SOME EFFECTS OF SOY-PROTEIN CONCENTRATE ON DOUGH AND BREAD CHARACTERISTICS

by

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INTRODUCTION

During recent years there has been considerable interest in the fortification of commonly used low-cost foods with protein, minerals, and vitamins as a means of bettering the nutritional status of people in all economic brackets.

Wheat proteins, like many other cereal proteins, are relatively low in their nutritional value. They lack some of the essential amino acids---especially lysine---and can be much improved by a judicious supplementation with soybean protein. The protein-rich fraction of soybean is the main by-product from commercial soybean oil extraction and costs much less than other high quality proteins from animal sources (1). Addition of soybean proteins to wheat flour not only increases the overall protein level, but also renders wheat proteins more nutritionally efficient.

The use of soy flour in the baking industry, and specifically for increasing the nutritive value of white bread, has been widely investigated. In general, studies have included oxidation requirements, buffering capacity, loaf volume, palatability, and the use of raw and heat-treated soy flours. Only limited work has been reported on the use of soy-protein concentrate grits to produce specialty breads.

The object of the present work was to assess the baking quality of three grinds of commercially produced soy-protein concentrate grits and to determine their effects on dough characteristics.

REVIEW OF LITERATURE

Soybean Composition

The soybean seed consists principally of protein, oil, carbohydrate, and mineral constituents. The proportions in which these various components are present are influenced considerably by soil, climatic conditions and variety. The variation in composition, as revealed by analysis of hundreds of samples, have been summarized by Bailey et al. (2) and are shown in Table 1.

TABLE 1

CHEMICAL COMPOSITION OF SOYBEANS

	Minimum %	Maximum %	Average %
Moisture	5.02	9.42	8.0
Ash	3.03	6.35	4.6
Fat	13.50	24.20	18.0
Fiber	2.84	6.27	3.5
Protein	29.60	50.30	40.0
Pentosan	3.77	5.45	4.4
Sugar	5.65	9.46	7.0
Starch-like substances by diastace	4.65	8.97	5.6

The chief protein of soybean is the globulin fraction (3) which contains all the essential amino acids necessary for growth. However, soybean protein is relatively poor in sulfur containing amino acids.

The following enzymes are in soybeans: urease, amylase, protease, allantoniase, ascorbic acid oxidase, carborylase, catalase, β-glycosidase, lipase, lipoxidase, phytase, and uricase (3).

According to Markley and Goss (4) the soybean oil fraction is composed of glycerides of saturated and unsaturated fatty acids, and several other lipoid materials. Included among the lipoid materials is a mixed phosphatide fraction (soy lecithin) which makes up 1.8 to 3.2% of the oil (5).

The carbohydrate material of soybean consists of sugars, dextrin, pentosans, galactans, cellulose, and organic acids. Starch is practically absent, or at best present in amounts of less than 3%. The principle sugars present in soybean are sucrose, raffinose, and stachyose (6).

Soybeans contain considerably more calcium and phosphorus than any of the cereal grains and it constitutes an excellent source of available iron. Sodium, potassium, magnesium, and trace minerals such as copper, cobalt, zinc, manganese, etc., are also present in soybeans (4, 7).

Soybeans contain a high level of thiamine, which is largely destroyed by heat treatments necessary to prepare soybeans for human consumption (7). Soybeans also contain other water soluble vitamins such as riboflavin, pyridoxine, pantothenic acid, folic acid, and niacin in varying amounts. Inosital and choline are present as components of the soy lecithin fraction (7). Other fat-soluble vitamins or vitamin-like substances such as carotene and tocopherols (vitamin E) are also present in soybeans.

Several physiologically active factors present in soybeans are: antioxygenic, allergenic, goitrogenic, blood coagulant, antiamylase, and anti-tryptic (trypsin inhibitor) (3). More recently other physiologically active constituents have been reported in soybeans (8). These include saponin, hemagglutinin (soyin), and estrogenic substances (isoflavones).

Soy-protein Concentrates

Soy-protein concentrate has been defined as "the product prepared from high quality, sound, clean, dehulled soybeans by removing most of the oil and water-soluble nonprotein constituents and shall contain not less than 70% protein (N x 6.25) on a moisture-free basis" (9). Products conforming to this definition were made a number of years ago for industrial usage as adhesives (10). However, it is only since 1959 that edible products of this type have become commercially available (11).

Soy-protein concentrates are manufactured from hexane-defatted flakes or flour by three processes, which differ primarily in the means utilized to immobilize the major protein components during separation of the low molecular weight carbohydrates, mineral matter, and other minor constituents. One process takes advantage of the fact that the protein components are insoluble in aqueous alcohol solution of about 60 to 80% concentration (12, 13, 14). Various solvent compositions and extraction temperatures can be employed and are chosen to give the minimal loss of protein compatible with an economical rate of extraction of sugars and soluble matter. For economic reasons the organic solvent must be recovered and rectified in an efficient manner. Another process is based upon the long-known fact that the major soy globulins have limited solubility in aqueous acid at their average isoelectric point of about pH 4.5 (3, 15, 16). In this process, there is a greater loss of protein nitrogen because of the solubility of the "whey" proteins at this pH. In a third process, the proteins of the soybean source material are denatured by moist-heat treatment to insolublize them. The sugars and other constituents are then extracted with water (17).

"All three processes are amenable to batch or continuous extraction operations. After drainage of solvent, the residual material is desolventized and dried. The product prepared by aqueous acid leaching may be neutralized with food-grade alkali prior to drying. Drying may be accomplished in various ways, using for example, range driers, Schnecken driers, flash driers, or spray driers. The last type is most often used with the neutral product arising from the aqueous acid leaching process. The yield of dried concentrate from each process is about 60 to 70%, based on the weight of defatted soybean flakes or flour."

"Since the recovery of solvent is mandatory in alcohol-solvent processing, the solubles are concentrated sufficiently to permit their economical recovery in the form of a molasses-like sirup or in a dry state. This product contains primarily, the sugars, sucrose, stachyose, and raffinose, together with minor sugars, nitrogenous constituents, and mineral matter, and can be used as an additive in feedstuffs. With aqueous processing, the soluble solids can also be recovered by evaporative means."

"The commercial soy-protein concentrates derived by means of the three basic processes have the same gross compositional characteristics. The residual polysaccharides in the concentrate consist mainly of arabinogalactan and acidic pectin-type polysaccharide together with some galactomannan, xylan hemicellulose, and cellulose arising from the soybean hull and cell walls. The crude fiber content is indicative of the efficiency of the dehulling operation in preparing the defatted source material. The concentrates prepared by the aqueous alcohol and the water extraction processes have low nitrogen solubility indices because of protein denaturation, by the solvent in the former instance, and through moist heat in the latter. In contrast, the product of aqueous acid extraction, when neutralized before drying shows a higher nitrogen solubility index. The essential amino acid composition of the three commercial concentrates are also about the same; some minor differences may arise from varietal differences in the bean and in the nature of the nitrogenous substances removed through extraction."

"Soy-protein concentrates have a low flavor level and range in color from cream-yellow to light tan. High nitrogen solubility is retained by the concentrate prepared by aqueous acid leaching followed by neutralization. All soy-protein concentrates possess water absorption and fat-finding characteristics, functional properties of value in various food systems. The low flavor level, together with improved absorption characteristics as compared to commercial soy flours, have been major factors in the acceptance of soy-protein concentrates for food use (11)."

Soy-protein concentrates can be classified according to particle size (1). The term "flour" generally refers to materials ground fine enough to pass through a 100-mesh screen. Soy grits refer to particles of larger size and are described in terms of the following U.S. standard sieves:

Coarse	No. 10 to No. 20
Medium	No. 20 to No. 40
Fine	No. 40 to No. 80

Properties of Soy and Doughs Containing Soy

Doughs containing soy products require more water to reach a standard consistency than doughs without soy products (18, 19). Bohn and Favor (20) reported that full-fat and low-fat soy flours had water absorptions of 85% and 110% respectively. Pollock and Geddes (18), working with a laboratory extracted soy flour, found that heat treatment increased water absorption of the soy flour. Finney et al. (21) reported that the water absorption of doughs containing soy flour was increased approximately 1% for each 1% of soy flour added. However, Rainey and Horan (22) found no significant differences in water absorption when doughs were made with or without 3% of a chemically treated soy flour. These workers also reported no significant change in farinogram peak time when doughs were made with and without the same soy flour.

Pollock and Geddes (18) reported farinogram dough characteristics of doughs made with and without the addition of raw and heat-treated (one hour at 100°C.) soy flours. These workers found that, as little as, 1% of unheated soy flour imparted to the dough the farinogram characteristics considered typical of a strong flour and the 5% of heat-treated soy flour altered the control curve less than 1% of raw soy flour. These authors also made "rest period" farinograms and again, the raw soy flour gave the most pronounced effects.

Farinograms were made and reported by Paulsen and Horan (23). These workers tested five commercial edible soy flours, four of them were heat-treated and the fifth chemically-treated. Very significant differences were found among the heat-treated samples, each with a different protein dispersibility index (PDI). The farinograms of heat-treated soy flour were also quite different from that of the chemically-treated, even though they had the same PDI.

Doughs containing soy flour according to Hafner (24) provide some resistance to dough expansion. This effect is somewhat proportional to the level of soy flour used and can be partially overcome by adjustment of the quantity of water used in the dough and by prolongation of proofing time. Turro and Sipos (25) recently reported that extensigram characteristics of doughs (made by sponge and dough method) made with soy flour added at the sponge stage and doughs made with soy flour added at the dough stage varied considerably.

Doughs with soy flour added at the sponge stage gave less resistance to extension and greater extensibility readings than doughs with soy flour added at the dough stage.

Pollock and Geddes (26) found that raw soy flour slightly increased gas production, however, the gas retention of doughs containing raw soy flour were less than those without them. These workers also reported that laboratory heat-treated soy flour improves gas retention but decreases gasing power. Pomeranz (19) reported that carbon dioxide production in soy-wheat flour doughs was unaffected by the particle size of soy, but was reduced by heat treatment or by desugaring the soy flour. Gas retention was higher in doughs containing coarse soy particles than finely pulverized soy flour. Excessively toasted soy flour also reduced gas retention more than did slightly toasted soy flour.

Commercial soy products vary greatly in their PDI values. The PDI refers to the percentage of total protein that will dissolve in water under standardized conditions. The PDI of raw, unprocessed soy protein products is in the range of 80 to 100%, and that of toasted soy protein products, 0 to 20% (27). Investigations made by Ofelt et al. (28, 29), Finney et al. (21), and Pollock and Geddes (18, 26) indicated no correlation between soy products PDI and the quality of bread made with these products.

Paulsen and Horan (23) reported that temperature, chemical-treatment, and pH affect PDI values. These authors found that monovalent salts, e.g., sodium chloride and potassium acetate, do not decrease PDI values as much as divalent salts, e.g., calcium chloride and barium chloride, and acids (citric, phosphoric, and hydrochloric). Circle (3) reported that in the presence of dilute salt solutions (0.05 to 0.30 N) of sodium floride, sodium chloride, sodium bromide, sodium sulfate, and calcium chloride, soybean protein dispersibility sharply decreases and varies with the kind of salt used. Heat-treatment at various pH values resulted in a decrease in PDI values (23).

Soy in Breadmaking

Although the nutritional advantages of soy flour have been appreciated by many, its acceptance as a bread ingredient has been rather limited because of functional disadvantages and nonuniformity of commercial soy flours in early stages of their development. The functional problems generally associated with using soy flours include: (a) alteration of absorption, mixing, and machining properties; (b) adverse effects on color and flavor; (c) changes in fermentation rates; and (d) effects on the gluten complex, including oxidation requirements (30, 20, 31).

Early work of Bailey et al. (2) and of Bohn and Favor (18) showed that the quality of soy-enriched bread was poor because soy flour harmed dough quality, impaired crumb color and texture, and decreased loaf volume. It was shown that for best results soy flour should be added at the sponge stage. More recently Turro and Sipos (25) reported that adding soy flour to the dough stage of bread made by the sponge and dough method produced the best results.

Heat treatment of soy products has been one of the properties most extensively studied with reference to the effects on breadmaking. Raw soy flour is rich in many enzymes such as lipoxidase, amylase, and proteases. Lipoxidase preparations from raw soy flour have been used in small quantities for dough bleaching and overall improvements in conventional breadmaking for more than 40 years (19). The additives bleach the carotenoid pigments of flour (32). Ofelt et al. (28), Finney (31), and Pollock and Geddes (18) have shown that raw (unheated) soy flour causes softening of bread dough and loss of loaf volume. These effects may be caused by the amylases (33), proteases (34), or some other unidentified enzymes or reducing substances in the soy flour. Commercial soy flours, however, are usually heated enough to substantially inactivate all their enzymes. Finney et al. (21) found that the effects of heat-treatment was more pronounced for soy flours than for grits. Heat-treatment of flours usually resulted in higher water absorption and a decrease in mixing time. Double heat-treatment of flours resulted in impaired crumb grain and in lowered loaf volume. These effects were not detectable when grits were added.

Many of the functional disadvantages of soy flour as a bread supplement can be overcome in part by the addition of the proper amount of oxidant (30, 29, 35, 36). A study by Finney et al. (21) clearly correlated oxidation requirements with protein dispersibility of soy flours used in breadmaking. Ofelt et al. (29) found that the optimum bromate requirement for commercial defatted soy flours show good agreement when all characteristics such as loaf volume, external loaf character, crumb grain, and texture are considered. These workers found that 3.0 to 5.0 mgs. of potassium bromate per 100 g. of flour gave the best loaf volume and crumb characteristics in a dough containing 5% of soy flour.

Almost without exception, the addition of commercial soy flour to bread doughs yields bread which has a harsh crumb as compared with non-soy loaves (19). Bayfield and Swanson (30) reported that for optimum texture in bread, extra bromate and shorter fermentation are required when soy flour is used.

Pollock and Geddes (26) found, as a result of fractionation studies on soy flour, that sugars, sulfhydryl groups, and inorganic constituents were relatively unimportant in the performance of soy flour. These workers concluded that removing any specific constituent would probably not substantially improve the baking quality of soy flour. Finney et al. (21) found that a water-nondispersible soy protein isolate was preferable to the soluble one.

Use of products dispersible in water resulted in lower loaf volume and poorer crumb grain. The water-nondispersible protein isolate was equal to properly processed soy flour (both used at 2.5% soy protein level). Adding a 70% soy-protein concentrate resulted in bread of inferior quality. Pomeranz (19) reported that soy-protein concentrates or isolates showed no advantage (on an equal protein basis) over soy flour in baking bread from wheat flour of varying extractions by a lean formula. Ehle and Jansen (37) found that on an isonitrogenous basis the effects on loaf volume of a protein isolate were equal to those of a toasted soy flour. Studying the effects on baking characteristics of including isolated soybean proteins (isoelectric and calcium coagulated) in wheat bread, Mizrahi et al. (38) reported that loaf volume decreased proportional with the level of protein addition. These workers also found that bread flavor was not significantly effected by addition of up to 8% of isolated proteins.

Adding soy flour of various particle sizes to wheat flour affects breadmaking and loaf quality; doughs incorporating finely powdered soy products required more water and dough mixing and slightly more bromate than those containing coarse soy products or controls (21). Adding coarse soy products gave bread that had better crumb grain and color and larger loaf volume than were obtained by use of the less granular soy products. The use of toasted soy grits gave more appetizing breads and overcame the objectionable brown color of breads containing finely powdered soy flours (19).

Due to the fact that a soy product increases water absorption of dough, the high moisture content renders the crumb softer. Ying and Geddes (39) reported that 3 to 5% additions of soy flour increased the softness of fresh bread but had little or no effect on rate of decrease in softness during storage. Crumb swelling power during storage was unaffected but crumbliness was increased by adding soy flour. Soy flour increased moisture retaining capacity of the crumb. Hale (40) reported that soy bread had good toasting quality.

Crumb color of bread containing any appreciable amount of soy flour has long been a problem. Pollock and Geddes (18) working with raw and heat-treated soy flours reported that a 5% level of any soy flour sample used in their experiment was sufficient to cause a significant crumb discoloration. They also found that samples heated to 100° or 125°C. gave progressively more undesirable color. It was reported by Ofelt et al. (29) that while some of the commercial defatted soy flours they studied caused the bread crumb to appear whiter than the control, the majority gave a crumb that had an off-white or gray cast that was more often dull than bright. Finney et al. (21) found the darkening of crumb color to be closely related to heat treatment that the particular sample had received and correlated this with the loss of water-dispersible protein of the sample.

Palatibility studies made by Finney et al. (36) indicated that bread made from wheat flour was preferable to that containing 4% or more soy flour. Ofelt et al. (41) found no significant flavor differences in a bread containing 5% soy flour. Raney and Horan (22) reported that a commercial soy flour was completely satisfactory in concentrations up to 3%. Ehle and Jansen (46) found that adding 4.1% toasted soy flour had little effect, but that 10.8% or more substantially harmed organoleptic properties of bread. Mugler et al. (42) using a 70% soy-protein concentrate reported an improvement in bread flavor with the addition of 7.5% of the concentrate. Unheated or under-heated soy flour gives a distinctly "beany" flavor to the product to which it is added a fairly strong heating is necessary to dispel this undesirable flavor (29, 21).

Continuous Baking Process

Continuous-dough methods take advantage of the development of the brew or liquid ferment process (43) which culminated in the ADMI Stable Ferment process (44). The basic elements of a continuous-dough system (Figure 1) are: (a) a liquid ferment system; (b) a means of bringing together all the materials for dough into a homogenous mass; (c) a unit for developing the dough and for extruding and dividing it into individual pieces for immediate panning. After panning the dough goes directly to the proof chamber and from there to the oven. There is, in contrast to conventional doughmaking, no bulk fermentation, no overhead proof or bench proof, and no moulding of the dough pieces.

With regard to their over-all composition, the formulae for continuous-dough bread do not differ from those of conventional batch bread, being largely determined by the Federal Bread Standards. However, there is considerable divergence in the sequence in which the formula ingredients are added. Table 2 shows how the ingredients of a typical continuous-dough white bread formula are brought together. In this example 30% of the total flour is used in the brew. However, there has been a recent trend toward the use of up to 70% flour in the brew (45, 46) some bakeries are still using no flour in the brew (47). Using flour in the brew has created some controversy as to its effectiveness for improving the over-all quality of continuous bread. Trum and Snyder (48) reported that high percentages of flour in the brew resulted in stronger bread crumb and body without loss of softness; an increase in flavor was also noted. High-flour brews also allow the use of less added sugar, yet maintain, or improve the sweetness level in the baked bread (45, 48). In a later publication Trum (49) expanded on the list of advantages of high-flour brews reporting: (a) increased loaf volume; (b) stronger crumb body; (c)

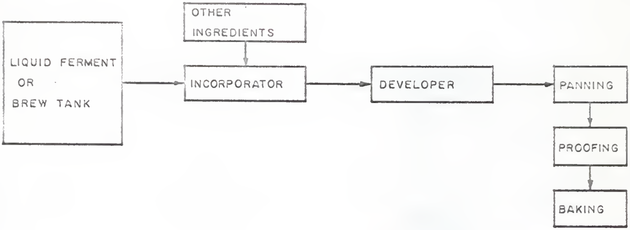

Fig. 1. Schematic Diagram of Continuous-Dough Method Bread Baking

TABLE 2

TYPICAL CONTINUOUS-DOUGH WHITE BREAD FORMULA

Time Location	0 min. Brew Tank	105 min. Brew Tank	150 min. Incorporator	Total %
Flour	30		70	100
Water	58	5	4.5	67.5
Yeast	3			3
Yeast Food	0.5			0.5
Salt		2		2
Sugar	2		5	7
Milk		2		2
Inhibitor		0.1		0.1
Fat			3	3
Oxidant			75 ppm	75 ppm

greater retention of crumb resistance; (d) reduction of mechanical work input requirements; (e) greater consumer acceptance. Snell et al. (50) reported advantages of firmer sidewalls and less amylose in the crumb due to the action of the amylases on the damaged starch when using high-flour brews. These workers also cited disadvantages to be a required absorption decrease of 1% for every 20% of flour in the brew and a higher cost of equipment for handling. Recently Redfern et al. (51) reported that a taste panel could not distinquish between bread made with no brew, bread made with a standard 2.5 hr. fermentation time with no flour in the brew, and bread made with a standard 2.5 hr. fermentation time with 30% flour in the brew.

The type of flour used in continuous-dough method has also been shown to be an important factor. Schiller and Crandall (52) worked with flours that had extreme protein ranges. They found that certain flours by themselves produced high quality bread. This finding agreed with what was known about flour blending in conventional breadmaking processes. Schiller (53) reported on what he called the "time factor" involved in various steps of the continuous-doughmaking process as compared with the time for similar steps with the sponge dough process. He concluded that this time factor placed limitations on the type of flour that could be used. He stated that since the times for such things as fermentation and mixing were shorter in the continuous-dough method, greater stresses were placed on the flour. Trum and Rose (54) found that in calculating flour absorption for the continuous system an increase of 3% should be added to the farinograph value. They also reported that flours with arrival time and departure time ranges between 2 to 4 min. and 9 to 12 min. respectively produced the best results.

Maselli (43) stated the needs for pH control in the brew include: (a) pH effect on the elastic properties of gluten; (b) pH effects on particular enzyme systems; and (c) to produce bread with good flavor, texture, shelf-life, and toasting characteristics. Reed (55) reported that there are basically three ways of controlling the pH of brews. These are: (a) the use of inorganic salts or buffers, (b) the use of high levels of flour, and (c) the use of high levels of non-fat dry milk in the brew. Other workers (56, 50, 57) have confirmed that brews containing adequate amounts of either of the above listed ingredients (or commonly a mixture of them) will achieve a desired final pH value of the brew between 4.5 and 5.2.

The level of oxidation is also a critical factor in the continuous-dough method. Little or no air is incorporated into the dough at the developer stage of the continuous process so that no natural oxidation takes place in the mixer as it does in a conventional mixer. This fact, coupled with the tremendous stress on the dough during development, short mixing time, and a short period of time between mixing and oven are all reasons for a required increase in oxidation. The major factors affecting oxidation level are the flour type and the flour age (58). Schiller and Gillis (59) reported that as the oxidant level increased, developer speed also had to be increased. These authors used 60 to 90 ppm of total oxidant with a bromate to iodate ratio of 4:1. Redfern et al. (60) also showed that in using a 20% flour brew, as the oxidant ($KBrO_3$ and KIO_3) level was increased, mixing requirements increased, power requirements increased, and crumb structure was strengthened. Barrett and Joiner (61) in a more recent publication reported on the beneficial oxidizing effects of azodicarbonamide-potassium bromate combinations in continuous mix doughs as reduced mixing requirements, considerable improvement in mixing tolerance, and overall better bread quality as expressed by whiter crumb, closer grain, and improved symmetry and loaf volume. These workers used 60 to 90 ppm of total oxidant with a bromate to azodicarbonamide ratio of 2:1.

Just as shortening quantity and quality are important to conventional batch made bread, they have been shown to be very important factors in the production of continuous mix bread. In the continuous mix processes the doughs are prepared on the warm side, coming from the extruder at 96 to 104°F. The softening point of the shortening should be about 5 to 10°F. higher than the dough temperature at the extruder. The high dough temperature yields better pan flow. A shortening with a lower melting point would tend to leak out from the dough and thereby create additional problems. Thus, common shortenings and lard need to be hardened by the addition of about 5% of hydrogenated cottonseed oil or lard flakes. Continuous mix bread formulations generally contain 2 to 5% fat based on flour weight (55, 62, 63).

No previously reported work has been found on the use of soy products as a major baking ingredient in continuous breadmaking.

The present investigation was undertaken to increase the scope of information on the use of a commercial 70% soy-protein concentrate in bread baking. The effects of three grinds of soy concentrate on physical dough properties were studies with the farinograph and extensigraph; bread baking-potentialities were surveyed by a straight dough method, no-time dough method and extended to include the continuous-dough method.

MATERIALS AND METHODS

Wheat Flour Samples

A flour milled from a Hard Red Spring wheat was obtained from the Pillsbury Company. This was a straight grade flour with a protein content of 14.9% and an ash content of 0.49%. The flour was chosen because of its wide-spread commercial use in strengthening weak flours for breadmaking. Another flour from a Hard Red Winter wheat blend that was milled on the Kansas State University Pilot mill was also used. This was a straight grade flour having a protein content of 11.8% and an ash content of 0.42%. These two flours were blended in equal parts on the blending system of the Kansas State University mill. The resultant blend had a protein content of 13.4% and an ash content of 0.45%. This blend was then used as a control and as the base flour for all soy-protein concentrate-wheat flour blends.

Soy-protein Concentrate Samples

Three granulations of a commercial soy-protein concentrate were obtained from Swift Chemical Company. The three granulations were: a) (fine) screened to pass through a U.S. Std. No. 60 screen and be retained on a U.S. Std. No. 100 screen; b) (medium) screened to pass through a U.S. Std. No. 20 screen and be retained on a U.S. Std. No. 40 screen; c) (coarse) screened to pass through a U.S. Std. No. 8 screen and be retained on a U.S. Std. No. 20 screen.

The typical amino acid composition of the soy-protein concentrate used in the study is shown in Table 3 (64).

Analysis of Soy-protein Concentrates

The soy-protein concentrates were analyzed chiefly by routine methods. Moisture was determined by method 44-40 of the AACC (65). Total nitrogen was determined as prescribed in section 2.044 of AOAC Methods (66). To convert percent nitrogen to percent protein the 6.25 conversion factor was used. Ash content was obtained by AACC method 08-16 (65). To determine fat content the samples were dried at 95-100°C. under less than 100 mm. pressure for 5 hr., then crude fat was determined on the dried material by AACC method 30-25 (65).

TABLE 3

AMINO ACID COMPOSITION OF SOY-PROTEIN CONCENTRATE

Amino Acid	Grams [a]
Lysine	4.40
Histidine	2.05
Agrinine	5.40
Aspartic Acid	8.11
Threonine	2.70
Serine	2.62
Glutamic Acid	12.25
Proline	3.51
Glycine	3.16
Alanine	3.48
1/2 Cystine	0.83
Valine	4.35
Methionine	1.10
Isoleucine	3.88
Leucine	6.24
Tryosine	2.66
Phenylalamine	3.94
Tryptophane	0.80

[a] Grams of amino acid per 100 g. of original sample.

In the fat determination Skelly F was used as the extraction solvent in place of petroleum ether. Crude fiber content was determined by AACC method 32-17 (65) after the fat content of the sample was removed as described above.

Water dispersibility of the protein in the soy-protein concentrate samples was determined as a criterion of the influence of processing conditions on the protein. Although this property is considered important in the soy industry, no standard method has been accepted. In the present work the "protein dispersibility" was determined by a method similar to that described by Pollock and Geddes (18). A 5 g. sample with 100 ml. of distilled water was mechanically shaken for one hour at 25-27°C., centrifuged at 2700 x g for 15 min., and the percent protein (N x 6.25) determined in an aliquot of the centrifugate (66). Protein dispersibility was then calculated based on the following formula.

$$\text{Protein Dispersibility} = \frac{\text{water-soluble protein}}{\text{total protein}} \times 100$$

Physical Dough Testing

Farinograph

The effects of 7.5 and 15.0% levels of the three granulations of soy-protein concentrate were evaluated by replacing a portion of wheat flour with an equal weight of soy-protein concentrate and making farinograph tests (large mixing bowl) by AACC method 54-21 (65) using the constant dough weight procedure.

Farinograph curves on the same dough compositions were also prepared by adding 30 ppm of a 4:1 ratio of bromate to iodate (potassium salts) based on the flour weight at 14% moisture and by adding 2% of NaCl based on the flour weight at 14% moisture.

All farinograph curves were run in duplicate and centered on the 500-B.U. line at maximum consistency.

For evaluating dough behavior with the farinograph the following numerical readings were recorded (65):

(a) Absorption: Obtained as the amount of water required to center the farinograph curve on the 500-B.U. line for a given dough.

(b) Peak Time: The time from the first addition of water to the development of the dough's maximum consistency, or minimum mobility, measured to the nearest half-min.

(c) Stability: The difference, to the nearest half-min., between the time when the curve first intercepted the 500-B.U. line and the time when the curve left the 500-B.U. line.

(d) Tolerance Index: The difference in B.U. from the top of the curve at the peak to the top of the curve measured 5 min. after the peak.

(e) Valorimeter Value: A numerical value based on a logarithmic function of the peak time in relation to the breakdown of the dough 12 min. after peak time. This value was determined by placing a logarithmic template, supplied by the manufacturer of the instrument, over the farinograph curve and noting where the lines intersected.

Extensigraph

The effects of the same soy-protein concentrate-wheat flour blends as described above were tested on the extensigraph by AACC method 54-10 (65), except that the ratio setting of the extensigraph scale was 500 g. = 300-B.U. and 1000 g. = 600-B.U. This adjustment was made in order to keep all curves on the Kymograph chart.

In addition, extensigraph curves on the same dough compositions and with the same ratio setting as before were prepared by adding 30 ppm of a 4:1 ratio of bromate to iodate (potassium salts) based on the flour weight at 14% moisture.

For evaluating dough behavior with the extensigraph the following numerical readings were recorded (67):

(a) Resistance to Extension: The height of the curve in B.U. at 50 mm. after the start of the curve.

(b) Extensibility: The distance, measured in mm., from the start of the curve to the maximum force (measured along the base line).

Baking Methods

For the baking studies each of the three granulations of soy-protein concentrate was substituted into the bread formula for 7.5 and 15.0% of the wheat flour. Formulae and experimental procedures for the three baking methods used are listed below.

Straight Dough and No-Time Dough Method

The straight dough formula employed was an average commercial-type formula (Table 4) without any dough improver or yeast food. In the no-time dough formula (Table 5) a higher level of yeast was used to maintain approximately the same proof time and a reduced amount of sugar was added to compensate for the lesser fermentation. For both baking methods the control contained no soy-protein concentrate and the only formula adjustment for the soy-protein concentrate bread was an increase in water.

The doughs were mixed 30 sec. at speed 1, then three different times were used for each treatment (see below) at speed 2, in a Hobart A-200 mixer

TABLE 4

STRAIGHT DOUGH FORMULA AND BAKING PROCEDURE

Ingredients	% Flour [a]
Wheat Flour	100 - 92.5 - 85.0
Soy-protein Concentrate	7.5 - 15.0
Sugar (sucrose)	6.0
Salt	2.0
Lard	2.0
Yeast (compressed)	3.0
$KBrO_3/KIO_3$ (4:1)	0 - 30 ppm
Water	Variable [b]

Procedure:

Dough temp. from mixer...83°F.

Fermentation...86°F. - 84% R.H. for 160 min.

Punch at 110 min.

Scale (500 g.) at 160 min.

Bench proof 20 min.

Mould (Century Drum Moulder) and pan.

Proof to 2 cm. height or for 70 min. at 98°F. - 88% R.H.

Bake at 425°F. for 30 min.

[a] Based on wheat flour at 14% moisture.

[b] See Table 6.

TABLE 5

NO-TIME DOUGH FORMULA AND BAKING PROCEDURE

Ingredients	% Flour [a]
Wheat Flour	100 - 92.5 - 85.0
Soy-protein Concentrate	7.5 - 15.0
Sugar (sucrose)	6.0
Salt	2.0
Lard	2.0
Yeast (compressed)	3.0
$KBrO_3/KIO_3$ (4:1)	0 - 30 ppm
Water	Variable [b]

Procedure:

Dough temp. from mixer...88°F.

Scale (500 g.) after mixing.

Bench proof 20 min.

Mould (Century Drum Moulder) and pan.

Proof to 2 cm. height or for 70 min. at 98°F. - 88% R.H.

Bake at 425°F. for 25 min.

[a] Based on wheat flour at 14% moisture.

[b] See Table 6.

equipped with the standard bread bowl and fork. The baking procedures followed after mixing are shown in Table 4 and 5. Two loaves were baked from each dough.

Loaf volumes were determined by rape-seed displacement 1 hr. after baking, and the loaves were scored the following day for other characteristics. Crumb compressibility was measured, on three 2-inch slices from each loaf, with a Bloom gelometer. The plunger, 25 mm. in diameter, was depressed 4 mm. into the bread crumb. The weight in g. required to depress the plunger was taken as the compressibility parameter. Compressibility was measured on wrapped and sealed loaves after three days storage at room temperature (about 25°C.).

Experimental Procedure

Two independent baking experiments were designed. The design of experiment 1, consisted of 7 x 3 x 2 factorial experiment. The experiment included a combination of seven levels and granulations of soy-protein concentrate (Table 6); three mixing times (10 min., 18 min., and 26 min.); and the two baking methods.

In the 2nd experiment 30 ppm (based on flour at 14% moisture) of a 4:1 ratio of bromate to iodate (potassium salts) was added to each baking formula (Tables 4 and 5) and only one mixing time was used per treatment. The mixing time used for each treatment was the time from the 1st experiment that yielded loaves with the highest total bread score. The baking procedures after mixing were the same as before.

The design of the 2nd experiment consisted of a 7 x 2 x 2 factorial experiment. The experiment included the same seven combinations of soy-protein concentrate as before (Table 6); two formulae (one without the bromate-iodate mixture and the other with the mixture); and the two baking methods.

TABLE 6

COMBINATIONS OF SOY-PROTEIN CONCENTRATE USED IN FACTORIAL EXPERIMENTS AND ABSORPTIONS USED IN BAKING FORMULAE

Combinations	Absorption (%)[a]
1. Control Base Flour	64.4
2. 7.5% Fine S.P.C.[b] plus 92.5% Base Flour	70.7
3. 7.5% Medium S.P.C. plus 92.5% Base Flour	70.4
4. 7.5% Coarse S.P.C. plus 92.5% Base Flour	69.4
5. 15.0% Fine S.P.C. plus 85.0% Base Flour	79.6
6. 15.0% Medium S.P.C. plus 85.0% Base Flour	77.8
7. 15.0% Coarse S.P.C. plus 85.0% Base Flour	77.4

[a] Based on wheat flour at 14% moisture.

[b] S.P.C. = Soy-protein Concentrate.

Continuous-Dough Method

The AMF laboratory continuous pilot doughmaking unit (Figure 2) was used in this baking study. It was a completely integrated unit that consisted of component parts that make up a complete dough-making system. The system consisted of two 30-gallon jacketed brew tanks with high and low speed agitators for mixing the brew ingredients. The water jackets allowed for setting and holding the brew at any desired temperature.

The baking formula (Table 7) was a 30% flour brew formula. When soy-protein concentrate was included in the formula it replaced an equal weight

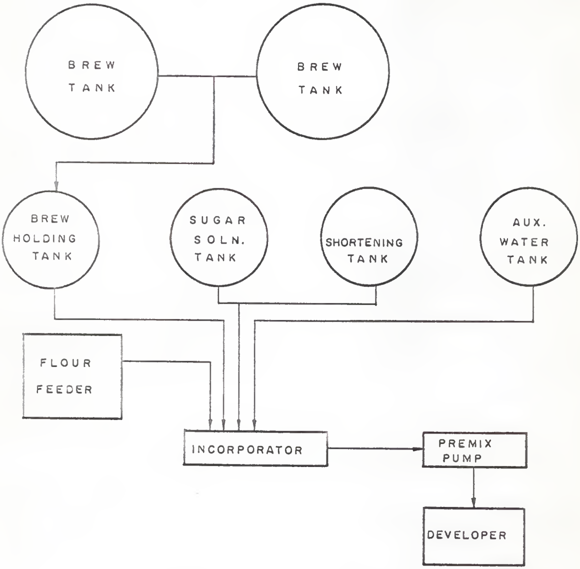

Fig. 2. Schematic Diagram of AMF Continuous Mix Laboratory Unit.

TABLE 7

CONTINUOUS-DOUGH METHOD FORMULA

Ingredients	% Flour	Phase I [a/]	Phase II [b/]	Mixing Phase
Flour	100.0-92.5-85.0	30.0-22.5-15.0		70.0
Soy-protein concentrate	7.5-15.0	7.5-15.0		
Water	Variable [c/]	Variable	6.0	11.0
Yeast	3.5	3.5		
Malt Flour	0.4	0.4		
Yeast Food [d/]	0.5	0.5		
Salt	2.0		2.0	
Sugar	6.0	1.0		5.0
Fat	3.0 [e/]			3.0
$KBrO_3/KIO_3$ (4:1)	75 ppm		75 ppm	
Ca Propionate	0.15		0.15	
Dough Improver [f/]	0.375			0.375

a/ Initial ingredients of brew.

b/ Ingredients added to brew after 1.75 hr. fermentation.

c/ See Table 6.

d/ Arkady

e/ 0.3% hydrogenated vegetable oil flakes and 2.7% lard.

f/ Verv (calcium stearoyl-2-lactylate).

of the control flour in the brew at Phase I. The only other formula adjustment for the soy-protein concentrate bread was an increase in water at Phase I of the brew. All brews were set by a method described by Schanefelt (68). During brew fermentation pH readings were taken every 30 min.

After the brew had fermented for 2.5 hr., it was pumped by a positive displacement pump into a holding tank. This holding tank and three other ingredient tanks were connected to separate variable speed pumps that allowed metering of the brew, sugar solution, fat (heated to form a liquid), and auxiliary water into the incorporator. The auxiliary water tank was used, when necessary, to adjust absorption until the proper dough consistency was obtained. Flour was fed into the system by a volumetric feeder above the incorporator. From the incorporator, the ingredients entered a positive displacement pump and were pumped to a variable speed dough developer head. The dough was given final development at this stage. The dough was then extruded and cut into pieces of about 540 g. by a semiautomatic cut-off device. The panning was performed manually by manipulating the pan in such a position as to allow center positioning of the dough. After panning the doughs were proofed at 110°F. and 93% humidity to a 2 cm. height. Doughs were baked at 468°F. for 19 min.

Loaf volumes were determined by rape-seed displacement several hr. after baking, and the loaves were scored the following day for other characteristics. Crumb compressibility was determined on wrapped and sealed loaves stored at room temperature on the 1st, 3rd, and 5th day after baking by the same method as before.

Experimental Procedure

The design of this experiment consisted of a 7 x 4 factorial experiment. The experiment included the same seven combinations of soy-protein concentrate (Table 6) as before and four developer speeds for testing dough mixing tolerance; these were: (a) 148 r.p.m., optimum control dough consistency as determined by "feel"; (b) 102 r.p.m., about 40 r.p.m. under the optimum; (c) 125 r.p.m., about 20 r.p.m. under the optimum and; (d) 171 r.p.m., about 20 r.p.m. over the optimum. For convenience these values will be referred to as optimum, -20, -40, and +20 r.p.m., respectively throughout the thesis.

Bread Scoring Procedure

A scoring system was designed that included five loaf characteristics. The maximum score possible with the system used was 100 points. Characteristics scored and points allotted to each characteristic included 25 points for volume, 15 points for external loaf appearance, 25 points for crumb texture, 25 points for crumb grain, and 10 points for break and shred. The volume score was based on specific loaf volume. The systems used in allowing for volume score were slightly different for the straight dough and no-time dough method than for the continuous-dough method and are shown in Table 8. Other characteristics scored and points allotted to each characteristic were the same for all baking methods.

Statistical Analyses

The farinogram, extensigram, and baking data was tested by the analysis of variance for significance between the various experimental factors (69). A fixed effects model was used for calculating F-ratios. If the F-ratio indicated significance existed between means Fisher's Least Significant Difference (LSD) was used to make comparisons among main factor means.

TABLE 8

SPECIFIC VOLUME LOAF SCORE CONVERSION FOR BREAD

Loaf Score	Loaf Specific Volume (cc/g)	
	No-Time & St. Dough Method	Continuous Dough Method
25	6.0 or greater	6.4 or greater
23	5.8	6.2
21	5.6	6.0
19	5.4	5.8
17	5.2	5.6
15	5.0	5.4
13	4.8	5.2
11	4.6	5.0
9	4.4	4.8
7	4.2	4.6
5	4.0	4.4
3	3.8	4.2
1	3.6	4.0
0	3.4 or less	3.8 or less

RESULTS AND DISCUSSION

Analysis of Soy-protein Concentrate

Analytical data from the three commercial soy-protein concentrates (fine, medium, and coarse grind) are recorded in Table 9. The three concentrates were similar in all respects except protein dispersibility and crude fiber. Protein was less dispersible in water for the medium and coarse concentrate than for the fine. The opposite relation was observed with respect to crude fiber. These effects probably were due to the differences in particle size rather than to processing differences.

Relatively low protein dispersibility of all concentrates indicated they were prepared by either the aqueous alcohol or the water extraction process described by Meyer (11).

TABLE 9

ANALYSIS OF SOY-PROTEIN CONCENTRATE

	Fine Grind	Medium Grind	Coarse Grind
Moisture, %	6.6	6.3	6.2
Protein (N x 6.25), % [a]	70.4	69.8	71.6
Protein Dispersibility, % [b]	2.5	1.6	1.5
Crude Fat, % [a]	0.7	0.3	0.3
Crude Fiber, % [a]	2.2	3.2	2.8
Ash, % [a]	3.3	3.6	3.5

[a] Reported on dry matter basis.

[b] $\% \text{ Protein dispersibility} = \frac{\text{water-soluble protein}}{\text{total protein}} \times 100$

Effects of Soy-protein Concentrate on Physical Dough Characteristics

Effects on Farinograph Characteristics

Farinograms for doughs made with fine, medium, and coarse soy-protein concentrates (7.5 and 15.0%) with and without 30 ppm of oxidant (4:1 ratio of

$KBrO_3:KIO_3$) are shown in Figure 3. Farinogram readings, and statistical analyses of these readings are given in Table 10 and Tables 11 and 12, respectively.

Addition of oxidant to the doughs had no significant effects on any of the farinogram readings (Table 11). However, granulation and level of the concentrates (treatments) in the doughs produced significant changes in all farinogram readings. Fine concentrate had the smallest effect on all farinogram characteristics, except absorption; the 15.0% level of fine altered the control curve less than the 7.5% level of coarse soy concentrate. Absorption increased most with 15.0% fine and least with 7.5% coarse. The average absorption of doughs containing soy concentrate increased approximately 0.66% for each 1.0% addition of concentrate.

Peak times increased with increasing percentages of soy-protein concentrate in the dough. The average peak times increased approximately 0.1, 0.3, and 0.5 min. for each 1.0% addition of fine, medium and coarse grind, respectively. These results indicate that whereas soy concentrate added to dough increased peak time, the extent of the increase depended on the amount added and the particle size. The particle size effect is likely due to slower hydration of the more granular soy concentrate material.

The control curve stability increased as dough soy concentrate levels were increased, except for the fine. Seven and one-half percent of fine did not significantly change the control dough stability, but 15.0% fine produced a significant stability decrease from the 7.5% fine dough (Table 12). The greatest dough stability reading occurred when 15.0% coarse concentrate was added to the dough.

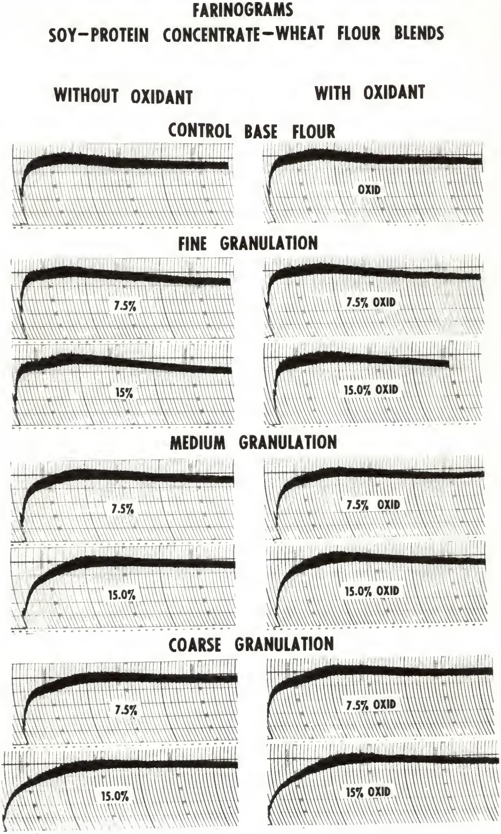

Fig. 3. Effects of granulation, soy-protein concentrate level, and oxidant on farinogram characteristics.

TABLE 10

EFFECTS OF GRANULATION, SOY-PROTEIN CONCENTRATE LEVEL, AND OXIDANT ON FARINOGRAM READINGS

	Absorption [a/] (%)		Peak Time (Min.)		Stability (Min.)		Tolerance Index (B.U.)		Valorimeter (V.U.)	
Oxidant Level [a/]	0 ppm	30 ppm	0 ppm	30 ppm	0 ppm	30 ppm	0 ppm	30 ppm	0 ppm	30 ppm
Control Base Flour	61.4	61.4	7.0	7.0	13.0	13.0	30	25	68	70
7.5% Fine S.P.C. [b/]	66.4	66.4	8.0	8.0	14.5	14.5	25	20	71	72
7.5% Medium S.P.C.	66.1	66.1	10.0	10.0	15.5	15.0	15	15	78	78
7.5% Coarse S.P.C.	65.1	65.1	11.0	11.0	18.5	18.5	10	10	83	84
15.0% Fine S.P.C.	71.8	71.8	8.0	8.5	12.5	13.0	20	20	73	74
15.0% Medium S.P.C.	71.2	71.2	11.0	11.0	17.0	16.5	15	20	83	84
15.0% Coarse S.P.C.	70.2	70.2	14.5	13.0	20.0	19.5	15	15	89	87

a/ Based on flour at 14% moisture.

b/ S.P.C. = soy-protein concentrate.

TABLE 11

ANALYSIS OF VARIANCE OF FARINOGRAM READINGS

Analysis of Variance of Peak Time

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	136.25	22.71	141.30**
Oxidant	1	0.04	0.04	0.22
T x O	6	2.96	0.49	3.07*
Error	14	2.25	0.16	
Total	27	141.50		

Analysis of Variance of Stability

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	173.34	28.89	37.62**
Oxidant	1	2.28	2.28	2.98
T x O	6	3.34	0.56	0.72
Error	14	10.75	0.77	
Total	27	189.71		

Analysis of Variance of Tolerance Index

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	585.71	97.62	8.41**
Oxidant	1	0.89	0.89	0.08
T x O	6	17.86	2.98	0.25
Error	14	162.50	11.61	
Total	27	766.96		

Analysis of Variance of Valorimeter Value

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	1,213.86	202.31	115.61**
Oxidant	1	1.75	1.75	1.00
T x O	6	10.00	1.67	0.95
Error	14	24.50	1.75	
Total	27	1,250.11		

** Significant at 1% level.

* Significant at 5% level.

TABLE 12

MAIN FACTOR MEANS OF FARINOGRAM READINGS

Treatments	Peak Time [a/]	Stability [a/]	Tolerance Index [a/]	Valorimeter Value [a/]
1. Control Base Flour	7.00[a]	13.50[ab]	26.25[a]	69.50[a]
2. 7.5% Fine S.P.C. [b/]	8.00[b]	14.00[bc]	23.75[ab]	71.25[ab]
3. 7.5% Medium S.P.C.	9.88[d]	15.12[c]	17.50[cde]	78.00[c]
4. 7.5% Coarse S.P.C.	11.38[e]	18.25[e]	12.50[e]	83.50[d]
5. 15.0% Fine S.P.C.	8.62[c]	12.50[a]	22.50[abc]	73.25[b]
6. 15.0% Medium S.P.C.	11.12[e]	16.75[d]	18.75[bcd]	83.75[d]
7. 15.0% Coarse S.P.C.	14.00[f]	19.88[f]	15.00[de]	88.00[e]
$LSD_{0.05}$	0.61	1.33	5.17	2.01

a/ Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

b/ S.P.C. = soy-protein concentrate.

Adding medium and coarse concentrate to the dough significantly decreased tolerance index values (smaller values indicate stronger doughs) but when fine was added no significant changes occurred (Table 12). For all granulations, increasing levels (7.5 to 15.0%) of concentrate did not produce a significant change in tolerance index readings. Seven and one-half percent of coarse yielded a dough with the best mixing tolerance.

Valorimeter value, which is an empirical single figure quality score, based on the peak time and the tolerance to mixing of the dough, followed a pattern similar to peak time when concentrates were added to the doughs. These values increased with increasing percentages of concentrate in the dough, and only 7.5% fine was not significantly different from the control. The highest valorimeter value was obtained with 15.0% coarse in the dough.

Salt Effects on Farinograph Characteristics

The effects, on farinogram characteristics, of adding 2.0% salt (NaCl) to dough containing 0.0, 7.5, and 15.0% of the three soy-protein concentrates are shown in Figure 4. These curves were prepared to establish dough absorption and peak times for the extensigraph test. The resulting farinogram readings, and those previously obtained without using salt are shown in Table 13. Adding 2.0% salt increased dough stability, tolerance index, valorimeter value, and dough development times; these increases were augmented with increasing percentages of soy-protein concentrate in the dough.

Adding salt to the control dough produced a curve with a double peak (Figure 4) and lowered the dough absorption by 2.0%. Unlike the control, all doughs containing soy-protein concentrate increased in absorption with the addition of salt. The decreased absorption of the control dough likely resulted from the decreased hydration capacity of the wheat protein (gluten) in the presence

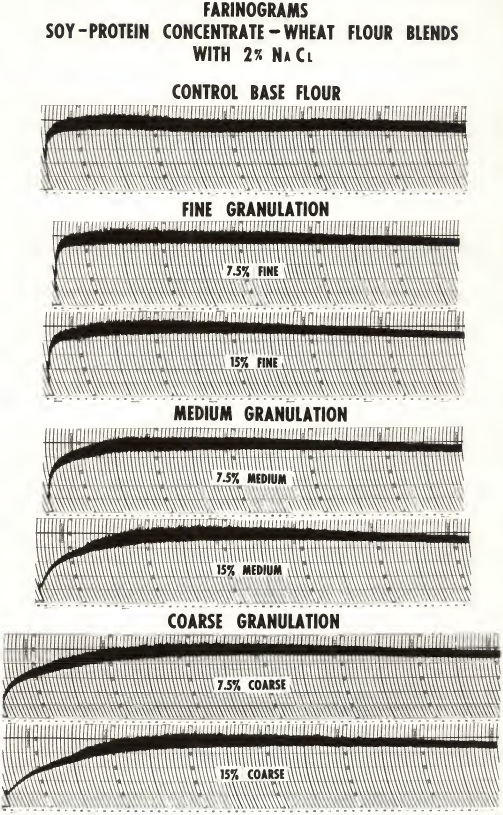

Fig. 4. Effects of granulation, soy-protein concentrate level, and NaCl on farinogram characteristics.

TABLE 13

EFFECTS OF GRANULATION, SOY-PROTEIN CONCENTRATE LEVEL, AND NaCl ON FARINOGRAM READINGS

	Absorption [a/] (%)		Peak Time (Min.)		Stability (Min.)		Tolerance Index (B.U.)		Valorimeter (V.U.)	
NaCl Level [a/]	0%	2%	0%	2%	0%	2%	0%	2%	0%	2%
Control Base Flour	61.4	59.4	7.0	9.5	13.0	50.5	30	10	68	77
7.5% Fine S.P.C. [b/]	66.4	67.7	8.0	10.5	14.5	42.0	25	15	71	84
7.5% Medium S.P.C.	66.1	67.4	10.0	12.5	15.5	38.5	15	<5	78	90
7.5% Coarse S.P.C.	65.1	66.4	11.0	29.0	18.5	43.0	10	5	83	>100
15.0% Fine S.P.C.	71.8	76.6	8.0	14.0	12.5	36.0	20	<5	73	89
15.0% Medium S.P.C.	71.2	74.8	11.0	22.0	17.0	35.5	15	5	83	98
15.0% Coarse S.P.C.	70.2	74.4	14.5	26.0	20.0	38.5	15	10	89	100

a/ Based on flour at 14% moisture.

b/ S.P.C. = soy-protein concentrate.

of salt. This observation agrees with previous findings (70, 71). The increased absorption reflects an appreciable change in the water-binding capacity of the soy-proteins in the presence of salt. It has been shown (3) that soy-proteins are less soluble in dilute NaCl solutions (0.05 to 0.40 N) than in water, and this may account for some of the absorption differences noted with the soy doughs.

In the presence of salt the average absorption of doughs containing soy-protein concentrate increased approximately 1.0% for each 1.0% addition of the concentrate. This ratio agrees with previous findings (21, 31).

Effects on Extensigraph Characteristics

Extensigrams for doughs made with fine, medium, and coarse soy-protein concentrate (7.5 and 15.0%) with and without 30 ppm of oxidant (4:1 ratio of $KBrO_3$:KIO_3) are shown in Figure 5. Extensigram readings and statistical analyses of these values are presented in Table 14 and Tables 15 and 16, respectively.

Like the farinogram readings, extensigram readings were significantly affected by soy-protein concentrate granulation and level (treatments) used in the doughs. Dough became considerably less extensible and more resistant to extension with increasing percentages of soy concentrate. With 15.0% soy, dough extensibility decreased by 68% and resistance to extension increased by 95% from that of the control. Extensigram readings of doughs containing 7.5% soy concentrate were significantly altered by particle size, but at the 15.0% level particle size caused no significant changes. Using oxidant in the doughs caused a significant increase in dough resistance to extension but had no effect on dough extensibility. Both dough resistance to extension and extensibility changed significantly when the same dough pieces were

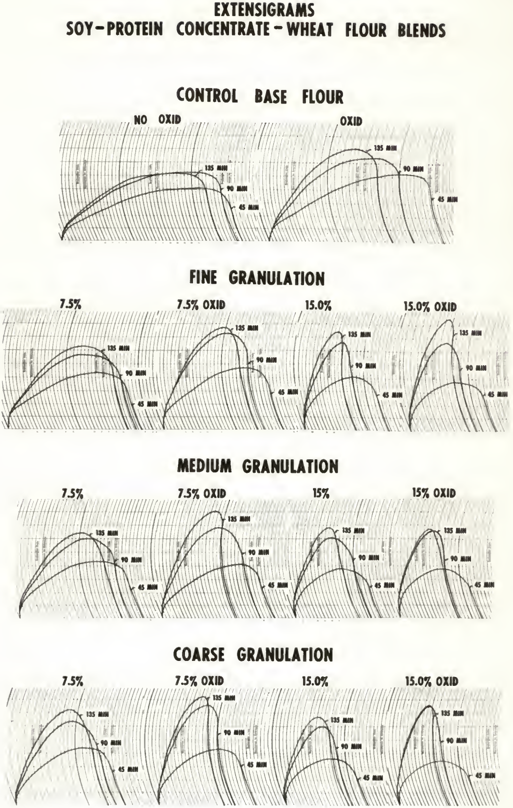

Fig. 5. Effects of granulation, soy-protein concentrate level, and oxidant on extensigram characteristics.

TABLE 14

EFFECTS OF GRANULATION, SOY-PROTEIN CONCENTRATE LEVEL, AND OXIDANT ON EXTENSIGRAM READINGS

	Stretch Time (min.)	Resistance to Extension [a] (B.U.)		Extensibility [b] (mm.)	
Oxidant Level [c]		0 ppm	30 ppm	0 ppm	30 ppm
Control Base Flour	45	192	222	192	186
	90	200	312	171	139
	135	263	373	158	116
7.5% Fine S.P.C. [d]	45	262	285	120	113
	90	343	523	104	81
	135	375	450	100	89
7.5% Medium S.P.C.	45	265	278	109	106
	90	377	457	90	83
	135	422	570	86	72
7.5% Coarse S.P.C.	45	295	298	95	87
	90	442	562	74	66
	135	533	685	70	60
15.0% Fine S.P.C.	45	332	320	66	64
	90	601	603	49	47
	135	668	766	45	45
15.0% Medium S.P.C.	45	313	327	62	56
	90	548	615	52	44
	135	610	620	44	41
15.0% Coarse S.P.C.	45	318	305	59	57
	90	518	707	48	40
	135	627	718	41	40

[a] Curve height at 5 cm.

[b] Measured from the start of curve to maximum force.

[c] Based on flour at 14% moisture.

[d] S.P.C. = soy-protein concentrate.

TABLE 15

ANALYSIS OF VARIANCE OF EXTENSIGRAM READINGS

Analysis of Variance of Extensibility

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	57,345.0	9,557.5	203.2**
Oxidant	1	57.2	57.2	1.2
Stretch Time	2	5,064.9	2,532.4	53.8**
T x O	6	1,415.3	235.9	5.0**
T x ST	12	826.8	68.9	1.5
O x ST	2	40.6	20.3	0.4
T x O x ST	12	564.3	47.0	
Total	41	65,314.1		

Analysis of Variance of Resistance to Extension

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	357,167.2	59,527.9	31.1**
Oxidant	1	27,157.7	27,157.7	14.2**
Stretch Time	2	520,013.9	260,006.9	135.8**
T x O	6	2,749.3	4,581.7	2.4
T x ST	12	87,804.8	7,317.1	3.8*
O x ST	2	11,974.8	5,987.4	3.1
T x O x ST	12	22,973.1	1,914.4	
Total	41	1,054,581.9		

** Significant at 1% level.

* Significant at 5% level.

TABLE 16

MAIN FACTOR MEANS OF EXTENSIGRAM READINGS

For Treatments:

Treatments	Extensibility [a]	Resistance To Extension [a]
1. Control Base Flour	159.3[a]	273.7[a]
2. 7.5% Fine S.P.C. [b]	101.2[b]	373.0[b]
3. 7.5% Medium S.P.C.	91.0[c]	394.8[b]
4. 7.5% Coarse S.P.C.	75.3[d]	469.2[c]
5. 15.0% Fine S.P.C.	52.7[e]	548.3[d]
6. 15.0% Medium S.P.C.	49.8[e]	505.5[cd]
7. 15.0% Coarse S.P.C.	47.5[e]	532.2[d]
$LSD_{0.05}$	8.6	55.0

For Oxidant:

Oxidant Level	Extensibility [c]	Resistance to Extension [a]
1. 0 ppm	N.S.	416.9[a]
2. 30 ppm		468.8[b]
$LSD_{0.05}$		29.4

For Stretch Time:

Time	Extensibility [a]	Resistance to Extension [a]
1. 45 min.	97.6[a]	288.7[a]
2. 90 min.	77.7[b]	489.9[b]
3. 135 min.	71.9[c]	548.6[c]
$LSD_{0.05}$	5.6	36.0

a/ Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

b/ S.P.C. = soy-protein concentrate.

c/ N.S. = none significant.

stretched at 45, 90, and 135 min. Dough extensibility decreased and resistance to extension increased with time.

The observed large changes of the extensigram control dough curve from adding soy concentrate (7.5 and 15.0%) indicated that the soy doughs would probably be difficult to machine and/or mould after fermentation.

Effects of Soy-protein Concentrate on Bread Baking Characteristics

Effects on Bread Baked by Straight and No-Time Dough Methods

Dough Characteristics

Preliminary baking tests were performed on the control flour to determine its "full formula" absorption and mixing requirements. Results indicated that the standard farinograph absorption plus 3% and a 10 min. mixing time yielded an optimum dough by "feel" on the Hobart A-200 mixer. Based on control dough absorption and the farinograph absorptions of doughs containing soy concentrate, the with salt (NaCl) farinograph absorption plus 3% was selected as the baking absorption for the wheat flour-soy concentrate mixtures. The increased dough stability and dough development time imparted to the control dough with increasing percentages of soy concentrate in the dough, as observed by the farinograph method, were related to actual laboratory mixing and baking conditions by using three mixing times for each treatment. These mixing times were: (a) 10 min., the time for optimum development of the control flour dough; (b) 26 min., the average farinograph (with salt) peak time of soy concentrate doughs yielding a peak time of 20 or more min.; (c) 18 min., chosen as an intermediate mixing time.

The inclusion of soy-protein concentrate in dough still yielded a fully developed dough by feel, with 10 min. of mixing. As mixing times increased

(18 and 26 min.) all doughs became over developed and slightly sticky; the control dough had the most mixing tolerance and the soy concentrate doughs, especially at the 15.0% level, the least tolerance.

Doughs processed by the no-time method were easily moulded without tearing, except for the 15% fine and medium concentrate doughs mixed 18 and 26 min. The control doughs made by the straight dough procedure were easily moulded. Doughs containing soy concentrate, processed by the straight dough method, were very tight and inelastic after fermentation, and difficult to mould. This condition was particularly true of all doughs with 15.0% soy concentrate and the over-mixed (18 and 26 min.) 7.5% fine and medium soy concentrate doughs.

Adding 30 ppm of oxidant (4:1 ratio of $KBrO_3$:KIO_3) had no noticeable effects on dough mixing. Moulding characteristics of no-time doughs were unaffected, but straight doughs became "bucky", a characteristic of over oxidation, and even more difficult to mould than before. These observations agree with previous extensigraph results.

Bread Characteristics

The loaves obtained from doughs, processed by the straight and no-time dough baking procedure, containing 0.0, 7.5, and 15.0% of fine, medium, and coarse soy-protein concentrate are shown in Figures 6 through 11. The resulting loaf specific volume, total score, and three-day compressibility are presented in Table 17.

Adding increasing amounts of soy-protein concentrate to bread baked by either the straight or no-time dough method caused a progressive crumb discoloration. The fine grind gave the crumb a dull, slightly yellow color but had little effect on crust color. Crumbs of bread made with medium and coarse soy concentrate had a slightly reddish-brown color and the small reddish colored grits imparted a speckled crumb appearance. Crust color of bread containing the medium and coarse grinds was not appreciably different from the control, except that it was also speckled with the deep brownish colored grits.

Statistical analyses of the effects of the treatments (granulation and soy-protein concentrate level), mixing times (10, 18, and 26 min.), and baking methods (straight and no-time) on loaf specific volume and total score are summarized in Tables 18 and 19. The analysis of variance (Table 18) indicates that specific volume and total score were significantly affected by granulation and soy-protein concentrate level, mixing time, and baking method, and also indicated the existence of 2nd and 3rd order interactions between the main factors. A comparison of the main factor means (Table 19) shows that loaf specific volume and total score gave similar responses to the main factors tested. Loaf specific volume and total score were highest with the control flour, least affected by 7.5% coarse soy concentrate, and most affected by 15.0% fine soy concentrate in the formula. The 10 min. mixing time proved to be better than 18 or 26 min. Thus, the characteristic strengthening of the control farinograph curve by adding soy concentrate does not carry over to actual laboratory mixing and baking conditions. The no-time dough baking method was better than the straight dough method. It would seem, therefore, some type of deleterious interaction took place between the soy-proteins and some functional constituent in wheat flour during the fermentation period.

As mentioned above, 2nd and 3rd order interaction effects existed among all the main factors tested. Unless stated otherwise, no attempt was made to analyze these interactions statistically other than to show significance or non-significance with the F-ratio. It would seem beneficial, however, to examine the effects of mixing on the individual treatments. Each treatment made by the straight dough method and most of the treatments processed by the no-time dough method gave best response to loaf specific volume and total score (Table 17) with a 10 min. mixing time. On the other hand, the control flour and 7.5% fine soy concentrate responded best to 26 and 18 min. mixing times, respectively; all other treatments, when made by the no-time method, were only slightly impaired with an 18 min. mixing time. This again indicates that most of the deleterious action of soy on bread quality probably takes place during fermentation.

Bread baked by the no-time method consistently had a softer crumb, as determined by crumb compressibility after storage for three-days (Table 17), than did breads baked by the straight dough method. Crumb compressibility responded to mixing and soy concentrates in the same manner as did loaf specific volume and total score.

The effects on loaf specific volume, total score, and crumb compressibility of adding 30 ppm of oxidant (4:1 ratio of $KBrO_3$:KIO_3) to the doughs which yielded the highest total loaf score from the above mixing experiment are shown in Table 20. The loaves obtained from the doughs with the added oxidant and processed by the no-time and straight dough methods are shown in Figures 6 through 11 (column D). Statistical analyses of the effects of the treatments (granulation and soy-protein concentrate level), oxidant level (0 and 30 ppm) and baking methods on loaf specific volume, total score, and compressibility are summarized in Tables 21 and 22.

Oxidant had no apparent effect on crust and crumb color but generally caused the crumb grain to become slightly more open.

The analysis of variance (Table 21) indicated that loaf specific volume, total score, and compressibility were affected significantly by granulation and soy-protein concentrate level, oxidant level, and baking method; it also indicated the existence of interaction between main factors. A comparison of the main factor means (Table 22) shows that loaf specific volume and total score gave the same responses as before to granulation and soy-protein concentrate level and baking methods. No oxidant in the doughs, as rated by the main factor means, produced greater loaf specific volume and total score than 30 ppm. There was a difference, however, between the effects of oxidant on bread made by different methods (Table 20). Adding oxidant improved bread characteristics of the no-time doughs and was detrimental to straight dough bread characteristics. The deleterious effects of oxidant on the straight dough loaves were due to over-oxidation of the doughs, as mentioned before.

The main factor means of crumb firmness (compressibility) showed almost the same responses as loaf specific volume to the experimental factors tested. This would indicate that crumb softness depended to a large extent on loaf volume, although crumb firming was not significantly affected by adding 7.5% of coarse soy concentrate and was only slightly affected by adding 15.0% coarse soy concentrate to the baking formula.

Baking results indicated bread containing soy-protein concentrate made by the no-time method, using 7.5% coarse grind, had the best characteristics. This loaf (7.5% coarse grind; no-time baking method) was tested by a trained flavor panel. The panel found that the coarse soy grits imparted no objectionable off-flavors or odors, and that the bread had good flavor factors and toasting characteristics. Because the panel was unavailable for more taste testing, only this loaf was tested.

Fig. 6. Bread made with fine granulation soy-protein concentrate by straight dough method. From left to right: A) 10 min. mixing time, B) 18 min. mixing time, C) 26 min. mixing time, D) listed mixing time with oxidant.

Fig. 7. Bread made with medium granulation soy-protein concentrate by straight dough method. From left to right: A) 10 min. mixing time, B) 18 min. mixing time, C) 26 min. mixing time, D) listed mixing time with oxidant.

Fig. 8. Bread made with coarse granulation soy-protein concentrate by straight dough method. From left to right: A) 10 min. mixing time, B) 18 min. mixing time, C) 26 min. mixing time, D) listed mixing time with oxidant.

Fig. 9. Bread made with fine granulation soy-protein concentrate by no-time dough method. From left to right: A) 10 min. mixing time, B) 18 min. mixing time, C) 26 min. mixing time, D) listed mixing time with oxidant.

Fig. 10. Bread made with medium granulation soy-protein concentrate by no-time dough method. From left to right: A) 10 min. mixing time, B) 18 min. mixing time, C) 26 min. mixing time, C) listed mixing time with oxidant.

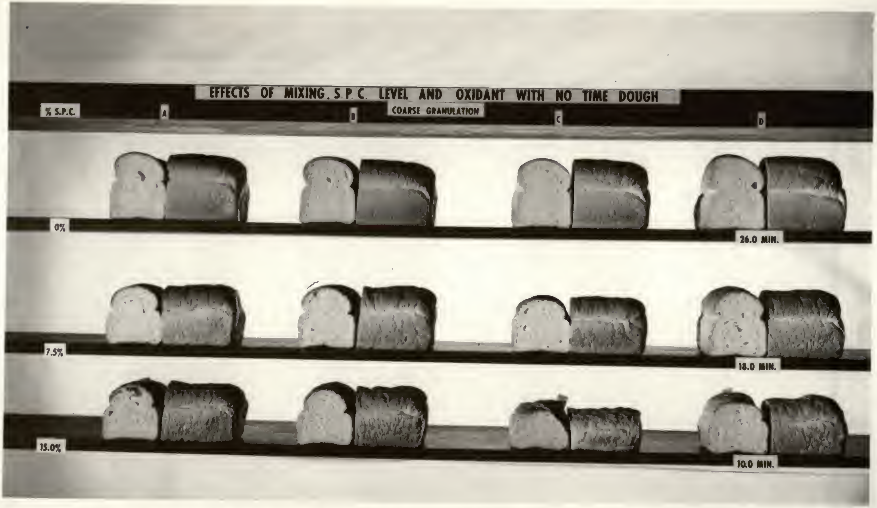

Fig. 11. Bread made with coarse granulation soy-protein concentrate by no-time dough method. From left to right: A) 10 min. mixing time, B) 18 min. mixing time, C) 26 min. mixing time, D) listed mixing time with oxidant.

TABLE 17

EFFECTS OF GRANULATION, SOY-PROTEIN CONCENTRATE LEVEL, BAKING METHOD, AND MIXING ON BREAD CHARACTERISTICS

Treatments	Mixing Time (min.)	Specific Volume (cc/g)		Total Score		3-Day Compressibility (g.)	
		Straight Dough	No-Time Dough	Straight Dough	No-Time Dough	Straight Dough	No-Time Dough
Control Base Flour	10	7.10	6.85	88.9	83.0	138.4	126.5
	18	6.92	6.90	81.0	83.0	185.2	112.6
	26	6.73	7.07	74.5	88.0	236.6	141.0
7.5% Fine S.P.C. [a/]	10	5.46	5.83	58.5	67.7	246.7	168.5
	18	4.14	5.84	33.0	64.0	>325.0	143.5
	26	3.40	4.92	16.0	47.0	>325.0	239.8
7.5% Medium S.P.C.	10	5.25	5.90	60.0	68.0	288.1	149.0
	18	4.00	5.83	31.5	65.7	>325.0	202.3
	26	3.13	5.46	13.0	51.5	>325.0	220.1
7.5% Coarse S.P.C.	10	6.05	5.81	73.5	71.0	172.5	115.8
	18	4.60	6.65	44.5	75.7	295.8	109.0
	26	3.95	5.26	30.0	56.0	>325.0	153.5
15.0% Fine S.P.C.	10	3.07	3.65	13.0	22.0	>325.0	>325.0
	18	2.33	3.33	7.0	13.0	>325.0	>325.0
	26	1.90	2.60	4.0	7.0	>325.0	>325.0
15.0% Medium S.P.C.	10	3.26	5.90	18.5	68.0	>325.0	242.8
	18	2.63	5.83	8.0	65.7	>325.0	>325.0
	26	2.11	5.46	5.0	51.5	>325.0	>325.0
15.0% Coarse S.P.C.	10	4.38	5.36	40.5	59.2	206.5	100.8
	18	3.31	5.32	19.5	55.2	>325.0	129.2
	26	2.76	3.57	13.0	21.5	>325.0	300.5

a/ S.P.C. = soy-protein concentrate.

TABLE 18

ANALYSIS OF VARIANCE OF BREAD CHARACTERISTICS FOR STRAIGHT AND NO-TIME DOUGH BAKING METHODS

Analysis of Variance of Specific Volume

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	142.25	23.71	2,371.00**
Mixing Time	2	30.52	10.26	1,026.00**
Method	1	18.30	18.30	1,830.00**
T x MT	12	3.80	0.32	35.00**
T x M	6	4.47	0.74	74.00**
MT x M	2	2.22	1.11	111.00**
T x MT x M	12	3.50	0.29	29.00**
Error	42	0.38	0.01	
Total	83	195.44		

Analysis of Variance of Total Score

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	44,187.74	7,364.62	1,984.37**
Mixing Time	2	7,371.72	3,685.86	993.14**
Method	1	5,209.31	5,209.31	1,403.63**
T x MT	12	1,703.65	141.97	38.25**
T x M	6	1,440.00	240.00	64.67**
MT x M	2	646.95	323.47	87.16**
T x MT x M	12	1,546.43	128.87	34.72**
Error	42	155.88	3.71	
Total	83	62,261.68		

** Significant at 1% level.

* Significant at 5% level.

TABLE 19

MAIN FACTOR MEANS OF BREAD CHARACTERISTICS FOR STRAIGHT AND NO-TIME DOUGH BAKING METHODS

For Treatments:

Treatments	Specific Volume [a/]	Total Score [a/]
1. Control Base Flour	6.93[a]	82.83[a]
2. 7.5% Fine S.P.C. [b/]	4.93[c]	47.79[c]
3. 7.5% Medium S.P.C.	4.92[c]	48.42[c]
4. 7.5% Coarse S.P.C.	5.29[b]	58.83[b]
5. 15.0% Fine S.P.C.	2.81[f]	11.17[f]
6. 15.0% Medium S.P.C.	3.09[e]	16.29[e]
7. 15.0% Coarse S.P.C.	4.12[d]	34.88[d]
$LSD_{0.05}$	0.07	1.12

For Mixing Times:

Mixing Times	Specific Volume [a/]	Total Score [a/]
1. 10 min.	5.18[a]	54.39[a]
2. 18 min.	4.60[b]	42.82[b]
3. 26 min.	3.97[c]	31.44[c]
$LSD_{0.05}$	0.05	0.73

For Methods:

Methods	Specific Volume [a/]	Total Score [a/]
1. Straight Dough	4.11[b]	35.01[b]
2. No-Time Dough	5.05[a]	50.76[a]
$LSD_{0.05}$	0.04	0.60

a/ Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

b/ S.P.C. = soy-protein concentrate.

TABLE 20

EFFECTS OF GRANULATION, SOY-PROTEIN CONCENTRATE LEVEL, BAKING METHOD, AND OXIDANT ON BREAD CHARACTERISTICS

Treatments	Oxidant Level[a/] (ppm)	Straight Dough Method				No-Time Dough Method			
		Mixing Time	Specific Volume	Total Score	3-day Compressibility	Mixing Time	Specific Volume	Total Score	3-day Compressibility
Control Base Flour	0	10	7.10	88.0	138.4	26	7.07	88.0	141.0
	30	10	6.28	76.0	177.4	26	7.10	86.0	146.2
7.5% Fine S.P.C. [b/]	0	10	5.46	58.5	246.7	10	5.83	67.7	168.5
	30	10	4.12	31.0	>325.0	10	6.18	71.5	132.3
7.5% Medium S.P.C.	0	10	5.25	60.0	288.1	10	5.90	68.0	149.0
	30	10	4.68	42.5	>325.0	10	6.52	74.0	110.8
7.5% Coarse S.P.C.	0	10	6.05	73.5	172.5	18	6.65	75.7	109.0
	30	10	5.31	54.5	221.1	18	6.56	77.0	118.8
15.0% Fine S.P.C.	0	10	3.07	13.0	>325.0	10	3.65	22.0	>325.0
	30	10	2.84	11.0	>325.0	10	4.32	31.0	264.8
15.0% Medium S.P.C.	0	10	3.26	18.5	>325.0	10	4.55	38.7	242.8
	30	10	3.12	13.0	>325.0	10	5.30	50.0	183.5
15.0% Coarse S.P.C.	0	10	4.38	40.5	206.5	10	5.36	59.2	100.8
	30	10	4.13	29.5	254.7	10	5.21	53.0	129.6

a/ Based on flour at 14% moisture.

b/ S.P.C. = soy-protein concentrate.

TABLE 21

ANALYSIS OF VARIANCE OF BREAD CHARACTERISTICS FOR STRAIGHT AND NO-TIME DOUGH BAKING METHODS MADE WITH AND WITHOUT OXIDANT

Analysis of Variance of Specific Volume

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	65.13	10.86	624.58**
Oxidant	1	0.12	0.12	7.16**
Methods	1	15.06	15.06	866.46**
T x O	6	1.08	0.18	10.39**
T x M	6	2.27	0.37	21.81**
O x M	1	3.36	3.36	193.40**
T x O x M	6	0.71	0.12	6.78
Error	28	0.49	0.02	
Total	55	88.23		

Analysis of Variance of Total Loaf Score

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	24,713.21	4,118.87	865.50**
Oxidant	1	345.02	345.02	72.50**
Methods	1	4,464.28	4,464.28	938.09**
T x O	6	443.86	73.98	15.54**
T x M	6	778.59	129.76	27.27**
O x M	1	1,003.02	1,003.02	210.76**
T x O x M	6	233.98	39.00	8.19**
Error	28	133.25	4.76	
Total	55	32,115.21		

Analysis of Variance of Compressibility

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	263,298.32	43,883.05	194.08**
Oxidant	1	1,373.76	1,373.76	6.08**
Methods	1	226,086.66	226,086.66	999.89**
T x O	6	17,873.52	2,928.92	13.17**
T x M	6	60,524.51	10,087.42	44.61**
O x M	1	18,207.44	18,207.44	80.52**
T x O x M	6	2,680.05	446.67	1.98
Error	56	12,662.21	226.11	
Total	83	602,706.48		

** Significant at 1% level.

* Significant at 5% level.

TABLE 22

MAIN FACTOR MEANS OF BREAD CHARACTERISTICS FOR STRAIGHT AND NO-TIME DOUGH BAKING METHODS MADE WITH AND WITHOUT OXIDANT

For Treatments:

Treatments	Specific Volume a/	Total Score a/	Compressibility a/
1. Control Base Flour	6.89[a]	84.44[a]	154.82[a]
2. 7.5% Fine S.P.C. b/	5.40[d]	57.31[d]	225.01[c]
3. 7.5% Medium S.P.C.	5.59[c]	61.12[c]	225.16[c]
4. 7.5% Coarse S.P.C.	5.98[b]	70.25[b]	157.83[a]
5. 15.0% Fine S.P.C.	3.47[g]	19.19[g]	320.19[e]
6. 15.0% Medium S.P.C.	4.06[f]	30.19[f]	267.49[d]
7. 15.0% Coarse S.P.C.	4.77[e]	45.50[e]	181.38[b]
$LSD_{0.05}$	0.14	1.58	12.28

For Oxidant:

Oxidant Level	Specific Volume a/	Total Score a/	Compressibility a/
1. 0 ppm	5.22[a]	55.05[a]	214.79[a]
2. 30 ppm	5.12[b]	50.09[b]	222.88[b]
$LSD_{0.05}$	0.07	0.84	6.56

For Methods:

Method	Specific Volume a/	Total Score a/	Compressibility a/
1. Straight Dough	4.65[b]	43.64[b]	270.72[b]
2. No-Time Dough	5.69[a]	61.50[a]	166.96[a]
$LSD_{0.05}$	0.07	0.84	6.56

a/ Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

b/ S.P.C. = soy-protein concentrate.

Effects on Bread Baked By Continuous-Dough Method

Brew and Dough Characteristics

The data in Table 23 show the pH results for brews containing 0.0, 7.5, and 15.0% of fine, medium, and coarse soy-protein concentrate. Adding increasing amounts of concentrate to the brews generally caused a pH decrease. The control brew pH after 3.25 hr. (final brew pH) of fermentation was least affected by adding 7.5% of coarse soy concentrate. The final brew pH, however, was within the desired range (4.5 to 5.2) only for brews containing 7.5% fine and medium and 15.0% fine, medium, and coarse soy concentrate.

TABLE 23

EFFECTS OF GRANULATION AND SOY-PROTEIN CONCENTRATE LEVEL ON BREW pH

	Brew pH						
Time (hr.)	0.25	0.75	1.25	1.75[a]	2.25	2.75	3.25
Control Base Flour	5.15	5.05	5.00	5.35	5.40	5.40	5.45
7.5% Fine S.P.C.[b]	5.15	5.05	5.05	5.05	5.10	5.05	5.05
7.5% Medium S.P.C.	5.10	5.05	5.05	5.05	5.05	5.10	5.10
7.5% Coarse S.P.C.	5.30	5.25	5.25	5.35	5.35	5.35	5.40
15.0% Fine S.P.C.	5.05	5.00	4.95	5.10	5.15	5.15	5.15
15.0% Medium S.P.C.	5.05	5.00	5.00	5.10	5.10	5.05	5.05
15.0% Coarse S.P.C.	5.25	5.20	5.15	5.30	5.30	5.25	5.20

a/ After addition of salt, oxidant, and calcium propionate

b/ S.P.C. = soy-protein concentrate.

Some difficulty was encountered in metering the brews containing the 15.0% level of concentrate. These brews became very viscous during the fermentation period, a great deal of gas being entrapped in these brews. This caused the brew flow to be uneven and made calibrating the flow rate difficult. To correct this problem the water from the auxiliary water tank, that would normally be metered into the incorporator, was shut off and added to the brew; the brews were then degassed with the high speed agitator for several min. before going on stream. Even after this treatment the brew flow rate was somewhat uneven, though not so uneven as to affect the calibrated weight fed to the incorporator substantially.

Dough absorption for each granulation and level of soy-protein concentrate was calculated on an empirical basis, with salt farinograph dough absorptions plus 3%, and not on actual baking tests; hence an adjustment in absorption was sometimes necessary to obtain optimum dough consistency. The absorption adjustment, when necessary, was made by adjusting the flow rate on the auxiliary water tank, after going on stream, until the proper dough consistency was obtained. Then after each experiment, the flow of water was measured and the actual absorption was calculated. Absorption adjustments were necessary for the 15% soy concentrate doughs; the percent increase over the previously calculated absorptions was 4.2, 3.8 and 3.1% for fine, medium, and coarse soy concentrate, respectively.

Doughs containing soy-protein concentrate generally had a very small tolerance to varied developer speeds. The optimum developer speed for the control dough usually produced an over-mixed soy concentrate dough. The soy concentrate doughs normally had the best consistency at the -20 r.p.m. developer speed. Granulation differences of the soy concentrate appeared to have no appreciable effect on dough consistency.

Adding the concentrate had little effect on dough temperature at the developer, although increasing developer speed increased dough temperature. The average dough temperature for the various developer speeds were -40 r.p.m., 92°F.; -20 r.p.m., 93°F.; optimum r.p.m., 96°F.; +20 r.p.m., 98°F.

Bread Characteristics

The loaves obtained from doughs, processed by the continuous-dough method containing 0.0, 7.5, and 15.0% of fine, medium, and coarse soy-protein concentrate, are shown in Figures 12, 13, and 14, respectively. The resulting loaf specific volumes and total scores are presented in Table 24.

Adding increasing percentages of soy concentrate to bread baked by the continuous-dough method caused a progressive crumb discoloration, though less than in bread made by the other baking methods. Unlike the bread made by the other methods containing medium and coarse soy concentrate, the continuous-mix bread crumb and crust appeared less speckled with soy grits even though the same percentages were used.

Statistical analyses of the effects of treatments (granulation and soy-protein concentrate level) and developer speed (optimum, -20, -40, and +20 r.p.m.) on loaf specific volume and total score are summarized in Tables 25 and 26. The analysis of variance (Table 25) indicates that specific volume and total score were significantly affected by granulation and soy-protein concentrate level and developer speed, and also indicated 2nd order interaction. A comparison of the main factor means (Table 26) shows that loaf specific volume and total score normally responded to the experimental factors in a similar manner. Loaf specific volume and total score were highest with the control flour, least affected by 7.5% medium soy concentrate, and most affected by 15.0% fine soy concentrate. At the 15.0% level the loaves with coarse soy concentrate had slightly better specific volumes and total scores than did loaves with medium or fine concentrate. The -20 r.p.m. developer speed, which produced the best-appearing soy concentrate dough, produced the best loaf specific volumes and total scores; proportional increases and decreases in developer speed reduced loaf specific volume and total score.

The effects of adding soy concentrate and varying developer speed on crumb compressibility of bread stored up to five days at room temperatures are shown in Table 27. Statistical analyses of the effects of these factors (soy concentrate in the bread and developer speed) on compressibility readings are presented in Tables 28 and 29. The analysis of variance (Table 28) indicates compressibility was significantly affected by all factors and denotes the existence of 2nd and 3rd order interaction. The comparison of the main factor means (Table 29) shows crumb firmness was significantly retarded by adding soy concentrate. Only when 15.0% fine concentrate was added, was the crumb significantly firmer than the control. Crumb firming was retarded most by 15.0% coarse and medium and only slightly less by the 7.5% fine, medium, and coarse concentrate. By and large, developer speed effects on crumb softness paralleled those of specific volume, indicating a direct relationship between these values. Crumb compressibility, as expected, increased over the five-day storage period.

The crumb moisture content, although not taken in this experiment except by tactual examination, was observed to be appreciably increased by increasing amounts of soy concentrate. In fact, loaves containing the 15.0% level of concentrate were so moist that mould growth was observed on the wrapped loaves, even though the baking formula contained the recommended level of mold inhibitor (calcium propionate), stored at room temperature (about 25°C.) for five-days.

Fig. 12. Bread made with fine granulation soy-protein concentrate by continuous-dough method.

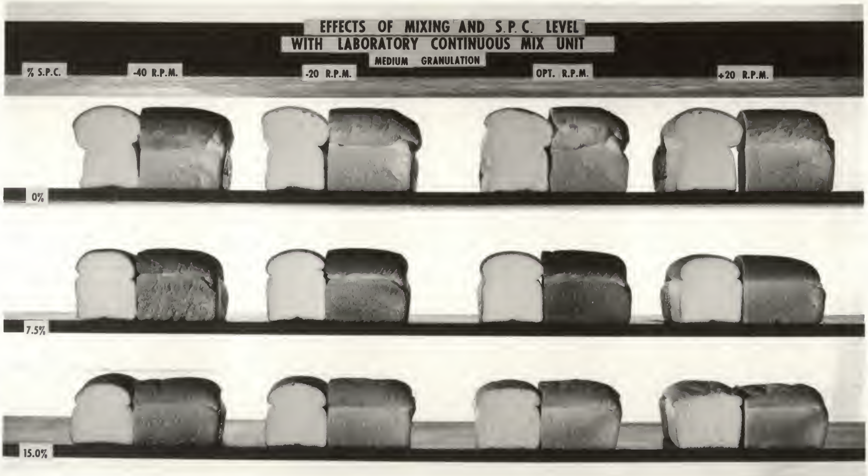

Fig. 13. Bread made with medium granulation soy-protein concentrate by continuous-dough method.

Fig. 14. Bread made with coarse granulation soy-protein concentrate by continuous-dough method.

TABLE 24

EFFECTS OF GRANULATION, SOY-PROTEIN CONCENTRATE LEVEL, AND DEVELOPER SPEED ON LOAF SPECIFIC VOLUME AND TOTAL SCORE OF BREAD MADE BY CONTINUOUS-DOUGH METHOD

Treatments	Developer Speed [a]	Specific Volume (cc/g)	Total Score
Control Base Flour	- 40	7.42	84.5
	- 20	7.55	86.5
	opt.	6.55	90.0
	+ 20	7.07	89.5
7.5% Fine S.P.C. [b]	- 40	5.64	71.5
	- 20	6.22	80.0
	opt.	5.93	77.0
	+ 20	5.85	74.0
7.5% Medium S.P.C.	- 40	6.10	79.0
	- 20	6.11	81.5
	opt.	6.33	81.5
	+ 20	5.91	78.5
7.5% Coarse S.P.C.	- 40	5.60	52.5
	- 20	6.33	78.5
	opt.	6.22	79.5
	+ 20	5.66	71.5
15.0% Fine S.P.C.	- 40	4.07	13.5
	- 20	4.35	50.0
	opt.	5.15	62.0
	+ 20	4.40	57.0
15.0% Medium S.P.C.	- 40	4.98	63.5
	- 20	4.61	56.0
	opt.	4.49	55.0
	+ 20	4.49	54.0
15.0% Coarse S.P.C.	- 40	5.05	61.5
	- 20	5.51	65.5
	opt.	4.94	58.0
	+ 20	4.64	52.5

[a] - 40 = 102 r.p.m.; - 20 = 125 r.p.m.; opt. = 148 r.p.m.; + 20 = 171 r.p.m.

[b] S.P.C. = soy-protein concentrate.

TABLE 25

ANALYSIS OF VARIANCE OF BREAD CHARACTERISTICS
FOR CONTINUOUS-DOUGH METHOD

Analysis of Variance of Specific Volume

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	108.80	18.13	228.78**
Developer Speed	3	2.56	10.85	10.62**
T x DS	18	9.47	0.53	6.62**
Error	112	8.78	0.08	
Total	139	129.62		

Analysis of Variance of Total Score

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	10,318.75	1,719.79	173.22**
Developer Speed	3	1,061.14	353.71	35.62**
T x DS	18	3,208.11	178.23	17.95**
Error	28	278.00	9.93	
Total	55	14,866.00		

** Significant at 1% level.

* Significant at 5% level.

TABLE 26

MAIN FACTOR MEANS OF BREAD CHARACTERISTICS FOR CONTINUOUS-DOUGH METHOD

For Treatments:

Treatments	Specific Volume [a/]	Total Score [a/]
1. Control Base Flour	7.17[a]	87.62[a]
2. 7.5% Fine S.P.C. [b/]	5.91[c]	75.62[c]
3. 7.5% Medium S.P.C.	6.12[b]	80.12[b]
4. 7.5% Coarse S.P.C.	5.95[bc]	70.50[d]
5. 15.0% Fine S.P.C.	4.49[e]	45.62[f]
6. 15.0% Medium S.P.C.	4.62[e]	57.12[e]
7. 15.0% Coarse S.P.C.	5.04[d]	59.38[e]
$LSD_{0.05}$	0.18	3.22

For Developer Speed:

Developer Speed [c/]	Specific Volume [a/]	Total Score [a/]
1. - 40	5.54[bc]	60.86[c]
2. - 20	5.81[a]	71.14[a]
3. opt.	5.66[b]	71.85[a]
4. + 20	5.45[c]	68.14[b]
$LSD_{0.05}$	0.13	2.44

[a/] Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

[b/] S.P.C. = soy-protein concentrate.

[c/] - 40 = 102 r.p.m.; - 20 = 125 r.p.m.; opt. = 148 r.p.m.; + 20 = 171 r.p.m.

TABLE 27

EFFECTS OF GRANULATION, SOY-PROTEIN CONCENTRATE LEVEL, AND DEVELOPER SPEED ON CRUMB FIRMING OF BREAD MADE BY CONTINUOUS-DOUGH METHOD

Treatments	Compressibility (g)											
	1st Day				2nd Day				3rd Day			
	- 40	- 20	Opt.	+ 20[a/]	- 40	- 20	Opt.	+ 20[a/]	- 40	- 20	Opt.	+ 20[a/]
Control Base Flour	40.6	42.7	49.5	45.7	49.4	50.7	57.9	64.2	62.9	55.5	83.4	64.3
7.5% Fine S.P.C. [b/]	42.3	38.0	35.2	46.7	51.1	58.6	56.8	60.2	61.5	62.0	53.8	54.4
7.5% Medium S.P.C.	34.5	42.3	41.6	41.4	54.2	52.4	56.5	63.9	59.1	63.1	65.2	71.3
7.5% Coarse S.P.C.	46.1	34.7	40.2	41.3	56.2	45.9	44.2	55.1	66.0	58.5	50.8	76.6
15.0% Fine S.P.C.	154.3	49.7	49.0	47.3	136.6	58.2	60.3	64.5	156.3	56.7	78.8	71.8
15.0% Medium S.P.C.	36.2	43.1	36.0	42.9	49.0	53.4	44.7	53.8	49.2	56.4	51.1	61.6
15.0% Coarse S.P.C.	40.9	35.1	38.3	42.3	49.3	41.5	49.0	51.6	60.8	48.0	52.3	61.2

a/ Developer speed: - 40 = 102 r.p.m.; - 20 = 125 r.p.m.; opt. = 148 r.p.m.; + 20 = 171 r.p.m.

b/ S.P.C. = soy-protein concentrate.

TABLE 28

ANALYSIS OF VARIANCE OF BREAD COMPRESSIBILITY FOR CONTINUOUS-DOUGH METHOD

Source	D.F.	S.S.	M.S.	F-Ratio
Treatments	6	31,281.30	5,213.55	204.70**
Developer Speed	3	8,729.09	2,909.70	114.24**
Days	2	15,546.24	7,773.12	305.19**
T x DS	18	49,699.72	2,761.10	108.41**
T x D	12	899.04	74.92	2.94**
DS x D	6	472.14	78.69	3.09**
T x DS x D	36	2,964.74	82.35	3.23**
Error	168	4,278.86	25.46	
Total	251	113,871.13		

** Significant at 1% level.

* Significant at 5% level.

TABLE 29

MAIN FACTOR MEANS OF BREAD COMPRESSIBILITY FOR CONTINUOUS-DOUGH METHOD

For Treatments:

Treatments	Compressibility[a/]
1. Control Base Flour	55.83[d]
2. 7.5% Fine S.P.C.[b/]	50.05[bc]
3. 7.5% Medium S.P.C.	53.80[d]
4. 7.5% Coarse S.P.C.	51.30[c]
5. 15.0% Fine S.P.C.	81.97[e]
6. 15.0% Medium S.P.C.	48.12[ab]
7. 15.0% Coarse S.P.C.	47.52[a]
$LSD_{0.05}$	2.33

For Developer Speed:

Developer Speed[c/]	Compressibility[a/]
1. - 40	64.74[d]
2. - 20	49.36[a]
3. opt.	51.66[b]
4. + 20	56.29[c]
$LSD_{0.05}$	1.76

For Days:

Days	Compressibility[a/]
1. 1st day	45.64[a]
2. 3rd day	56.05[b]
3. 5th day	64.85[c]
$LSD_{0.05}$	1.53

a/ Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

b/ S.P.C. = soy-protein concentrate.

c/ - 40 = 102 r.p.m.; - 20 = 125 r.p.m.; opt. = 148 r.p.m.; + 20 = 171 r.p.m.

SUMMARY AND CONCLUSIONS

The effects of a commercial 70% soy-protein concentrate were studied by substituting three grinds (fine, medium, and coarse) of the concentrate for 7.5 and 15.0% of wheat flour and making farinograph, extensigraph, and baking tests.

Inclusion of soy-protein concentrate in farinograph doughs imparted to the control dough curve the characteristics of a strong flour, the effects increasing with concentrate level. Fine grind soy concentrate had less strengthening effects than either the medium or coarse grind. Although water absorption increased with decreasing particle size. Adding 30 ppm of 4:1 bromate-iodate mixture (potassium salts) had no significant effect on farinograph dough characteristics. Addition of salt (2%) greatly increased mixing time of both soy and non-soy farinograph doughs, decreased water absorption of the control dough, and substantially increased water absorption of the soy doughs. These changes are likely a result of increased solubility of wheat proteins (70) and decreased solubility of soy proteins (3) in dilute salt solutions.

Doughs containing soy concentrate were significantly less extensible and more resistant to extension than those of the control. These effects generally increased with soy concentrate level and with increasing particle size. Addition of 30 ppm of a 4:1 bromate-iodate mixture (potassium salts) to all doughs had no effect on extensibility but significantly increased dough resistance to extension. These results indicated that adding soy concentrate to doughs makes them difficult to machine and reduces their ability to retain gas during baking.

Three baking methods were used in this study: straight, no-time, and continuous-dough methods. For each method water absorption of most doughs, although 3% higher, paralleled that found when farinograph doughs were mixed with 2% salt. The exception being doughs made by the continuous method containing the 15% level of soy concentrate; water absorption of these doughs averaged 6.7% above farinograph doughs mixed with salt.

The improved mixing tolerances and increased development times imparted to the control farinograph dough by addition of soy concentrate was not found when these doughs were mixed on laboratory mixing equipment. Soy concentrate doughs mixed equal to or slightly under that of the control dough time produced bread with the best characteristics.

Loaf specific volumes for all the soy concentrate-wheat flour blends made by straight, no-time, and continuous-dough methods were significantly lower than the average volume for the basic wheat flour formulae. Bread made by the continuous-dough method was least affected by adding soy concentrate; it produced bread that had better crumb grain and color and larger loaf specific volume than did the straight or no-time dough methods. Of the last two methods, the no-time dough method was found to produce better quality bread than the straight dough method.

It was found that adding 30 ppm of a 4:1 bromate-iodate mixture (potassium salts) to doughs improved bread made by the no-time dough method but was injurious to bread made by the straight dough method.

Granulation and soy-protein concentrate level also influenced bread characteristics. For each method the 7.5% level of soy concentrates had a less deleterious effect on bread quality than did the 15% level. Bread made with the coarse and medium grinds had less crumb discoloration than that made with the fine grind soy concentrate. In the straight and no-time dough methods bread made with coarse grind was better than bread made with the less granular medium and fine grinds. By the continuous-dough method the coarse and medium grinds yielded bread of equal quality and better than that made with the fine.

By the continuous-dough method crumb softness of bread made with the 15% level of soy concentrates were significantly softer than those with the 7.5% level or the control flour. However, for bread made by the straight and no-time dough methods only the 7.5% level of coarse soy concentrate did not significantly retard the control crumb softness.

It was concluded that the continuous-dough method gives best results when soy concentrate is to be incorporated in bread, and that coarse or medium grind concentrate is more suitable than fine grind for producing high quality bread.

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SOME EFFECTS OF SOY-PROTEIN CONCENTRATE
ON DOUGH AND BREAD CHARACTERISTICS

by

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ABSTRACT

This investigation was undertaken to increase the scope of information on the use of a commercial 70% soy-protein concentrate in bread baking. The effects of three grinds (fine, medium, and coarse) of soy concentrate on physical dough properties were studied with the farinograph and extensigraph; bread baking-potentialities were surveyed by a straight dough method, no-time dough method, and extended to include the continuous-dough method. The data from these studies, when applicable, were subjected to statistical analyses by factorial analysis and the analysis of variance.

Inclusion of soy concentrate in farinograph doughs at levels of 7.5 and 15.0% imparted to the control curve the characteristics of the curve of a strong flour, the effects increasing with concentrate level. Fine grind soy concentrate had less strengthening effects than either the medium or coarse grind. Addition of salt (2%) greatly increased mixing time of both soy and non-soy farinograph doughs, decreased water absorption of the control dough, and substantially increased water absorption of the soy doughs. Adding 30 ppm of a 4:1 ratio of $KBrO_3$:KIO_3 had no significant effect on farinograph dough characteristics.

Dough containing soy concentrate were significantly less extensible and more resistant to extension than those of the control. These effects generally increasing with soy concentrate level and with increasing particle size. Adding 30 ppm of a 4:1 ratio of $KBrO_3$:KIO_3 had no effect on dough extensibility but significantly increased dough resistance to extension.

In baking studies, loaf specific volumes of loaves of all the soy concentrate-wheat flour blends made by straight, no-time, and continuous-dough methods were significantly lower than for the basic wheat flour formulae, the difference

being greater at the higher level of addition. However, the same soy concentrate-wheat flour blends produced loaves with varied quality when made by different methods. Bread made by the continuous-dough method was least affected by adding soy concentrate; it produced bread that had better crumb grain and color, and larger loaf specific volume than did the straight or no-time dough methods. Of the last two methods, the latter was found to produce better quality bread than the former.

Unlike farinograph results, baking results, for all methods, showed doughs containing soy concentrate had about the same development time and less mixing tolerance than the control dough. The best quality bread was produced when soy doughs were mixed equal to or slightly under the control dough mixing time. Adding 30 ppm of a 4:1 ratio of $KBrO_3$:KIO_3 to doughs improved bread made by the no-time dough method, but was injurious to bread made by the straight dough method.

Soy concentrate particle size influenced characteristics of bread made by all methods. Bread made with either the coarse or medium grind had less crumb discoloration than that made with the fine grind. In the straight and no-time dough method bread made with coarse grind was significantly better than breads made with the less granular medium and fine grinds. By the continuous-dough method the coarse and medium grinds yielded breads of equal quality and better than that made with the fine.

Crumb compressibility evaluations were made. Crumb softness of bread containing the 15% level of soy concentrates made by the continuous-dough method was significantly softer than those containing 7.5% level or the control flour. For bread made by the straight and no-time dough methods only that with 7.5% level of coarse soy concentrate had crumb softness equal to that of the control.

It was concluded that the continuous-dough method gives best results when soy concentrate is to be incorporated in bread, and that coarse or medium grind concentrate is more suitable than fine grind for producing high quality bread.