bc	85.0ab	53.3c	125.0a
30	24.2a	61.3a	315.0c	39.4ab	84.1bc	49.7c	123.7a

[a]Means in a column within source of variation followed by like letters do not differ according to Tukey's Range Test ($p > 0.05$).
[b]TIBL = time of initial viscosity increase.
[c]TPBL = temperature of initial viscosity increase.
[d]MXVIS = maximimum viscosity.
[e]TIMVIS = time at which maximum viscosity occured.
[f]TPMVIS = temperature at which maximum viscosity occured.
[g]HVIS = holding viscosity.
[h]COOL = cooling peak viscosity.

at which maximum viscosity was obtained. The Tennessee barley also exhibited less viscosity decrease with holding at 95°C than did the Alaska barley ($p < 0.0001$) and a higher cooling peak viscosity ($p < 0.0001$).

These results would not have been predicted from proximate analysis data. Although the same barley variety, Thual, was grown in both locations, differences in composition (Table 5, p. 50) were found. The Tennessee grain contained less carbohydrate plus ash than did the Alaska grain. Protein content varied inversely with starch content (Table 5). In reconstitution studies, replacement of wheat starch with an equal weight of gluten proteins resulted in a decrease in maximum viscosity (Anker and Geddes, 1944); the Tennessee barley exhibited increased viscosity in spite of increased protein content. Further, the higher protein content of the Tennessee grain would be expected to decrease viscosity by increasing starch damage during milling. Grain kernel hardness, which is generally related to protein content, has been positively correlated with wheat starch damage (Meredith and Pomeranz, 1982).

The higher maximum viscosity and time and temperature of maximum viscosity (Table 7) that are characteristic of the Tennessee grain, may be a result of higher β-D-glucan levels. This nonstarch polysaccharide, which is primarily present in the endosperm cell walls, is partially water soluble and becomes viscous when hydrated. A mixture of 1,3 and 1,4 β-D-glucans have been reported (Munck, 1981). Bhatty (1986) attributed higher maximum viscosity of a pearled hull-less barley flour to its

higher β-D-glucan content. This barley flour also required a longer time and thus a higher temperature to acheive maximum viscosity (Bhatty, 1986) as was found for the Tennessee barley in this study. The higher holding viscosity obtained for the Tennessee barley when compared to the Alaska barley is likely a reflection of the higher maximum viscosity achieved. The cooling peak height for both sources is approximately double the holding viscosity, indicating association of the starch and/or β-D-glucans on cooling.

Effect of Barley Percentage

Means for apparent viscosity as affected by percentage barley are reported in Table 7; mean squares are reported in Table B1 (Appendix B). Increasing barley percentage from 0 to 30% did not alter time or temperature of initial viscosity increase, indicating that the ease with which the flour components imbibed water, did not differ as a result of barley level. Therefore, gluten-starch interaction should occur at all levels of barley incorporation (Kulp and Lorenz, 1981).

Maximum viscosity ($p < 0.0001$) and time and temperature ($p < 0.01$) of maximum viscosity differed as a result of barley level (Table B1). As barley percentage increased from 0 to 20, there was a decrease in maximum viscosity. In preliminary studies, maximum viscosity values of 1000 BU were obtained for 100% Alaska barley flour samples; maximum viscosity values for 100% Tennessee barley were beyond the capacity of the instrument when flour concentration was held constant. However, barley level does not appear to alter the ability of the starch or other flour

components to act as a "water sink," making water available for protein hydration during breadmaking (Hoseney et al., 1978).

Based on the main effects observed, it is not surprising that barley source X barley percentage interaction was significant for maximum viscosity ($p < 0.05$) and time and temperature ($p < 0.0001$) at which maximum viscosity occurred. These interactions are presented graphically in Figures 6 and 7; interaction means are supplied in Table C1 (Appendix C). A decrease in maximum viscosity occurred when either Tennessee or Alaska barley was substituted for the whole-wheat flour, the effect on maximum viscosity differed with barley source. The decrease in maximum viscosity continued as Alaska barley level increased from 10 to 30%. No difference was noted as the level of Tennesse barley flour increased.

Because temperature at which maximum viscosity occurs is dependent on heating time, only the interaction graph for the temperature at which maximum viscosity occurs is presented (Figure 7). As Alaska barley substitution increased from 0 to 30%, there was a continued decrease in the temperature at which maximum viscosity occurred. Likewise, a decrease in the temperature of maximum viscosity occurred when Tennessee barley flour was substituted for whole-wheat flour at the 10% level. Conversely, when Tennessee barley was substituted at higher levels, an increase in the temperature at which maximum viscosity occurred was observed. Despite statistical significance, implcations for breadmaking are questionable.

Although holding viscosity was found to decrease ($p < 0.0001$) as barley flour percentage increased to 20%, it did not change with an

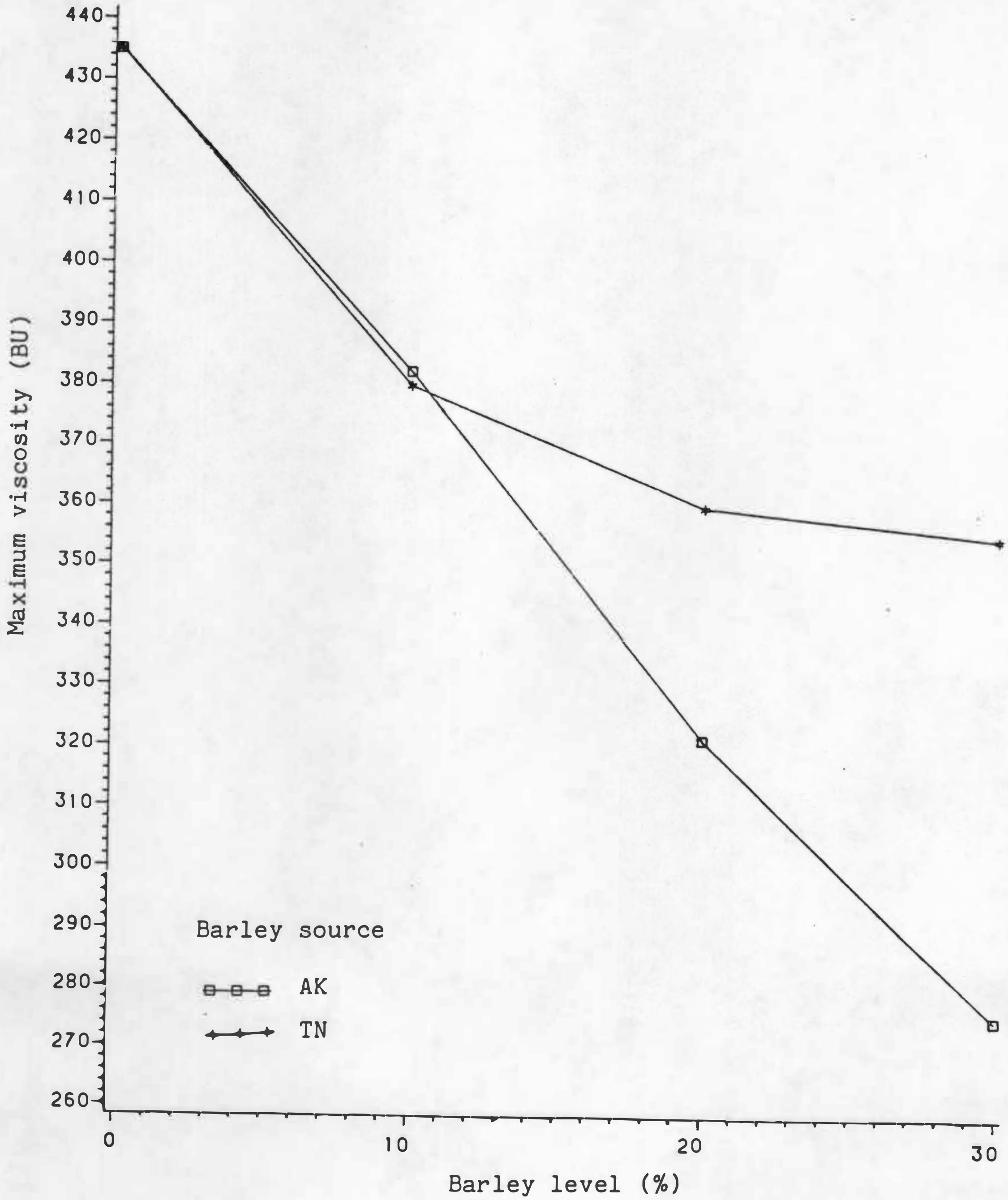


Figure 6—Maximum viscosity as a function of barley level and source in simple apparent viscosity systems.

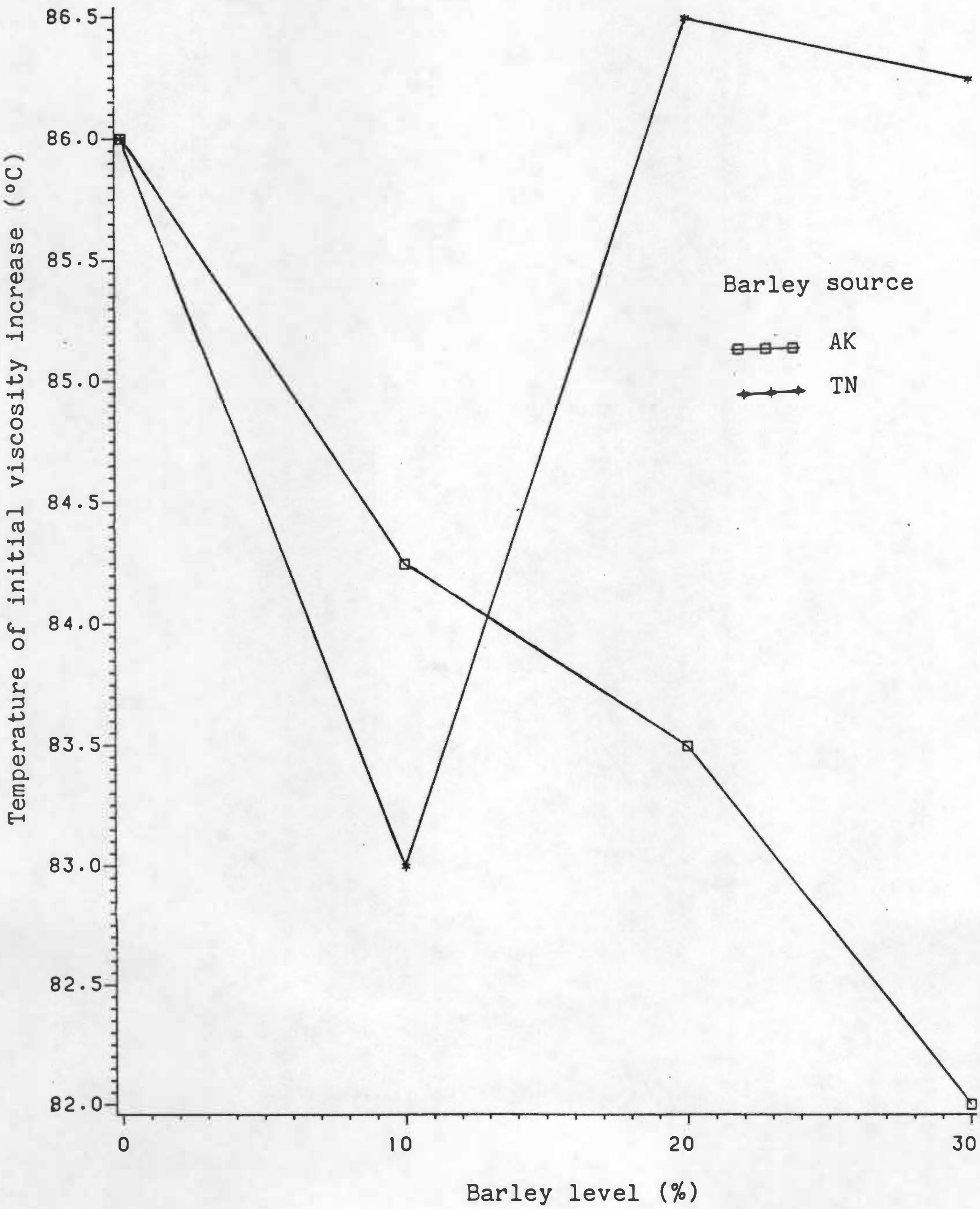


Figure 7—Temperature of maximum viscosity as a function of barley level and source in simple apparent viscosity systems.

increase in barley flour to 30%. The difference between maximum viscosity and holding viscosity decreased as barley percentage increased, indicating greater stability of the barley flour containing pastes to heating (Table 7). The interaction, barley source X barley percentage ($p < 0.0001$) is depicted in Figure 8. Interaction means are found in Table C1 (Appendix C). Although increasing levels of each barley resulted in a decrease in holding viscosity, the decrease was less for the Tennessee barley than it was for the Alaska barley. Increasing the Alaska barley levels from 20 to 30% resulted in a continued decrease in holding viscosity. Further decreases in holding viscosity did not occur as Tennessee barley levels increased from 20 to 30%.

No significant differences in cooling peak height occurred as a result of the main effect, barley percentage. However, the interaction, source X barley percentage (Figure 9; Tables B1 and C1, Appendixes B and C), was significant. Cooling peak viscosity of the Tennessee barley increased at 20%, whereas a decrease in cooling peak viscosity was observed at the 20% level of Alaska barley flour incorporation. Therefore, the lack of significance for the main effect barley percentage is attributed to the "balancing out" of the effect of source.

Part B: Salt Effect on Apparent Viscosity in Simple Systems

Apparent viscosity parameters were evaluated with variation in salt percentage as well as barley source and barley percentage. Means are reported in Table 8 and mean squares in Table B2 (Appendix B). As

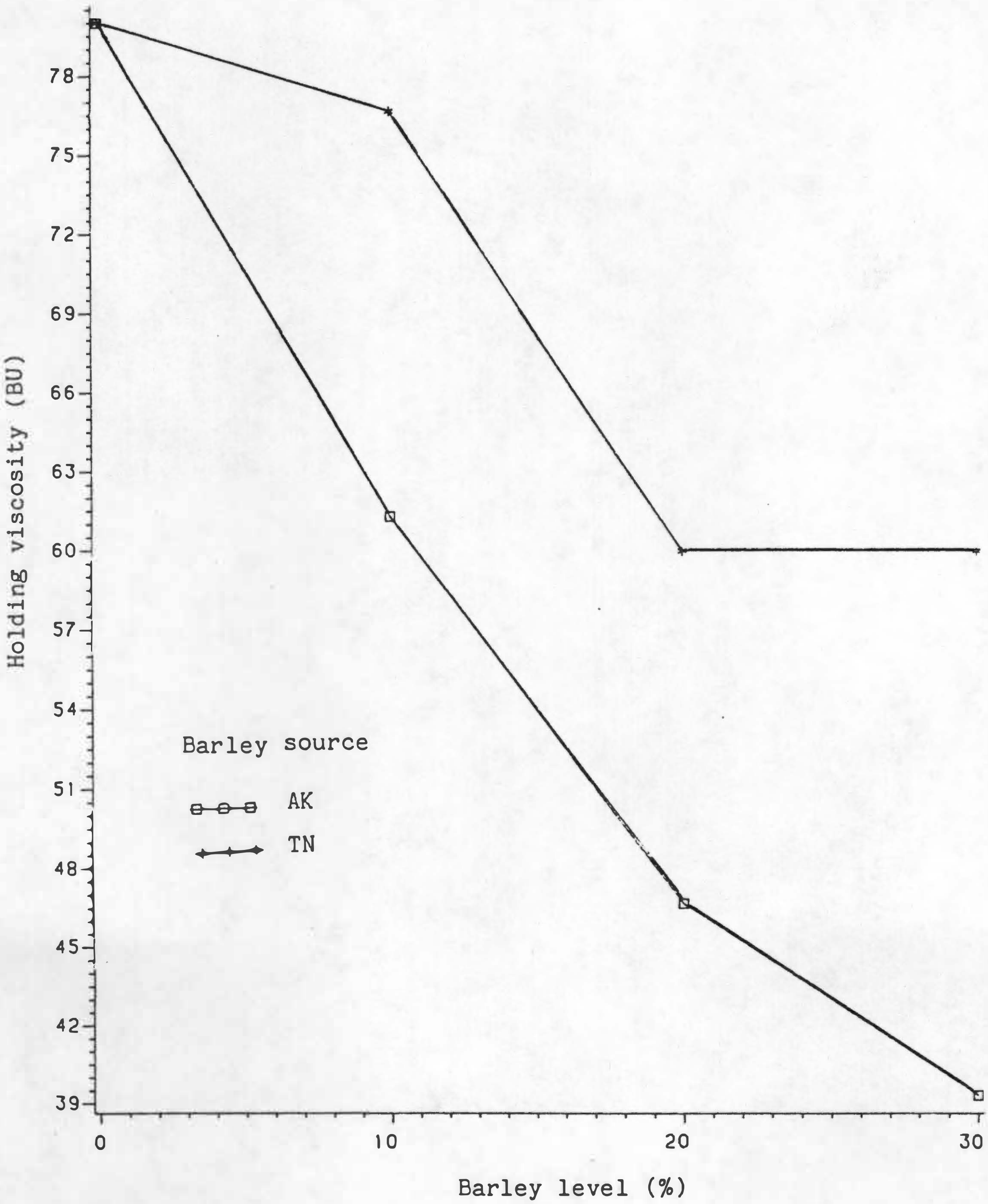


Figure 8—Holding viscosity as a function of barley level and source in simple apparent viscosity systems.

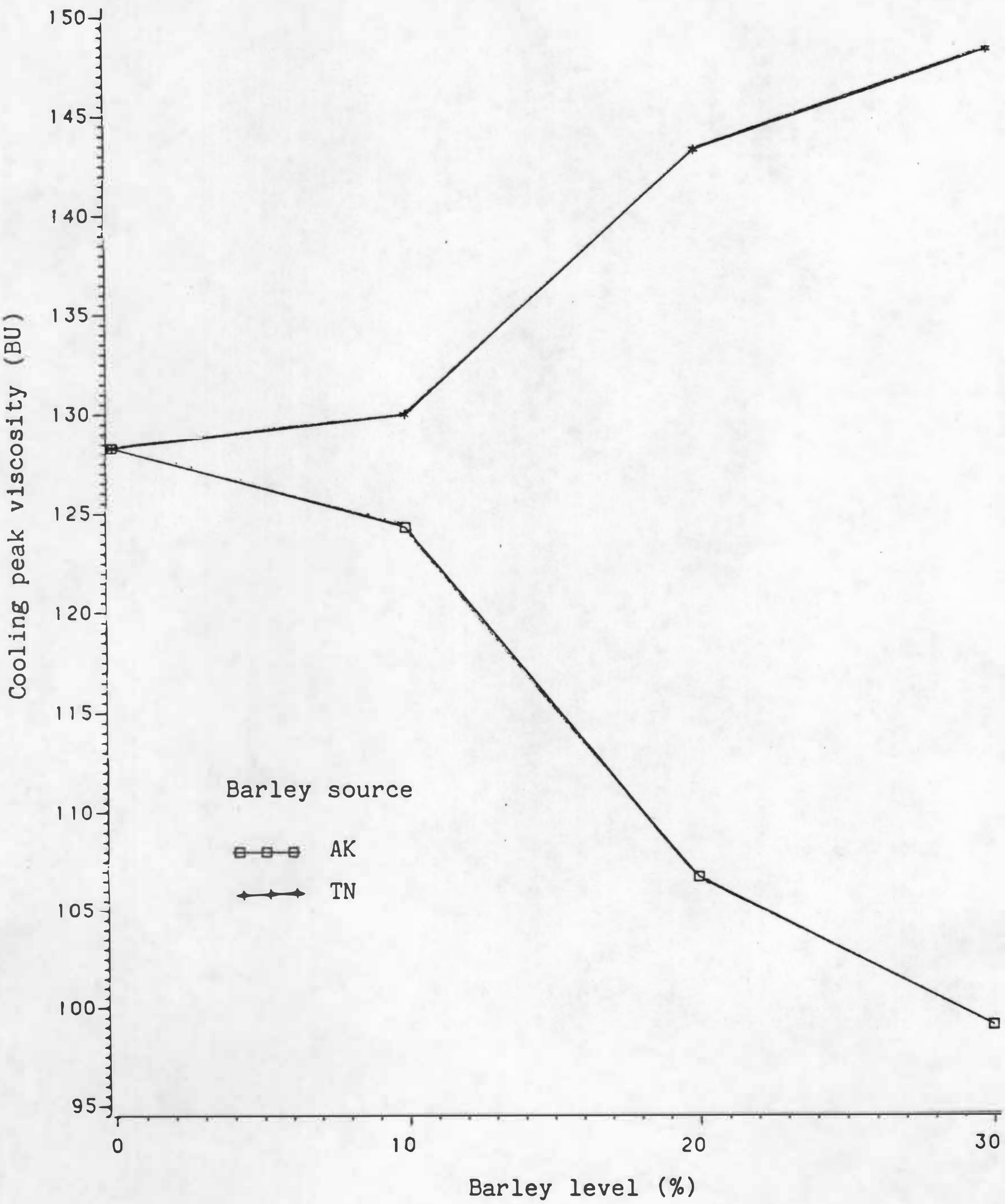


Figure 9—Cooling peak viscosity as a function of barley level and source in simple apparent viscosity systems.

Table 8—Amylogram characteristics of simple system containing salts[a]

Variation	TIBL[b] (min)	TPBL[c] (°C)	MXVIS[d] (BU)	TIMVIS[e] (min)	TPMVIS[f] (°C)	HVIS[g] (BU)	COOL[h] (BU)
Salt level (%)							
1.5	24.4a	61.6a	510.5a	42.1a	88.2a	122.9a	282.9a
2.0	24.9b	62.3b	550.2b	42.3ab	88.5ab	140.0b	325.7b
2.5	25.2c	62.8c	590.1c	42.5b	88.7b	161.3c	374.6c
3.0	25.4c	63.1c	618.3d	42.5b	88.7b	181.0d	417.4d
Barley source							
Tennessee	25.0a	62.5a	584.7a	42.5a	88.7a	162.2a	372.9a
Alaska	25.0a	62.5a	549.9b	42.2b	88.3b	140.4b	327.5b
Barley level (%)							
0	25.4a	63.1a	614.2a	42.9a	89.3a	185.8a	405.8a
10	25.2a	62.8a	578.1b	42.4b	88.6b	154.0b	349.6b
20	24.7b	62.1b	549.7c	42.1c	88.1c	137.5c	328.2c
30	24.5b	61.8b	527.0d	41.9d	88.0d	127.9d	317.0d

[a]Means in a column within source of variation followed by like letters do not differ according to Tukey's Range Test ($p > 0.05$).
[b]TIBL = time of initial viscosity increase.
[c]TPBL = temperature of initial viscosity increase.
[d]MXVIS = maximimum viscosity.
[e]TIMVIS = time at which maximum viscosity occured.
[f]TPMVIS = temperature at which maximum viscosity occured.
[g]HVIS = holding viscosity.
[h]COOL = cooling peak viscosity.

in the absence of salt, a two-stage apparent viscosity curve was obtained. As salt increased between 1.5 and 3.0% fwb, maximum, holding and cooling peak viscosities increased linearly; each salt increment resulted in a significant increase in viscosity (Table 8). Linko et al. (1984) found similar results with the addition of salt (0.5 to 2.5% fwb) to 100% barley and 100% wheat flours. Time and temperature at which initial viscosity increase occurred were increased with salt incorporation, although the increase was not statistically significant as salt level increased from 2.5 to 3.0% fwb. Increasing salt content resulted in a slight increase in the time and temperature at which maximum viscosity was reached. No differences were found when the 2% fwb salt level commonly used in commercial breads (Ponte, 1978), was compared to all other salt levels studied. The salt effect on composite flour system apparent viscosity parameters is consistent with D'Appolonia's (1972) suggestion that salt increases starch granule resistance to breakdown, resulting in increased viscosity.

Effect of Barley Source

There was no effect of barley source on time or temperature of initial viscosity increase across all barley percentages and salt levels (Table 8). These results paralleled the effect noted in the absence of salt (Table 7, p. 58). Barley source did alter maximum viscosity as well as holding and cooling peak viscosities in the presence of salt. As found in the absence of salt, substitution of Tennessee barley flour rather than the Alaska barley flour resulted in higher maximum, holding

and cooling peak viscosities. Time at which maximum viscosity occurred was delayed longer when Tennessee rather than Alaska barley replaced whole-wheat flour in the system. The delay in the time at which Tennessee maximum viscosity occurred resulted in a higher temperature of maximum viscosity. D'Appolonia (1972) suggested that salt increases starch granule resistance to breakdown, resulting in increased viscosity. Although the interaction source X salt percentage is significant for holding viscosity ($p < 0.05$), the interaction is an unimportant one.

Effect of Barley Percentage

When salt was introduced into the simple apparent viscosity system, a gradual decrease in the time and temperature of initial viscosity increase occurred as barley level increased (Table 8). The temperature differed by 1.3°C. Despite statistical significance, the observed trend is unlikely to be of practical importance. Kulp and Lorenz (1981) found that a variation of 10°C in the temperature at which starches exhibited their initial viscosity increase did not alter the breadmaking properties of an experimental system.

Although maximum viscosity values were higher in the presence of salt, the effect of increasing barley percentage in the presence of salt (Table 8), paralleled the results found in the absence of salt (Table 7, p. 58). Maximum viscosity decreased as barley level increased. The interaction, source X barley percentage (Table C2, Appendix C) depicted in Figure 10, is similar to the interaction in the absence of salt (Figure 6, p. 62). Increasing the Alaska barley percentage decreased

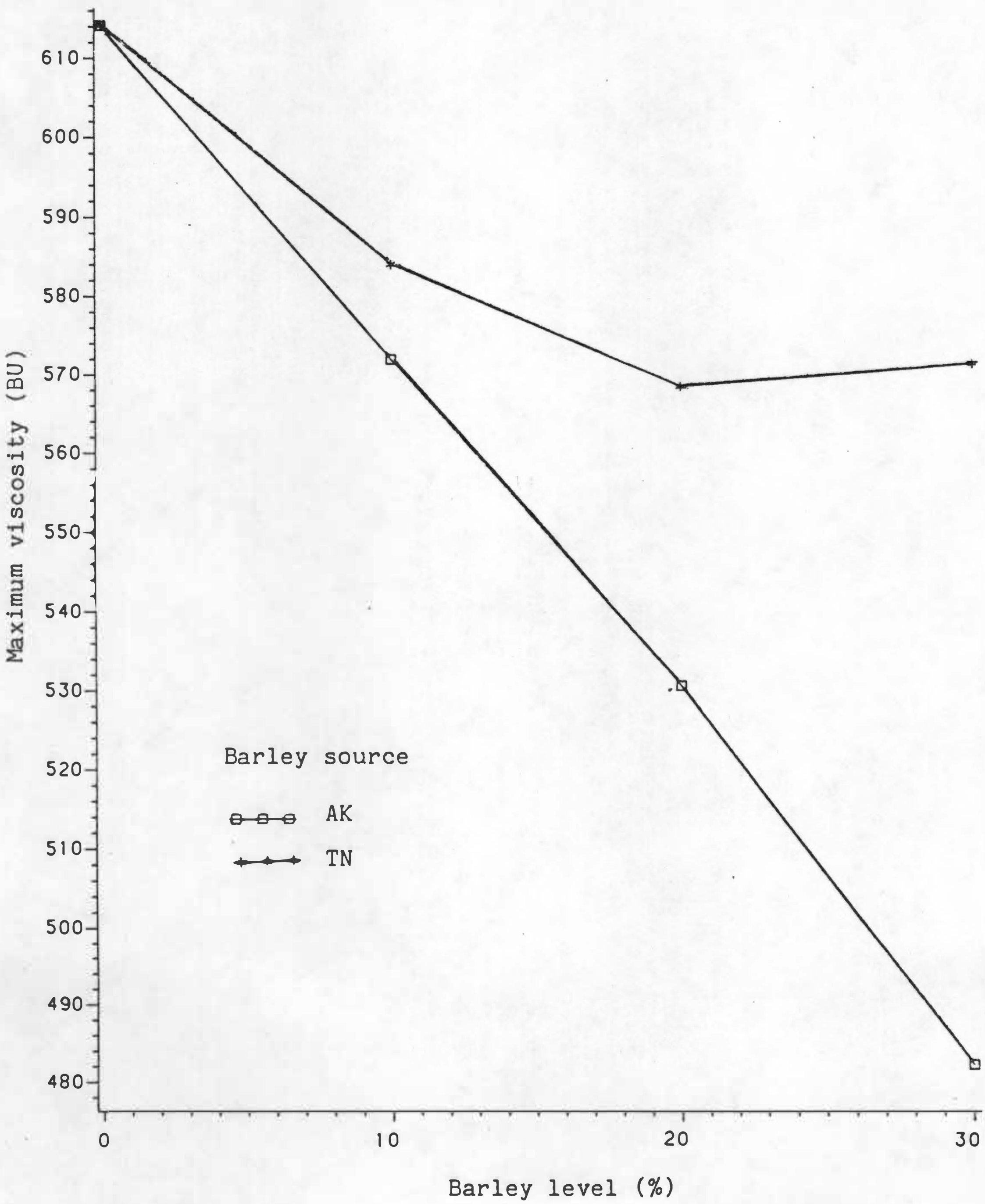


Figure 10—Maximum viscosity as a function of barley level and source in simple apparent viscosity systems containing salt.

maximum viscosity despite increasing starch levels (Table 5, p. 50). An increase in the level of Tennessee barley had less effect on maximum viscosity overall. As Tennessee barley levels increased from 20 to 30%, maximum viscosity levels were essentially the same as the maximum viscosity level found when Alaska barley was substituted at the 10% level.

The interaction, barley percentage X salt percentage also was significant for maximum viscosity (Tables B2 and C3, Appendixes B and C); this interaction is presented in Figure 11. When the sensitivity of the visco/amylograph is considered (±20 BU), it is unlikely that this interaction is important. However, this interaction does show that altering the salt level would allow the effect of whole-wheat flour replacement by barley flour to be overcome. Assuming incorporation of salt at the 2% level commonly used in commercial bread, a salt level of 2.5 would result in essentially the same maximum viscosity when barley flour levels are 10 and 20%. When salt was incorporated at the 2.5 and 3.0% levels, maximum viscosity of the 20 and 30% barley system also approximated the viscosity of a 0% barley system containing 2.0% salt.

Time of maximum viscosity was delayed by approximately 2 min, whereas temperature of maximum viscosity was increased by about 4°C with salt addition. Despite differences in the actual temperatures that were attributable to salt incorporation, the salt addition did not alter the trend toward decreasing temperature of maximum viscosity as barley percentage increased. The interaction, barley source X barley percentage, was significant for time ($p < 0.0001$) and temperature ($p < 0.01$) of

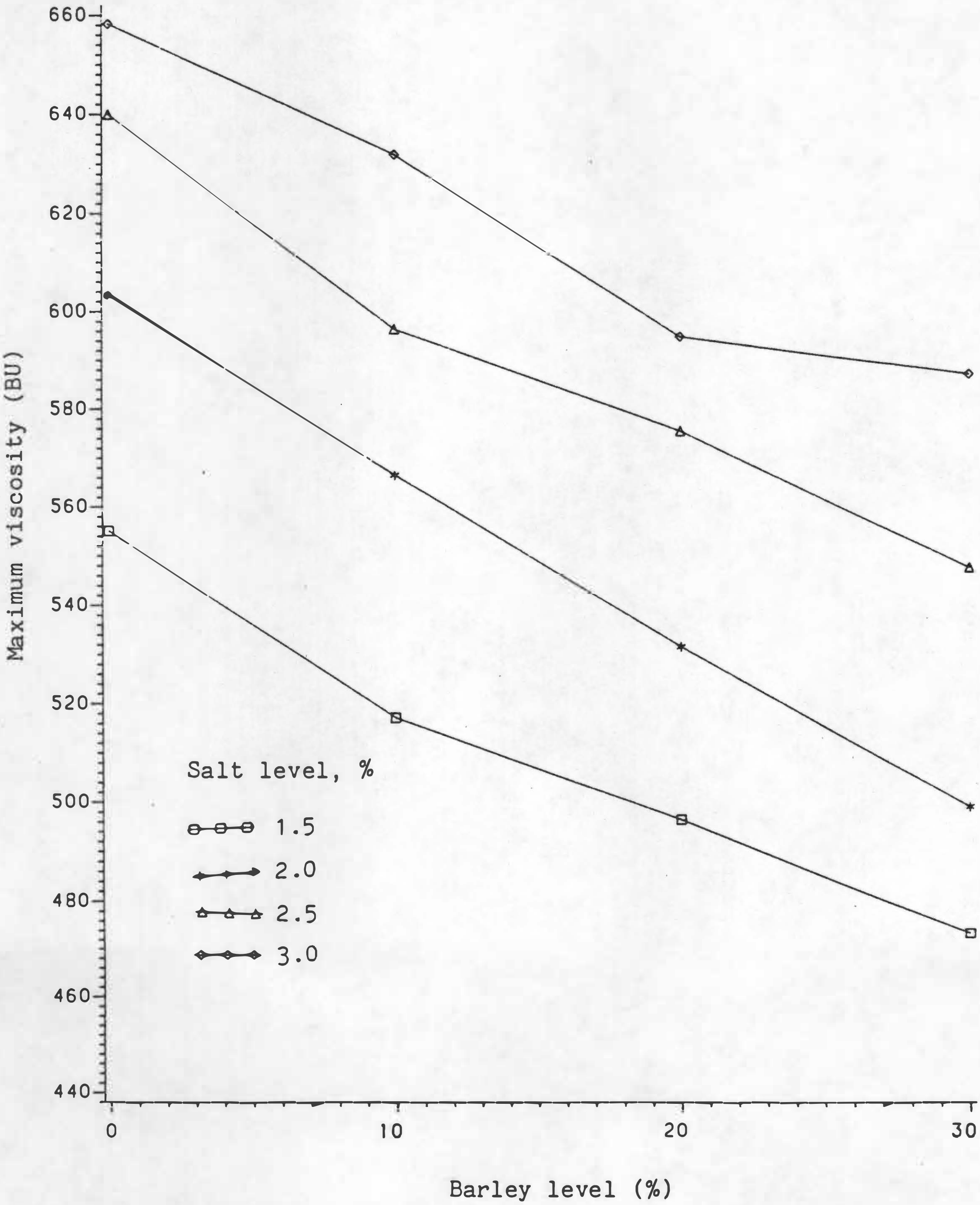


Figure 11—Maximum viscosity as a function of barley and salt levels in simple apparent viscosity systems containing salt.

maximum viscosity (Figure 12; Tables B2 and C2, Appendixes B and C). Although statistically significant, the magnitude of the difference is unlikely to be of importance,

Addition of salt to the simple apparent viscosity system did not alter the trend toward decreased holding viscosity as barley percentage increased (Table 8), although overall holding viscosity was increased. An interaction between barley percentage and salt percentage ($p < 0.0001$) was found (Figure 13; Tables B2 and C3, Appendixes B and C). After considering the sensitivity of the instrument (±20 BU), it is unlikely that this interaction is important. However, once again it is apparent that increasing the salt level above 2.0% as barley level is increased will result in holding viscosities that approximate those found when 2% salt is incorporated in the 0% barley system.

Overall, cooling peak viscosity was increased when salt was incorporated into the simple apparent viscosity system (Tables 7, p. 58, and 8). In the presence of salt, cooling peak viscosity decreased significantly as barley percentage increased (Table 8). This relationship implies that salt addition will decrease staling of bread as increasing percentages of whole-grain barley flour are incorporated. When the interaction, source X barley percentage is examined (Figure 14; Tables B2 and C2, Appendixes B and C), incorporation of the Alaska whole-grain barley is observed to result in decreasing viscosity. This trend was not evident in the Tennessee data. Increasing the salt level (Figure 15; Tables B2 and C3, Appendixes B and C) increased the cooling peak viscosity although barley incorporation modified the extent to

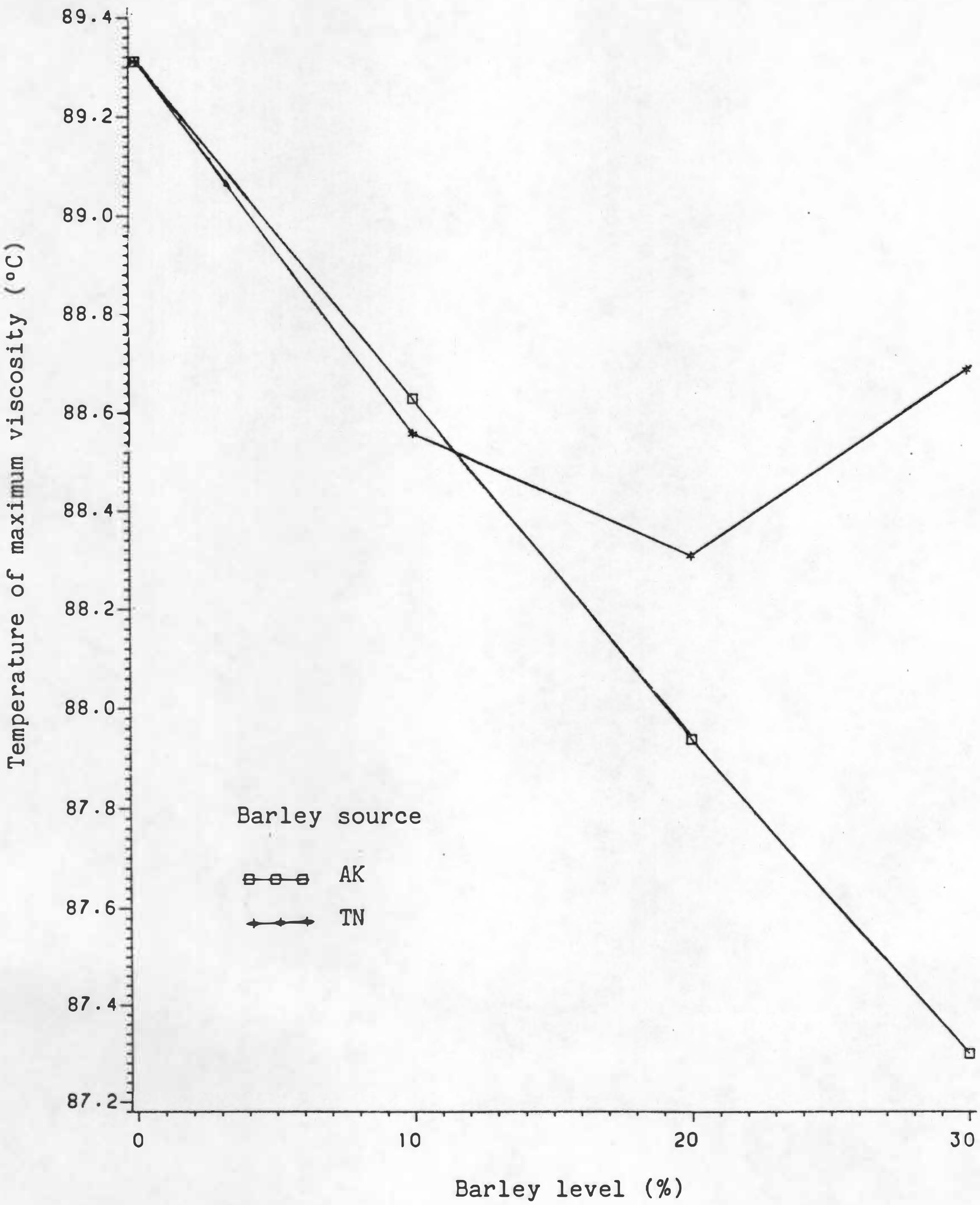


Figure 12—Temperature of maximum viscosity as a function of barley level and source in simple apparent viscosity systems containing salt.

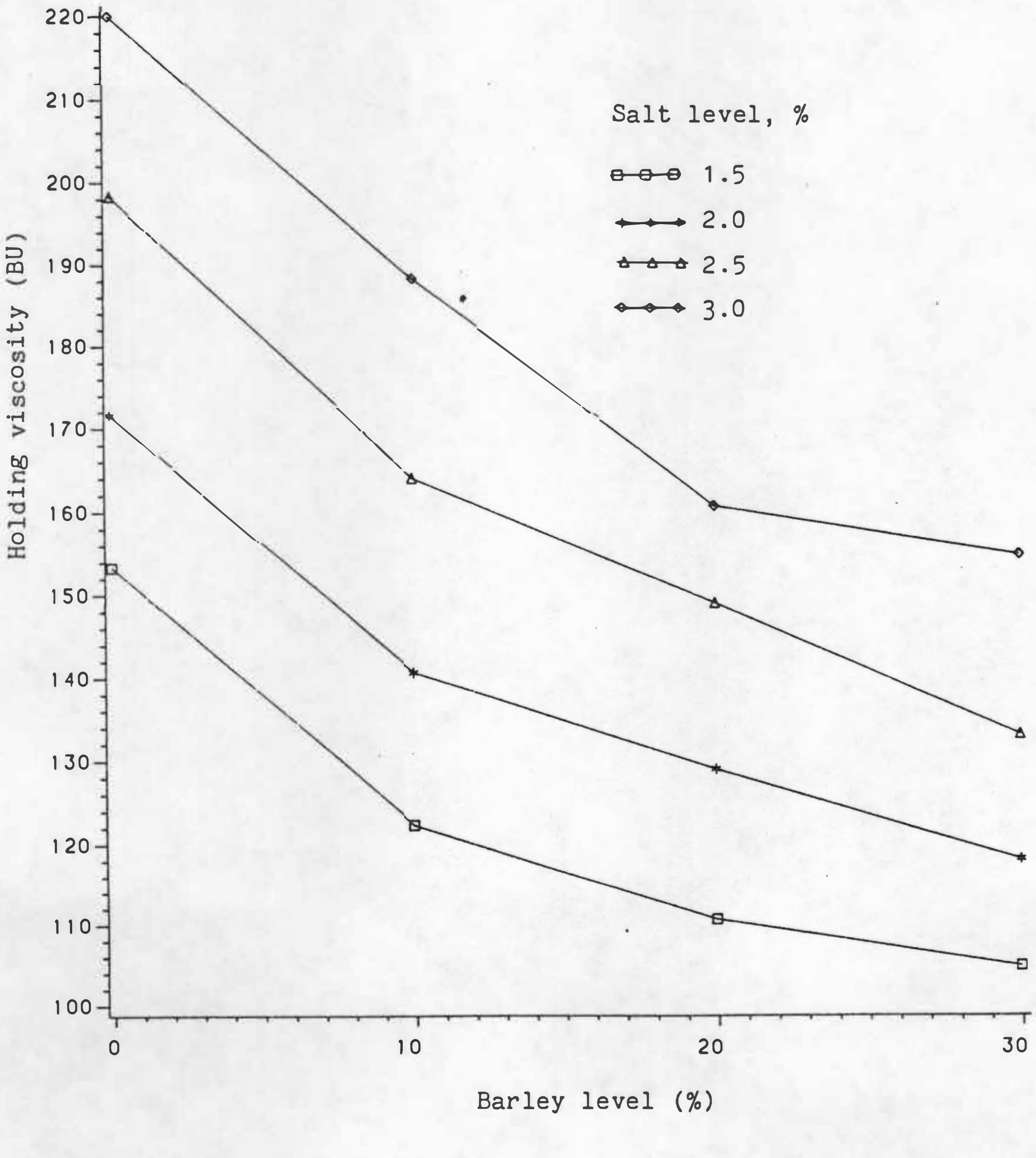


Figure 13—Holding viscosity as a function of barley and salt levels in simple apparent viscosity systems containing salt.

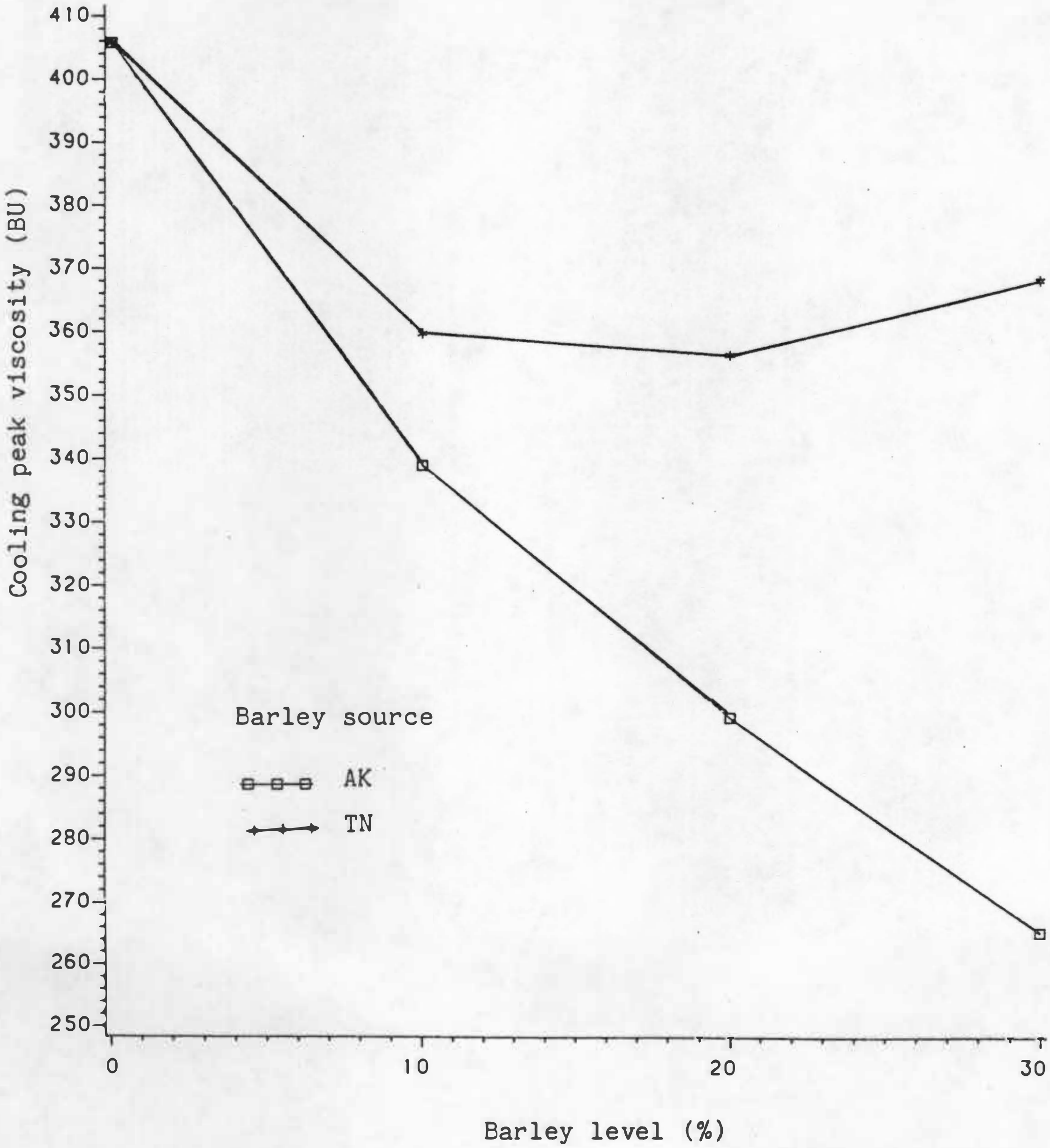


Figure 14—Cooling peak viscosity as a function of barley level and source in simple apparent viscosity systems containing salt.

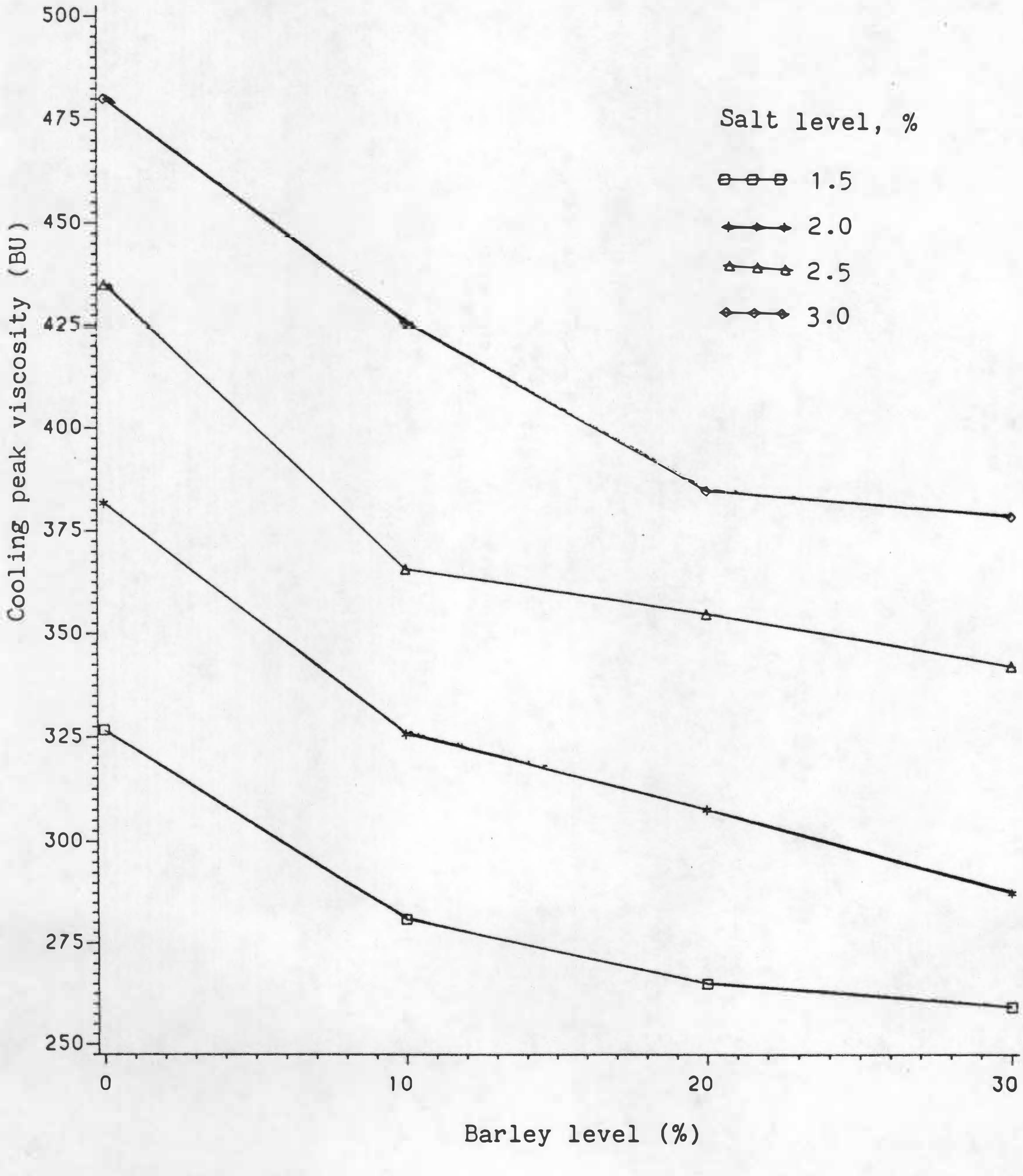


Figure 15—Cooling peak viscosity as a function of barley and salt levels in simple apparent viscosity systems containing salt.

which cooling peak viscosity was increased. The interaction is significant ($p < 0.01$) because the decrease in viscosity that occurred with increasing salt levels was not the same for all barley levels. Similar patterns were observed for 0 and 10% barley and for 20 and 30% barley levels. The three-way interaction, source X barley percentage X salt percentage that is significant for cooling peak viscosity, reflects the two-way interactions previously discussed.

Part C: Apparent Viscosity of Complete Dough Systems

Apparent viscosity characteristics of the complete dough systems (Table 3, p. 31) were investigated with variation in barley source, barley percentage and salt level. Apparent pH of the systems was varied according to the results of the dough apparent pH study (Table 4, p. 37). In general, complete dough apparent viscosity amylograms revealed a slightly increased time and temperature of initial viscosity increase, a decrease in maximum viscosity and a decrease in the time and temperature at which maximum viscosity occurred (Table 9) when compared to simple apparent viscosity amylograms (Tables 7 and 8, pp. 58 and 67). These results are attributed to dilution of the flour present, as other dry ingredients replaced approximately 25% of the flour present. The inclusion of specific dough ingredients also probably influenced this altered amylogram.

Wheat gluten that was added on a flour-weight basis at 2.5%, has been found to reduce maximum viscosity of simple wheat starch systems (Anker and Geddes, 1944). Malt flour with an α-amylase activity of 50 units/gram, was incorporated at 0.25% fwb (Table 3). The addition of

Table 9—Amylogram characteristics of complete dough system containing salts[a]

Variation	TIBL[b] (min)	TPBL[c] (°C)	MXVIS[d] (BU)	TIMVIS[e] (min)	TPMVIS[f] (°C)
Salt level (%)					
1.5	26.3a	64.5a	112.0a	34.0a	76.0a
2.0	26.6a	64.9a	108.9a	33.9a	75.9a
2.5	26.3a	64.5a	119.4b	34.3a	76.5a
3.0	26.4a	64.6a	124.4c	34.8b	77.2b
Barley source					
Tennessee	26.5a	64.4a	121.7a	34.5a	76.7a
Alaska	26.3b	64.8b	110.6b	34.1b	76.1b
Barley level (%)					
0	27.3a	66.0a	121.1a	34.8a	77.2a
10	26.1b	64.1b	120.6a	34.3b	76.5b
20	26.2b	64.3b	112.3b	34.0bc	76.0bc
30	26.0b	64.0b	110.7b	33.9c	75.9c

[a]Means in a column within source of variation followed by like letters do not differ according to Tukey's Range Test ($p > 0.05$).
[b]TIBL = time of initial viscosity increase.
[c]TPBL = temperature of initial viscosity increase.
[d]MXVIS = maximimum viscosity.
[e]TIMVIS = time of maximum viscosity.
[f]TPMVIS = temperature of maximum viscosity.

malt flour would be expected to reduce maximum viscosity and perhaps delay the time and temperature of initial viscosity increase through the breakdown of starch granules. Anker and Geddes (1944) reported that a sequential increase in the amount of α-amylase added to a wheat starch slurry resulted in a curvilinear decrease in maximum viscosity and a decrease in the temperature and time at which maximum viscosity was reached at higher levels of α-amylase inclusion.

The acidity of the systems (Table 4, p. 37) also likely decreased maximum viscosity. Anker and Geddes (1944) found a positive linear relationship between acidity over a pH range of 5.2-6.7 and maximum viscosity of a wheat starch slurry, therefore at the acidity level used in this study (Table 4), it is likely that some hydrolysis of the starch granules occurred. The addition of sugar to a starch system has been reported to slightly increase the temperature of initial viscosity increase, increase maximum viscosity and delay the time and temperature at which maximum viscosity was reached (D'Appolonia, 1972). Complete dough amylograms obtained in this study reveal a slight increase in time and temperature of initial viscosity increase although maximum viscosity and the time and temperature at which maximum viscosity was acheived were reduced.

The addition of SSL to the complete dough system would be expected to decrease the extent and rate of viscosity increase, as SSL has been found to complex with amylose in the starch granule (Ghiasi et al., 1982a), resulting in decreased water absorption by the starch granules (Ghiasi et al., 1982b). The effect of nonfat dried milk on starch

gelatinization characteristics is unclear (D'Appolonia, 1972). As the oxidant system used contained various oxidizing agents, it is impossible to suggest an effect on apparent viscosity characteristics.

Because of the complexity of the complete dough system, the results reported in simple starch apparent viscosity studies do not always apply. Therefore, the effect of salt level on apparent viscosity of the complete dough system was studied.

Effect of Salt

Unlike the simple apparent viscosity study, salt level did not significantly affect time or temperature of initial viscosity increase in the range studied. Salt did have a significant effect ($p < 0.0001$) on maximum viscosity; an increase in maximum viscosity occurred (Table 9). Time and temperature of maximum viscosity were significantly increased at the 3.0% level. These results paralleled those found in the simple apparent viscosity study except that higher salt levels were required before the salt effect was seen (Table 8, p. 67).

Effect of Barley Source

A significant effect of source was found for all apparent viscosity parameters (Tables 9 and B3, Appendix B). The values obtained reflected the contribution of protein and starch fractions to the overall apparent viscosity characteristics of a flour (Arenson, 1969). The Tennessee flour, which has a higher protein content exhibits a decreased time and temperature of initial viscosity increase ($p < 0.05$), a higher maximum viscosity ($p < 0.0001$) and an increase in the time ($p < 0.01$) and

temperature ($p < 0.01$) needed to acheive maximum viscosity. These results may be attributed to higher β-D-glucan levels in the Tennessee barley. These results differed from the simple apparent viscosity study containing salt for the time and temperature at which initial viscosity occurred (Table 9).

Effect of Barley Percentage

Barley percentage influenced ($p < 0.0001$) apparent viscosity parameters (Table B3, Appendix B). The substitution of only 10% barley resulted in a significant decrease in the time and temperature at which initial viscosity increase occurred (Table 9). However, increasing barley percentage to 30% did not further decrease time or temperature of initial viscosity increase (Table 9). This statistically significant decrease in temperature is unlikely to have any practical importance as the range is narrow (Kulp and Lorenz, 1981); similarly, the interaction between barley percentage and salt level is of no practical importance (Figure 16; Tables B3 and C4, Appendixes B and C).

Unlike the simple viscosity system that contained salt, maximum viscosity did not decrease significantly until barley levels reached 20%. No significant difference was found when barley percentage further increased to 30%. The significant interaction between barley source and level (Tables B3 and C5, Appendixes B and C) is illustrated in Figure 17 and may be attributed to differences between sources at the 20% level. The interaction barley percentage X salt percentage (Tables B3 and C4, Appendixes B and C) is presented in Figure 18. This interaction may be attributed to differing effects of salt level at 0% barley level.

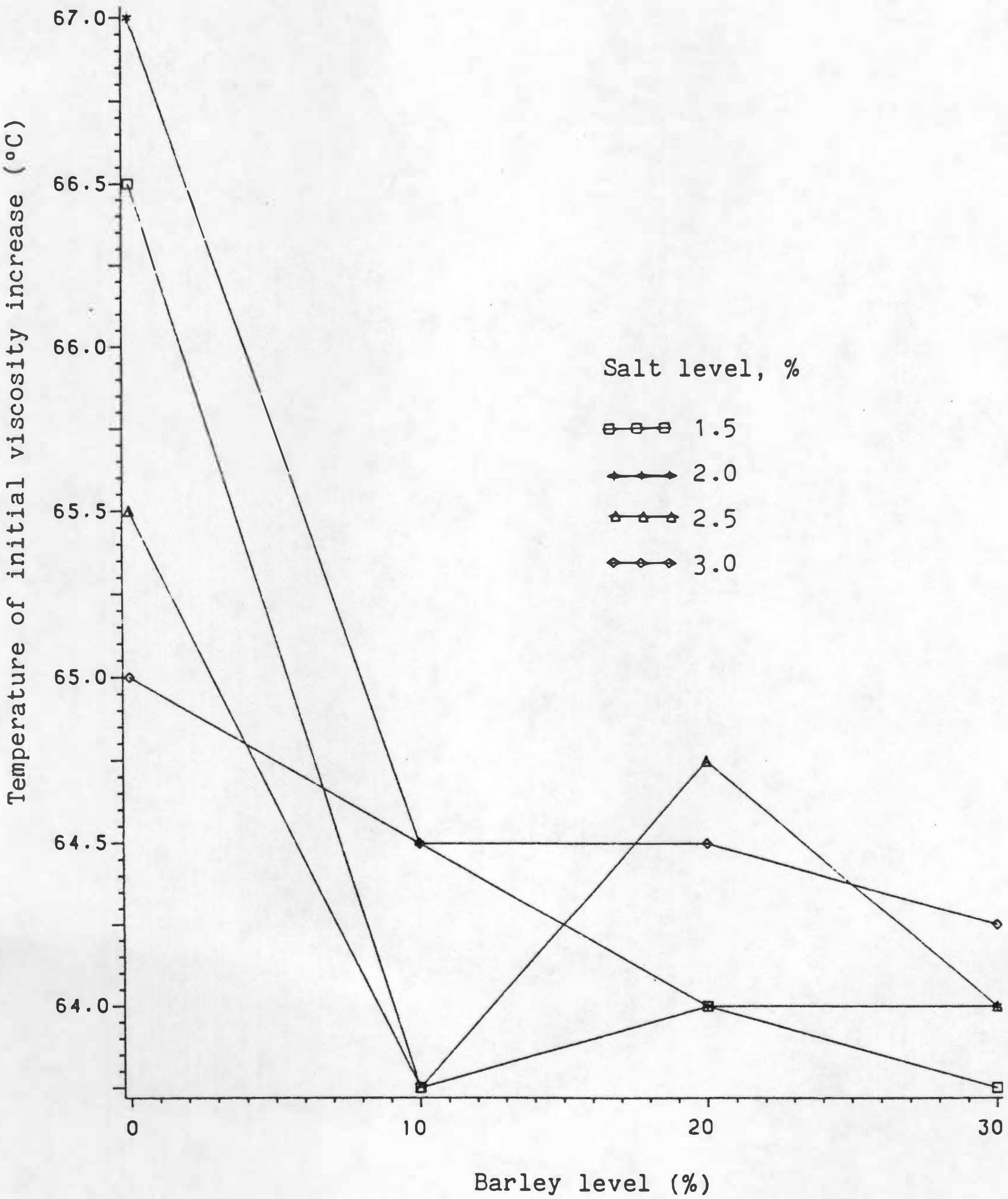


Figure 16—Temperature of initial viscosity increase as a function of barley and salt levels in complete dough apparent viscosity systems.

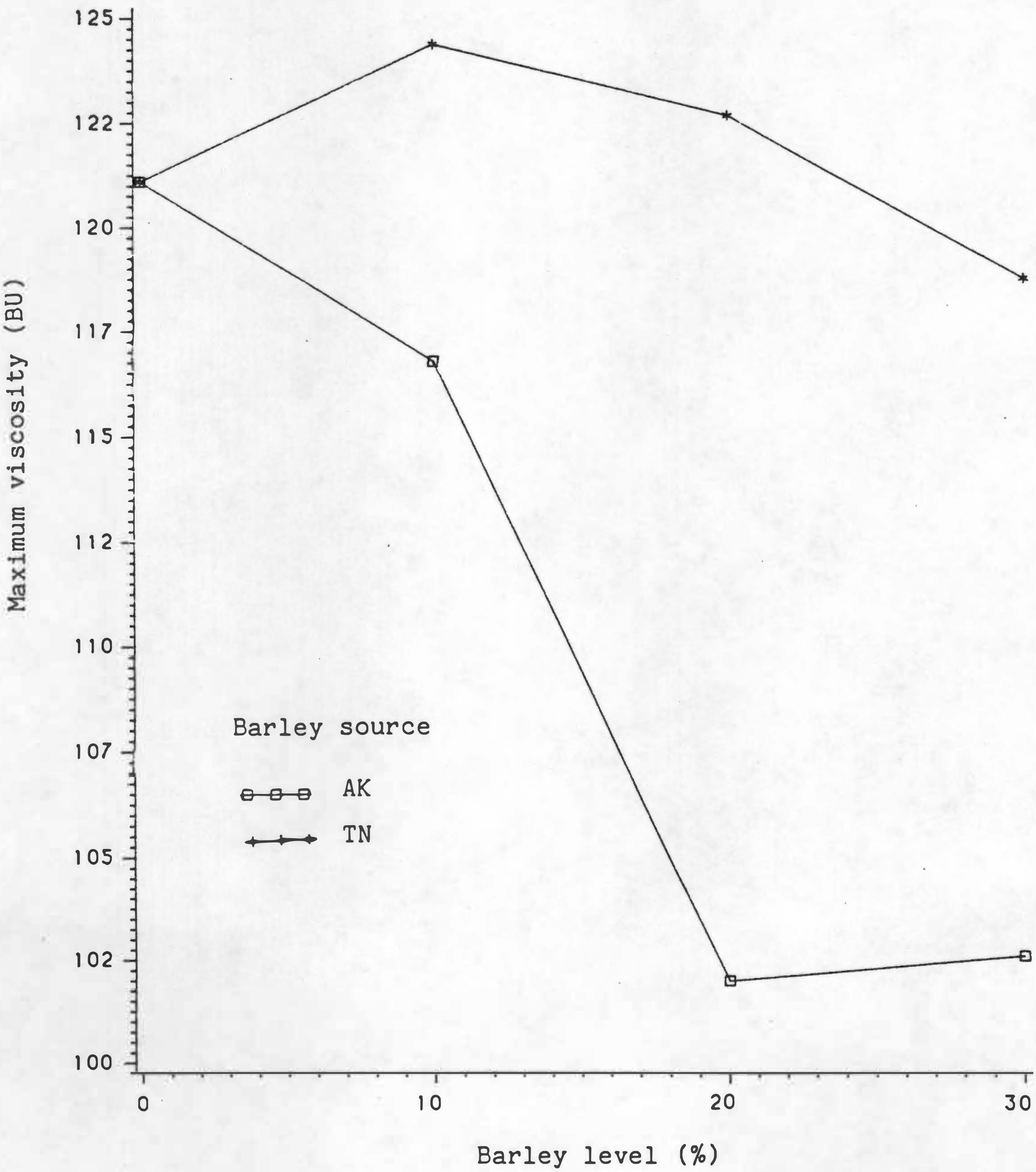


Figure 17—Maximum viscosity as a function of barley level and source in complete dough apparent viscosity systems.

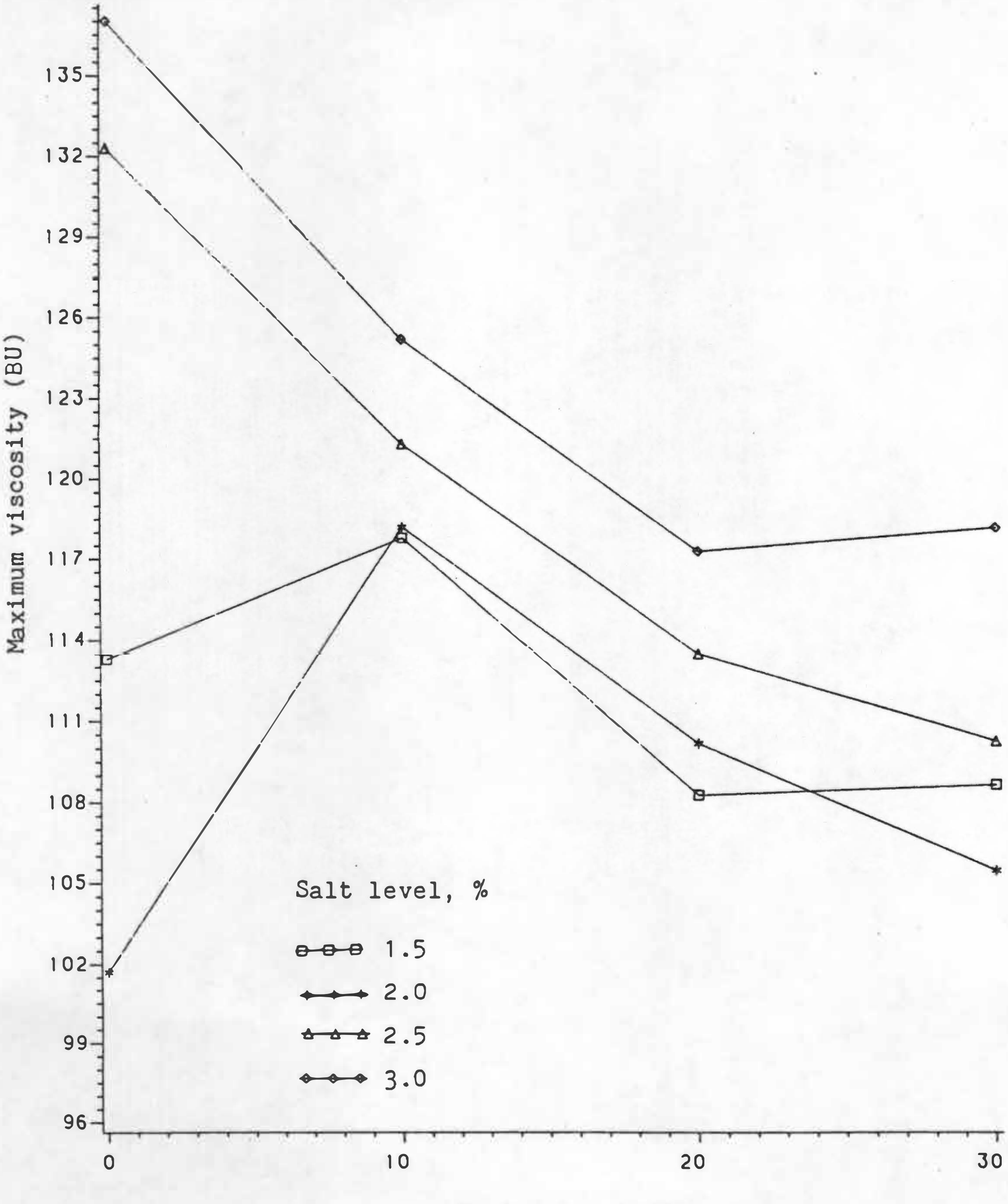


Figure 18—Maximum viscosity as a function of barley and salt levels in complete dough apparent viscosity systems.

As in the simple systems (Table 7, p. 58), time and temperature of maximum viscosity ($p < 0.0001$) were decreased as barley percentage increased (Tables 9 and B3, Appendix B). However, a source effect was found as indicated by the interaction, source X barley level (Tables B3 and C5, Appendixes B and C). Decreasing temperatures of maximum viscosity at upper levels of Alaska barley incorporation were observed. Tennessee barley levels did not result in a decrease in temperature of maximum viscosity (Figure 19). These results were not altered by the inclusion of complete dough ingredients (Figures 12 and 14, pp. 74 and 76). Although not significant in the simple apparent viscosity study, barley percentage X salt percentage (Figure 20; Tables B3 and C4) was significant in the complete dough study. The effect of increasing salt levels on temperature of maximum viscosity differed with barley level as shown in Figure 20. This interaction is attributed to dough ingredients incorporated into the complete dough systems. The observed differences are unlikely to have practical implications.

III. DOUGH DEVELOPMENT STUDIES

Part A: Dough Development in Simple Systems

Dough development characteristics of the composite flours (Table 2, p. 30) were evaluated with variation in barley source and barley percentage, using a National mixograph. Optimal water levels of the composite flours ranged from approximately 71.0 to 74.5% (Figure 21).

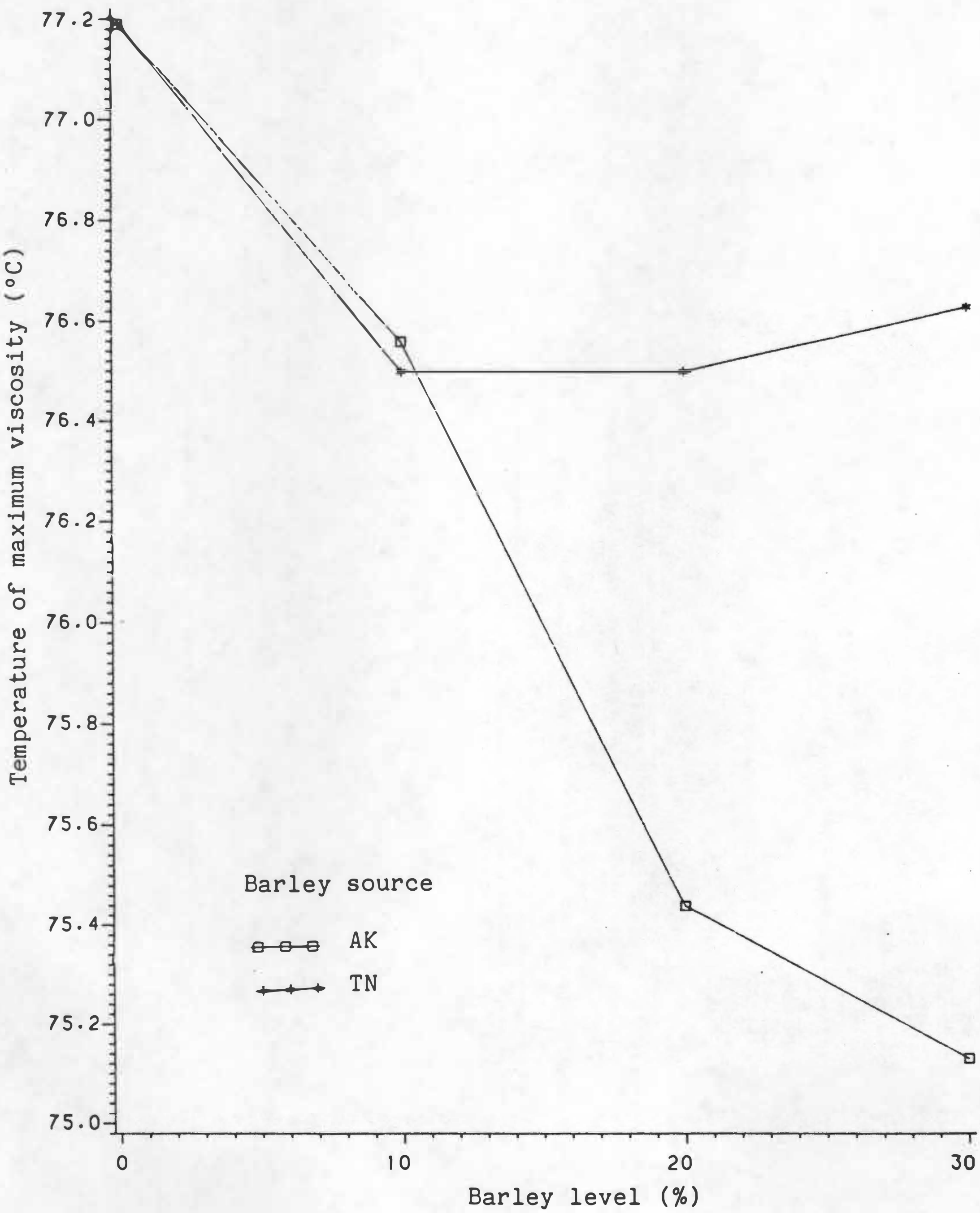


Figure 19—Temperature of maximum viscosity as a function of barley level and source in complete dough apparent viscosity systems.

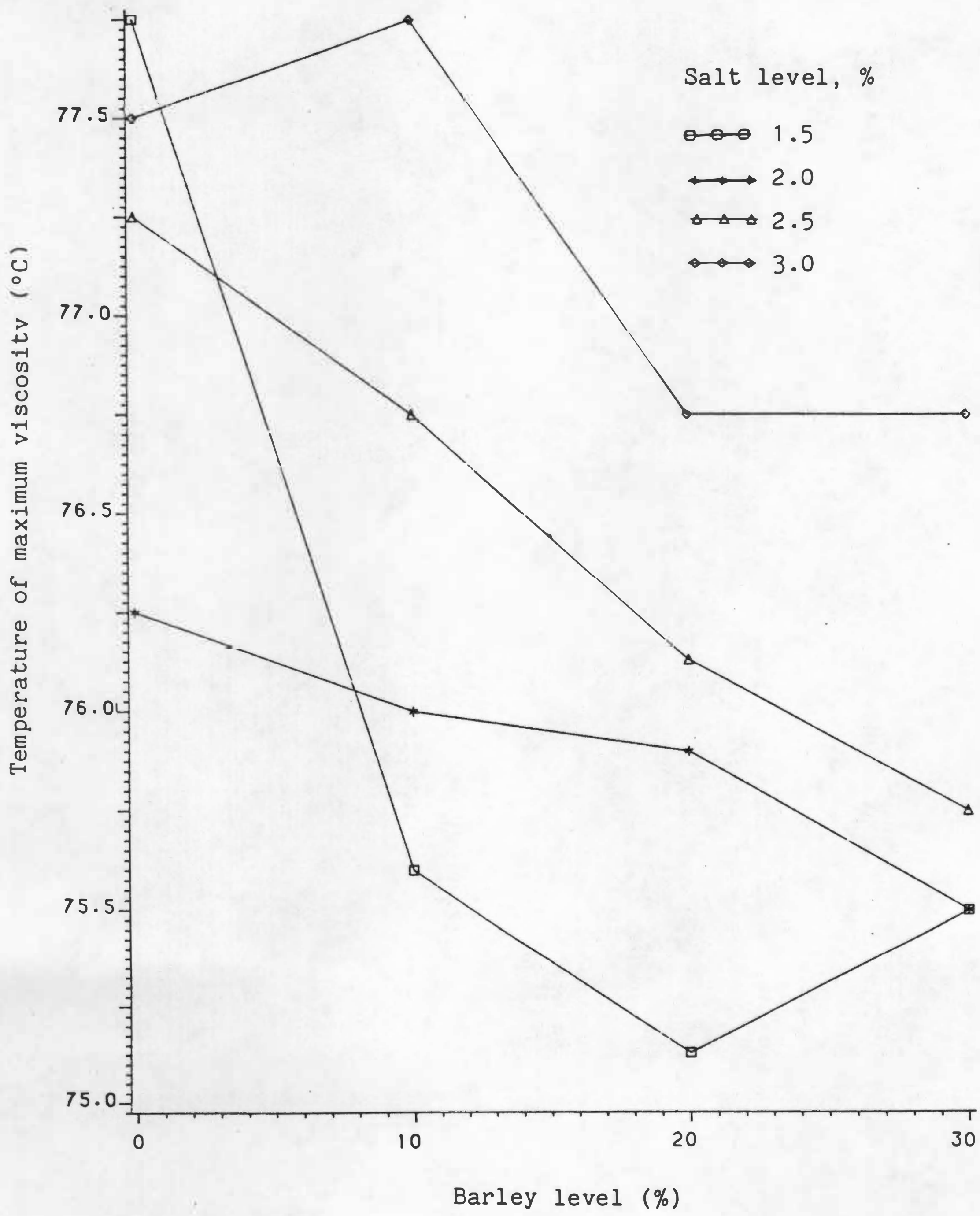


Figure 20—Temperature of maximum viscosity as a function of barley and salt levels in complete dough apparent viscosity systems.

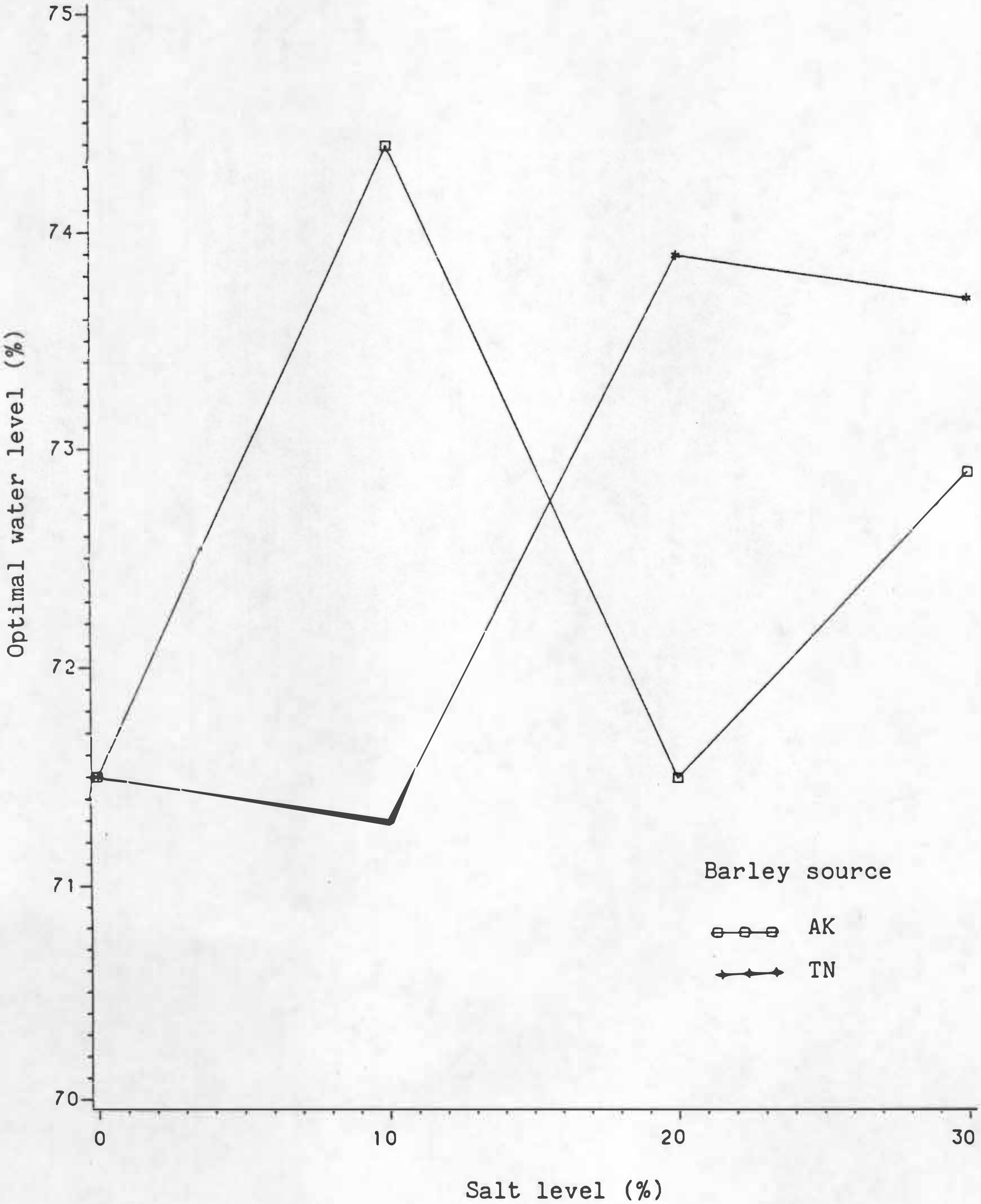


Figure 21—Optimal water level as a function of barley level and source in simple dough development systems.

The overall trend toward increased optimal water levels is attributed in part to decreased flour particle size when barley particle size is compared to the whole-wheat flour it replaced (Table 1, p. 26); there is no appreciable difference in particle size attributable to barley source. Based on proximate analysis (Table 5, p. 50) and amino acid composition (Table 6, p. 53), it would be expected that the Tennessee barley flour would exhibit lower optimal water levels than would the Alaska barley flour. The Tennessee barley flour has a lower starch content, and a higher protein content (Table 5) than does the Alaska barley flour. Substitution of Tennessee barley flour rather than Alaska barley flour for the whole-wheat flour also would increase overall protein content (Tables 2, p. 30 and 5). Barley "gluten" has been reported to have a lower water absorption capacity than does wheat gluten (Cunningham et al., 1955). The nonpolar amino acids also constitute a higher percentage of the amino acids in the Tennessee flour than the percentage present in the Alaska flour (Table 6). The irregular trend found for Alaska flour probably reflects the altered particle size and reduced protein content at the 10% level of substitution. At the 20 and 30% levels of Alaska barley flour incorporation, the lower water absorption capacity of the barley protein when compared to wheat protein (Cunningham et al., 1955) overcomes the effect of particle size and reduced protein content. The optimal water levels for the 20 and 30% Alaska barley composite systems approximate those levels found in the absence of barley.

Effect of Barley Source

Barley source affected time of development and peak height. Means are reported in Table 10; mean squares are found in Table B4 (Appendix B). Angles of development and breakdown did not differ as a result of barley source. Time of development, which represents the time required to hydrate the flour components and develop the protein matrix, was significantly shorter for the Tennessee flour than it was for the Alaska flour. This shorter development time may be a result of the higher protein content (Table 5, p. 50) and the reduced competition with other flour components for the water present, despite the higher percentage of nonpolar amino acid residues present (Table 6, p. 53). Within a wheat variety, similar results have been reported when protein content was 12% or above (Finney and Shogren, 1972). Peak height was higher ($p < 0.05$) when the Tennessee flour rather than the Alaska flour was incorporated (Table 10). As both systems were evaluated at optimal water levels, the increased peak height was a reflection of protein content and quality.

Effect of Barley Percentage

Incorporation of barley resulted in differences ($p < 0.0001$) in development time, angle of development, peak height and angle of breakdown. Increasing barley percentage resulted in increasing development time. This relationship reflects a decrease in the rate of barley flour hydration and "gluten" maxtrix formation when compared to the whole-wheat flour it replaced. The increase in dough development time with increasing barley incorporation was reflected in angle of development.

Table 10—Mixogram characteristics of simple systems[a]

Variation	Development time (min)	Development angle (°)	Peak height (cm)	Breakdown angle (°)
Source				
Tennessee	3.14a	22.00a	6.21a	9.08a
Alaska	3.24b	21.25a	6.03b	9.04a
Barley level (%)				
0	2.70a	30.00a	6.97a	12.50a
10	3.03b	22.17b	6.17b	10.33b
20	3.35c	19.08c	5.88c	8.75c
30	3.67d	15.25d	5.47d	4.67d

[a]Means in a column within source of variation followed by like letters do not differ according to Tukey's Range Test ($p > 0.05$).

The angle of development decreased as barley percentage increased (Table 10). According to Johnson et al. (1943) the angle of development is inversely related to dough development time in wheat doughs.

Peak height decreased as barley percentage increased, indicating that protein quality was reduced with increasing barley flour incorporation. The interaction, source X barley percentage ($p < 0.001$) was significant for peak height (Figure 22 and Tables B4 and C6, Appendixes B and C). Incorporation of Alaska barley at the 10% level resulted in a greater decrease in peak height than did incorporation of 10% Tennessee barley. When barley flour was incorporated at levels greater than 20%, no effect of barley source was found. This interaction reflects the dilution effect of the Alaska barley on the overall protein level present at the 10% level of incorporation; Alaska barley flour proximate analysis revealed a lower protein content than was found for the Tennessee barley flour or whole-wheat flour. When barley flour was used at the 20 and 30% levels, the effect of protein quality likely overrode the effect of dilution.

Angle of dough breakdown, which is a measure of mixing tolerance, decreased with increasing barley percentage. The decreased angle of dough breakdown indicates less breakdown of the "gluten" matrix with overmixing. Rather than being a reflection of a stronger gluten matrix, this decreased breakdown is likely a result of less "gluten" matrix formation. The overall mixogram shape is similar to mixograms obtained when low protein wheat flour samples are evaluated (Finney and Shogren,

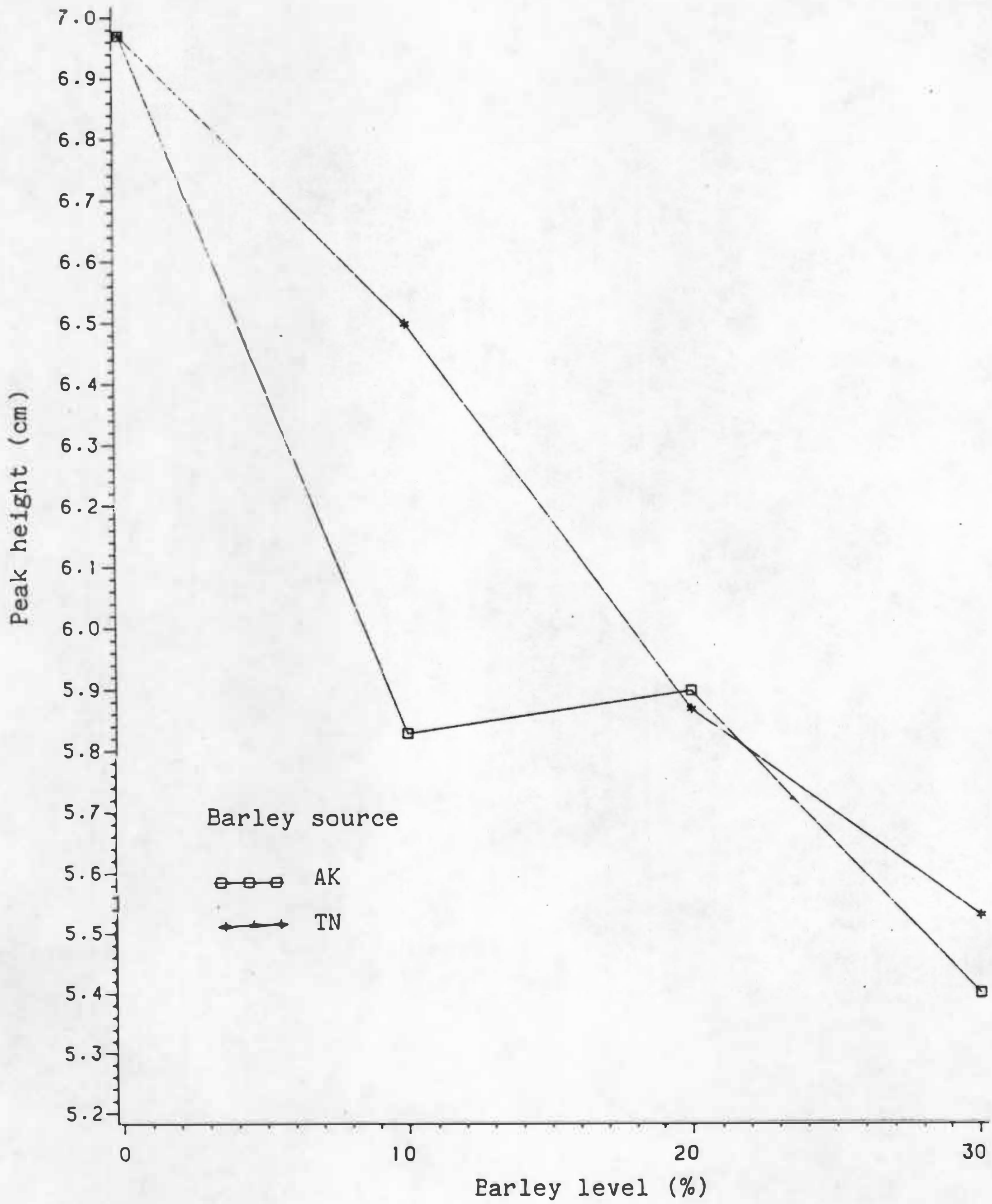


Figure 22—Peak height as a function of barley level and source in simple dough development systems.

1972). An interaction between source and barley percentage for angle of dough breakdown ($p < 0.05$) also was found (Tables B4 and C6, Appendixes B and C). This interaction (Figure 23) reflects the differing protein content of the barley flour attributable to source and the resulting effect on "gluten" matrix formation as previously described for peak height.

Part B: Salt Effect on Dough Development in Simple Systems

Dough development parameters of composite flours (Table 2, p. 30) were evaluated with variation in salt percentage as well as barley source and percentage. Optimal water levels depicted in Figure 21 were used regardless of salt level. As salt increased from 1.5 to 3.0% fwb, time of development increased ($p < 0.0001$) and development angle decreased ($p < 0.0001$) as reported in Table 11. Increased development time with salt addition to wheat flour has been reported by Danno and Hoseney (1982) and Hlynka (1962). Linko et al. (1984) reported similar results when salt ranging in concentration from 0 to 2.5% fwb was added to a wheat-barley flour dough. The salt effect has been attributed to an alteration in the net positive charge on the flour protein, resulting in slower protein hydration (Danno and Hoseney, 1982). Salt addition to wheat flours also reportedly alters the ionic charge on flour nonstarch polysaccharides (Neukom et al., 1967), delaying their hydration. Peak height increased with increasing salt levels (Table 11), as previously reported for wheat doughs by Danno and Hoseney (1982), whereas dough breakdown angle, a measure of mixing tolerance, was decreased (p <

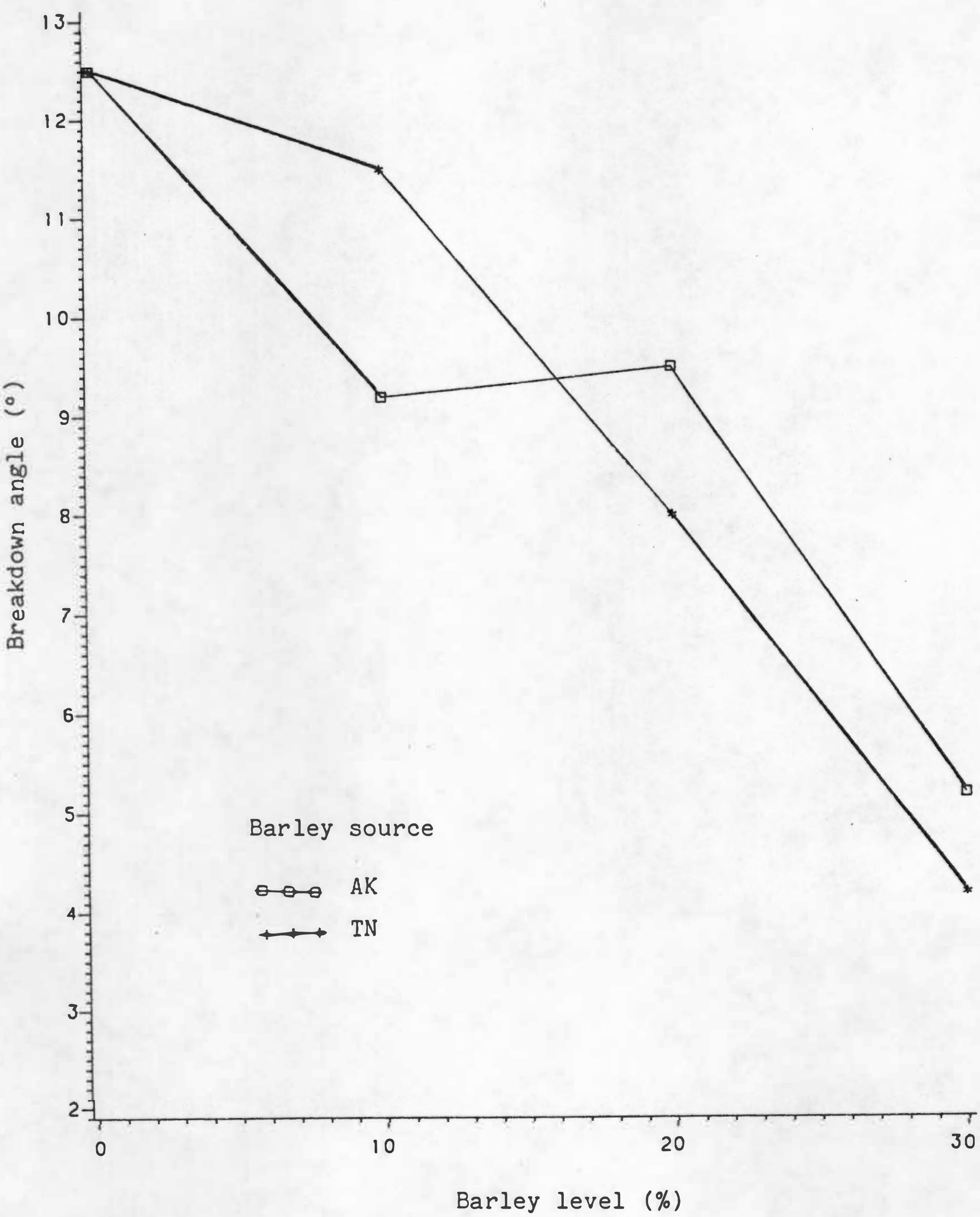


Figure 23—Breakdown angle as a function of barley level and source in simple dough development systems.

Table 11—Mixogram characteristics of simple system containing salts[a]

Variation	Development time (min)	Development angle (°)	Peak height (cm)	Breakdown angle (°)
Salt level (%)				
1.5	4.14a	18.73a	6.54a	6.69a
2.0	4.58b	18.17b	6.68b	6.27b
2.5	4.92c	18.33ab	6.78c	5.67c
3.0	5.48d	15.21c	6.72bc	5.10d
Source				
Tennessee	4.87a	17.30a	6.65a	5.94a
Alaska	4.69b	17.92b	6.71b	5.93a
Barley level (%)				
0	3.62a	23.88a	7.24a	6.79b
10	4.15b	20.98b	6.95b	7.37a
20	5.19c	15.17c	6.53c	6.19c
30	6.16d	10.42d	6.00d	3.37d

[a]Means in a column within source of variation followed by like letters do not differ according to Tukey's Range Test ($p > 0.05$).

0.0001). Decreased dough breakdown angles indicate increased mixing tolerance.

Effect of Source

Barley source significantly affected dough development time, with Tennessee barley exhibiting the longer development time (Table 11). In the absence of salt, the Alaska barley systems exhibited a longer dough development time than did the Tennessee barley systems. This longer development time for the Tennessee barley in the presence of salt, is attributed in part to decreased hydration rates of the protein and the nonstarch polysaccharides present. Tennessee barley dough development angle was smaller than was the Alaska barley dough development angle, reflecting the increased dough development time (Johnson et al., 1943). Despite this relationship, these parameters do not reflect exactly the same factors as the interaction, source X salt percentage, is significant ($p < 0.0001$) only for dough development angle. Inspection of Figure 24 and Table C7 (Appendix C) does not reveal differences in the pattern of change in dough development angle with increasing salt levels.

The strengthening effect of salt on flour proteins was reflected in peak height and dough breakdown angle (Table 11). In the absence of salt, Tennessee barley had a higher peak height, whereas in the presence of salt, the Alaska barley had a higher peak height despite lower protein levels. The interaction source X salt percentage ($p < 0.05$) depicted in Figure 25 was significant (Tables B5 and C7, Appendixes B and C) for peak height, but as with dough development angle, the differences in patterns were not discernible. The higher percentages of lysine

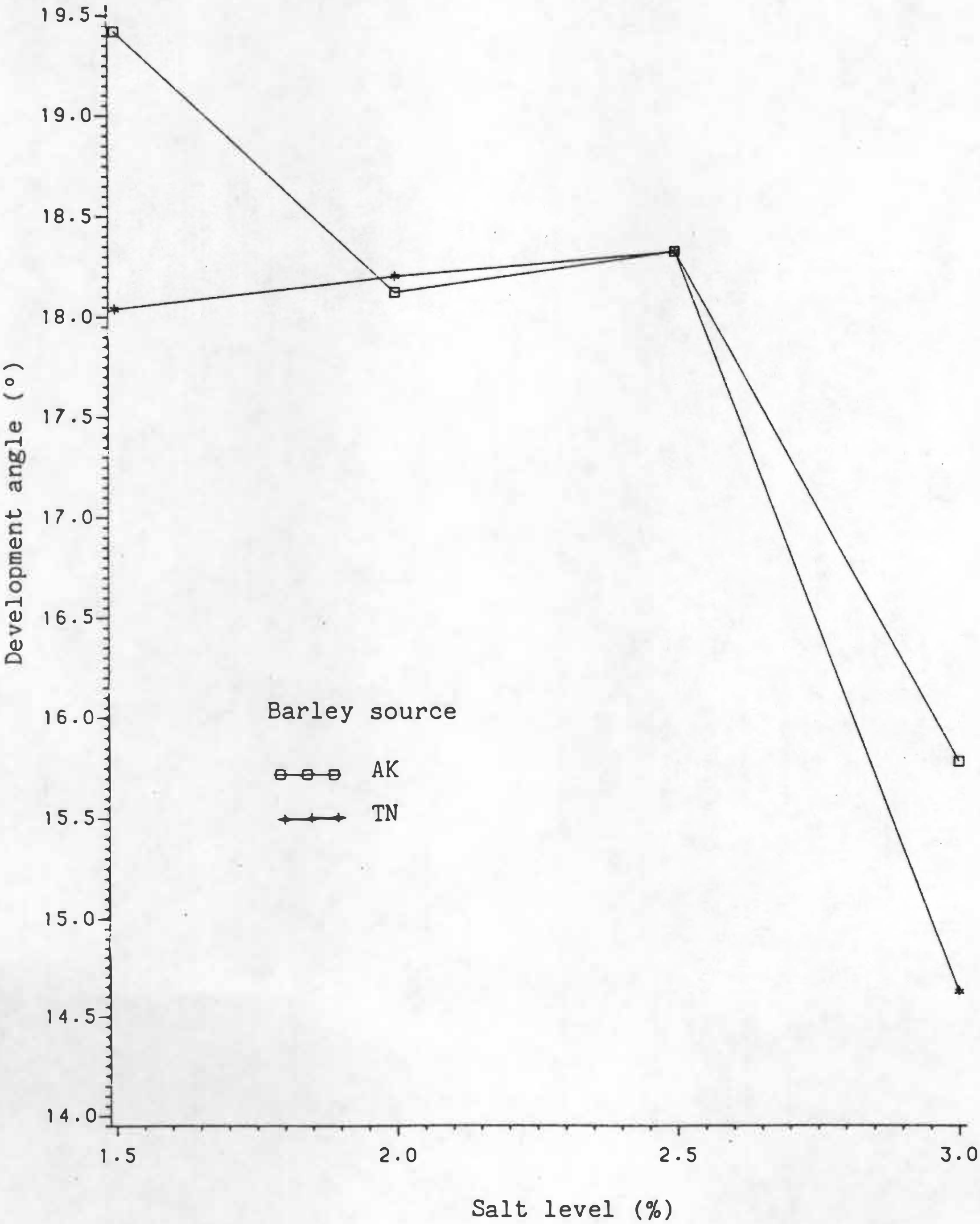


Figure 24—Dough development angle as a function of salt level and barley source in simple dough development systems containing salt.

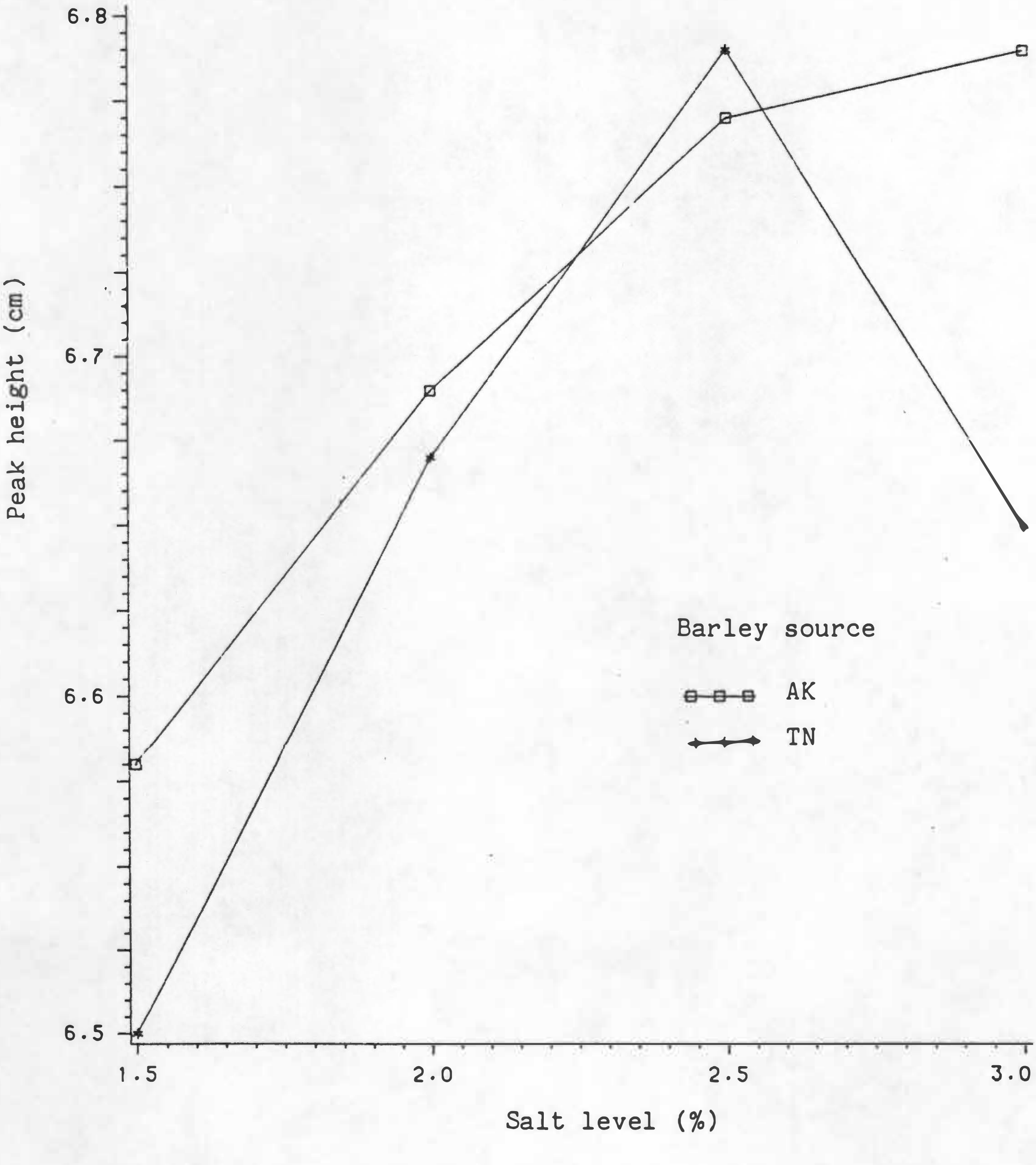


Figure 25—Peak height as a function of salt level and barley source in simple dough development systems containing salt.

and arginine in the Alaska-produced grain (Table 6, p. 53) increased the possibilities for protein ionic bonding, suggesting that the salt effect on protein solubility would be greater. Preston (1981) reported that low salt concentrations reduced protein solubility when the charge on the protein ionic groups was altered. Insoluble proteins have been reported to strengthen wheat doughs whereas proteins that are more soluble weaken wheat doughs (Kasarda et al., 1971). However, at high salt concentrations, neutralization of the ionic charge resulted in increased solublity (Preston, 1981) and therefore, weaker doughs.

Dough breakdown angles did not differ with source whether or not salt was present, however the magnitude of the breakdown angle was decreased in the presence of salt, indicating a stronger dough and a greater mixing tolerance (Tables 10 and 11). Although this decrease in dough breakdown angle may reflect a greater mixing tolerance, it is more likely that it is a reflection of the the lower peak height attained when salt was present at the 3.0% level. Reduced dough breakdown angles are observed when low protein wheat flours are compared to high protein wheat flours. Peak heights are higher and lower for high protein and low protein flours, respectively (Finney and Shogren, 1972). The interaction, source X salt percentage ($p < 0.05$), is presented in Figure 26, however differences in patterns were not apparent (Table C7, Appendix C).

Effect of Barley Percentage

Incorporation of salt into the simple dough development system did not change the effect of increasing barley percentage (Tables 10 and

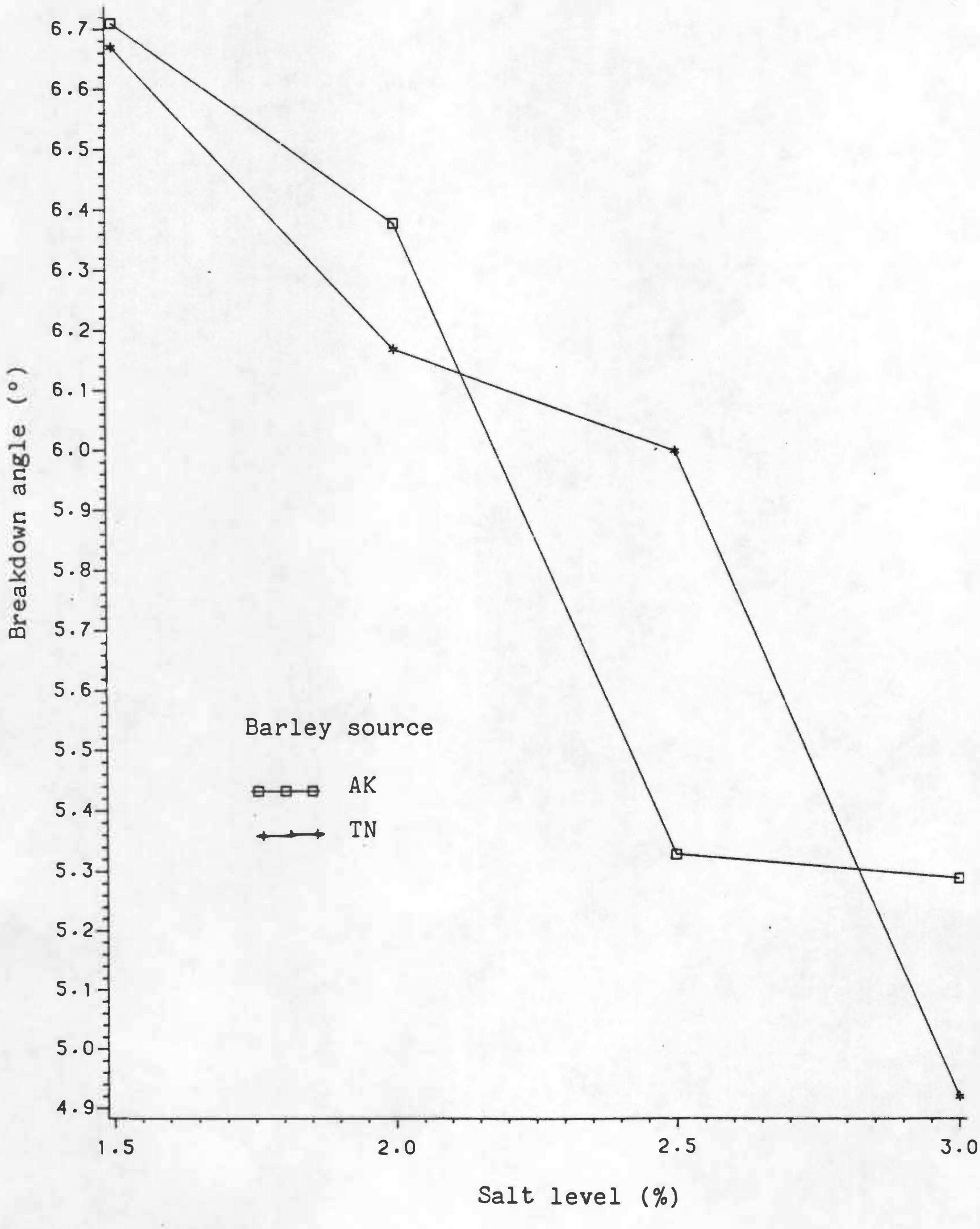


Figure 26—Breakdown angle as a function of salt level and barley source in simple dough development systems containing salt.

11). Significant effects ($p < 0.0001$) were found for all dough development parameters (Table B5, Appendix B).

Increasing barley percentage in the presence of salt increased dough development time and decreased dough development angle, reflecting the slower rate of barley protein hydration and "gluten" martix formation (Cunningham et al., 1955). The interaction, source X barley percentage (Tables B5 and C8, Appendixes B and C), is depicted in Figure 27. Development time of the composite flour systems containing Tennessee barley was increased as barley level increased from 10 to 30%. A difference of 20% in Alaska barley flour level was required before differences in dough development time were noted. When the interaction, barley percentage X salt percentage (Figure 28; Tables B5 and C9, Appendixes B and C) was examined, it appeared that the effect of barley incorporation overrode the salt effect. The three-way interaction, source X barley percentage X salt percentage, reflects the two-way interactions previously discussed. Significant development angle interactions are identical to the significant interactions found for development time. As expected, an inverse relationship between dough development time and dough development angle was observed.

As in the absence of salt, an inverse relationship was found between peak height and barley percentage (Table 11). As shown in Figure 29, there is an interaction between source and barley percentage (Tables B5 and C9). At the 10% level of incorporation, Tennessee barley substitution had little effect on peak height, whereas the Alaska barley flour resulted in a decrease in peak height. These results reflect the

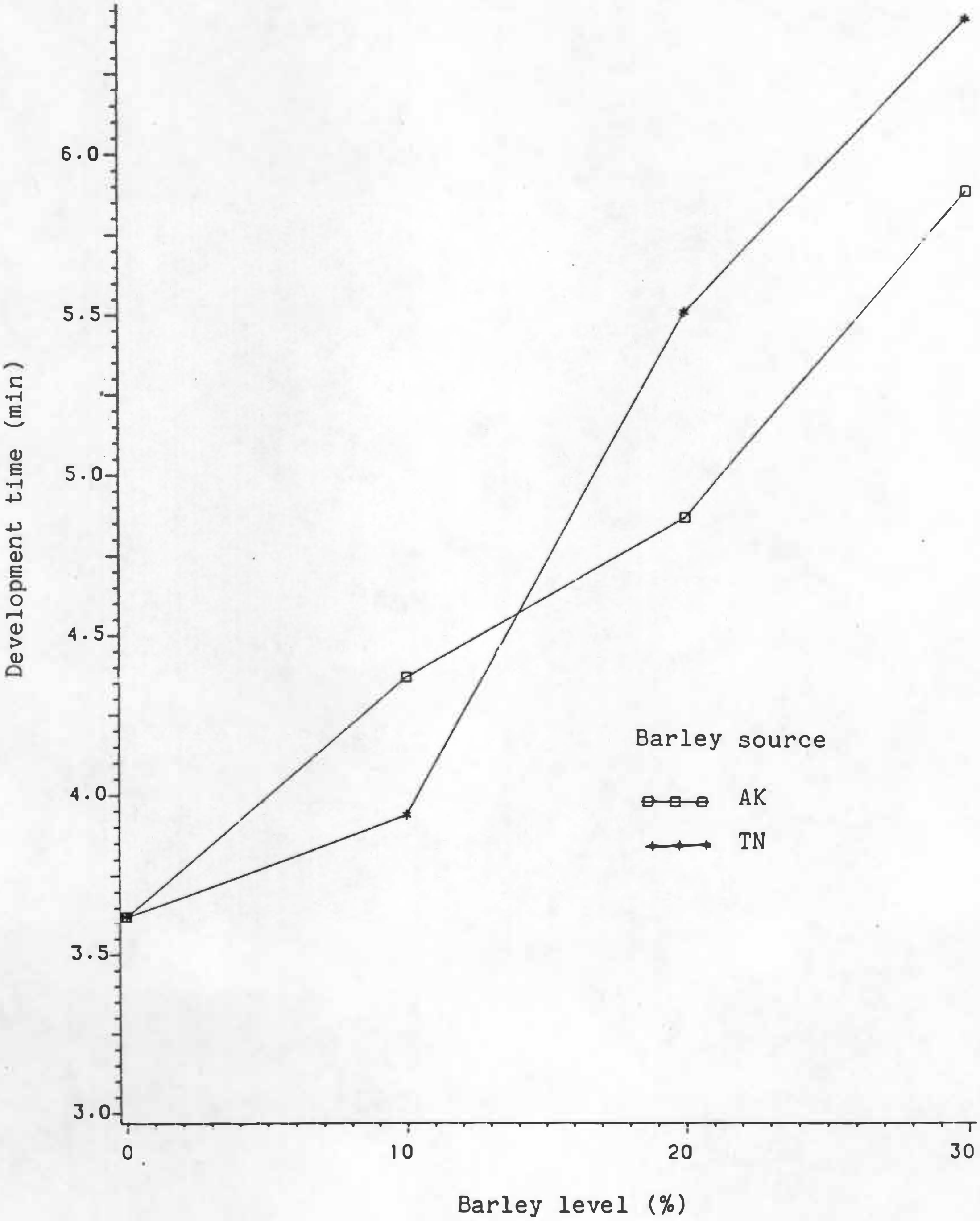


Figure 27—Dough development time as a function of barley level and source in simple dough development systems containing salt.

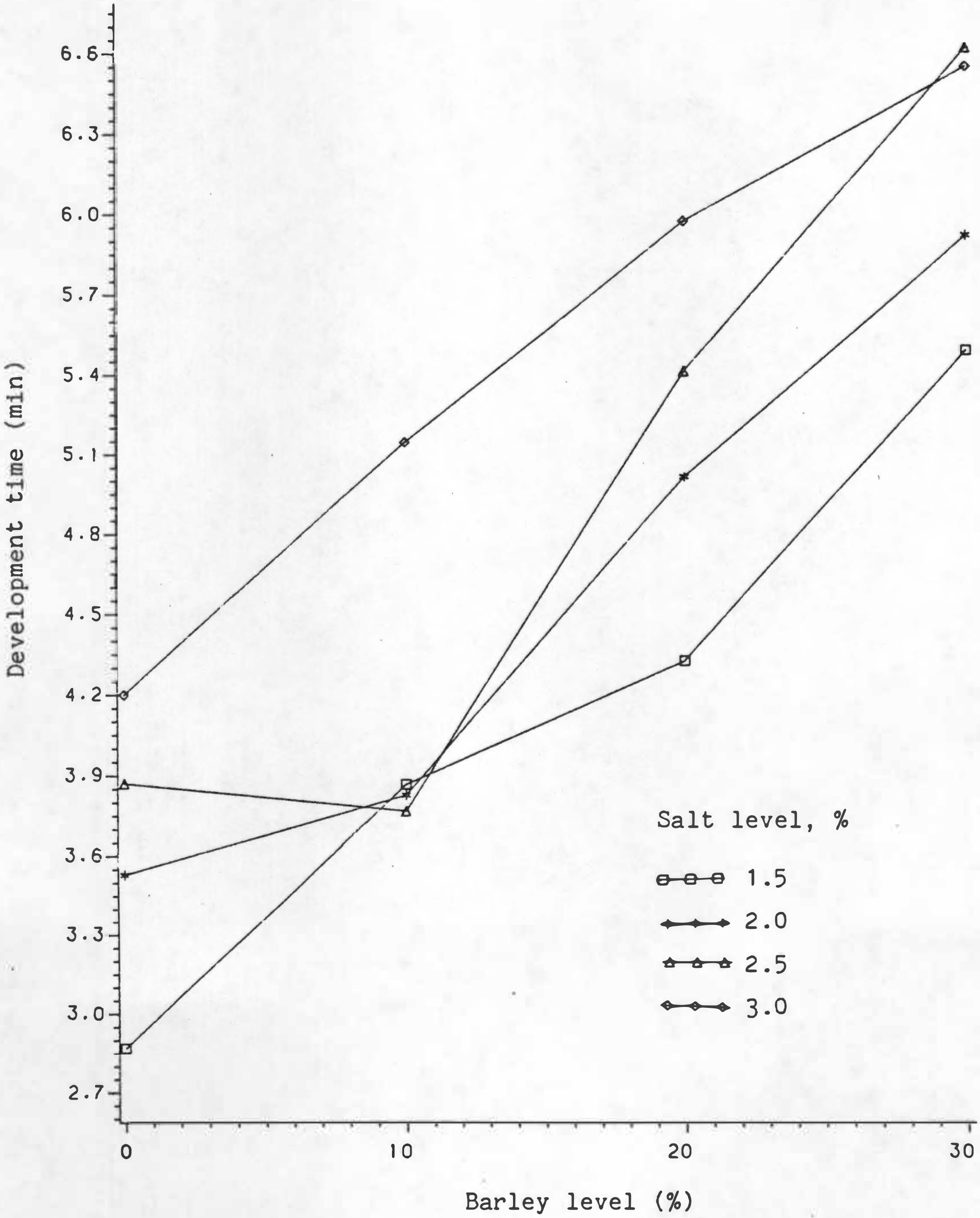


Figure 28—Dough development time as a function of barley and salt levels in simple dough development systems containing salt.

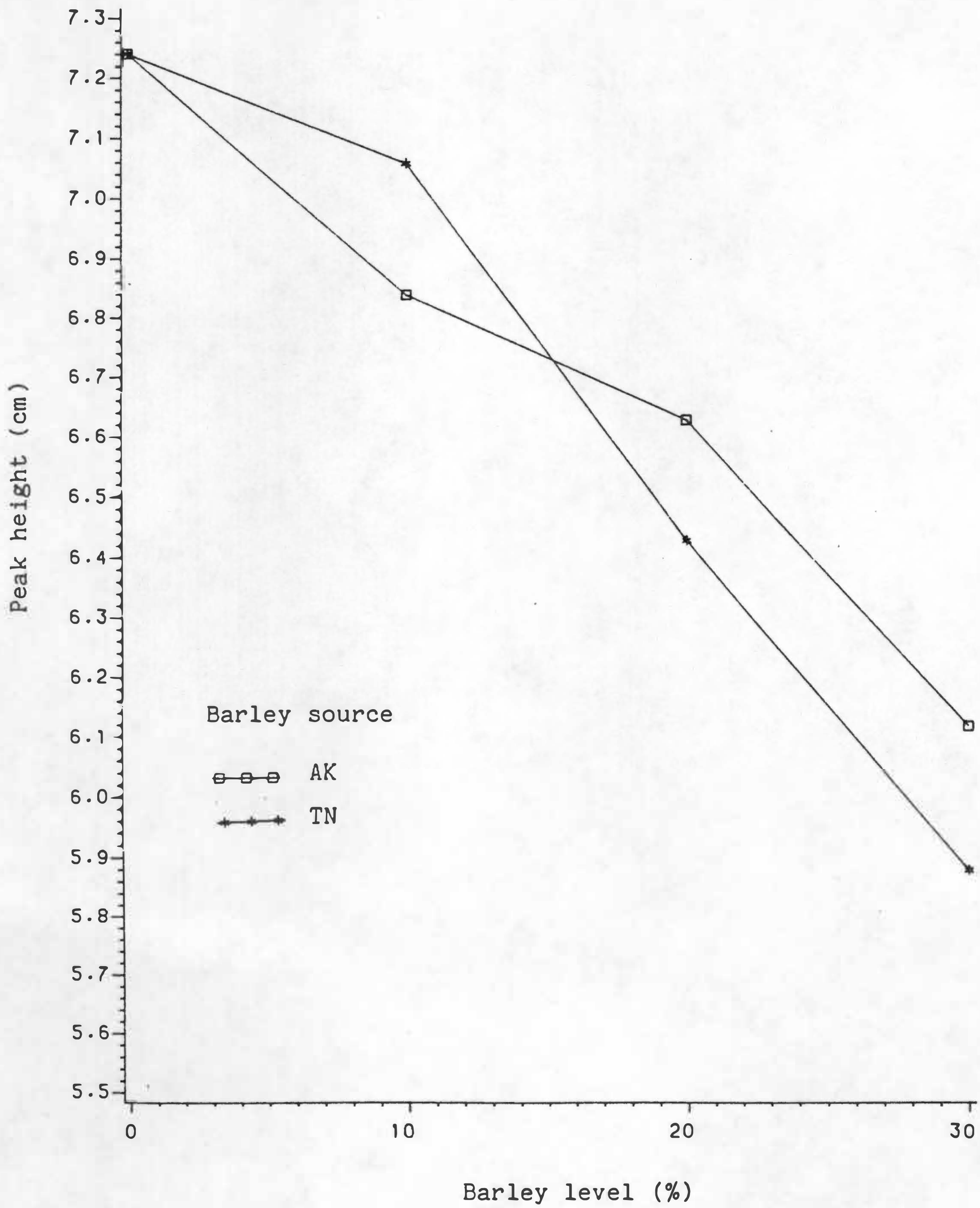


Figure 29—Peak height as a function of barley level and source in simple dough development systems containing salt.

lack of protein dilution when Tennessee barley was incorporated at the 10% level (Table 5, p. 50); protein quality was not altered to any great extent (Table 6, p. 53). Alaska barley flour was lower than was the Tennessee barley in protein content (Table 5) and protein quality (Table 6). At higher levels of incorporation, the greater strengthening effect of salt on the Alaska barley protein (Table 11, p. 97) is attributed to amino acid composition. Therefore, although salt did have a strengthening effect on flour proteins, the effect differed with grain source.

The interaction, barley percentage X salt percentage, ($p < 0.0001$) is depicted in Figure 30. Interaction means are presented in Table C9 (Appendix C). No effect of salt percentage was observed at the 30% barley level. At the 20% level of barley incorporation, an increase in salt from 2.0 to 2.5% increased peak height. No effect of salt was seen at lower or higher levels of useage. At higher levels of barley incorporation, the effect of salt level was overridden. At the 10% barley level, little difference in peak height was noted as salt level increased in increments of 0.5% from 2.0% to 3.0%; a lower peak height was observed when salt was incorporated at 1.5%. These differences are attributed to the numbers of ions available to participate in ionic bonding. The three-way interaction, source X barley percentage X salt percentage, reflects the two-way interactions previously discussed.

Dough breakdown angle was significantly affected by barley percentage in the presence of salt (Table 11). Breakdown angle was largest when barley level was 10% and decreased with each subsequent increase in

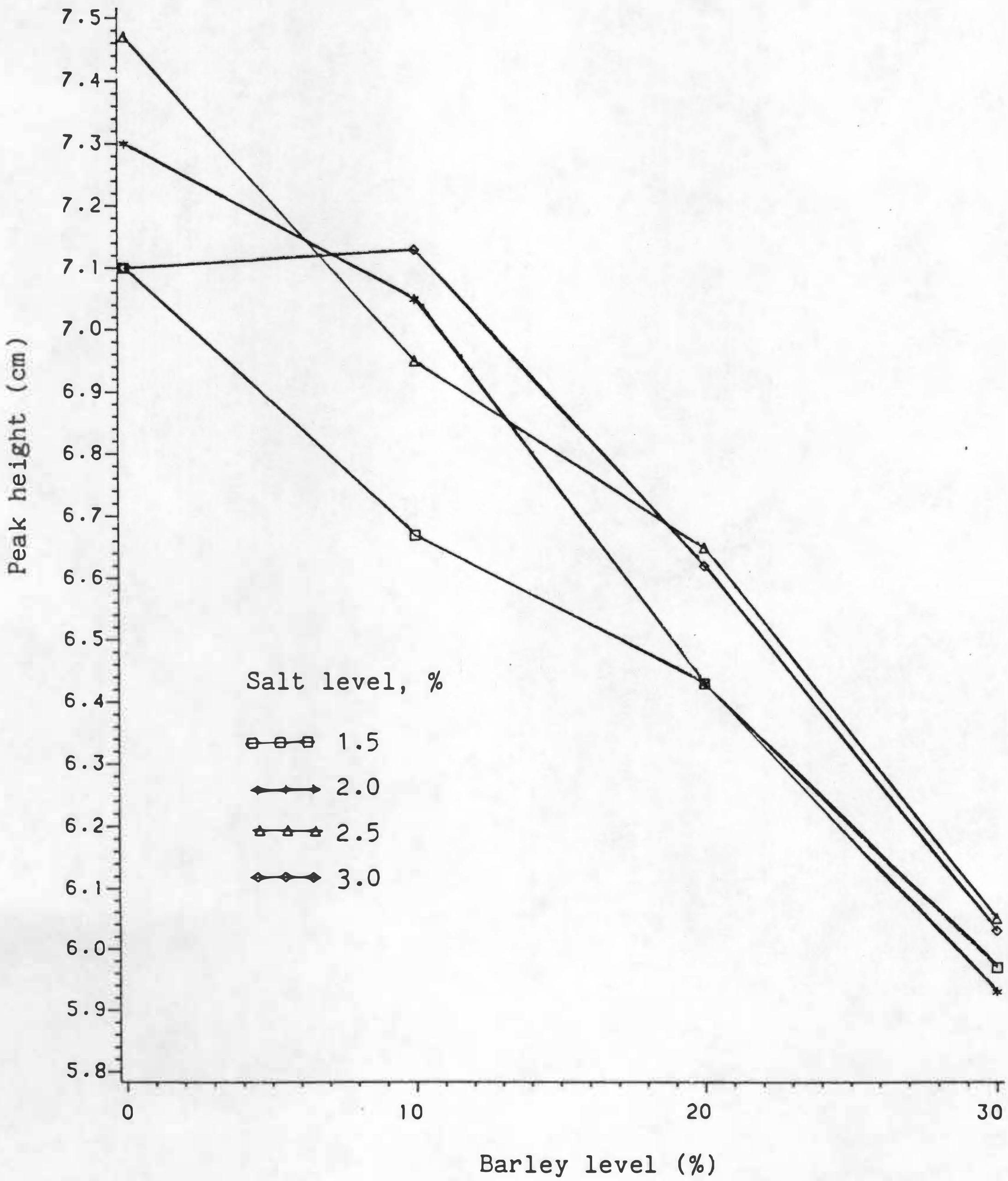


Figure 30—Peak height as a function of barley and salt levels in simple dough development systems containing salt.

barley level (Table 11, p. 97), indicating increased mixing tolerance. In the absence of salt, dough breakdown angle decreased as barley level increased (Table 10, p. 92).

The interaction, source X barley percentage, is depicted in Figure 31; means are given in Table C8 (Appendix C). A decrease in breakdown angle was noted as barley levels increased from 20 to 30% for both barley sources; no difference in breakdown angle occurred for either source when barley flour was incorporated at lower levels. According to Johnson et al. (1943), there is a linear relationship between larger angles of dough breakdown and decreased loaf volume. Higher levels of barley useage resulted in decreased dough breakdown as previously seen in systems containing no salt. As previously discussed, this effect is attributed to less initial "gluten" matrix formation rather than a stronger "gluten" matrix (Finney and Shogren, 1972). The three-way interaction, source X barley percentage X salt percentage ($p < 0.05$) reflects the two-way interactions that have been described.

Part C: Dough Development Characteristics of Complete Dough Systems

Dough development characteristics of complete dough limited-water systems (Table 3, p. 31) were investigated with variation in barley source, barley percentage and salt level. Water levels in Table 12 were used in this phase of the dough development study. In general, dough development characteristics as evaluated using a mixograph, revealed increased dough development time, decreased angle of development,

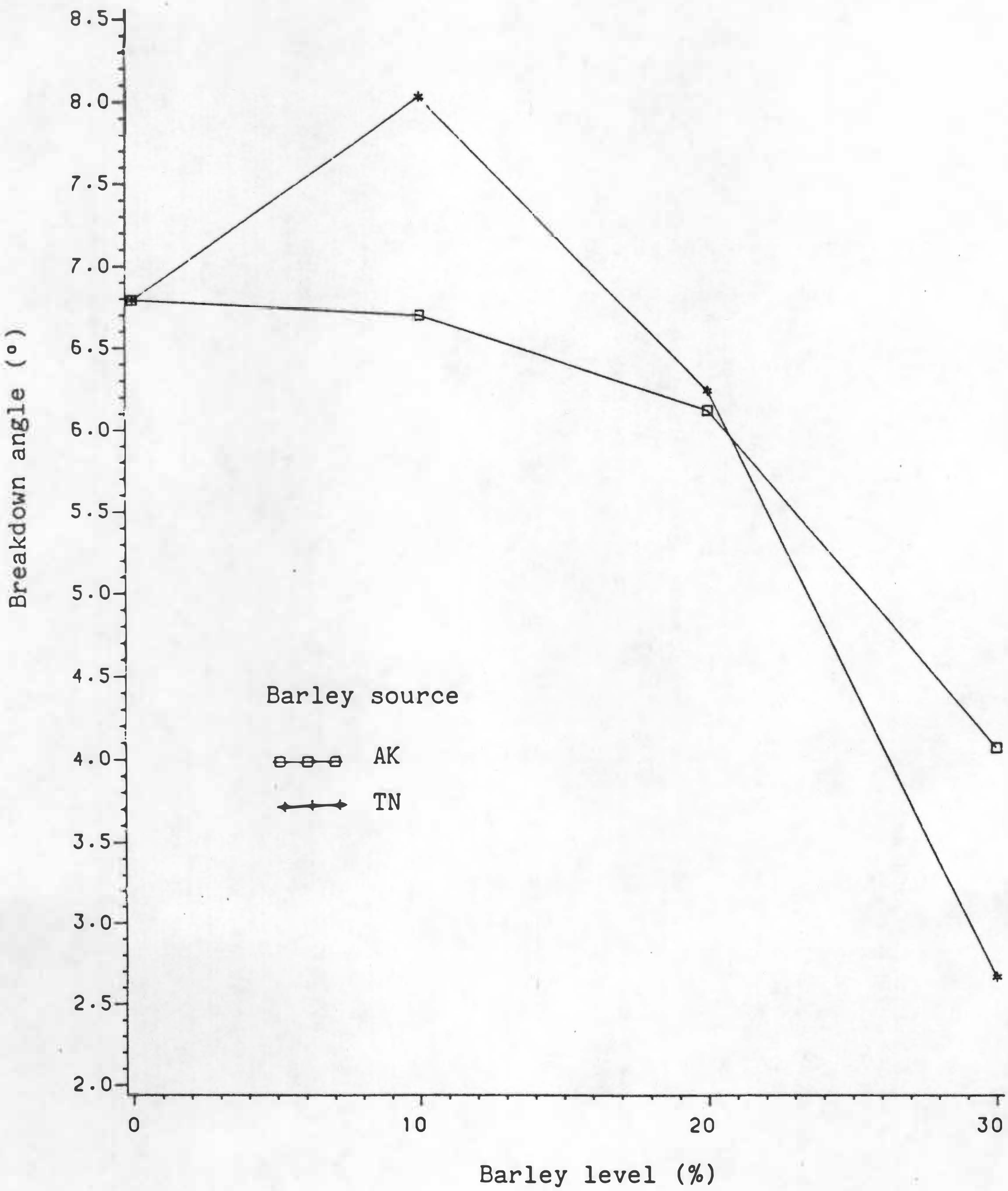


Figure 31—Breakdown angle as a function of barley level and source in simple dough development systems containing salt.

Table 12—Appropriate water levels (g) for complete dough mixograms as a function of barley source and barley and salt levels[a]

Salt level (%)	Barley level (%) 0	10	20	30
Tennessee barley composite flours				
1.5	18.7	19.7	19.7	19.7
2.0	18.7	19.7	19.7	19.7
2.5	19.7	19.7	19.7	19.7
3.0	19.7	19.7	19.7	19.7
Alaska barley composite flours				
1.5	18.7	18.7	18.7	18.7
2.0	18.7	18.7	18.7	19.7
2.5	19.7	19.7	19.7	19.7
3.0	19.7	19.7	19.7	19.7

[a]Quantity of water added to 35 g of dry material.

reduced peak height, and less dough breakdown with overmixing when compared to the simple dough development studies. When other dry ingredients, as specified in Table 3 (p. 31), were incorporated, approximately 25% of the flour was replaced. Specific ingredients incorporated probably influenced the altered characteristics through effects other than dilution.

The addition of vital wheat gluten (2.5% fwb) would be expected to modify the effect of composite flour dilution and to reduce the effect of fibrous materials present due to whole-wheat and whole-grain barley flour bran incorporation (Dubois, 1978). Thus, an effect on peak height would be expected. Due to the increased protein content, an effect on mixing time also would be expected. In high fiber breads (approximately 20% fiber), the amount of additional gluten required to overcome the effects of fiber alone, results in an increased mixing time (Dubois, 1978). As mixing time increased as a result of the presence of more protein requiring hydration, angle of development would be expected to decrease (Johnson et al., 1943).

The addition of SSL to the formula would be expected to further alter mixogram parameters, specifically peak height and angle of dough breakdown. SSL has a dough-strengthening effect as it complexes with gluten, therefore stabilizing the gluten matrix (Tsen et al., 1971).

Oxidizing agents are reported to strengthen doughs by stabilizing the gluten matrix, therefore their effect on dough development characteristics should approximate the effect of SSL. However, specific effects have been found to vary with oxidizing agent. Potassium bromate,

a slow-acting oxidant, has little effect on mixogram properties, whereas potassium iodate, a rapid-acting oxidant, has been reported to decrease mixing time and increase the rate of dough breakdown (Hoseney and Finney, 1974). The oxidant system used in this study contained potassium bromate and two fast-acting oxidants--azodicarbonamide and ascorbic acid, as well as other excipients. Therefore, it is impossible to predict the specific effect of incorporation of this dough ingredient on mixogram parameters.

The addition of shortening (3.0% fwb) reportedly increases mixing time of wheat flour as approximately half of the added shortening becomes bound to the protein fraction (Chiu et al., 1968). However, Bhatty (1986) reported that although hull-less barley fractions absorbed between 68.0 and 113.0% of the flour weight in oil, there did not appear to be a relationship between fat absorption and protein content of the hull-less barley fractions from two varieties. Sugar has been reported to have little effect on dough development characteristics, although wheat doughs containing 3.0% sugar on a flour-weight basis were less tolerant to overmixing than were control doughs that contained no sugar (Galal et al., 1978).

Effect of Salt

The effect of salt on complete dough mixogram parameters was investigated. As a result of the complexity of the complete dough system, it could not be assumed that the results found in the simple system studies would apply. Salt level, which was varied as in the simple systems

study (Table 13), significantly affected all dough development parameters ($p < 0.0001$). As found in the simple systems study, dough development time significantly increased and dough development angle decreased as salt percentage increased (Tables 11, p. 97, and 13).

Peak height ($p < 0.0001$) differed as a result of salt level (Table B6, Appendix B). In the complete dough system, peak height decreased as salt percentage increased (Table 13). Unlike the simple systems study in which increasing salt percentage was associated with increasing peak height, suggesting a positive effect on dough strength as described by Preston (1981), the addition of other ingredients reversed this trend. A salt level of 2.5% was required before any significant difference in the effect of salt on complete dough peak height was seen. Increasing salt percentage to 3.0% did not further decrease peak height (Table 13).

Angle of dough breakdown, which is related to the ease of overmixing, decreased as salt percentage increased (Tables 13 and B6, Appendix B). However, the reduced breakdown may reflect the decrease in peak height as salt percentage increased and therefore may be symptomatic of a low-protein flour (Finney and Shogren, 1972).

Effect of Source

The composite flour in which the Tennessee grain was a component exhibited a longer dough development time than did the Alaska composite flour ($p < 0.0001$); this effect parallels the results found when salt was investigated in simple systems, although the additional ingredients

Table 13—Mixogram characteristics of complete dough systems[a]

Variation	Development time (min)	Development angle (°)	Peak height (cm)	Breakdown angle (°)
Salt level (%)				
1.5	6.13a	18.13a	6.24a	5.27a
2.0	6.76b	16.21b	6.22a	4.63b
2.5	7.35c	14.98c	6.10b	4.08c
3.0	8.06d	13.83d	6.09b	3.85c
Barley source				
Tennessee	7.53a	15.32a	6.26a	4.68a
Alaska	6.62b	16.25b	6.06b	4.24b
Barley level (%)				
0	5.53a	22.50a	6.90a	6.04a
10	6.74b	16.63b	6.39b	4.92b
20	7.30c	13.79c	5.85c	3.50c
30	8.74d	10.23d	5.51d	3.37c

[a]Means in a column within source of variation followed by like letters do not differ according to Tukey's Range Test ($p > 0.05$).

present increased dough development time overall (Tables 11, p. 97, and 13). This relationship does suggest that the salt effect on dough development time may be attributed to rate of protein hydration as influenced by percentage barley protein. The Tennessee barley flour was higher in protein than was the Alaska barley flour (Table 5, p. 50). Angle of dough development was inversely related to dough development time (Johnson et al., 1943). The angles are smaller than are those development angles found in the simple systems study, reflecting the increased development time of the complete dough system. Source X salt percentage was significant for dough development time ($p < 0.0001$) and dough development angle ($p < 0.05$). As the same inverse relationship between dough development time and angle of dough development as previously discussed is present, only the interaction, source X salt percentage (Tables B6 and C10, Appendixes B and C), for dough development time is presented graphically (Figure 32). An increase in salt in increments of 0.5% did not alter dough development time of systems containing Tennessee barley, whereas dough development time of the Alaska barley flour system at the 3.0% salt level was greater than was this composite flour system at 1.5% salt.

Peak heights obtained reflected barley source. Tennessee barley flour had a peak height that was significantly higher than was the Alaska barley peak height ($p < 0.0001$); therefore simple systems containing salt and the complete dough systems produced conflicting results. The source effect and actual peak heights found in the complete dough systems study were nearly identical to those found in the

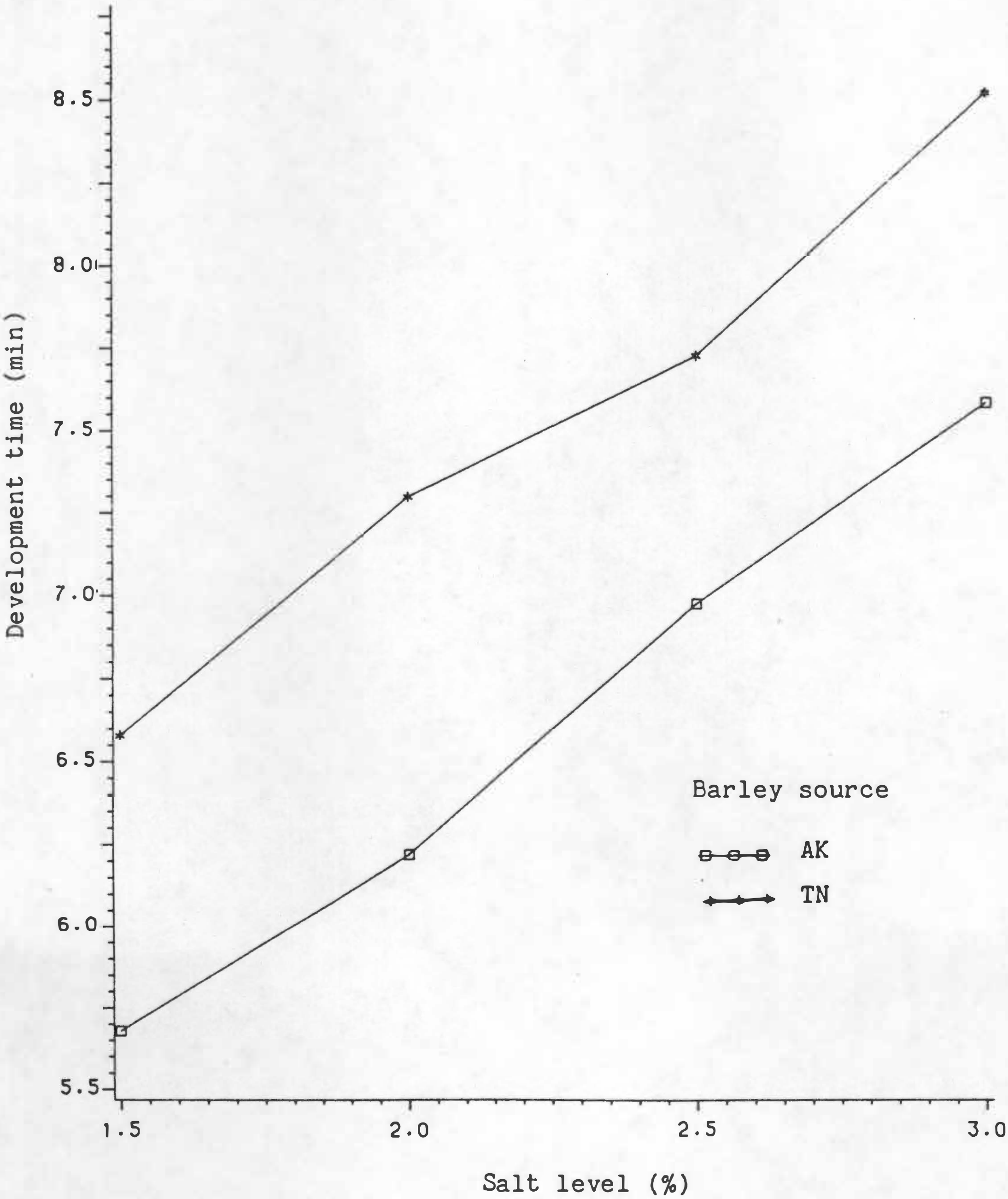


Figure 32—Dough development time as a function of salt level and barley source in complete dough development systems.

simple systems study without salt. It appears that increased protein in bread systems regardless of the grain source will improve the structure of the "gluten" matrix. Angle of dough breakdown differed with barley source (Table 13). The Tennessee barley flour exhibited greater breakdown than did the Alaska barley flour. However, breakdown angles for both barley flour sources were small (Table 13), indicating an improved tolerance to overmixing when additional ingredients were incorporated into the doughs (Tables 11, p. 97, and 13).

Effect of Barley Percentage

Barley percentage ($p < 0.0001$) altered dough development time and dough development angle (Table B6, Appendix B). The inverse relationship previously described was found between these parameters for main effects and interactions. Increasing barley percentage increased dough development time (Table 13), indicating that barley protein had a slower rate of protein matrix formation than did wheat protein (Cunningham et al., 1955).

The interaction, source X barley percentage, was significant for both dough development parameters (Tables B6 and C11, Appendixes B and C). As seen in Figure 33, incorporation of 20% Tennessee and 30% Alaska barley increased dough development time. The interaction, barley percentage X salt percentage ($p < 0.0001$), is depicted in Figure 34; interaction means are presented in Tables C12 (Appendix C). Although there was a general trend toward increased development time as barley levels and salt levels increased, the magnitude of the salt effect differed

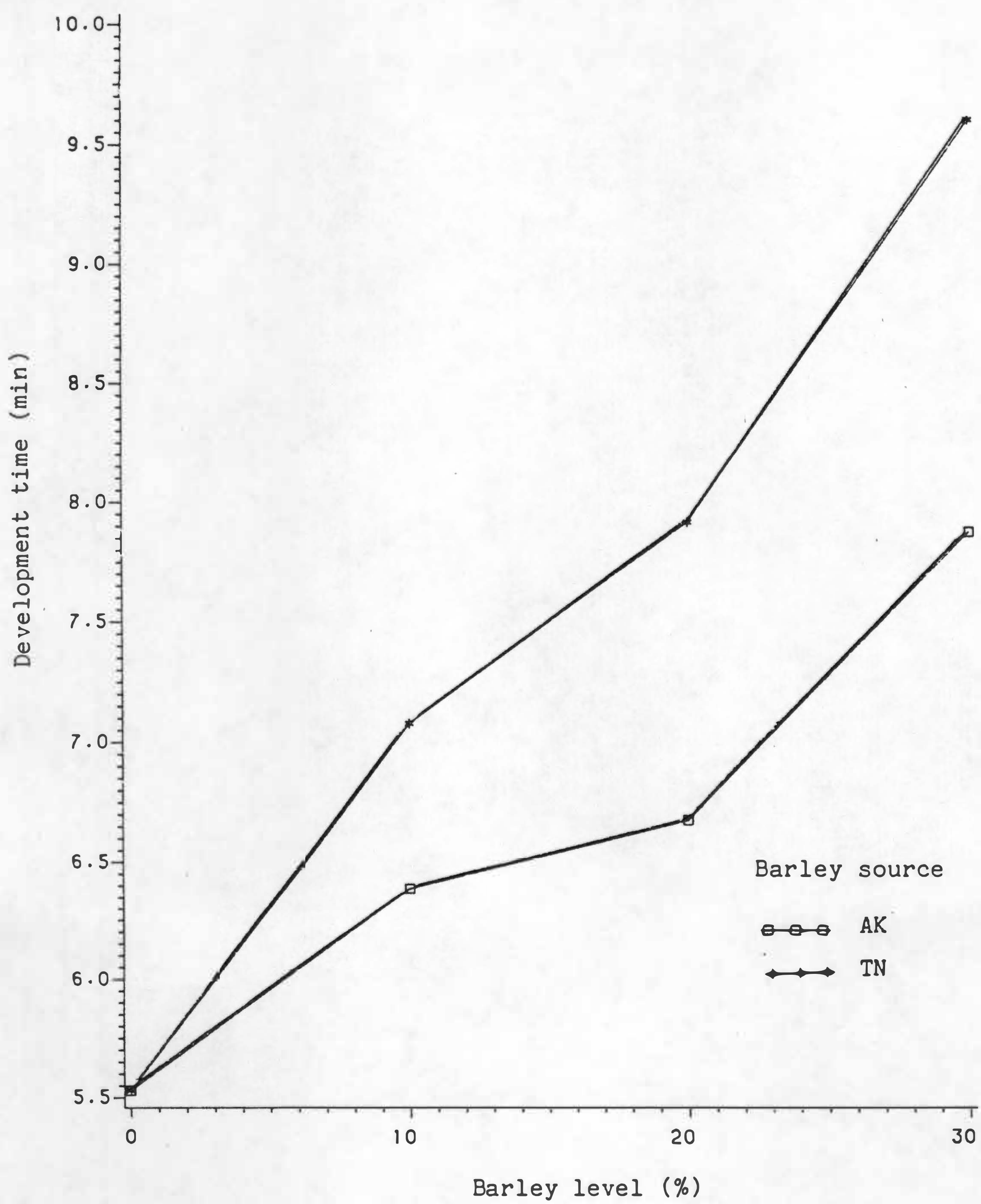


Figure 33—Dough development time as a function of barley level and source in complete dough development systems.

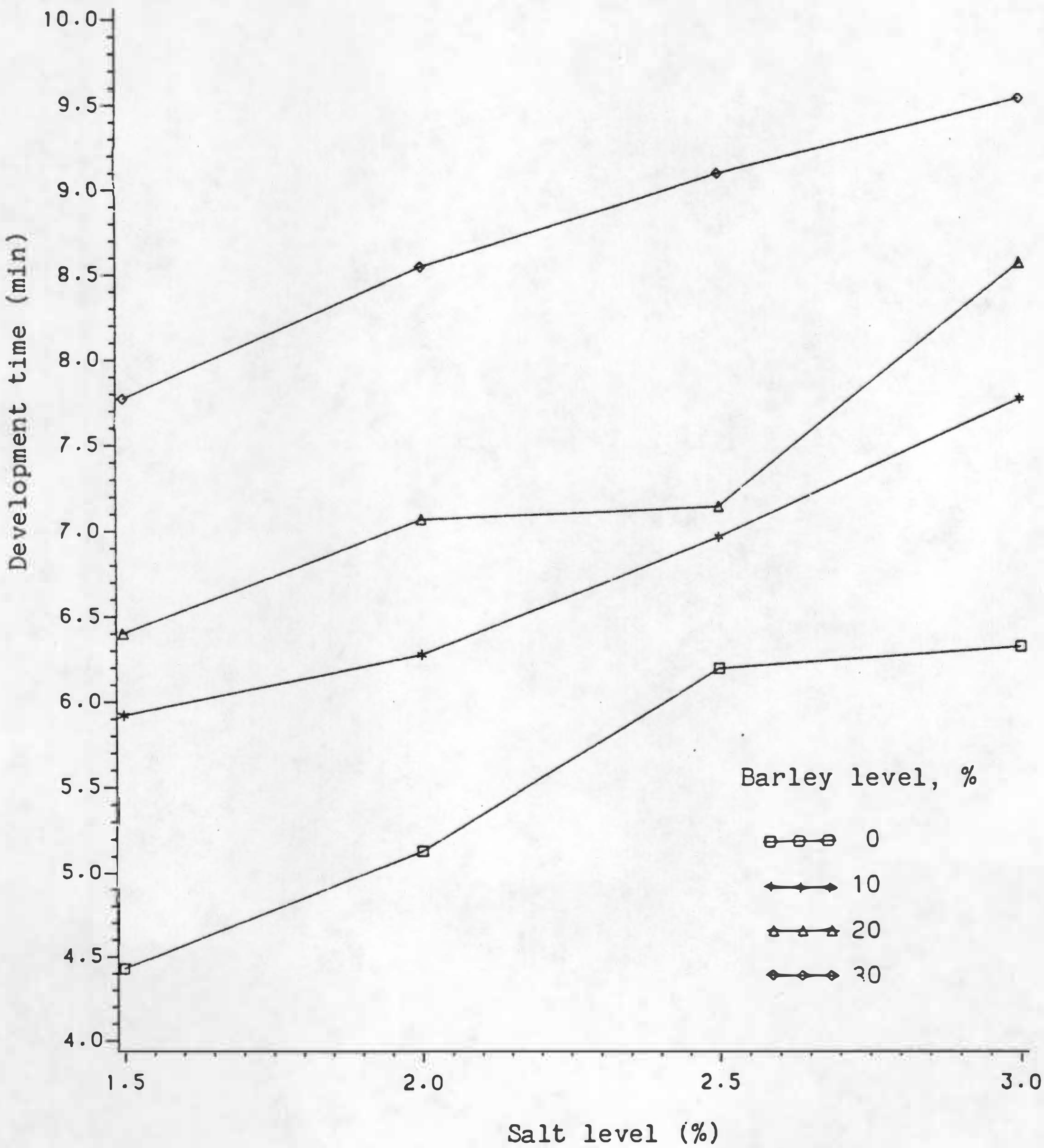


Figure 34—Dough development time as a function of salt and barley levels in complete dough development systems.

with barley level. As barley level is increased, the effect of salt is overridden. The three-way interaction, source X barley percentage X salt percentage ($p < 0.0001$), reflects the two-way interactions previously discussed.

Peak height (Tables 13 and B6, Appendix B) decreased as barley percentage increased ($p < 0.0001$) as previously reported for the simple systems studies (Tables 11, p. 97, and B5, Appendix B), indicating less protein matrix formation as barley percentage increased. The interaction source X barley percentage was significant ($p < 0.0001$) for peak height (Figure 35; Tables B6 and C11, Appendixes B and C). Increasing Tennessee barley in increments of 10% decreased peak height at all levels, whereas an increase in Alaska barley incorporation from 10 to 20% decreased peak height, although no effect was found at higher and lower levels of Alaska barley incorporation. Barley percentage X salt percentage ($p < 0.0001$) also was significant for peak height (Figure 36; Tables B6 and C12, Appendixes B and C). Peak height differed when the 1.5 and 3.0% salt levels are compared at each barley level. Differences in peak height at intermediate salt levels were related to the percentage barley present. The three-way interaction, source X barley percentage X salt percentage ($p < 0.001$), reflected the two-way interactions previously described.

Angle of dough breakdown is related to ease of overmixing; smaller angles indicate a greater tolerance to overmixing. Barley percentage affected the extent to which dough breakdown occurred. Dough breakdown was reduced as barley percentage increased (Table 13). This

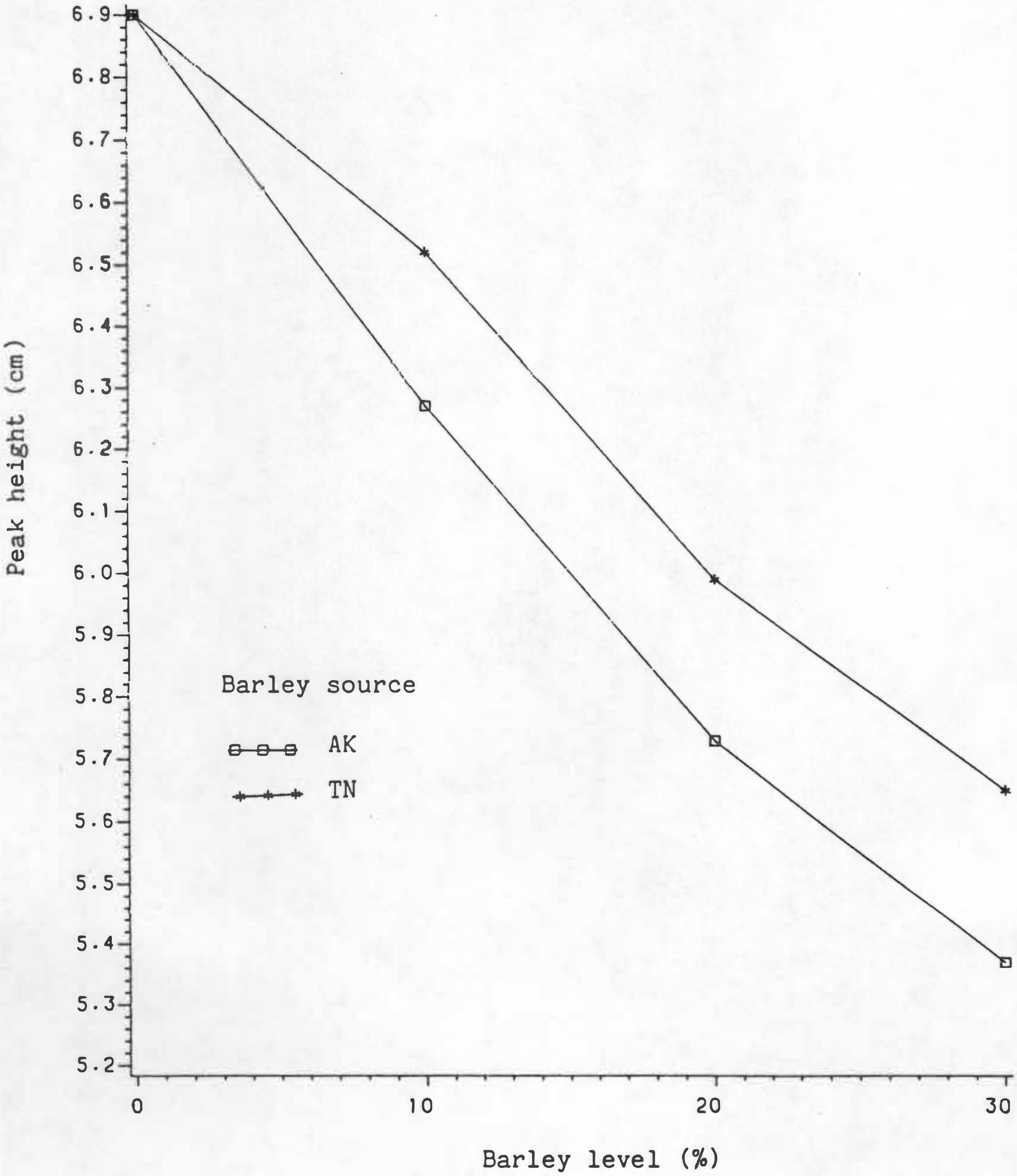


Figure 35—Peak height as a function of barley level and source in complete dough development systems.

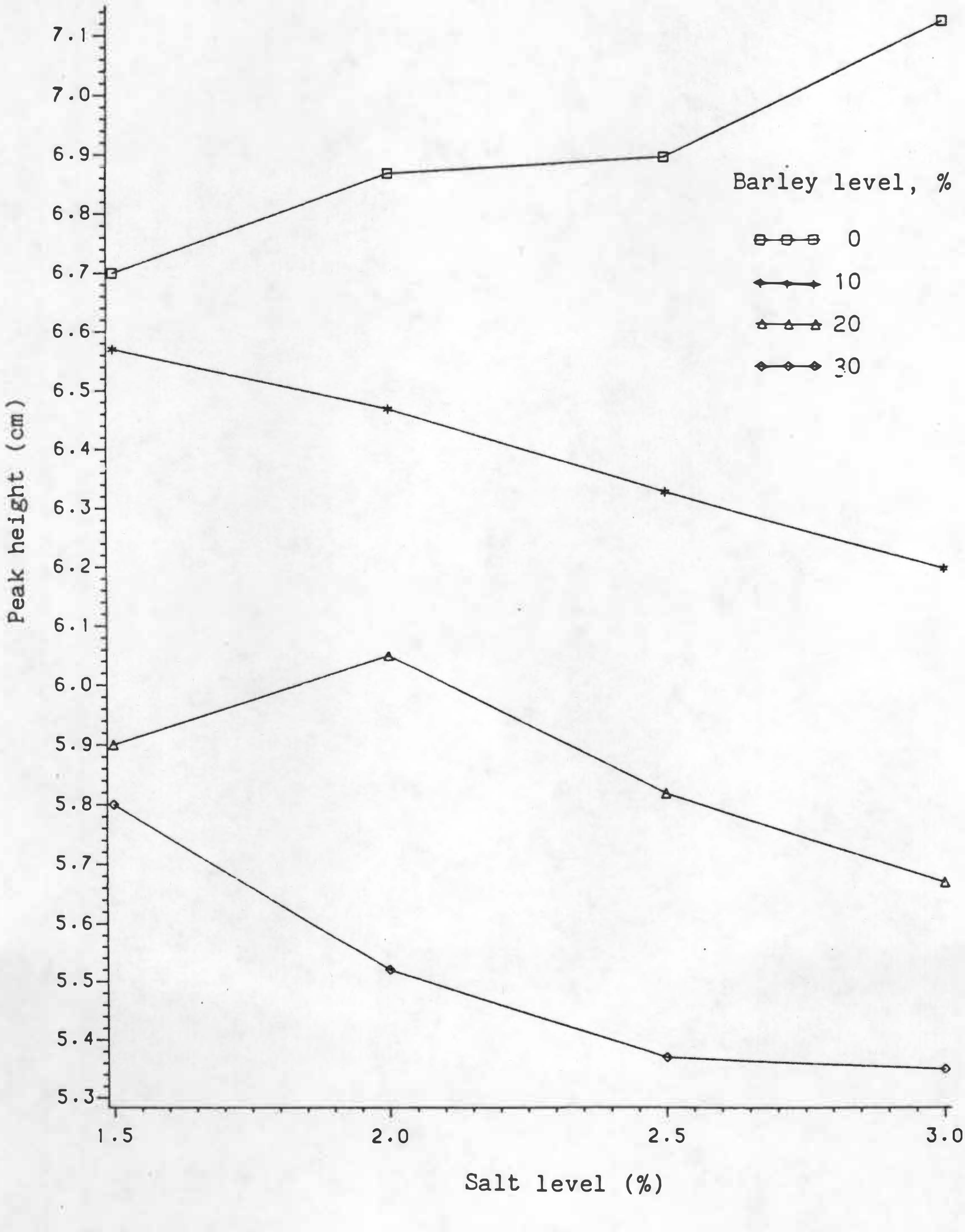


Figure 36—Peak height as a function of salt and barley levels in complete dough development systems.

relationship parallels that found in the simple system study (Table 10 and 11, pp. 92 and 97) and probably reflects the lower quality barley proteins in spite of dough strengthening agents incorporated in the formula. The interactions, source X barley percentage ($p < 0.05$), barley percentage X salt percentage ($p < 0.0001$) and source X barley percentage X salt percentage ($p < 0.0001$), are significant for dough breakdown. Data for interactions are presented in Table 14.

IV. DOUGH EXPANSION DURING FERMENTATION

A study of dough expansion during fermentation was undertaken to determine if the cohesive forces present in the doughs containing varying percentages of whole-grain barley flour were strong enough to retain the gas necessary for leavening. The dough expansion test, which is essentially a creep test, is independent of volume increase during fermentation (Hoseney et al., 1979).

Dough cohesion depends upon the strength of the gluten matrix and dough consistency. Added ingredients that influence gluten strength such as vital wheat gluten, SSL or salt would be expected to increase dough cohesive forces. Inherent differences in flours attributable to environmental or agronomic conditions or type that would alter dough consistency also would be expected to influence dough cohesion. In addition to cohesion, gravity and pressure influence fermenting dough rheology. The force of gravity is largely responsible for dough flow or increased spread ratios; strong cohesive forces within the dough will limit the flow and expansion, decreasing the spread ratios (Hoseney

Table 14—Breakdown angle as a function of barley source and barley and salt levels in complete dough systems

Salt level (%)	Barley level (%) 0	10	20	30	Means
	Breakdown angle for Tennessee barley				
1.5	6.33	6.00	4.00	5.33	5.41
2.0	6.33	5.50	3.50	4.00	4.83
2.5	5.50	4.33	3.83	3.00	4.17
3.0	6.00	4.50	3.83	2.83	4.29
Means	6.04	5.08	3.79	3.79	
	Breakdown angle for Alaska barley				
1.5	6.33	6.33	3.83	4.00	5.12
2.0	6.33	4.17	4.50	2.67	4.42
2.5	5.50	5.00	2.50	3.00	4.00
3.0	6.00	3.50	2.00	2.17	3.42
Means	6.04	4.75	3.21	2.96	

et al., 1979). A dough that spreads rapidly due to gravity will accumulate gas cells on top, whereas a dough that does not spread will not expand during proofing as a result of gas poduction. Both extremes are undesirable states, making a proper balance of these properties important (Bloksma, 1978). Volume increase in all directions is related to gas expansion pressure (Hoseney et al., 1979). The doughs studied contained the ingredients indicated in Table 3 (p. 31). All spread ratios obtained in this study were less than 1.0 throughout the fermentation period (Table 15), indicating no flow and potential problems with dough expansion during proofing. A trend toward increasing spread ratios as fermentation progressed was observed (Table 15). Conversely, Hoseney et al. (1979) found decreasing spread ratios with increasing fermentation time when studying white pan bread doughs.

Effect of Salt Percentage

Increasing salt resulted in increased spread ratios, indicating a weakening effect of salt on dough cohesive forces or increased dough mobility (Table 15). These results suggest that less water is held by flour components in the presence of salt or that the presence of salt weakens the gluten matrix. A weakened gluten matrix was previously suggested by the inverse relationship between increasing salt percentage and peak height in the complete dough development model system study (Table 13, p. 115). The weakened protein matrix may be a function of salt induced reduced protein hydration.

Table 15—Spread ratios of complete doughs[a]

Variation	Spread ratios[b]
Fermentation time (min)	
15	0.87a
30	0.89b
45	0.90bc
60	0.91c
Salt (%)	
1.5	0.87a
2.0	0.89b
2.5	0.90bc
3.0	0.91c
Source	
Tennessee	0.87a
Alaska	0.91b
Barley (%)	
0	0.94a
10	0.90b
20	0.88c
30	0.85d

[a]Means followed by like letters within source of variation do not differ according to Tukey's Range Test ($p > 0.05$).
[b]Spread ratio = dough width/dough height.

Effect of Barley Source

Significant differences in spread ratios as a result of barley source were found (Table 15). The dough expansion ratio across all barley and salt levels was 0.87 and 0.91 for Tennessee and Alaska barley, respectively. Barley source ($p < 0.0001$) was significant (Table B7, Appendix B). These results probably reflected the higher protein content of the Tennessee flour (Table 5, p. 50), which was associated with higher levels of amino acids important in cohesive proteins (Table 6, p. 53). The postulated higher β-D-glucan content of the Tennessee grain also may decrease spread ratios by increasing dough consistency. These effects were previously suggested by the source effect on complete dough peak height from the simple dough development study (Table 13, p. 115).

Effect of Barley Percentage

Increasing barley percentage decreased spread ratios significantly (Tables 15 and B7, Appendix B), suggesting that barley incorporation increased dough cohesion. The interaction barley source X barley percentage ($p < 0.0001$) was significant (Table B7). Although spread ratios decreased when either barley was incorporated, the effect was greater when Tennessee barley was used at all barley levels. According to Cunningham et al. (1955) barley "gluten" is less cohesive than is wheat gluten. Rather than indicating increased cohesion due to protein quality and content, this relationship may reflect differences in dough consistency attributable to β-D-glucans in the barley.

The interaction between barley percentage and salt percentage ($p < 0.05$) was significant. Generally, altering the salt level had little effect on spread ratios in the absence of barley. Previously, Hoseney et al. (1979) reported that elimination of salt from a white pan bread system did not alter spread ratios. However, when barley flour was incorporated into the whole-grain bread system, salt level did affect spread ratios. Increasing salt levels from 0.5 to 2.5% increased spread ratios, potentially increasing dough expansion as barley level increased. When 3.0% salt was incorporated into the whole-grain bread system, spread ratios were generally decreased at higher levels of barley flour useage. Data for the three-way interaction, barley source X barley percentage X salt percentage ($p < 0.0001$) is presented in Table 16. This interaction reflects the two-way interactions previously described. Despite the significant effect of barley source, barley and salt levels and the interactions (Table B7, Appendix B), it is unlikely that the differences are great enough to have any practical importance.

V. FOOD SYSTEM

Barley and salt levels most appropriate for use in bread systems were identified for each barley source using reponse surface methodology (Giovanni, 1983). This technique allows the effect of the interaction between barley flour and salt over a series of levels to be seen graphically. Because the range of the effect of barley flour and salt levels present on amylogram parameters had no practical importance in yeast

Table 16—Spread ratios as a function of barley source and barley and salt levels

Salt level (%)	Barley level (%) 0	10	20	30	Means
Tennessee barley					
1.5	0.93	0.84	0.82	0.80	0.85
2.0	0.94	0.86	0.86	0.83	0.87
2.5	0.95	0.87	0.84	0.82	0.88
3.0	0.95	0.87	0.87	0.84	0.88
Means	0.94	0.86	0.85	0.82	
Alaska barley					
1.5	0.93	0.90	0.84	0.88	0.89
2.0	0.94	0.90	0.91	0.87	0.91
2.5	0.95	0.93	0.93	0.90	0.93
3.0	0.95	0.99	0.93	0.86	0.93
Means	0.94	0.93	0.90	0.88	

bread systems (Kulp and Lorenz, 1981; Rasper et al., 1974), these response surfaces are not presented. Further the differences in dough expansion ratios as a function of barley flour and salt level although significant were small (Table 16); response surfaces were not drawn. Only the interactions between barley flour and salt levels in the dough development studies were used to identify the optimal bread formula for each barley source.

Response surfaces for the complete dough development parameters, except dough development angle which reflects dough development time (Johnson et al., 1943), are presented in Figures 37 through 42. Because peak height has been positively correlated with loaf volume (Johnson et al., 1943), the effects of barley flour and salt levels on peak height were examined first. Dough tolerance to overmixing as measured by dough breakdown angle was considered second. Finally, the effect of both factor levels on development time was considered. Excessive dough development time would make the production of the bread impractical. Optimal barley and salt levels were determined for each barley source.

The response surface in Figure 37 depicts the effect of barley and salt levels on Tennesse barley peak height. Barley flour level decreased peak height; salt level had little effect. Although all barley flour levels investigated would likely produce adequate loaf volume, the postulated high β-D-glucan content may have produced a bread that was gummy. Gumminess, which is related to the denseness that persists throughout chewing (Szczesniak et al., 1963), is a characteristic associated with breads of poor quality. Therefore, incorporation of 20%

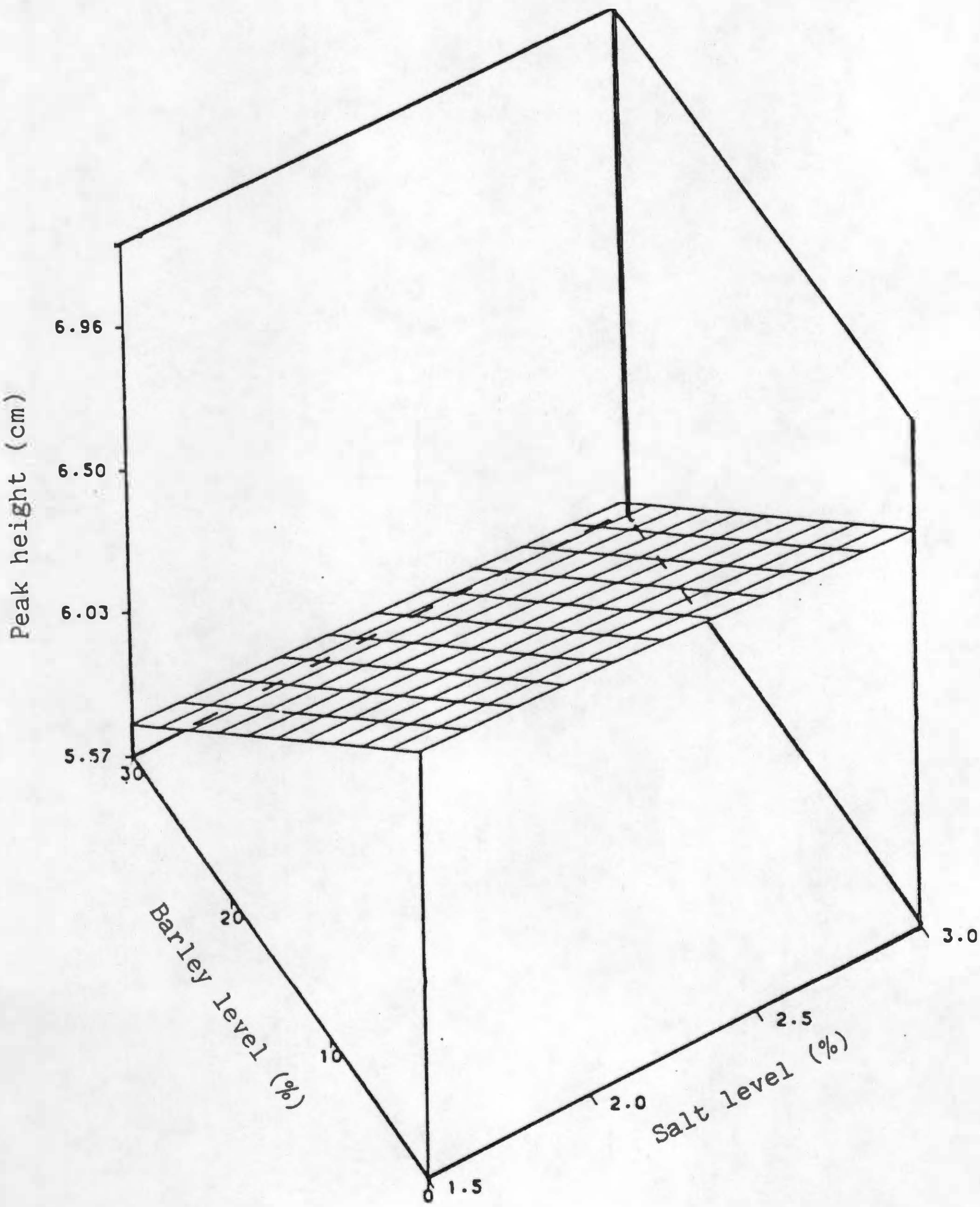


Figure 37—Peak height as a function of barley and salt levels in complete dough development systems containing Tennessee barley flour.

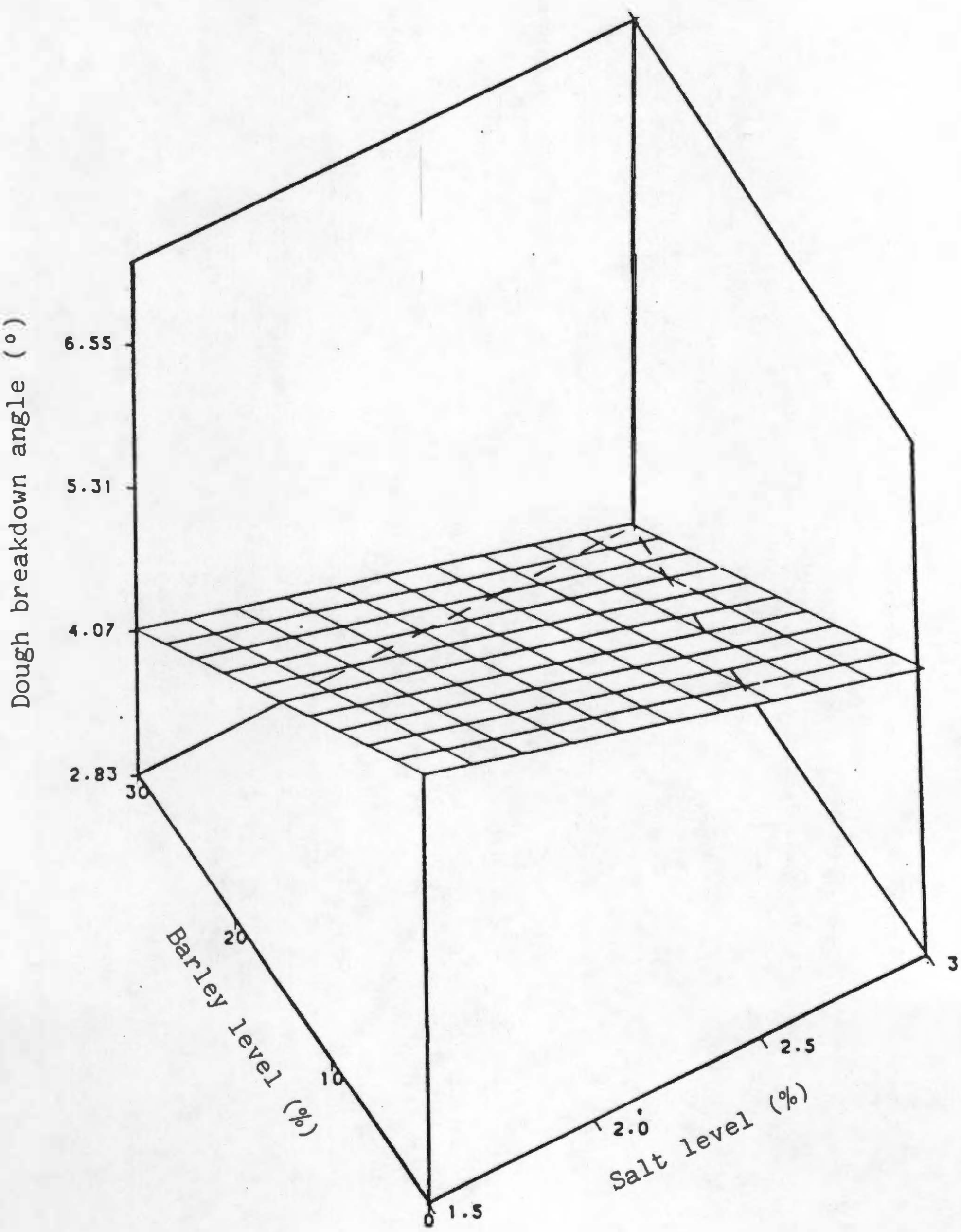


Figure 38—Dough breakdown angle as a function of barley and salt levels in complete dough development systems containing Tennessee barley flour.

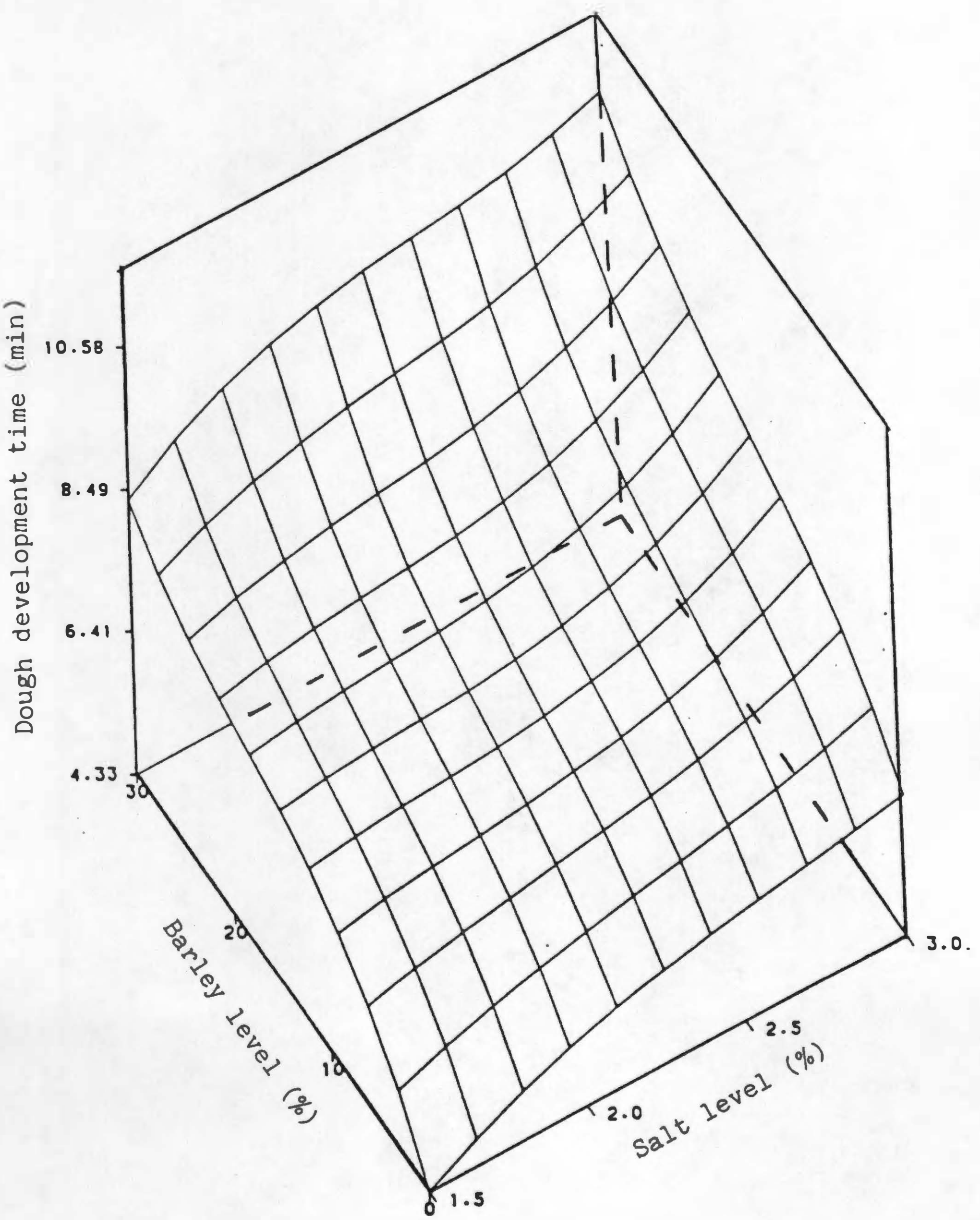


Figure 39—Dough development time as a function of barley and salt levels in complete dough development systems containing Tennessee barley flour.

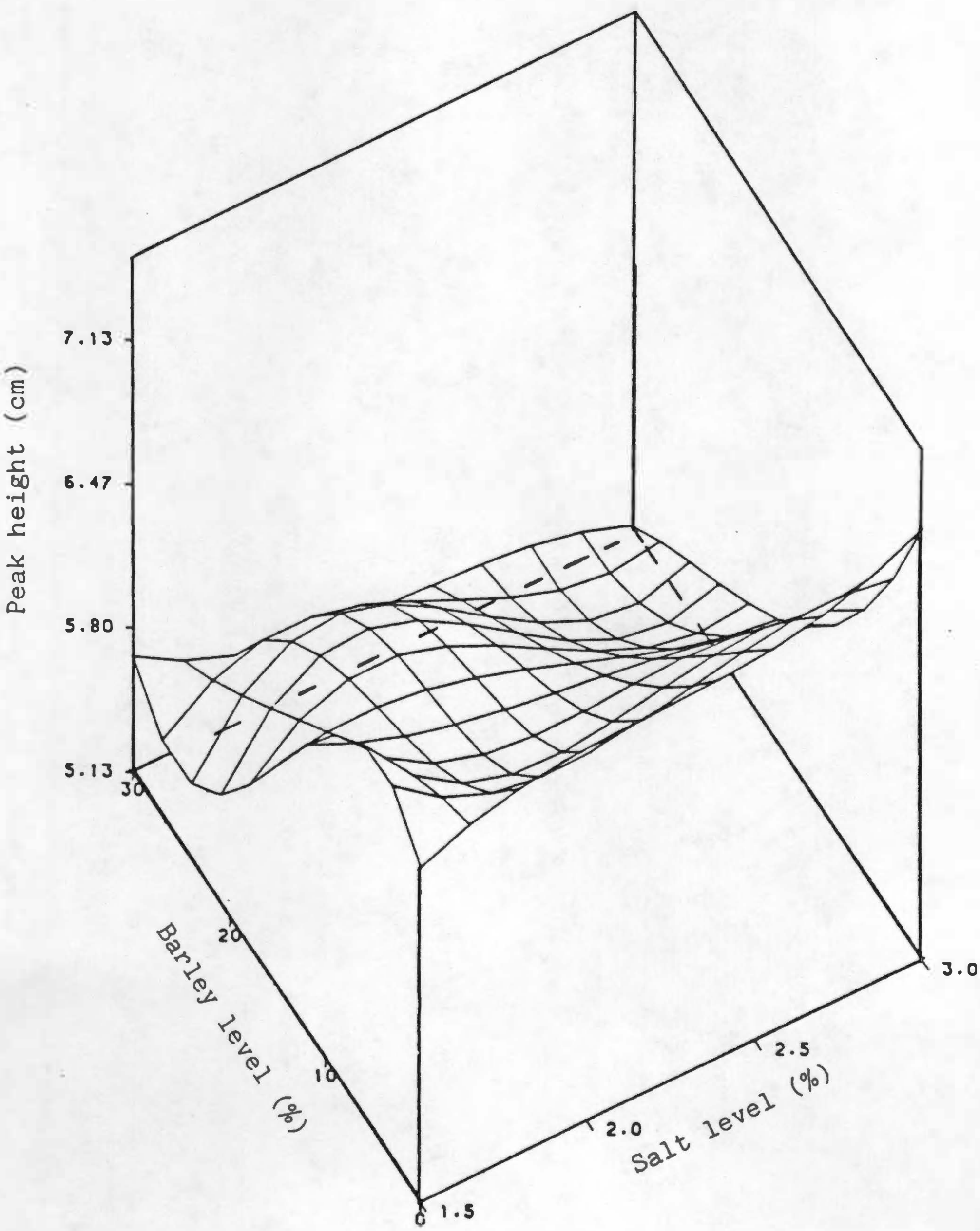


Figure 40—Peak height as a function of barley and salt levels in complete dough development systems containing Alaska barley flour.

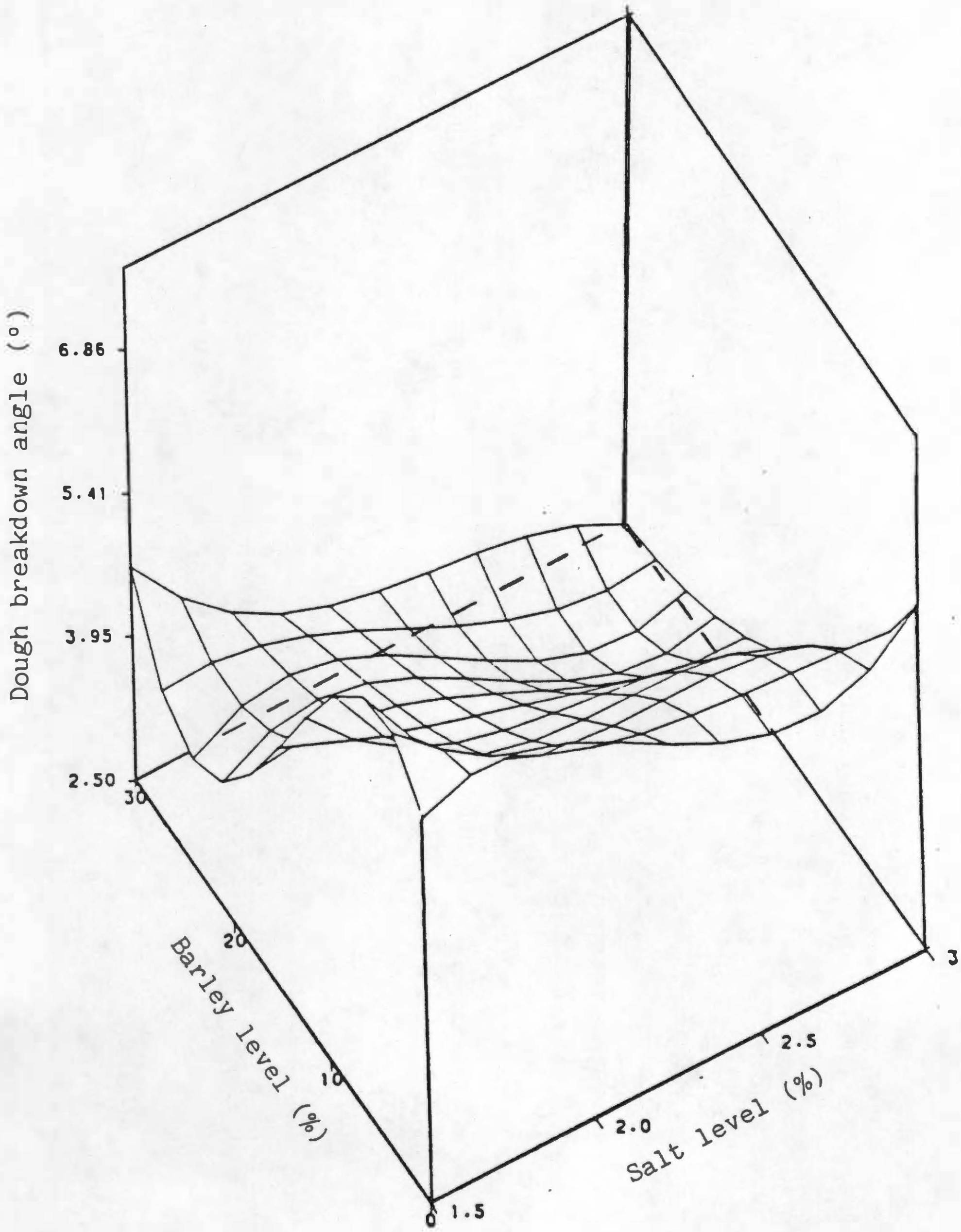


Figure 41—Dough breakdown angle as a function of barley and salt levels in complete dough development systems containing Alaska barley flour.

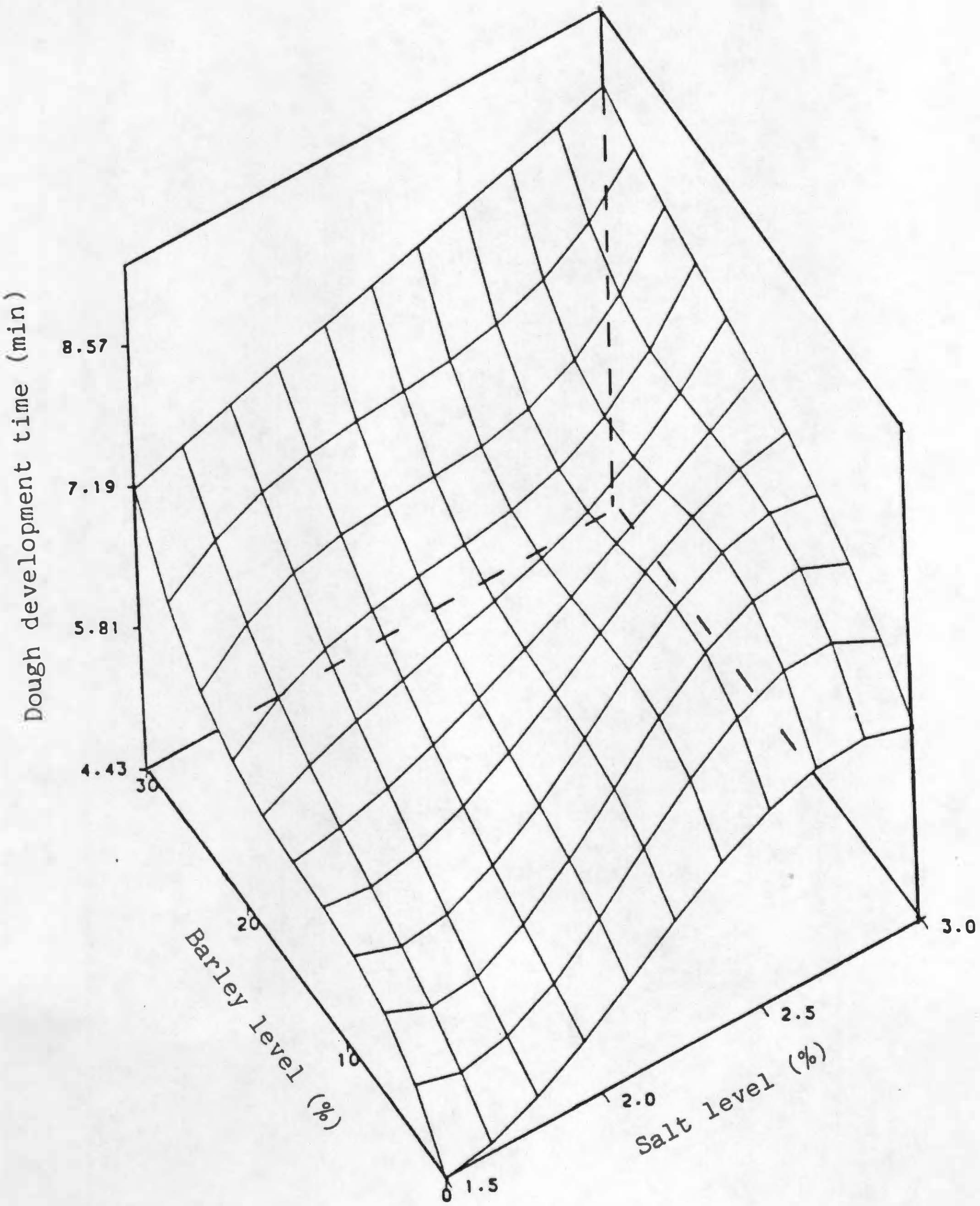


Figure 42—Dough development time as a function of barley and salt levels in complete dough development systems containing Alaska barley flour.

barley appeared to be the best choice. Dough breakdown angle (Figure 38) was decreased as salt level increased, indicating that increasing salt level increased mixing tolerance. However, increasing salt level also increased dough development time (Figure 39). At the 20% Tennessee barley level, 2.0% salt appeared to increase mixing tolerance without greatly increasing dough development time. In addition, flavor was unlikely to be adversely affected by the 2.0% salt level as it is the customary level used in commercial yeast bread (Ponte, 1978).

The selection of appropriate Alaska barley flour and salt levels was less obvious. The response surface for peak height is presented in Figure 40. In systems containing barley flour, peak height at 20% barley flour and 2.0% salt was essentially the same as the peak height when 10% barley flour and 2.5% salt were incorporated. Therefore, it appeared that a salt level of 2.0% would allow a higher level of Alaska barley flour incorporation. Although a barley level of 20% and a salt level of 2.0% resulted in increased dough breakdown (Figure 41), the breakdown angle was small, indicating good tolerance to overmixing. Dough development time (Figure 42) at 20% barley and 2.0% salt was acceptable.

Part A: Physical Tests

End and center slices from whole-grain breads made from whole-wheat and barley flours are seen in Plate 2. The whole-wheat bread that contained 50% whole-wheat flour and 2.0% salt served as the control.

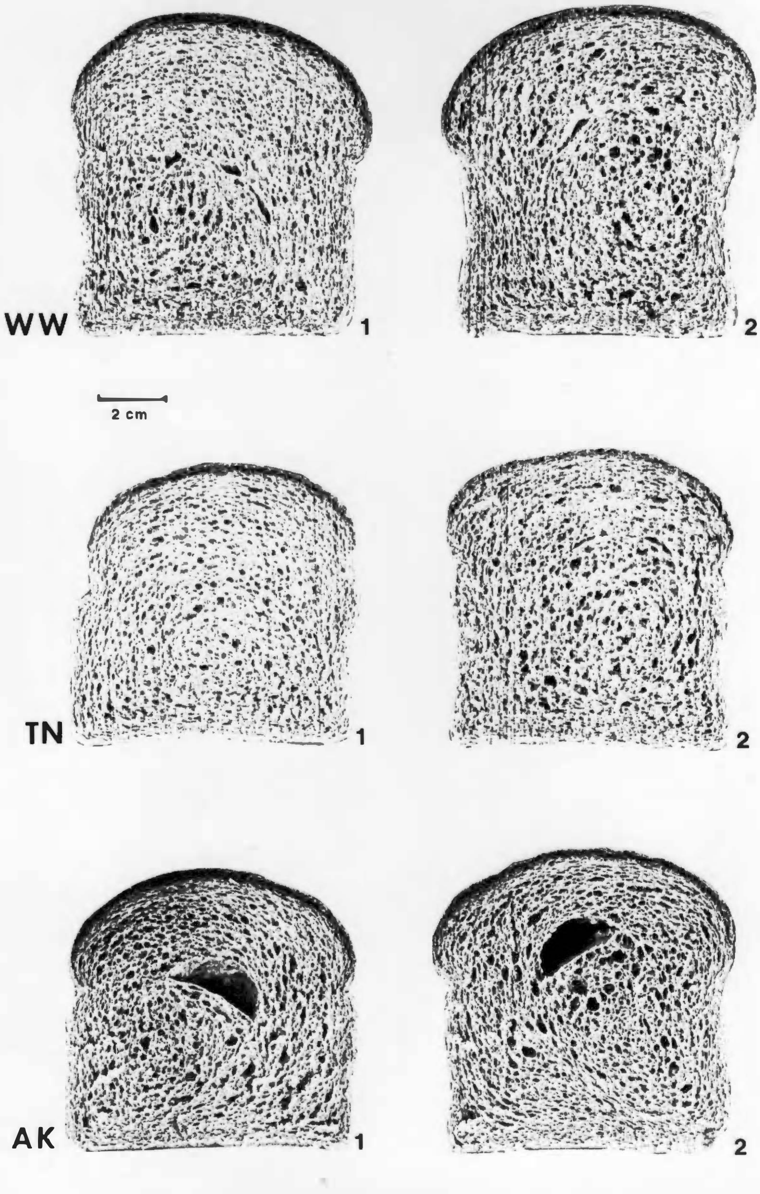


Plate 2—Xerographs of end (1) and center (2) slices from whole-grain breads made from composite flours containing 50% whole-wheat (WW) and 20% Tennessee barley (TN) or 20% Alaska barley (AK) flours.

Unlike the barley breads studied by Hart et al. (1970), both barley breads as well as the whole-wheat control bread exhibited smooth domed crusts without the addition of gums. However, other dough strengthening agents, SSL and vital wheat gluten, were components of the dough (Table 3, p. 31). The crumb appearance did not differ greatly from the whole-wheat control when the Tennessee barley flour replaced a portion of the whole-wheat flour. Conversely, the crumb appearance of the Alaska barley bread was characterized by the presence of tunnels or holes. It appeared that there was a lack of adhesion between layers of the molded dough. The presence of the holes may be caused by loose molding of the sheeted dough. Moen (1929) reported that loosely molded doughs produced breads with coarser crumb characteristics. Excess flour on the dough surface prior to sheeting also may produce these crumb characteristics. However, the dough pieces were not dusted with flour prior to sheeting, making this possible explanation unlikely.

Loaf volume and specific volume were significantly decreased when whole-grain barley flour replaced a portion of the whole-wheat flour (Tables 17 and B8, Appendix B). Previously, Bhatty (1986) reported that incorporation of 5% hull-less barley flour into a white-variety bread formula decreased loaf volume by 14%. Although 20% barley flour was used in this study, loaf volume was reduced by only 5-6%. Specific loaf volume followed a similar trend. Kim et al. (1978) reported a decrease in specific loaf volume of more than twice that found in this study, when a 10:90 barley-wheat composite flour was investigated in a white-variety bread system. Despite the lower protein content of the

Table 17—Baking data on 50% whole-wheat, 20% Alaska and 20% Tennessee barley breads containing 2.0% salt[a]

Bread type	Loaf volume (cm^3)	Specific volume (cm^3/g)	Baking weight loss (%)
Whole-wheat	1322.5a	4.45a	9.9ab
TN barley[b]	1243.3b	4.16b	9.4b
AK barley[c]	1257.5b	4.23b	10.2a

[a]n = 6; means in a column followed by like letters do not differ according to Tukey's Range Test ($p > 0.05$).
[b]TN = Tennessee.
[c]AK = Alaska.

Alaska barley flour (Table 5, p. 50) and the higher levels of amino acids (Table 6, p. 53) that have been found to be detrimental to wheat bread loaf volume (Shoup et al., 1966), no significant differences in loaf volume or specific volume were found as a result of barley source (Table 17). These discrepancies were attributed to the dough strengthening agents used in the whole-grain barley bread formula (Table 3, p. 31). Although percentage baking loss differed with barley source (Table 17), neither whole-grain barley bread differed from the whole-wheat control.

Instron Texture Profile Analysis values are presented in Table 18; mean squares are reported in Table B9 (Appendix B). The Alaska barley bread was significantly more gummy than was the whole-wheat control, although the Tennessee barley bread did not differ ($p > 0.05$) from either the whole-wheat control or the Alaska barley bread. The increased gumminess of the Alaska barley bread was attributed to the higher carbohydrate plus ash content of the Alaska barley flour (Table 5). Although hardness of the breads was not significantly different at $p < 0.05$, significance was present at $p < 0.1$. Two of the six samples of the Alaska barley bread evaluated, although relatively soft, were much firmer than were the other samples. Differences in hardness should have been small because all loaves evaluated were from the same bake and had been stored under identical conditions. It was observed that these two samples were from loaves with large tunnels as seen in Plate 2. Therefore, these samples were likely more dense because the lower two-thirds of the loaf exhibited less volume increase than did the samples taken from loaves where small or no tunnels were present.

Table 18—Texture Profile Analysis data for 50% whole-wheat, 20% Alaska and 20% Tennessee barley breads containing 2.0% salt[a]

Bread type	Hardness (kg)	Cohesiveness	Springness (cm)	Gumminess (kg)	Chewiness (kg-cm)
Whole-wheat	0.40a	0.48a	0.98a	0.19a	0.18a
TN barley	0.40a	0.54a	1.01a	0.22ab	0.22a
AK barley	0.64a	0.54a	0.95a	0.34b	0.32a

[a]n = 6; means in a column followed by like letters are not significantly different according to Tukey's Range Test ($p > 0.05$).

Part B: Sensory Evaluation

The three yeast breads described above also were evaluated by a consumer sensory panel. Forty-eight experienced but untrained panelists participated in the test. The consumer texture profile technique (Szczesniak et al., 1975) modified to include appearance and flavor was used for bread evaluation. This technique also allowed each panelist to describe his/her "ideal" bread. The panelists who were frequent consumers of whole-grain breads (Appendix A), described widely different "ideal" breads (Table 19 and Tables B10-12, Appendix B). Mean scores for the "ideal" and the three whole-grain breads evaluated are reported in Table 20. Figures 43, 44 and 45 show the consumer profiles for appearance, texture and flavor respectively. On each profile, the "ideal" product is shown as a straight vertical line. The profiles for the whole-wheat, Tennessee barley and Alaska barley breads are shown as deviations from the "ideal." All three breads studied differed only slightly from the "ideal," suggesting that the model systems results were successfully applied to the food system through the use of response surface methodology.

Appearance profiles of the whole-grain breads depicted in Figure 43 show only small deviations from the "ideal." The crust of all breads evaluated was slightly darker than was the crust of the "ideal" bread. The crumb grain was finer than was the crumb grain in the "ideal" bread, although the cell distribution was more uneven than was desired (Figure 43 and Table 20).

Table 19—Simple statistics for sensory parameters used to describe panelists "ideal" bread[ab]

Sensory parameter	Mean ± SD	Minimum value	Maximum value
Appearance			
dark crust	3.7 ± 1.1	1	6
coarse crumb grain	3.4 ± 1.3	1	6
even cell distribution	4.8 ± 0.9	1	6
fine crumb grain	3.2 ± 1.4	3	6
Texture			
good	5.6 ± 0.8	1	6
soft	4.3 ± 1.4	3	6
chewy	4.0 ± 1.3	2	6
crumbly	2.2 ± 1.3	2	6
dry	1.7 ± 1.0	1	5
hard	1.8 ± 1.1	1	4
rough	2.3 ± 1.2	1	5
gummy	1.6 ± 0.9	1	5
bad	1.1 ± 0.3	1	2
moist	4.6 ± 1.0	2	6
Flavor			
strong	3.1 ± 1.4	1	6
good	5.7 ± 0.6	4	6
bland	2.3 ± 1.1	1	5
salty	2.3 ± 1.0	1	5
sweet	3.2 ± 1.1	1	5
bad	1.1 ± 0.3	1	3

[a] n = 48.
[b] 1 = not at all; 6 = very much so.

Table 20—Means for sensory parameters used to describe "ideal," whole-wheat and Tennessee and Alaska whole-grain barley breads[ab]

Sensory parameter	Bread type[c]			
	"Ideal"	Whole-wheat	TN barley[d]	AK barley[d]
Appearance				
dark crust	3.7a	4.2b	4.0ab	4.1b
coarse crumb grain	3.4a	2.3b	3.0a	3.3a
even cell distribution	4.8a	4.3a	3.5b	3.2b
fine crumb grain	3.2a	4.4b	3.6a	3.4a
Texture				
good	5.6a	4.4b	4.5b	4.3b
soft	4.4a	5.1b	5.1b	4.6ab
chewy	4.0a	4.0a	4.1a	3.9a
crumbly	2.2a	1.5b	1.4b	1.6b
dry	1.7a	1.9a	1.3a	1.8a
hard	1.8a	1.3b	1.3b	1.7ab
rough	2.3a	1.4b	1.4b	1.6b
gummy	1.6a	3.4b	3.3b	3.4b
bad	1.1a	1.9b	2.0b	2.0b
moist	4.6a	4.5ab	4.8a	4.1b
Flavor				
strong	3.1a	2.9a	3.2a	3.5a
good	5.7a	4.2b	4.3b	4.3b
bland	2.3a	2.9b	2.7ab	2.4ab
salty	2.3a	2.1a	2.0a	2.1a
sweet	3.2a	2.9ab	2.8ab	2.7b
bad	1.1a	2.0b	2.0b	2.1b

[a]n = 48; means in a row followed by like letters do not differ according to Tukey's Range Test ($p > 0.05$).
[b]1 = not at all and 6 = very much so.
[c]Formula in Table 3, p. 31; salt level = 2.0%.
[d]TN = Tennessee barley; AK = Alaska barley; barley flour level was 20%.

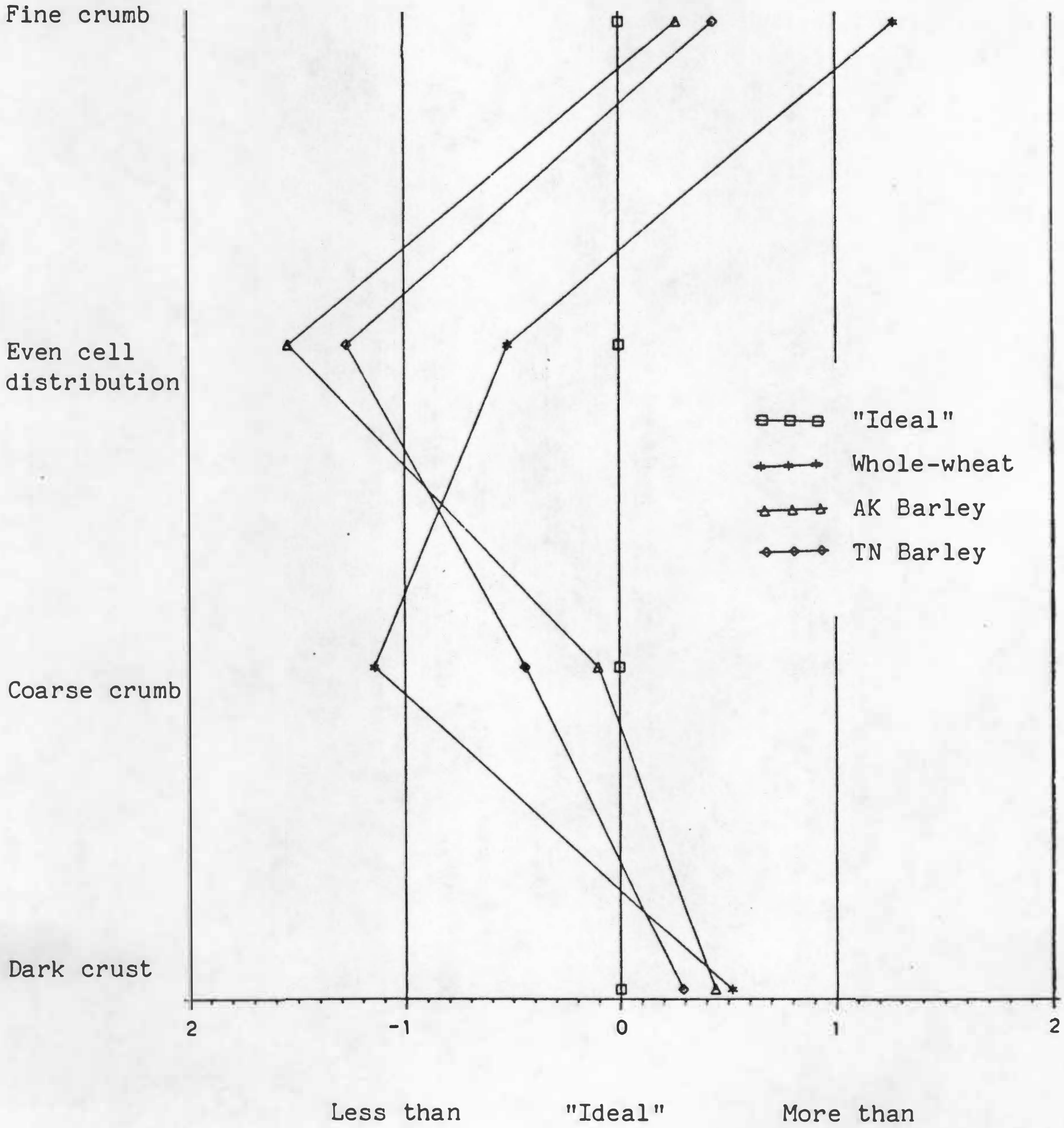


Figure 43—Consumer appearance profile of whole-grain breads with results represented as deviations from an "ideal" product (n = 48 panelists).

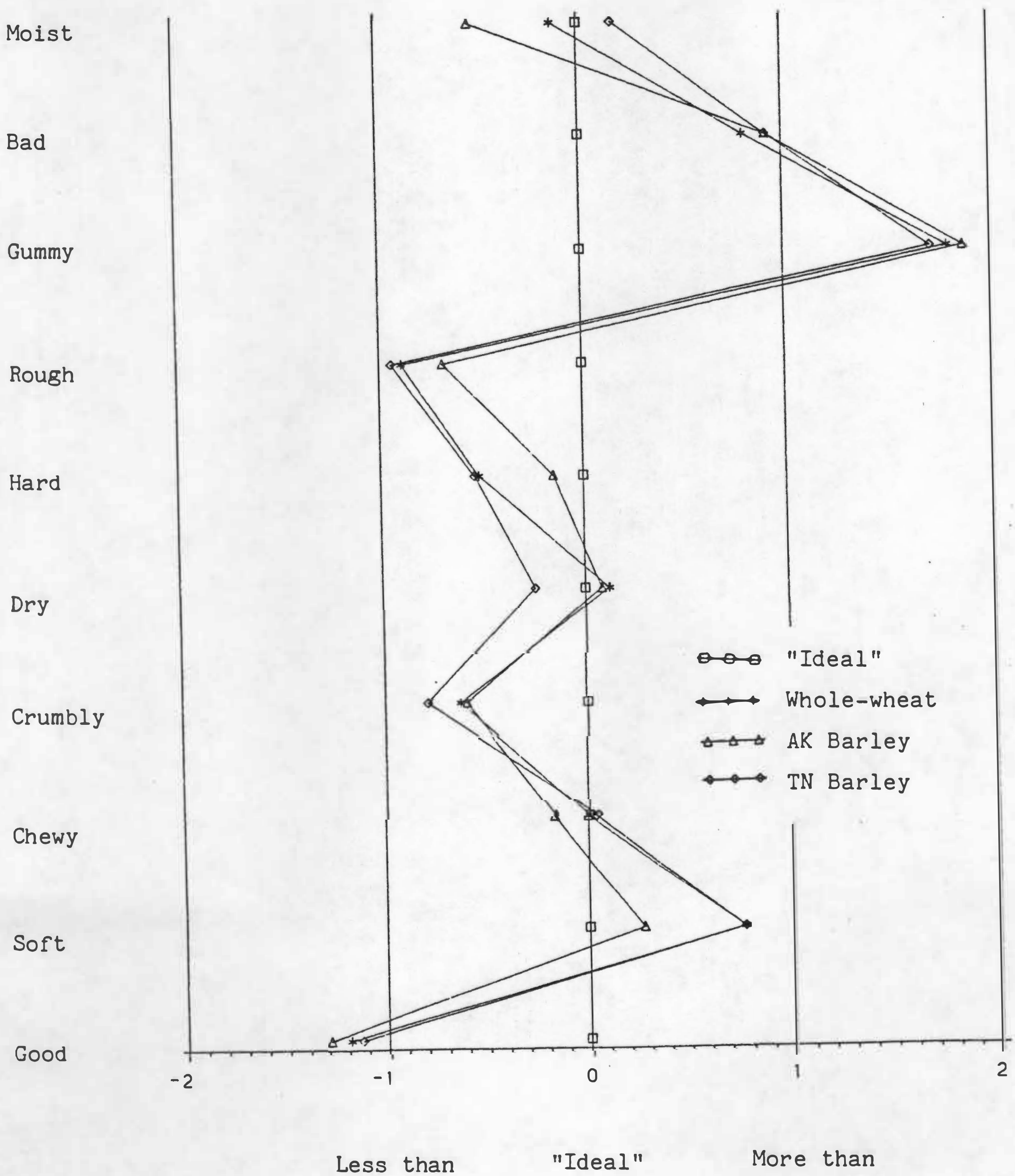


Figure 44—Consumer texture profile of whole-grain breads with results represented as deviations from an "ideal" product (n = 48 panelists).

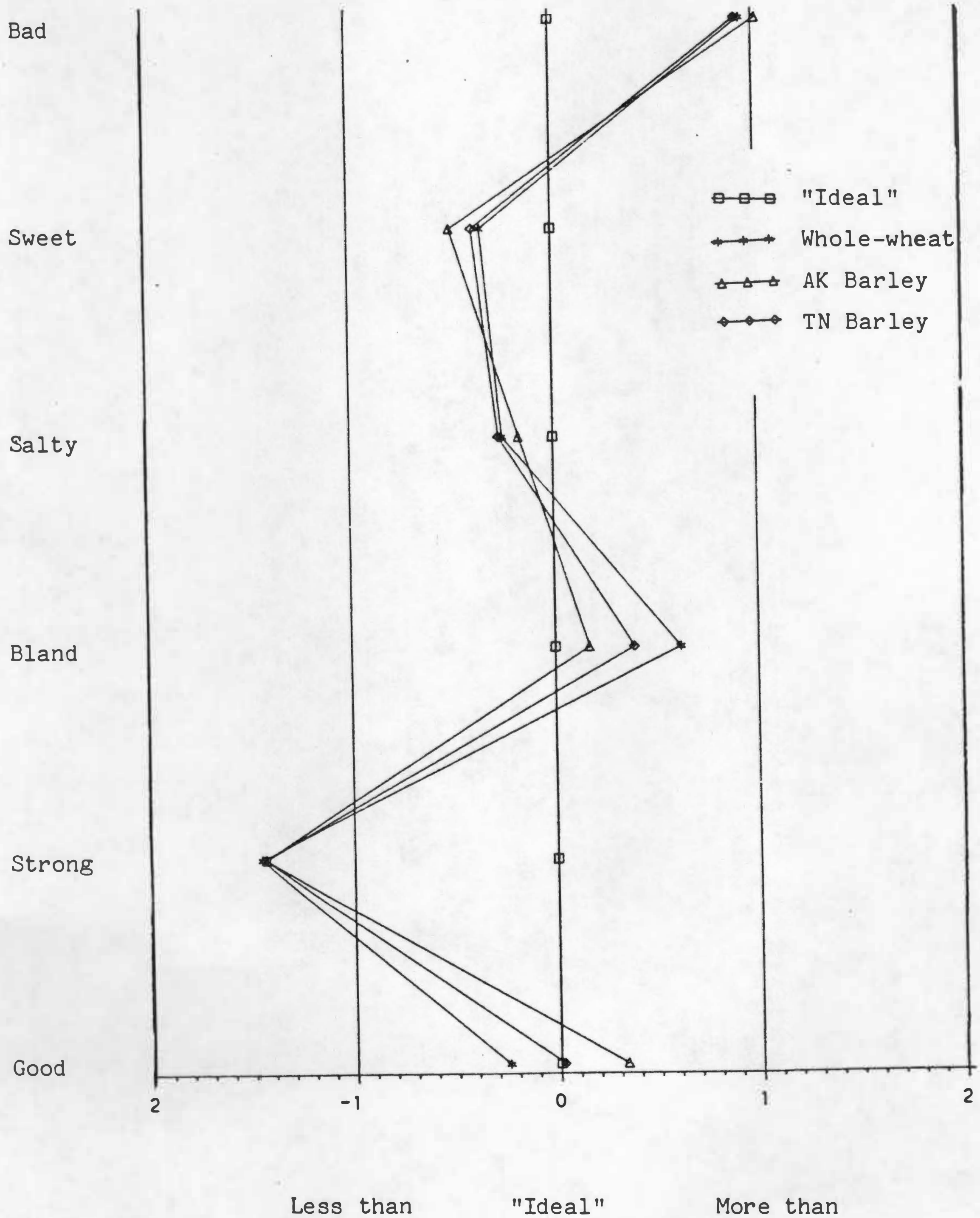


Figure 45—Consumer flavor profile of whole-grain breads with results represented as deviations from an "ideal" product (n = 48 panelists).

Texture profiles are shown in Figure 44; means are reported in Table 20. No significant differences ($p > 0.05$) in bread texture were found among the three breads, except that the Tennessee barley bread was perceived as more moist than was the Alaska barley bread. Thus, the sensory panelists evaluation of the whole-grain breads generally supported the conclusions drawn from the instrumental Texture Profile Analysis (Table 18). Apparently, although a difference in gumminess among the breads was found when the breads were evaluated using the instrumental technique (Table 18), these differences were not detectable by sensory panelists (Table 20). In general, the whole-grain breads evaluated were softer, more gummy, less crumbly and less rough than was the "ideal" bread described by the panelists (Figure 44).

Flavor profiles are depicted in Figure 45; means are reported in Table 20. Not only were no differences ($p > 0.05$) found among the three breads evaluated (Table 20) but few deviations from the "ideal" were found. It is interesting that neither barley bread differed from the "ideal" or the whole-wheat control bread for strongness (Table 20). Previously, Kim et al. (1978) reported that barley incorporation at the 10% level produced a strong flavor. Perhaps, consumers desire a stronger flavor in whole-grain breads than is desirable in white variety breads. This consumer reponse was suggested by the "ideal" score for blandness (Table 20). In this study, the whole-wheat control bread was more bland than was desired by the panelists, whereas the barley breads did not differ from the "ideal." The Alaska barley bread was less sweet than was the "ideal" bread.

Overall acceptablility was evaluated by the same 48 experienced panelists who completed the consumer profile ballots. The mean scores for each overall acceptability parameter for the three breads are reported in Table 21. No significant ($p > 0.05$) differences were found among the whole-wheat, Tennessee barley and Alaska barley breads when appearance, texture and flavor were evaluated (Table B13, Appendix B). All scores were greater than mid-point on the scale. The overall acceptability values obtained for texture and flavor reflected those obtained when the good parameter was evaluated using the consumer profile technique (Tables 20 and 21).

Table 21—Overall acceptability of whole-wheat, Tennessee and Alaska whole-grain barley bread[ab]

Overall acceptability	Bread type[c]		
	Whole-wheat	Tennessee[d]	Alaska[d]
Appearance	5.1a	4.7a	4.8a
Texture	4.2a	4.2a	4.1a
Flavor	4.3a	4.3a	4.2a

[a]1 = not acceptable and 6 = very acceptable.
[b]n = 48; means in a row followed by like letters do not differ according to Tukey's Range Test ($p > 0.05$).
[c]Formula in Table 3, p. 31; salt level = 2.0%.
[d]20% Thual whole-grain barley flour milled from barley grown in two locations.

CHAPTER V

SUMMARY AND IMPLICATIONS

Functional performance of whole-grain flour milled from Thual hull-less barley grown in Tennessee and Alaska was studied in model and food systems. Variables investigated in model systems were barley flour source and barley flour and salt levels. The composite flours studied included 50% bread flour and varying percentages of whole-wheat to whole-grain barley flour (50:0, 40:10, 20:30 and 30:20). Salt levels investigated were 1.5, 2.0, 2.5 and 3.0% (fwb).

Proximate composition of the barley flours differed with barley source, reflecting the environmental conditions under which the grain was produced. An inverse relationship was found between protein and carbohydrate plus ash content. Whole-grain flour milled from the Tennessee-produced barley had a protein content that equaled the level found in the whole-wheat flour (14.4%), whereas the whole-grain flour milled from the Alaska-produced barley had a lower protein content (10.5%). The amino acid composition of both sources reflected the overall protein content; the Tennessee-produced grain was higher in amino acids important in cohesive proteins, suggesting that production of the barley in Tennessee would improve the functional performance of barley flour in a yeast bread food system.

Dough development studies revealed that barley source, salt level and barley percentage would alter the apparent functionality of composite flours containing whole-grain barley flour in bread systems.

Increasing barley percentage decreased mixogram peak height, indicating a potential decrease in loaf volume. Dough development time which is related to the rate of flour hydration and protein matrix formation was increased as barley flour percentage increased. Tolerance to overmixing as measured by the dough breakdown angle was decreased as barley percentage increased. Barley source altered the extent to which barley incorporation detrimentally affected the mixogram results. As predicted from the proximate analysis and amino acid composition, incorporation of Tennessee barley produced more favorable results.

Increasing salt levels increased peak height, dough development time and tolerance to overmixing. These positive effects of salt on dough quality were greater when the whole-grain Alaska barley flour was a component of the composite flours. However, dilution of the composite flours by the remaining dough ingredients reduced the positive salt effect. Although barley flour source and barley flour and salt levels influenced gas retention in fermenting doughs, the differences observed were small and had no practical importance in the breadmaking system.

Microscopic examination of the whole-grain flours revealed that the barley flour starch granules were bimodal in distribution and approximated wheat starch granules in size and shape. Adhering matter was present. Therefore, the cohesive protein-starch interaction ncessary for successful breadmaking should occur. No differences attributable to barley source were noted.

Apparent viscosity studies revealed that flour components would absorb adequate water to serve as a "water sink" making water available

for protein hydration during breakmaking. Although differences in apparent viscosity characteristics were found when salt and barley levels were varied in both simple and complete dough model systems, the variations were not large enough to alter the functional performance of the composite flours in bread systems. In future studies in which suitability of composite flours for breadmaking is being investigated, only a simple apparent viscosity system that contains the composite flours and water needs to be studied.

It was interesting to note that although the carbohydrate plus ash content of the Tennessee barley flour was lower than was the carbohydrate plus ash content of the Alaska barley flour, the Tennessee barley flour composite systems consistently exhibited greater viscosity. This result led to the postulation that higher levels of water-soluble gums were present in the Tennessee-produced grain.

Results from the model systems studies were used to identify an optimal formula for each barley flour source. The formulas selected for further study using response surface methodology contained 20% barley flour and 2.0% salt.

Both 20% barley breads and a 50% whole-wheat control bread were evaluated using physical and sensory techniques. Loaf volume and specific loaf volume were reduced by 5-6% when either 20% barley bread was compared to the whole-wheat control. The appearance of the Tennessee barley bread did not differ from the whole-wheat bread, however the Alaska barley bread crumb tended to have tunnels or large holes.

Texture Profile Analysis revealed no differences among the three breads except for gumminess. The Alaska barley bread was significantly more gummy than was the Tennessee barley bread. When these breads were evaluated by 48 experienced consumer panelists who were frequent consumers of whole-grain breads, no difference in gumminess was noted. Otherwise, the sensory panelists evaluation of the texture of the three breads supported the conclusions drawn from the instrumental Texture Profile Analysis. The sensory panelists also evaluated appearance and flavor of the breads. No differences in appearance or flavor were found among the three breads, except that the whole-wheat bread was more bland than were the barley breads.

The sensory panelists also were asked to describe their "ideal" bread. It is interesting that the panelists differed widely in their description of their "ideal" bread. It was not surprising that the three breads evaluated did not match the panelists group "ideal" exactly, although deviations from the group "ideal" were small. Future work on several formulas is indicated, if the individual "ideal" breads are to be produced.

Overall acceptability of the appearance, flavor and texture of these breads was evaluated by the same 48 sensory panelisits. No differences were found. The breads were rated between 4 and 5 on a 6-point scale where 1 was not acceptable and 6 was very acceptable. In future studies, overall acceptability of texture and flavor could be evaluated using the parameter good. The overall acceptability values obtained for texture and flavor reflected the values obtained when goodness of

texture and flavor was evaluated. Goodness of appearance should be evaluated to determined if this overall acceptability parameter also could be eliminated in future studies.

Incorporation of barley flour in food systems is feasible. Use of a whole-grain hull-less barley flour rather than a 70% extraction barley flour appears to increase the level of barley flour that can be used successfully in variety breads. In general, consumer acceptability of the two 20% whole-grain barley breads did not differ from the 50% whole-wheat control bread in appearance, flavor or texture.

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APPENDIXES

APPENDIX A

LETTER, RESPONSE FORM, NOTIFICATION FORM, SCORECARD, QUESTIONNAIRE, TABLE OF QUESTIONNAIRE RESULTS

THE UNIVERSITY OF TENNESSEE
KNOXVILLE

College of Human Ecology
Nutrition and Food Science

TO: Former Sensory Panel Participants

FROM: Ruthann B. Swanson, Graduate Student, NFS
Marjorie P. Penfield, Professor, NFS *mpp*

DATE: March 7, 1986

RE: Sensory Panel Recruitment

We are recruiting sensory panelists to participate in the final phase of a whole-grain bread study. We are looking for experienced panelists. Because you have participated on sensory panels in the past, we hope that you will volunteer. You will be asked to come to the Sensory Evaluation Laboratory (Room 17 of the Jessie Harris Building) on March 14 to complete a short questionnaire and to taste several whole-grain bread samples. The session should take no longer than 15 minutes.

Please complete the attached form and return it to M. P. Penfield, NFS, 229 JHB by March 11 (Tuesday) if you are willing to participate. Please indicate the times that you will be available. We will notify you of time that you should come on March 14, after all panelists are scheduled.

Thank you for volunteering!

1215 West Cumberland Avenue, Room 229/Knoxville, Tennessee, 37996-1900/(615) 974-5445, 974-3491

Please complete this form and return to M. P. Penfield, NFS Department, 229 JHB by Tuesday, March 11, 1986 at noon.

Name ______________________________

Campus Address ____________________

Campus Phone ______________________

Please check all times that you are available on Friday, March 14.

_____ 10:00	_____ 1:30
_____ 10:30	_____ 2:00
_____ 11:00	_____ 2:30
_____ 11:30	_____ 3:00
	_____ 3:30
	_____ 4:00

THE UNIVERSITY OF TENNESSEE
KNOXVILLE

College of
Human Ecology

Nutrition and
Food Science

TO: ______________________________

FROM: Ruthann B. Swanson, Graduate Student, NFS
Marjorie P. Penfield, Professor, NFS mpp

DATE: March 11, 1986

RE: Your participation in the sensory evaluation panel on whole-grain bread.

Thank you for volunteering to participate on the sensory panel on whole-grain bread. Please come to the Sensory Evaluation Laboratory (Room 17, Jessie Harris Building) on March 14 at the time listed below.

Time for sensory panel:_____________

Please do not eat or smoke for 30 minutes prior to your participation on the sensory panel. If you find that you cannot come at the above time, please call us at extension 5089 or 6248. Thank you.

1215 West Cumberland Avenue, Room 229/Knoxville, Tennessee, 37996-1900/(615) 974-5445, 974-3491

Judge Number______

Sample Number _______

<u>APPEARANCE-visual</u> characteristics of the slice, crust, and crumb.

	Not at all					Very much so
Dark crust	☐	☐	☐	☐	☐	☐
Coarse crumb grain	☐	☐	☐	☐	☐	☐
Even cell distribution	☐	☐	☐	☐	☐	☐
Fine crumb grain	☐	☐	☐	☐	☐	☐

<u>TEXTURE-how</u> bread feels in the mouth.

	Not at all					Very much so
Good	☐	☐	☐	☐	☐	☐
Soft	☐	☐	☐	☐	☐	☐
Chewy	☐	☐	☐	☐	☐	☐
Crumbly	☐	☐	☐	☐	☐	☐
Dry	☐	☐	☐	☐	☐	☐
Hard	☐	☐	☐	☐	☐	☐
Rough	☐	☐	☐	☐	☐	☐
Gummy	☐	☐	☐	☐	☐	☐
Bad	☐	☐	☐	☐	☐	☐
Moist	☐	☐	☐	☐	☐	☐

PLEASE TURN THE PAGE OVER!

FLAVOR-how bread tastes throughout chewing.

	Not at all					Very much so
Strong	☐	☐	☐	☐	☐	☐
Good	☐	☐	☐	☐	☐	☐
Bland	☐	☐	☐	☐	☐	☐
Salty	☐	☐	☐	☐	☐	☐
Sweet	☐	☐	☐	☐	☐	☐
Bad	☐	☐	☐	☐	☐	☐

OVERALL ACCEPTABILITY- overall impression of product quality.

	Not acceptable					Very acceptable
Appearance	☐	☐	☐	☐	☐	☐
Flavor	☐	☐	☐	☐	☐	☐
Texture	☐	☐	☐	☐	☐	☐

THANK YOU!

Judge Number ______________.

Questionnaire

1. Gender: ____ Male ____ Female

2. Age:
   ____ under 18 years
   ____ 18-24 years
   ____ 25-34 years
   ____ 35-44 years
   ____ over 45 years

3. a. Have you moved to Knoxville since 1976?

   ____ Yes ____ No

   b. If yes, from where did you move? ______________________________

4. Check the time period which best describes the frequency with which you eat foods from the bread and cereals group. (Please check only one.)

   ____ one or more times per day
   ____ 2-4 times per week
   ____ once per week
   ____ 2-3 times per month
   ____ once per month
   ____ less than 12 times per year
   ____ never

5. Check the time period which best describes how frequently you eat whole-grain breads. (Please check only one.)

   ____ one or more times per day
   ____ 2-4 times per week
   ____ once per week
   ____ 2-3 times per month
   ____ once per month
   ____ less than 12 times per year
   ____ never

6. If you indicated that you consume whole-grain breads in question 5, please indicate the type of whole-grain bread most frequently consumed. Place a 1 next to the bread type that you eat most frequently, a 2 next to your second most frequent choice, and a 3 next to your third most frequent choice.

   ____ whole-wheat (100%)
   ____ multi-grain
   ____ whole-what (<100%)
   ____ rye or pumpernickel
   ____ other, please specify ________________________

Thank you for participating in this whole-grain bread study.

Frequency of response by sensory panelists to questionnaire

1. Gender: __5__ Male __43__ Female

2. Age:
   - __0__ under 18 years
   - __16__ 18-24 years
   - __22__ 25-34 years
   - __7__ 35-44 years
   - __3__ over 45 years

3. Residency since 1976:
   - __39__ South
   - __8__ Northeast
   - __6__ Midwest
   - __3__ West Coast

4. Check the time period which best describes the frequency with which you eat foods from the bread and cereals group. (Please check only one.)
   - __43__ one or more times per day
   - __4__ 2-4 times per week
   - __1__ once per week
   - _____ 2-3 times per month
   - _____ once per month
   - _____ less than 12 times per year
   - _____ never

5. Check the time period which best describes how frequently you eat whole-grain breads. (Please check only one.)
   - __31__ one or more times per day
   - __11__ 2-4 times per week
   - __15__ once per week
   - __1__ 2-3 times per month
   - _____ once per month
   - _____ less than 12 times per year
   - _____ never

6. If you indicated that you consume whole-grain breads in question 5, please indicate the type of whole-grain bread most frequently consumed. Place a 1 next to the bread type that you eat most frequently, a 2 next to your second most frequent choice, and a 3 next to your third most frequent choice.

1st Choice	2nd Choice	3rd Choice	
23	7	10	whole-wheat (100%)
17	15	6	multi-grain
7	11	7	whole-wheat (<100%)
1	7	13	rye or pumpernickel
	1[a]	1	[b]other, please specify

[a]Cracked wheat.
[b]Corn.

APPENDIX B

MEAN SQUARES TABLES

Table B1—Mean squares from statistical analyses using reduced models of simple apparent viscosity study parameters at different barley levels and for different barley sources

	Initial viscosity increase				Maximum viscosity						Holding viscosity		Cooling peak viscosity	
	Temperature^{NS}		Time^{NS}		Viscosity		Temperature		Time					
Source	df	ms	df	ms	df	ms	df	ms	df	ms	df	ms	df	ms
Source	1	2.34	1	1.04	1	5046.00**	1	13.50**	1	6.00**	1	912.67***	1	3151.04***
Barley,%	3	7.59	3	3.37	3	16418.78***	3	6.53**	3	2.90**	3	1192.44***	3	26.49^{NS}
Rep	2	1.13	2	0.50	2	11.63^{NS}	2	0.09^{NS}	2	0.04^{NS}	2	24.50^{NS}	2	19.04^{NS}
Source x barley,%	-	-	-	-	3	2255.44*	3	9.81***	3	4.36***	3	115.78***	3	854.82***
Barley,% x rep	-	-	-	-	-	-	-	-	-	-	-	-	6	128.82*
Error	17	1.78	17	0.79	14	266.86	14	0.57	14	0.25	14	6.98	8	21.37

$^{NS}p > 0.05$.
*$p < 0.05$.
**$p < 0.001$.
***$p < 0.0001$.

Table B2—Mean squares from statistical analyses using reduced models of simple apparent viscosity study parameters at different barley and salt levels and for different barley sources

	Initial viscosity increase				Maximum viscosity									
	Temperature		Time		Viscosity		Temperature		Time		Holding viscosity		Cooling peak viscosity	
Source	df	ms	df	ms	df	ms	df	ms	df	ms	df	ms	df	ms
Source	1	0.02^{NS}	1	0.01^{NS}	1	29085.84***	1	4.38*	1	2.34**	1	11375.26***	1	49458.78***
Barley,%	3	9.29***	3	4.13***	3	33966.01***	3	8.56***	3	4.13***	3	15494.71***	3	37450.51***
Salt,%	3	10.04***	3	4.46***	3	53066.73***	3	1.40*	3	0.84*	3	15334.98***	3	81916.06***
Rep	2	0.28^{NS}	2	0.13^{NS}	2	264.76^{NS}	2	0.58^{NS}	2	0.31^{NS}	2	253.39*	2	662.63*
Source x Barley,%	-	-	-	-	3	9420.34***	3	2.73**	3	1.52***	3	2461.37***	3	12361.43***
Source x Salt,%	-	-	-	-	-	-	-	-	-	-	3	137.76*	-	-
Source x rep	-	-	-	-	2	296.53*	-	-	-	-	-	-	-	-
Barley,% x salt,%	-	-	-	-	9	303.08*	-	-	9	0.29^{NS}	9	134.52*	9	4.37**
Salt,% x rep	-	-	-	-	6	198.36^{NS}	-	-	6	0.33^{NS}	-	-	-	-
Source x barley,% salt,%	-	-	-	-	-	-	-	-	-	-	-	-	12	263.54*
Barley,% x salt,% x rep	-	-	-	-	-	-	39	0.58^{NS}	24	0.27*	-	-	-	-
Error	86	0.43	86	0.19	66	93.41	44	0.38	44	0.15	71	44.13	62	112.04

$^{NS}p > 0.05$.
$^{*}p < 0.05$.
$^{**}p < 0.001$.
$^{***}p < 0.0001$.

Table B3—Mean squares from statistical analysis using reduced models of complete dough apparent viscosity parameters at various barley and salt levels and for different barley sources

	Initial viscosity increase				Maximum viscosity					
	Temperature		Time		Viscosity		Temperature		Time	
	df	ms	df	ms	df	ms	df	ms	df	ms
Source	1	1.76*	1	3.96*	1	2959.26***	1	9.37**	1	4.16**
Barley,%	3	9.34***	3	21.02***	3	711.95***	3	8.79***	3	3.91***
Salt,%	3	0.34[NS]	3	0.77[NS]	3	1188.32***	3	8.23***	3	3.66***
Rep	2	1.63*	2	3.66*	2	174.39**	2	8.20***	2	3.64***
Source x barley,%	-	-	-	-	3	505.54***	3	3.64***	3	1.62**
Barley,% x salt,%	9	0.95*	9	2.15*	9	261.26***	9	1.49*	9	0.66*
Barley,% x rep	-	-	-	-	6	114.29**	-	-	-	-
Barley,% x salt,% x rep	-	-	-	-	24	60.49*	-	-	-	-
Error	77	0.42	77	0.95	44	33.13	74	43.93	74	0.26

[NS] $p > 0.05$.
*$p < 0.05$.
**$p < 0.001$.
***$p < 0.0001$.

Table B4—Mean squares from statistical analysis using reduced models of simple dough development study parameters at different barley levels and for different barley sources

	Dough development parameters							
	Development time		Development angle		Peak height		Breakdown angle	
Source	df	ms	df	ms	df	ms	df	ms
Source	1	0.055*	1	3.375^{NS}	1	0.220*	1	0.010^{NS}
Barley,%	3	1.051***	3	235.069***	3	2.404***	3	65.705***
Rep	2	0.004^{NS}	2	0.375^{NS}	2	0.003^{NS}	2	3.969*
Source x barley,%	-	-	-	-	3	0.158**	3	4.344*
Barley,% x rep	-	-	-	-	6	0.045*	-	-
Error	17	0.007	17	2.341	8	0.100	14	0.683

^{NS}p > 0.05.
*p < 0.05.
**p < 0.001.
***p < 0.0001.

Table B5—Mean squares from statistical analysis using reduced models of simple dough development study parameters at different barley and salt levels and for different barley sources

	Dough development parameters							
	Development time		Development angle		Peak height		Breakdown angle	
Source	df	ms	df	ms	df	ms	df	ms
Source	1	0.844***	1	9.065***	1	0.076*	1	0.003^{NS}
Barley,%	3	30.487***	3	866.523***	3	7.024***	3	75.398***
Salt,%	3	7.605***	3	62.829***	3	0.245***	3	11.530***
Rep	2	0.017^{NS}	2	0.242^{NS}	2	0.027^{NS}	2	1.542*
Source x barley,%	3	1.472***	3	24.496***	3	0.265***	3	7.600***
Source x salt,%	-	-	3	3.496**	3	0.031*	3	1.260*
Source x rep	-	-	-	-	2	0.062*	9	1.016***
Barley,% x salt,%	9	0.545***	9	10.148***	9	0.097***	-	-
Barley,% x rep	-	-	-	-	6	0.045**	6	0.470*
Salt,% x rep	-	-	-	-	6	0.020^{NS}	6	0.392^{NS}
Source x barley,% x salt,%	12	0.089***	9	1.463*	9	0.023*	9	0.773**
Error	62	0.011	62	0.524	48	0.009	50	0.202

$^{NS}p > 0.05$.
$*p < 0.05$.
$**p < 0.001$.
$***p < 0.0001$.

Table B6—Mean squares from statistical analysis using reduced models of complete dough development study parameters at different barley and salt levels and for barley sources

	Dough development parameters							
	Development time		Development angle		Peak height		Breakdown angle	
Source	df	ms	df	ms	df	ms	df	ms
Source	1	20.075***	1	20.628***	1	0.960***	1	4.594***
Barley,%	3	42.758***	3	645.100***	3	8.935***	3	38.472***
Salt,%	3	16.383***	3	80.905***	3	0.153***	3	9.549***
Rep	2	0.036*	2	2.198**	2	0.031^{NS}	2	0.346^{NS}
Source x barley,%	3	3.316***	3	2.989***	3	0.108***	3	0.760*
Source x salt,	3	0.119***	3	1.169*	-	-	3	0.573^{NS}
Barley,% x salt,%	9	0.394***	9	4.905***	9	0.202***	9	1.076***
Barley,% x rep	-	-	6	0.545^{NS}	-	-	6	0.579*
Source x rep	-	-	-	-	2	0.046*	-	-
Salt,% x rep	-	-	-	-	-	-	6	0.603*
Source x barley,% x salt,%	9	0.172***	9	1.678***	12	0.048**	9	1.295***
Barley,% x salt,% x rep	30	0.027*	24	0.528*	30	0.031*	-	-
Error	32	0.009	32	0.239	30	0.010	50	0.221

$^{NS}p > 0.05$.
$*p < 0.05$.
$**p < 0.001$.
$***p < 0.0001$.

Table B7—Mean squares from statistical analysis using reduced models of spread ratios for doughs containing different levels of barley flour and salt and for different barley sources and fermentation times

Source	df	ms
Fermentation time	3	0.022***
Barley source	1	0.121***
Barley,%	3	0.096***
Salt,%	3	0.019***
Rep	1	0.000[NS,a]
Barley source x barley,%	3	0.014***
Barley,% x salt,%	9	0.003*
Barley source x barley,% x salt,%	12	0.004***
Error	219	0.000[a]

[NS] $p > 0.05$.
*$p < 0.05$.
***$p < 0.0001$.
[a] ms < 0.001.

Table B8—Mean squares from statistical analysis of loaf volume, specific loaf volume and baking loss

Source	df	Loaf volume	Specific loaf volume	Baking loss
		ms		
Bread type	2	10696.00*	0.13*	0.84*
Error	15	1568.00	0.02	0.18

*$p < 0.05$.

Table B9—Mean squares from statistical analysis of Texture Profile Analysis parameters

Source	df	Hardness	Cohesiveness	Springiness	Gumminess	Chewiness
Bread type	2	0.093^{NS}	0.006^{NS}	0.005^{NS}	0.032*	0.026^{NS}
Error	12	0.034	0.003	0.007	0.008	0.073

$^{NS}p > 0.05$.
*$p < 0.05$.

Table B10—Mean squares from statistical analyses of sensory appearance parameters

		Appearance parameters			
Source	df	Dark crust	Coarse crumb grain	Even cell distribution	Fine crumb grain
		ms			
Bread type	3	2.51*	12.67***	23.76***	2.93***
Judges	47	1.83***	2.60**	1.05^{NS}	14.41***
Error	141	0.66	1.22	1.44	1.28

$^{NS}p > 0.05$.
*$p < 0.05$.
***$p < 0.0001$.

Table B11—Mean squares from statistical analyses of sensory texture parameters

		Texture parameters									
Source	df	Good	Soft	Chewy	Crumbly	Dry	Hard	Rough	Gummy	Bad	Moist
		ms									
Bread type	3	17.55***	7.05***	0.41^{NS}	5.78***	1.35^{NS}	3.53**	9.05***	38.74***	9.45***	4.39***
Judges	47	2.17***	1.62*	2.85***	1.41***	2.26***	1.41***	1.16*	4.24***	3.05***	2.14*
Error	141	0.88	0.91	1.17	0.59	0.78	0.57	0.64	1.31	0.91	0.84

$^{NS}p > 0.05$.
*$p < 0.05$.
**$p < 0.001$.
***$p < 0.0001$.

Table B12—Mean squares from statistical analyses of sensory flavor parameters

Source	df	Flavor parameters: Strong	Good	Bland	Salty	Sweet	Bad
		ms					
Bread type	3	2.74^{NS}	24.38***	3.56*	0.73^{NS}	2.26*	11.12***
Judges	47	4.47***	2.43***	3.08***	2.93***	3.79***	3.30***
Error	141	1.28	0.98	1.07	0.46	0.75	1.01

$^{NS}p > 0.05$.
*$p < 0.05$.
***$p < 0.0001$.

Table B13—Mean squares from statistical analysis of overall acceptability parameters

Source	df	Overall acceptability parameters: Appearance	Flavor	Texture
		ms		
Bread type	2	1.86^{NS}	0.05^{NS}	0.11^{NS}
Judges	47	17.81^{NS}	2.93***	3.97***
Error	143	1.02	0.91	0.94

$^{NS}p > 0.05$.
***$p < 0.0001$.

APPENDIX C

INTERACTION MEANS TABLES

Table C1—Barley level x barley source interaction means ± SD for parameters from simple apparent viscosity systems

		Barley level (%)			
Parameter	Source	0	10	20	30
Maximum viscosity (BU)	TN	435.0 ± 0.0	380.0 ± 5.0	360.0 ± 17.3	355.0 ± 22.9
	AK	435.0 ± 0.0	382.3 ± 15.7	321.7 ± 24.7	275.0 ± 13.2
Temperature of maximum viscosity (°)	TN	86.0 ± 0.4	83.0 ± 0.9	86.5 ± 0.7	86.3 ± 0.4
	AK	86.0 ± 0.4	84.3 ± 0.0	83.5 ± 0.0	82.0 ± 0.5
Holding viscosity (BU)	TN	80.0 ± 0.0	76.7 ± 5.8	60.0 ± 0.0	60.0 ± 0.0
	AK	80.0 ± 0.0	61.3 ± 2.3	46.7 ± 5.8	39.3 ± 1.2
Cooling peak viscosity (BU)	TN	128.3 ± 2.9	130.0 ± 10.0	143.3 ± 15.3	148.3 ± 2.9
	AK	128.3 ± 2.9	124.3 ± 9.3	106.7 ± 5.8	99.0 ± 3.6

Table C2—Barley level x barley source interaction means ± SD for parameters from simple apparent viscosity systems containing salt

		Barley level (%)			
Parameter	Source	0	10	20	30
Maximum viscosity (BU)	TN	614.2 ± 42.3	584.2 ± 45.6	568.7 ± 44.8	571.7 ± 50.1
	AK	614.2 ± 42.3	572.1 ± 44.6	530.8 ± 38.1	482.3 ± 43.5
Temperature of maximum viscosity (°)	TN	89.3 ± 0.6	88.6 ± 0.6	88.3 ± 0.9	88.7 ± 0.8
	AK	89.3 ± 0.6	88.6 ± 0.6	87.9 ± 0.7	87.3 ± 0.5
Holding viscosity (BU)	TN	405.8 ± 60.4	360.0 ± 54.1	356.8 ± 53.2	363.8 ± 59.4
	AK	405.8 ± 60.4	339.2 ± 59.0	299.6 ± 44.1	265.2 ± 41.5

Table C3—Barley level x salt level interaction means ± SD for parameters from simple apparent viscosity systems

Parameter	Salt level (%)	Barley level (%)			
		0	10	20	30
Maximum viscosity (BU)	1.5	555.5 ± 11.8	517.2 ± 8.7	496.5 ± 19.4	473.3 ± 47.7
	2.0	603.3 ± 10.3	566.7 ± 18.3	531.7 ± 19.7	499.2 ± 45.7
	2.5	640.0 ± 11.8	596.5 ± 10.0	575.8 ± 26.7	595.0 ± 27.6
	3.0	658.3 ± 2.6	632.2 ± 9.1	548.0 ± 49.0	587.5 ± 6.4
Holding viscosity (BU)	1.5	153.3 ± 2.6	122.5 ± 4.2	110.8 ± 12.0	105.0 ± 20.2
	2.0	171.7 ± 9.3	140.8 ± 8.0	129.2 ± 13.9	118.3 ± 24.0
	2.5	198.3 ± 2.6	164.2 ± 17.7	149.2 ± 17.7	133.3 ± 28.0
	3.0	220.0 ± 0.0	188.3 ± 9.3	160.8 ± 21.3	155.0 ± 33.2
Cooling peak viscosity (BU)	1.5	326.7 ± 2.6	280.8 ± 13.2	265.0 ± 26.1	259.2 ± 47.2
	2.0	382.0 ± 9.3	325.8 ± 14.6	307.8 ± 31.8	287.5 ± 49.1
	2.5	435.0 ± 8.9	365.8 ± 19.6	355.0 ± 30.6	342.5 ± 64.4
	3.0	480.0 ± 4.5	425.8 ± 15.3	385.0 ± 42.2	378.8 ± 72.1

Table C4—Barley level x salt level interaction means ± SD for parameters from complete dough apparent viscosity systems

Parameter	Salt level (%)	Barley level (%)			
		0	10	20	30
Temperature of initial viscosity increase (°)	1.5	66.5 ± 0.8	63.0 ± 0.6	64.0 ± 1.6	63.8 ± 1.1
	2.0	67.0 ± 1.3	64.5 ± 1.2	64.0 ± 0.0	64.0 ± 1.3
	2.5	65.5 ± 0.0	63.8 ± 1.1	64.8 ± 0.8	64.0 ± 0.9
	3.0	65.0 ± 0.8	64.5 ± 1.2	64.5 ± 0.8	64.2 ± 1.1
Maximum viscosity (BU)	1.5	113.3 ± 11.3	117.8 ± 5.3	108.3 ± 17.0	108.3 ± 17.0
	2.0	101.7 ± 6.8	118.2 ± 10.8	110.2 ± 7.8	105.0 ± 10.3
	2.5	132.3 ± 7.8	121.3 ± 2.2	113.5 ± 12.0	110.0 ± 13.0
	3.0	137.0 ± 2.9	125.2 ± 5.7	117.3 ± 14.1	118.2 ± 5.0
Temperature of maximum viscosity (°)	1.5	77.8 ± 1.7	75.6 ± 0.6	75.1 ± 0.7	75.5 ± 1.2
	2.0	76.2 ± 0.4	76.0 ± 0.0	75.9 ± 1.1	75.5 ± 1.7
	2.5	77.2 ± 0.4	75.9 ± 1.1	76.1 ± 0.9	75.8 ± 1.2
	3.0	77.5 ± 0.0	75.5 ± 1.7	76.8 ± 1.3	76.8 ± 0.9

Table C5—Barley level x barley source interaction means ± SD for parameters from complete dough apparent viscosity systems

		Barley level (%)			
Parameter	Source	0	10	20	30
Maximum viscosity (BU)	TN	121.1 ± 16.7	124.4 ± 4.4	122.7 ± 5.9	118.8 ± 6.5
	AK	121.1 ± 16.7	116.8 ± 7.2	102.0 ± 8.5	102.6 ± 11.1
Temperature of maximum viscosity (BU)	TN	77.2 ± 1.0	76.5 ± 1.2	76.5 ± 1.2	76.6 ± 1.0
	AK	77.2 ± 1.0	76.6 ± 1.0	75.4 ± 0.9	75.1 ± 1.2

Table C6—Barley level x barley source interaction means ± SD for parameters from simple dough development systems

Parameter	Source	Barley level (%)			
		0	10	20	30
Peak height (cm)	TN	7.0 ± 0.2	6.5 ± 0.2	5.9 ± 0.0	5.5 ± 0.0
	AK	7.0 ± 0.2	5.8 ± 0.1	5.9 ± 0.1	5.4 ± 0.3
Breakdown angle (°)	TN	12.5 ± 1.5	11.5 ± 1.3	8.0 ± 1.0	4.2 ± 0.8
	AK	12.5 ± 1.5	9.2 ± 0.3	9.5 ± 0.5	5.2 ± 0.8

Table C7—Salt level x barley source interaction means ± SD for parameters from simple dough development systems

Parameter	Source	Salt level (%) 1.5	2.0	2.5	3.0
Development angle (°)	TN	18.0 ± 6.5	18.2 ± 6.5	18.3 ± 6.9	14.1 ± 5.1
	AK	19.4 ± 5.4	18.1 ± 4.7	18.3 ± 5.6	15.8 ± 3.9
Peak height (cm)	TN	6.5 ± 0.5	6.7 ± 0.6	6.8 ± 0.6	6.7 ± 0.6
	AK	6.6 ± 0.4	6.7 ± 0.6	6.8 ± 0.5	6.8 ± 0.4
Breakdown angle	TN	6.7 ± 1.9	6.2 ± 2.3	6.0 ± 2.3	4.9 ± 2.2
	AK	6.6 ± 1.9	6.5 ± 1.5	5.3 ± 1.1	5.3 ± 1.2

Table C8—Barley level x barley source interaction means ± SD for parameters from simple dough development systems containing salt

		Barley level (%)			
Parameter	Source	0	10	20	30
Development time (min)	TN	3.6 ± 0.5	3.9 ± 0.7	5.5 ± 0.6	6.4 ± 0.5
	AK	3.6 ± 0.5	4.4 ± 0.6	4.9 ± 0.7	5.9 ± 0.5
Peak height (cm)	TN	7.2 ± 0.2	7.0 ± 0.2	6.5 ± 0.2	5.9 ± 0.1
	AK	7.2 ± 0.2	6.8 ± 0.2	6.6 ± 0.2	6.1 ± 0.1
Breakdown angle (°)	TN	6.8 ± 1.1	8.0 ± 0.8	6.2 ± 1.2	2.7 ± 0.8
	AK	6.8 ± 1.1	6.7 ± 1.1	6.1 ± 0.5	4.1 ± 0.7

Table C9—Barley level x salt level interaction means ± SD for parameters from simple dough development systems

Parameter	Salt level (%)	Barley level (%) 0	10	20	30
Development time (min)	1.5	2.9 ± 0.1	3.9 ± 0.2	4.3 ± 0.4	5.5 ± 0.1
	2.0	3.5 ± 0.1	3.8 ± 0.5	5.0 ± 0.5	5.9 ± 0.5
	2.5	3.9 ± 0.1	3.8 ± 0.3	5.4 ± 0.4	6.6 ± 0.2
	3.0	4.2 ± 0.1	5.2 ± 0.2	6.0 ± 0.3	6.6 ± 0.4
Peak height (cm)	1.5	7.4 ± 0.1	6.7 ± 0.2	6.4 ± 0.2	6.0 ± 0.2
	2.0	7.3 ± 0.2	7.4 ± 0.8	6.4 ± 0.2	5.9 ± 0.1
	2.5	7.5 ± 0.1	7.0 ± 0.3	6.6 ± 0.1	6.0 ± 0.2
	3.0	7.1 ± 0.0	7.1 ± 0.1	6.6 ± 0.2	6.0 ± 0.2

Table C10—Salt level x barley source interaction means ± SD for time of dough development (min) in complete dough development systems

	Salt level (%)			
Source	1.5	2.0	2.5	3.0
TN	6.6 ± 1.5	7.3 ± 1.6	7.7 ± 1.5	8.5 ± 1.6
AK	5.7 ± 1.0	6.2 ± 1.0	7.0 ± 0.7	7.6 ± 0.9

Table C11—Barley level x barley source interaction means ± SD for parameters from complete dough development systems

Parameter	Source	Barley level (%)			
		0	10	20	30
Development time (min)	TN	5.5 ± 0.8	7.1 ± 0.8	7.9 ± 0.8	9.6 ± 0.9
	AK	5.5 ± 0.8	6.4 ± 0.9	6.7 ± 0.9	7.9 ± 0.6
Peak height (cm)	TN	6.9 ± 0.2	6.5 ± 0.2	6.0 ± 0.2	5.6 ± 0.2
	AK	6.9 ± 0.2	6.3 ± 0.3	5.7 ± 0.2	5.4 ± 0.2

Table C12—Barley level x salt level interaction means ± SD for parameters from complete dough development systems

Parameter	Barley level (%)	Salt level (%)			
		1.5	2.0	2.5	3.0
Development time (min)	0	4.4 ± 0.1	5.1 ± 0.1	6.2 ± 0.2	6.3 ± 0.2
	10	5.9 ± 0.5	6.3 ± 0.7	7.0 ± 0.1	7.8 ± 0.4
	20	6.4 ± 0.8	7.1 ± 0.8	7.2 ± 0.5	8.6 ± 0.6
	30	7.8 ± 0.7	8.6 ± 1.0	9.1 ± 1.1	9.6 ± 1.1
Peak height (cm)	0	6.7 ± 0.2	6.9 ± 0.1	6.9 ± 0.2	7.1 ± 0.2
	10	6.6 ± 0.1	6.5 ± 0.3	6.3 ± 0.2	6.2 ± 0.2
	20	5.9 ± 0.3	6.0 ± 0.1	5.8 ± 0.3	5.7 ± 0.2
	30	5.8 ± 0.2	5.5 ± 0.2	5.4 ± 0.1	5.4 ± 0.3

VITA

Ruthann Burroughs Swanson was born June 5, 1956, in Loris, South Carolina. She was graduated from Tabor City High School, Tabor City, North Carolina in June of 1974. She received a Bachelor of Science in Home Economics degree with a major in home economics education from the University of North Carolina-Greensboro in December 1977. From March 1978 to July 1979 she was employed by the North Carolina Agricultural Extension Service in Watauga County (Boone) as an Assistant Extension Agent, 4-H.

The author entered graduate school in the Department of Food Science, Nutrition and Food Systems Adminstration at The University of Tennessee, Knoxville, in the summer of 1980; she was employed as a Graduate Teaching Assistant. After receiving a Master of Science degree in food science with a collateral in nutrition in August 1981, she was employed as an instructor in the General Education and Service Technology Divisions of Tanana Valley Community College in Fairbanks, Alaska. She also was a consultant to the University of Alaska Agricultural Experiment Station, Fairbanks. In the summer of 1982, the author began her studies toward the Doctor of Philosophy degree in the Department of Nutrition and Food Sciences at The University of Tennessee, Knoxville. In January 1984, she was awarded an Agricultural Experiment Station Graduate Research Assistantship. Requirements for the Doctor of Philosophy degree in human ecology, food science option with a collateral in food technology and science were met in June 1986.

The author is a member of the Institute of Food Technologists, American Association of Cereal Chemists, Phi Kappa Phi, Omicron Nu, Phi Tau Sigma and Gamma Sigma Delta.

Ruthann Burroughs Swanson is the spouse of Samuel Edward Swanson and the daughter of Volley Reece Burroughs, Jr., and Annie Ruth Fowler Burroughs.