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RHEOLOGICAL AND SENSORY CHARACTERISTICS OF
BREAD FLOUR AND WHOLE WHEAT FLOUR DOUGHS AND
BREADS SUBSTITUTED WITH AIR-CLASSIFIED PINTO AND
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RHEOLOGICAL AND SENSORY CHARACTERISTICS OF BREAD FLOUR AND WHOLE WHEAT FLOUR DOUGHS AND BREADS SUBSTITUTED WITH AIR-CLASSIFIED PINTO AND NAVY BEAN CONCENTRATED PROTEIN FRACTIONS

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ABSTRACT

RHEOLOGICAL AND SENSORY CHARACTERISTICS OF BREAD FLOUR AND WHOLE WHEAT FLOUR DOUGHS AND BREADS SUBSTITUTED WITH AIR-CLASSIFIED PINTO AND NAVY BEAN CONCENTRATED PROTEIN FRACTIONS

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Efficient utilization of legumes (Phaseolus vulgaris L.) is needed to deal with the problem of food shortages on a world scale. Protein inadequacies are a problem facing risk population groups of the world, particularly populations in most developing countries whose diets consist mainly of cereals. Air-classification has enabled fractionation of the bean cotyledon into concentrated protein fractions which, when combined with wheat, such as in bread systems, exert a complementary effect and thereby result in a protein of higher biological value. Substituting with 0, 10, 15 and 20% pinto or navy bean protein concentrate was investigated. Water absorption, arrival and dough development time increased while stability decreased progressively as the percentage of legume protein increased. Increasing the legume protein was inversely related to dough extensibility. The longer the resting period, the shorter was the dough. A reduction in proportional number Resistance to extension/ Extensibility occurred with an increase in legume protein concentrate. Treatments with $KBrO_3$ and SSL improved dough strength. Most doughs reached a good balance R:E (hence

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appropriate fermentation time) after the 90-minute rest period. Increasing - proportionately - the baking water and mixing time and decreasing proportionately fermentation time for legume fortified breads for all levels contributed to good loaf volume. SSL and $KBrO_3$ improved crust and crumb color, tenderness, crumb grain, crumb softness and sometimes flavor. Consequently, bread with fair to good flavor and fairly acceptable ratings was produced at all substitution levels.

To

My Beloved Mother

Daisy P. (Zulu) Silaula "Ngiyabonga Mageba"

and

My daughter

Nontobeko "Teni" Dlamini

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INTRODUCTION

Available food resources must be efficiently utilized to meet world food shortages and nutritional demands of population groups under marginal nutrition. Food inadequacies (quantity and quality) are problems facing risk population groups in most developing countries as well as low income groups of developed countries. Nutritional needs assessment indicate that protein is the single nutrient found most lacking in diets in developing countries. Food enrichment programs of the Food and Agricultural Organization (FAO), World Health Organization (WHO) and other National Nutrition Advisory groups had for a long time concentrated on animal food sources for protein fortification of staple or commonly consumed foods. However, continuing to use them as major fortificants seems bleak because of the ever-rising costs of producing and obtaining them. In addition, present supply cannot cope with the world's rapidly growing population.

Plant protein sources, particularly legumes (Phaseolus vulgaris L.), are therefore good, feasible alternate fortificants since they are rich sources of protein, relatively inexpensive to produce, widely grown and consumed throughout the world. Because legumes have a high lysine content and low amounts of sulfur-containing amino acids, they have a superior net complimentary effect when used together with cereals whose proteins have low lysine. While the sulfur-containing amino acids in cereals are still below the FAO standard, they are however higher in cereals than in legumes. Legumes compliment cereals not only with protein but may provide fair amounts of calcium, iron, nicotinic acid and thiamine as well.

Heat treatment and other processing techniques are not only done to improve bean palatability but also to remove naturally occurring toxins and inactivate trypsin inhibitors and hemagglutinins. The result of these techniques is to make the protein, starch and some minerals and vitamins more available and digestible. Air-classification has made possible the separation of the bean cotyledon into concentrated protein fractions which can be incorporated into bread flour to improve the nutritional value of bread. Moreover, it has facilitated extended bean utilization. Bread, a staple food for some countries and a popular convenience food in most other countries, is a convenient and efficient vehicle for legume protein fortification. Hence, fortifying bread with bean protein would be beneficial from the nutritional and economical points of view. Although use of bean-concentrated protein fractions instead of whole bean flour would greatly improve the protein quality (on weight basis) the lack of technology to process high protein fractions from beans in developing countries is a limiting factor.

This study investigated rheological properties and bread characteristics of doughs and breads substituted with 0, 10, 15 and 20% pinto and navy bean protein concentrates - PPC and NPC respectively. Sodium stearoyl-2-lactylate (0, .5, 1%) potassium bromate (0, 10, 20 ppm) and salt (2%) were incorporated singly into and in combination with bread flour and whole wheat composite flours and their effects on dough rheology were investigated using the extensigraph. The objective of this study was to determine additive levels, combination and time optimum for good dough conditioning. Using the farinograph, hydration and mixing characteristics of bread and whole wheat flour and composite flour blends were investigated to determine the amount of water needed for proper dough consistency and the extent to which the dough could be mechanically manipulated. Breads were baked with 0, 10, 15 and 20% pinto and navy bean protein concentrate on the effect of low - low; low - high; high - low and high - high levels of potassium bromate ($KBrO_3$) and sodium stearoyl-2-lactylate (SSL) on bread volume, texture, color, softness and flavor were investigated. The low and high levels were the .5% SSL; 10 ppm $KBrO_3$ and 1% SSL; 20 ppm $KBrO_3$ respectively. The objective was to determine the level of bean flour in the composite blend which produced higher fortification without making the final product unacceptable.

REVIEW OF LITERATURE

Wheat Flour Proteins and Their Functionality

Basically more than 80 percent of starch-free dry matter of the wheat kernel is protein (Dimler, 1963). Gluten, a complex wheat protein is the key element to successful breadmaking. The inherent characteristics of wheat dough viscoelasticity and loaf volume are primarily due to gluten, a protein which consists of glutenin and gliadin and small amounts of albumins and globulins (Bietz et al., 1973). These proteins form a network upon hydration and input of physical energy (mixing and kneading) which imparts to the dough its peculiar elasto-viscous properties (Bloksma, 1972). Osborne (1907) first separated the gluten mass, on the basis of alcohol solubility, into glutenin and gliadin. Later, other methods of extraction using dilute acetic acid and by gel filtration chromatography were developed (Bietz et al., 1973). As a confirmatory procedure of the purity of the gluten moieties, more than one method should be used in the extraction process.

Glutenin and gliadin are different in structure, molecular weight and in their physical properties. Glutenin, with a molecular weight of (250,000), is alcohol-insoluble and is the major protein. It was isolated as the prime contributor to the functionality of gluten and dough (Bietz et al., 1973). Glutenin occurs only in the endosperm and probably serves both as structural and storage protein. Its quaternary structure is held together by disulfide bonds. Since glutenin imparts strength and elasticity to dough, it therefore determines dough stability and amount and extent of mixing to which the dough can be subjected. This functional property can be attributed to its high molecular weight and the tendency of its molecules to associate (Dimler, 1963).

Gliadin is soluble in aqueous alcohol and is cohesive and more extensible. It is flowy and syrupy. It has a smaller molecular weight (26,000). It is more symmetric and has less surface area for contact with other molecules (Dimler, 1963). Despite the seemingly dominant characteristics of glutenin, a good ratio between the two is necessary to achieve optimum dough performance and loaf volume.

Wheat proteins are rich in polar side chain residues of hydroxyl groups and especially in amide groups which are involved in hydrogen bonding. Glutamic acid is the most prominent amino acid which promotes hydrogen bonding between glutenin molecules. An appreciable number of non-polar amino acids such as valine and leucine contribute to hydrophobic bonding between protein chains. Glutenin dissolves only in acidic or basic solvents at low salt concentrations because it has few basic or acidic amino acids (Bietz, 1973).

<u>Chemical Bonding</u>

The proteins form a network which imparts to the dough its peculiar elasto-viscous properties. In this network, covalent disulfide bonds act as cross-links side by side with non-covalent bonds. Bloksma (1972) and Kuninori and Sullivan (1968) reported that dough viscoelasticity is considered to be caused by a network of protein molecules which form a 3-dimensional structure. The rheological properties of this network greatly depend on the number and type of cross-links between the protein molecules. It was further reported that mixing and kneading facilitated extensive intra and intermolecular association of the polypeptide chains.

Covalent bonds are strong and dissociate at high energy inputs whereas non-covalent bonds are variable in strength but largely dissociate at low energy inputs. Disulfide linkages are the only known covalent bonds significant in dough structure (Wehrli and Pomeranz, 1969) and have an energy of 49 Kcal per mole thus they are not broken at room temperature except by chemical reaction. Wehrli and Pomeranz (1969) reported that about 1.4 percent of the amino acids in gluten are either cystine or cysteine. Breaking and reformation of disulfide bonds by thiol-disulfide interchange is an important mechanism for viscous deformation. The SS bonds in cystine can link together portions of the same polypeptide chain or different polypeptide chains and contribute to dough firmness (Wehrli and Pomeranz, 1969). The reformation of cross links at other sites to maintain dough cohesion is facilitated by exchange reactions of free sulfhydryl with disulfide groups and hence impart required mobility to dough (Wehrli and Pomeranz, 1969). Consequently, baking quality of wheat is governed by protein content and disulfide-sulfhydryl (SS:SH) ratio (Belderok, 1967) which was reported to be 15 for optimum breadmaking and to increase with increasing storage. The ratio (SS:SH) and the total reactive SS and SH groups can be altered as may be the case when non-glutenous flours are added to wheat flour resulting in a marked change in rheological properties. According to Tsen and Bushuk (1968) total reactive and percentage of reactive SH and SS groups increase with decreasing strength. More SH groups were reported to facilitate the interchange of SS groups resulting in a more extensible dough as measured by the extensigraph or show some weakening as measured by the farinograph. Total disulfide groups appear to decrease slightly with decreasing strength. Tsen and Bushuk (1968) concluded that mixing strength appeared inversely related to total reactive SH and SS groups.

Non-covalent chemical bonds (ionic, hydrogen and Van der Waals forces) also occur in dough systems. The addition of salt in bread systems demonstrates the importance of ionic bonds. Ions reduce dipole-dipole attraction and repulsion of dough components, decrease the amount of free water that is essential to both hydrophobic bonding and dough mobility, enhance protein interaction and dissociation and may complex with ionic groups of lipids and pentosans (Wehrli and Pomeranz, 1969). The association of dough components via ionic interchange contributes to increased dough rigidity and decreased dough extensibility (Belderak, 1967). Consequently, protein aggregation may be decreased or increased by altering ionic strength.

Hydrogen bonds result from the affinity of hydrogens of hydroxyl, amide or carboxyl groups for the oxygen of carbonyl or carboxyl groups (Wehrli and Pomeranz, 1969). They are relatively weak with an energy of 8 Kcal per mole; however, their importance in dough systems comes about because of the nature of dough components which are highly polar and hence to a degree determine rheological properties of dough. Amino acids with amide groups and hydroxyl groups in flour starch participate in hydrogen bonding. Hydrogen bonds were found to affect solubility and aggregation of wheat proteins and the unique visco-elastic properties of wheat flour doughs and to a certain extent to govern oxidant requirements of flours (Pomeranz, 1966; Wehrli and Pomeranz, 1969).

Van der Waals forces provide very weak bonding but are significant in interactions between non-polar amino acid residues and fatty acid side chains in places where hydrophobic bonding is impossible. Their major role is to stabilize the starch glyceride complex which has been postulated to affect baking and bread properties (Wehrli and Pomeranz, 1969; Bloksma, 1972).

Hydrophobic bonds facilitate rapid interchange at room temperature and may contribute to dough plasticity. They may also contribute to dough elasticity by stabilizing conformations with small surfaces. Because of their endothermic nature, hydrophobic bonds can resist increasing oven temperatures up to 60°C and thereby play an important role in the early stages of baking (Wehrli and Pomeranz, 1969).

Legume Flours and their Complimentary Value to Wheat Flour

Legumes are most frequently considered in terms of their complimentary nutritional values (particularly in relation to amino acids) to cereal diets (FAO, 1982). However the size of the proportions is a subject of continuing debate (Bressani and Elias, 1979). Table 1 shows the distribution of essential amino acids for dried beans (navy bean and pinto bean) and wheat. Knowledge of both the proteins and carbohydrates in legume flours compared with those in wheat flour is essential to better understanding of the role of composite flours in breadmaking (Naivikul and D'Appolonia, 1978).

Table 1. Essential amino acid content for the dried bean (navy and pinto) and wheat kernel.

Amino Acid	FAO/WHO[a] Reference Pattern	Wheat[b] Kernel	Navy[c] Beans	Kidney[d] Beans
Histidine	-	2.9	2.4	2.6
Lysine	5.4	2.7	5.7	6.7
Methionine & Cysteine	3.5	2.8	1.7	1.9
Phenylalanine & Tyrosine	6.1	6.8	8.4	9.8
Leucine	7.0	10.1	6.7	8.1
Isoleucine	4.0	5.2	3.7	4.2
Valine	4.9	5.6	4.4	5.1
Threonine	4.0	3.7	4.1	4.2
Tryptophan	1.0	3.8	1.2	1.5

[a]FAO/WHO (1973) reference pattern.

[b]Department of Agriculture (MSU).

[c]Boloorforooshan (1977).

[d]Evans and Bandemer (1967).

Legumes are good sources of protein and are particularly rich sources of lysine; however they are low in methionine and other sulfur-containing amino acids. On the other hand wheat flour proteins are relatively higher in sulfur containing amino acids and poor in lysine. Legume proteins are primarily of two types - storage and non-storage (FAO, 1982). The major proteins of the mature seed are globulins with a high molecular weight. Albumins and glutelins are non-storage proteins mainly performing structural functions; legume proteins contain 70% globulins, 10-20% albumins and 10-20% glutelins (FAO, 1982). Other proteins which are present in significant amounts and which may influence the overall amino acid composition, protein availability and digestibility are haemagglutinins and trypsin inhibitors.

Legume flours have less starch, damaged starch and pentosan content than wheat flour but have comparatively high ash and acid detergent fiber. Total sugar content is higher in most legumes than wheat flour. Legumes particularly pinto and navy have high levels of sucrose, raffinose, stachyose and low levels of glucose. They are reported to have somewhat lower moisture values (9.9 - 10.8%) compared to those of wheat flour (12 - 14%) (Naivikul and D'Appolonia, 1978).

Dough Characteristics and Baking Qualities of Composite Flours

Although legume flours can be excellent protein fortificants for breads, they, however, not only lack gluten forming proteins but also impart a diluting/weakening effect on the gluten so that both the physical and sensory characteristics of dough and bread are adversely altered. In addition they have low contents of pentosans and damaged starch which are also important in good dough performance. Loaf quality depends upon the rheological properties of dough and baking quality is generally positively correlated to protein content (Bloksma, 1972). The dilution theory proposed by Knorr and Betschart (1978) suggests that protein fortificants such as legumes dilute the gluten with a resultant loss in strength of the gluten structure. The decreased loaf volume in legume flour enriched bread could be partially explained by this theory. Fleming and Sosulski (1978) reported that concentrated plant proteins disrupted the well defined protein - starch complex which was characteristic in wheat flour bread. According to the results of several research groups (McConnell et al., 1974; Sathe et al., 1981) adding bean flour above the 10% level to a wheat flour composite was detrimental to dough and bread quality; however these authors further reported that using protein concentrate in the wheat flour composite produced a more acceptable bread than using bean whole flour. Several studies have demonstrated that the amount of legume flour needed to obtain the desired level of fortification resulted in a decreased loaf volume, deteriorated crumb grain and color and difficulty in handling and manipulating the dough (Tsen et al., 1971; McConnell et al., 1974; D'Appolonia, 1977; Tenney, 1978; Knorr and Betschart, 1978, 1981; Deshpande et al., 1983). Nevertheless it was further demonstrated that these problems could be partially overcome by the use of dough conditioners such as sodium stearoyl-2-lactylate (SSL); dough strengtheners such as potassium bromate and surfactants such as ethoxylated mono and diglycerides. The mechanism by which these additives interact with flour components to improve strength is not well understood nor documented. It is thought that bromate improves flour by oxidizing the thiol SH groups. Sodium stearoyl-2-lactylate is thought to stabilize the disulfide linkages as the protein coagulates and starch gelatinizes.

The use of composite flours for breadmaking generally requires dough strengtheners. Deshpande et al. (1983) and Fleming and Sosulski (1977a) reported that adding .5% and 1% SSL produced a better crumb grain and compression values. McConnell et al. (1974) found that .5% SSL had no significant effect on loaf volume but confirmed that it improved crumb grain. Tsen et al. (1971) found that adding .5% and 1% SSL to breads substituted with 12% soy flour markedly improved the average specific volume by 16%

bringing it closer to specific volume of marketable bread.

Potassium bromate requirements, in general, increase with protein content but must not exceed 50 ppm by FDA standards. Tsen et al. (1971) found that increasing bromate to 20 ppm and reducing the fermentation period from 2 hours alleviated adverse effects of soy flour fortified bread. According to D'Appolonia (1978) roasting navy bean flour before using it in a composite flour produced bread with a higher volume than using untreated flour. Roasted navy beans caused an increase in water retention and a decrease in protease and lipoxygenase activity of the composite flour.

Flour water absorption is a linear function of protein content within a flour mixture; mixing tolerance and dough handling characteristics are related to protein content (Finney and Shogren, 1972). Bloksma (1972) reported that water absorption, dough development time and extensibility increased with increasing protein content. Sathe et al. (1981) and several other studies reported a progressive increase in water absorption as measured by the farinograph with an increase in the level of whole bean flour or protein concentrate in the composite flour; but that protein concentrate blends had higher absorption values than whole flour blends. One reason may be that the protein content was higher in the former. Increasing water by an additional 8 - 12% over that required to bring the farinograph curve to the 500 B.U. line resulted in an average increase of 27% in specific volume (Knorr and Betschart, 1981). These authors further suggested that it was appropriate to add an additional 1 percent water per 1 percent increase in protein concentrate above the farinograph absorption.

Mixing requirements and tolerance are other two important rheological and baking properties and are critical for good loaf volume. Knorr and Betschart (1981), Finney and Shogren (1972), and Tsen et al. (1971) reported that dough mixing was critical in determining quality of bread containing 12 percent soy flour and .5 percent SLL. Sathe et al. (1981) found that the addition of bean flour or protein to a wheat flour resulted in a decrease in mixing time and dough stability. This finding was later confirmed by Deshpande et al. (1983) who indicated that mixing tolerance index increased whereas mixing time and dough stability decreased. D'Appolonia (1977) found that stability and dough development time decreased with an increase in bean flour or protein. Overmixing resulted in dough slackening and weakening of the gluten matrix while inadequate mixing did not sufficiently develop the gluten mass (Finney and Shogren, 1972). Dough with unusually long mixing times generally are not extensible enough to be desirably elastic. Therefore mixing time can be used as a reliable index for loaf volume.

Extensibility is the only rheological property understood to relate to baking quality (Holmes, 1966). Extensigram data showed a reduction in the proportional number (R:E) as the percentage of legume flour or protein in the blend increased; the greater the proportional number the shorter was the dough (D'Appolonia, 1977). Extensibility of doughs generally decreased with an increase in the resting period as well as with an increase in the concentration of bean flour. Sathe et al. (1981) reported higher extensibility values for protein concentrate blends than whole flour blends and lower resistance to extension values for protein concentrate blends than whole flour blends. Resistance to extension increased with an increase in the resting period and decreased with an increased concentration of bean flour.

Function of Salt $KBrO_3$ and SSL in Breadmaking

Salt

Salt is an essential ingredient in breadmaking. Altering the salt content in a protein solution causes the breakdown of one of the physical bonds between protein molecules in bread systems (El-Minyawi, 1980). The ionic effect of salt facilitates hydrophobic bonding and dough mobility, enhances protein interaction and dissociation and may complex with ionic groups of lipids and proteins (Wehrli and Pomeranz, 1969). Salt contributes to increased dough rigidity and extensibility via ionic interchange (Belderok, 1967). The concentration of salt in most dough systems is 2% (Miller et al., 1947). Doughs with salt added were less sticky and more stiff as indicated by the extensograph studies (Grogg et al., 1967). There was an increase in resistance to extension and increase in extensibility. Salt is also essential in the control of fermentation.

Potassium Bromate

Oxidizing agents are used in dough systems to control dough consistency and strength (Kinsella, 1976). Oxidizing agents help to mask the grayish color of some beans, improve beneficial cohesive properties and lessen the hydrolytic and proteolytic effects of legume flour (D'Appolonia, 1977). According to Tsen et al. (1981), many deleterious effects of soy flour can be overcome by raising the bromate level. Twenty ppm potassium bromate was reported optimum to oxidize composite flour with 12 percent soy flour. However, they reported that overtreating and undertreating with bromate lowered baking quality of bread containing 12 percent soy flour and .5 percent SSL. Oxidizing agents are generally believed to control disulfide bond rupture and the extent of disulfide interchange reactions (Ewart, 1972; Wall, 1971).

Sodium Stearoyl-2-lactylate

Dough conditioners such as SSL have been reported to improve the handling properties of dough, increase loaf volume, improve crumb color and texture and increase water absorption and modify deleterious effects of non-glutenous flour (Tsen et al., 1971; Tenney, 1978). Sodium stearoyl-2-lactylate produced better volume than either calcium stearoyl-2-lactylate or polysorbate 60 or ethoxylated mono and diglycerides (Tenney, 1978). Fleming and Sosulski (1977a) reported that conditioners with a high hydrophilic-lipophilic balance (HLB) were required for best breadmaking results. Tsen and Hoover (1971) suggested that since SSL was more soluble than CSL it might have exerted a superior shortening-sparing effect and hence improved the baking performance of the fortified breads. Use and levels of food additives like potassium bromate and sodium stearoyl-2-lactylate are regulated by the Food and Drug Administration.

Sensory Evaluation of Composite Flour Breads

Many researchers have studied the effects of incorporating legume flours on bread quality and acceptability. Knorr and Betschart (1981) reported that the volume of the final product of legumes - wheat flour blends (LWFB) was not only dependent on the type of wheat flour but also on the level of substitution; the treatment of the legume flour, form of legume flour - whether whole or high protein fractions. These authors further indicated that the baking water and mixing were also important in obtaining a good loaf volume. It is reported that if high protein bread is to be of any value in the supply of protein and the protein quality of the diet, it must be organoleptically acceptable (Hoojjat, 1981). Tsen and Hoover (1973) found that bread fortified with 12 percent soy flour and .5% SSL was acceptable. Acceptable bread with 24% soy flour and .5% SSL was also produced under modified processing conditions. Taste panel analysis of breads containing 20% faba bean flour showed them to be inferior to commercially available whole wheat bread in both taste and general acceptability but it was not disliked (McConnell et al., 1974). Breads with faba bean protein concentrate were described as having a bland flavor or a slightly gummy or sticky texture. Sathe et al. (1981) found that breads with 10% legume protein concentrate were more acceptable than those with the same level of whole bean flour. Replacement of wheat flour with 10% navy bean or lentil were rated by 67% of the taste panel members as having a pleasant taste; 40% of the panel rated the pinto and faba bean bread as having a pleasant taste (D'Appolonia, 1977). Bread with 10% pinto bean gave the highest rating for mastication and was more acceptable than the control bread. Most of the adverse effects of legume flours can be minimized by the addition of bromate and dough conditioners such as SSL to produce acceptable bread (Tsen and Hoover, 1971; Fleming and Sosulski, 1974).

METHODS AND PROCEDURES

This study was carried out in three sections: physical dough testing, baking study, evaluation by objective tests. Physical dough testing was done first so that necessary mechanical and physical modifications in the bread formula could be determined for optimum dough performance and bread quality. The farinograph and extensigraph were used to determine the physical dough properties of the different pinto and navy bean protein fraction flour blends. Baking studies were done to evaluate effects on loaf volume, crumb texture and color, tenderness and flavor.

High protein fractions (protein II) of pinto and navy bean were incorporated into bread flour and whole wheat flour at the 0, 10, 15 and 20 percent levels of substitution. Their effects on rheological properties and baking qualities were investigated.

The farinograph was used to determine composite flour water absorption, arrival time, dough development time and dough stability. Results were used in the determination of water content and extent of mixing for the different blends in the bread formula. The extensigraph was used to determine composite flours' dough extensibility and resistence to extension. Load extension curves obtained from testing doughs after 45, 90 and 135 minutes rest period were used to determine appropriate fermentation time for the different legume - flour blends. Fermentation time for each dough sample was achieved when extensibility and resistence to extension were in good balance. From the data - a derived value - proportional number (R/E ratio) was calculated. The load extension curves and proportional number were then used as indexes for fermentation time.

The effects of salt (NaCl) (2%); potassium bromate, $KBrO_3$ (0, 10, 20 ppm) and sodium stearoyl-2-lactylate, SSL (0, .5, 1%) on composite flour's dough extensibility and resistance to extension were studied. Single additive treatment was salt (2%); double additive treatments had salt 2%, each level of $KBrO_3$; salt 2% with each level of SSL; triple additive treatment had salt (2%); each level of $KBrO_3$ and SSL (Table 2). This enabled additive interaction effects on dough extensibility and resistence to extension to be studied.

Baking proceeded in two series. Bread flour - legume protein concentrate bread were baked and evaluated for sensory characteristics (Appendix A) by an eight member taste panel. Whole wheat - legume protein concentrate breads were baked next and a different eight member taste panel was set up for sensory evaluation. The effects of $KBrO_3$ (0, 10 20 ppm) and SSL (0, .5 and 1%) (Table 3) at all possible combinations on bread quality (volume,

Table 2. Design of experiment for the investigation of effects of treatments on composite flour's dough extensibility and resistance to extension.

	Treatment									Resting Time		
	Salt 2%									Extensibility (mm) Resistance to Extension (B.U.)		
	Salt 2%	$KBrO_3$ (ppm)		SSL (%)		$KBrO_3$ ppm and SSL (%)				45 min	90 min	135 min
		10	20	.5	1	10 .5	10 1	20 .5	20 1			
Control BF	X	X	X	X	X	X	X	X	X	X	X	X
Control WW	X	X	X	X	X							
BF+10% PPC	X	X	X	X	X							
BC+10% NPC	X	X	X	X	X							
WW+10% PPC	X	X	X	X	X							
WW+10% NPC	X	X	X	X	X							
BF+15% PPC	X	X	X	X	X							
BF+15% NPC	X	X	X	X	X							
WW+15% PPC	X	X	X	X	X							
WW+15% NPC	X	X	X	X	X							
BF+20% PPC	X	X	X	X	X							
BF+20% NPC	X	X	X	X	X							
WW+20% PPC	X	X	X	X	X							
WW+20% NPC	X	X	X	X	X							

PPC = Pinto Protein Concentrate (% db. 42.48); NPC = Navy Protein Concentrate (% db 41.56).

BF = Bread Flour; WW = Whole Wheat Flour.

Table 3. Design of experiment for the investigation of effects of pinto or navy bean protein concentrate and treatments on bread quality.

	Chemical Treatment					Physical Treatment				
	$KBrO_3$: SSL					Fermentation[1] Time (min)	H_2O[2]			Mixing Time[3] (min)
	0	10:.5	10:1	20:.5	20:1		10%	15%	20%	
Control WW	X	X	X	X	X	X	X	X	X	X
Control BF	X	X	X	X	X	X	X	X	X	X
WW+10% PPC	X	X	X	X	X	X	X	X	X	X
WW+10% NPC	X	X	X	X	X	X	X	X	X	X
BF+10% PPC	X	X	X	X	X	X	X	X	X	X
BF+10% NPC	X	X	X	X	X	X	X	X	X	X
WW+15% PPC	X	X	X	X	X	X	X	X	X	X
WW+15% NPC	X	X	X	X	X	X	X	X	X	X
BF+15% PPC	X	X	X	X	X	X	X	X	X	X
BF+15% NPC	X	X	X	X	X	X	X	X	X	X
WW+20% PPC	X	X	X	X	X	X	X	X	X	X
WW+20% NPC	X	X	X	X	X	X	X	X	X	X
BF+20% PPC	X	X	X	X	X	X	X	X	X	X
BF+20% NPC	X	X	X	X	X	X	X	X	X	X

[1] Shorter fermentation for LWBF doughs (Tsen et al., 1971).

[2] H_2O absorption 1% extra water for each 1% legume concentrate added (Tsen et al., 1971).

[3] Mixing time variable.

texture, tenderness, color) were investigated. In addition, control breads for the various bean protein concentrate substitution levels were analyzed for moisture. Data was statistically analyzed by the analysis of variance procedure (using the MSU SPSS STAT Package) at the 95% level of probability.

Materials

Bread flour and whole wheat flour were purchased through the Michigan State University Food Stores. Mature pinto and navy beans (Phaseolus vulgaris L.) were obtained from Michigan Farmers; roasted and dehulled at the Food Protein Research and Development Center in Texas A and M. High protein fractions of each bean were prepared by grinding in a Model 250 .CW Study Impact Mill; Air classification in a Model 410 .MPVI air classifier with a break ring setting of 3; re-air classified (to obtain high protein fractions) with a break ring setting of 0 at the (Alpine American Corporation; Natick, Mass.) Chemical analysis below were done by the Food Science Department, Michigan State University (Table 4). Non-fat dried milk (NFDM) solids, hydrogenated shortening (Crisco); active dried yeast; granulated white sugar; malted barley; salt (NaCl) were purchased from Food Stores, Michigan State University. L-ascorbic acid was supplied by Fisher Scientific Company; potassium bromate (bromette oxidation tablets) were supplied by Cain Food Industries. Dough conditioners used

Table 4. Chemical composition of dry roasted edible bean flour fractions* processed at Alpine American Inc. Winter, 1983[1].

Bean Type	Sample Fraction	Moisture (% w/b)	Ash	Protein	ENDF[2]	NSI[3]
			(% db)			
Navy	High Protein II	7.50	4.95	41.56	3.73	40.99
Pinto	High Protein II	6.26	4.93	42.48	5.12	49.40

*From Project Report, 1983; "Utilization of Dry Heated edible bean flour"

[1] n=3

[2] Enzyme Neutral Detergent Fiber

[3] Nitrogen Solubility Index

were Emplex (SSL) which was obtained from Patco Products and polysorbate 60 (Tandem 8) with mono and diglycerides with 0.02 percent BHA which was obtained from Atlas Chemical Division.

Physical Dough Testing

Farinograph

A C.W. Brabender Instruments, Inc. farinograph with Model Type PL-2H Dynamometer; number 2092 and Type 3-S-300 measuring head was used. The temperature of the equipment was regulated by a Type P 60-B Thermobath and kept constant at $30 \pm 0.1^{o}C$.

To determine water absorption on "as is" moisture basis, arrival time, dough development time and stability, the 50 g bowl was used following AACC constant dough weight procedure 54-21B (AACC, 1982). Legume flour (pinto and navy) was sifted to minimize lumping. Wheat flour and bean flour were weighed separately on the Mettler P-1200 Balance to ±0.05 g. Fifty grams composite flour samples were each mixed in the farinograph bowl in the following wheat - bean flour proportions (100:0%; 90:10%; 85:15% and 80:20%). To obtain a fairly homogeneous sample, the two flours were mixed in the farinograph for one minute before water was added. At the 0 minute and 0 B.U. line, water was delivered from a fast-delivering burette and the farinograph was run at a low speed setting of 31.5 rpm. Bowl sides were scraped by a plastic spatula and covered with attached lid to prevent evaporation. Mixing was left to continue until the top of the farinogram curve dropped 20 units from the 500 B.U. line. If the curve was not centered at the peak on the 500 B.U. line, re-estimation of absorption was done according to the approximate relationship: 20 B.U. = 0.6 ml water. Each sample was done in triplicate and farinogram curves were obtained and evaluated under the following parameters:

Water Absorption: Amount of water in percentage required to bring the dough to the right consistency measured when farinogram curve reaches and centers along the 500 B.U. line. Values were corrected to 14 percent moisture basis as shown in note number 2 of Table 54-29 (AACC, 1982) of the AACC Test Procedure.

Arrival Time: The time taken by dough from start of mixing (0-time) with water until top of curve first intersects the 500 B.U. line.

Dough Development Time (Peak Time): Time taken by dough (from start of mixing with water) to peak or reach its highest point before it stabilizes along the 500 B.U. line.

Stability: The time difference between departure time and arrival time.

Extensigraph

The extensigraph Type E-1, number 762 from C.W. Brabender Instruments Inc. was used to test extensibility and resistence to extension of composite flour doughs. The temperature 30±0.1^{o}C and a pressure of 20 - 30 mm Hg were kept constant by the Type T-60-B thermoregulator. Dough samples for testing were prepared in the farinograph 300 g bowl following the AACC method 54-10 (AACC, 1982). Two observations per sample were made.

A 300 g sample was mixed in the following wheat/legume flour proportions (100:10%, 90:10%, 85:15%; 80:20%). Samples were treated with salt NaCl 2 percent; potassium bromate ($KBrO_3$) (0, 10, 20 ppm) and sodium stearoyl-2-lactylate (SSL) (0, .5, 1%) and their effects alone and in combination studied. Additives were made into solutions before they were added into the composite flour. The wheat flour and legume flour were premixed thoroughly (approximately 3 minutes) in the 300 g farinograph bowl. Water used for making solutions was subtracted from the total water as determined by the farinograph absorption to prepare doughs. Mixing continued for 2 minutes at low speed (31.5 rpm) until all the remaining water was delivered. The farinograph was stopped and dough allowed to rest for five minutes and re-started at high speed (63 rpm) until dough was fully developed (that is reached peak point). The dough was scaled into two 150 g pieces. Each piece was rounded in the dough moulder at 20 rpm and shaped in the dough roller. Doughs were clamped into the lightly greased dough holders. Doughs were put in the extensigraph's fermentation cabinets for conditioning and removed for testing after 45 minutes.

The dough was placed in the sample balance arm for testing. Starting at the 0 B.U. line, the dough hook was released on a downward stroke and left to run through the dough until dough broke. During this time torque readings and extensibility were transferred on the extensigram paper. The dough was reshaped and replaced in the fermentation cabinet. These processes were repeated at 90 and 135 minute rest periods. Load extension curves were evaluated for extensibility in (mm) and resistence to extension in B.U. A derived factor (proportional number) was calculated as follows:

$$\frac{\text{Resistence to Extension}}{\text{Extensibility}} = \text{proportional number}$$

Baking Study

Bread was baked following the AACC 10-10A Basic Straight Dough Method (AACC, 1982). Mixing time and water content were determined from farinograph studies and preliminary testing. Fermentation and proofing time were determined from extensigraph studies. The formula used below (Table 5) and method were adjusted for optimum bread quality and volume.

Dry ingredients were weighed on the Mettler Balance P1200 for large weight ingredients and on the Mettler H10

Table 5. Modified bread formulas for breads substituted with pinto or navy bean protein concentrates.

Ingredients	Flour Basis (%)	Level of PPC/NPC* (%) 0	10	15	20
Bread Flour (g) or Whole Wheat	100	100	90	85	80
Sugar	6	6.0	6.0	6.0	6.0
Active dried yeast	5	1.9	1.9	1.9	1.9
NDFM (solids)	4	4.0	4.0	4.0	4.0
Shortening (Crisco)	3	3.0	3.0	3.0	3.0
Salt	1.5	1.5	1.5	1.5	1.5
Malt (mls)	0.3	2.5	2.5	2.5	2.5
Ascorbic acid	40 ppm	0.4	0.4	0.4	0.4
Surfactant	0.5	0.5	0.5	0.5	0.5
Potassium bromate (0, 10, 20 ppm)					
SSL (0, .5, 1%)					approx.
Water[1] for BF PPC (mls)	variable	61.4	79.0	84.0	98.0
NPC		61.4	79.0	86.0	98.0
Water for WW PPC		67.7	84.0	92.0	100.0
NPC		67.7	83.0	91.0	98.0
Fermentation[2] (min) BF PPC	variable	90.0	80.0	75.0	70.0
Time for NPC		90.0	80.0	75.0	70.0
Fermentation WW PPC		90.0	75.0	70.0	65.0
NPC		90.0	75.0	70.0	65.0

*PPC=Pinto protein concentrate; NPC=navy protein concentrate; WW=whole wheat flour; BF=bread flour.

[1]Variable - values are approximate 1.0 mls

[2]Fermentation times determined from preliminary studies (extensograph data).

for ingredients weighing less than 1 g. A sugar - salt solution was made and the yeast hydrated in this medium and kept in a proofing cabinet at 30±1.0^{o}C for 4 minutes. Ascorbic acid solution was made according to note 2 under oxidizer solutions of AACC Method 10-10A. Dry ingredients were sifted into a 5-K mixer bowl and blended with shortening and surfactants. The ingredients were blended together at slow speed at 15 rpm 2. Following the specifications of the AACC 10-10A for pup loaves (AACC, 1982), doughs were mixed covered with a damp cloth to prevent drying of bowl sides and evaporation. Mixing time (Table 5) varied according to predetermined time from the farinograph dough development time. Doughs were allowed to rest for 2 minutes and scaled into 120 g pieces. Doughs were fermented at 31±1.0^{o}C for varied time lengths (Table 5). Doughs were kneaded at 2 different time periods and moulded into loaves with National Manufacturer Roller and Sheeter and then panned; loaves were proofed until they doubled in size approximately 30-35 minutes at 31±1.0^{o}C. The proofed doughs were baked in a National Manufacturer rotary oven for 24 minutes at 218^{o}C.

Baked bread was cooled for 1 hour after which it was wrapped in a plastic food wrap. Breads were measured for volume (approximately 10 hours after cooling) by the rapeseed displacement method. Loaf volume in (cc) represented the average of three replications. Breads were then sliced (approximately 1.2 cm) for sensory evaluation and for tenderness and compressibility. The slicing for the different test was done as illustrated in Figure 1.

Sensory Evaluation

The quality of the breads was evaluated according to a descriptive score card (Appendix A) using a 7 point scale. The control bread scores were used as reference for bread with 10, 15 and 20% pinto or navy bean protein concentrates. Breads were also evaluated for tenderness using the standard shear compression cell of the Food Technology Corporation Texturecorder, Model TR5, transducer 3000 lbs (serial no. 120, cal; 78.5%) and operated at the range 1/30. The downward stroke motion was completed after 30 seconds after which a reading was taken. The 5.5 cm diameter plunger of the experimental cell was used to determine compressibility at the range of 1/100. Breads were evaluated for color on the D25 - 2 model optical sensor Hunter color difference meter, using the yellow tile with standard values of L = 78.5; L_a = -3.2; L_b = 23.4. Each bread was evaluated for color in two ways; in slices and ground. An average of the two measurements for triplicate replications was reported. After color determination the ground bread was then used for moisture.

Moisture Analyses

The AACC method 44-40 (1982) was followed for moisture determination in flour blends. A well mixed sample of 2 g

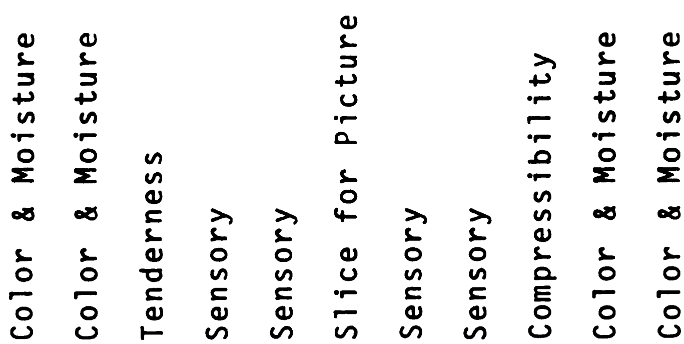

Figure 1. Assymmetry bread slice for chemical physical and sensory testing.

weighed to the nearest 0.0001 g was weighed into a predried and weighed aluminum dish. Samples were dried at 90°C overnight ± 10 hours under vacuum equivalent to 25-30 mm Hg in a Hotpack, #633 vacuum drying oven. Samples were cooled in a desiccator for 30 minutes and then reweighed. The percentage loss in weight was reported as percent moisture.

Bread moisture was determined according to the AACC method 44-40 (1982). Ground samples from color evaluation were weighed to ±2.0001 g, into a predried weighed aluminum dish. Samples were dried in a Hotpack moisture oven at 90°C overnight. Samples were cooled in a dessicator for 30 minutes and weighed, and percent moisture loss reported as percent moisture.

RESULTS AND DISCUSSION

Farinograph Studies of Bread Flour and Whole Wheat Flour Fortified with Pinto and Navy Bean Protein Concentrates

This study has shown that substituting with and increasing the level of pinto and navy bean protein concentrates resulted in significant differences in rheological properties of composite flour doughs (Tables 6, 7 and 8). At all levels of substitution - 10, 15 and 20% - there was a progressive, though not always significant, weakening of the dough as indicated by stability values. Replacing wheat flour with pinto or navy bean protein concentrates had similar results to those of previous researchers (Deshpande et al., 1983; Sathe et al., 1981; D'Appolonia, 1978). Water absorption was found to increase as the legume protein concentrate increased in the dough system (Figure 2). The amount of water needed to bring the dough to the correct consistency measured when the farinogram curve reaches and centers on the 500 B.U. line is determined by the amount of protein in the composite flour; the form of treatment of the navy and pinto bean flour and the amount of starch in the composite flour. Consequently the increased protein by the addition of bean

Table 6. Farinograph data with means[1] and standard deviations of bread flour doughs substituted with pinto and navy bean protein concentrates[2].

Source	Subst. Level (%)	H_2O Absorption[3] (%)	Arrival Time (min)	Dough Development Time (min)	Stability (min)
Pinto	0	61.4[a]±.1	7.3[a]±.3	8.7[a]±.6	7.0[a]±.5
	10	69.5[b]±.2	9.2[b]±.7	11.1[b]±.4	6.8[a]±.3
	15	73.6[c]±.2	10.2[c]±.3	11.2[b]±.3	3.8[b]±.2
	20	77.2[d]±.2	11.6[d]±.0	12.8[c]±.2	3.4[b]±.4
Navy	10	70.4[b]±.1	9.2[b]±.2	10.6[b]±.1	7.2[a]±.3
	15	74.5[c]±.4	9.7[b]±.3	10.8[b]±.3	6.3[a]±.3
	20	77.5[d]±.2	9.5[b]±.5	10.7[b]±.6	4.7[c]±.3

[1]Average of 3 replications.

[2]Absorption is expressed on 14% m.b.

[a,b,c,d]Means for each bean flour protein concentrate with the same superscript are not significantly different at $p \leq 0.05$ (Duncan, 1957).

Table 7. Farinograph data with means[1] and SD of whole wheat flour substituted with pinto and navy bean protein concentrate.

Source	Subst. Level (%)	H_2O Absorption[2] (%)	Arrival Time (min)	Dough Development Time (min)	Stability (min)
Pinto	0	67.7[a]±0.4	5.7[a]±0.3	8.0[a]±.0	11.2[a]±.4
	10	74.8[b]±0.2	8.0[b]±.5	9.8[b]±.3	8.2[b]±.8
	15	77.9[c]±0.1	8.6[c]±.2	10.3[c]±.3	7.3[bc]±.2
	20	79.4[d]±0.1	9.9[d]±.2	12.0[d]±.0	6.6[c]±.2
Navy	0	67.7[a]±0.4	5.7[a]±0.3	8.0[a]±.0	11.2[a]±.4
	10	73.3[b]±0.4	6.9[b]±.4	8.4[a]±.4	9.5[b]±.5
	15	76.1[c]±0.3	8.4[c]±.1	9.7[b]±.3	7.8[c]±.3
	20	77.3[d] 0.1	8.5[c]±.0	10.5[c] .0	7.5[c] .0

[1]Average of 3 replications

[2]Absorption is expressed on 14% m.b.

[a,b,c,d]Means for each bean flour protein concentrate with the same subscript are not significantly different at $p \leq 0.05$ (Duncans, 1957).

Table 8. Mean squares from analysis of variance for farinograph data of bread and whole wheat flour doughs substituted with pinto and navy bean protein concentrate.

Flour Type	Source of Variation	Degrees of Freedom	H_2O Absorption (%)	Arrival Time (min)	Dough Development Time (min)	Stability (min)
Bread			Pinto Bean			
	Level	3	70.8045***	10.2014***	8.5135***	11.1806***
	Within	8	.1412	.1510	.1563	.1354
			Navy Bean			
	Level	3	73.3369***	3.5191***	8.1163***	3.9097***
	Within	8	.0151	.1198	.1927	.1250
Whole Wheat			Pinto Bean			
	Level	3	50.5005***	8.3204***	6.7374***	11.5780***
	Within	8	.0073	.1176	.0476	.2426
			Navy Bean			
	Level	3	35.7924***	5.0189***	3.2828***	8.0806***
	Within	8	.0209	.0714	.0655	.1488

***Significant at $p \leq 0.001$.

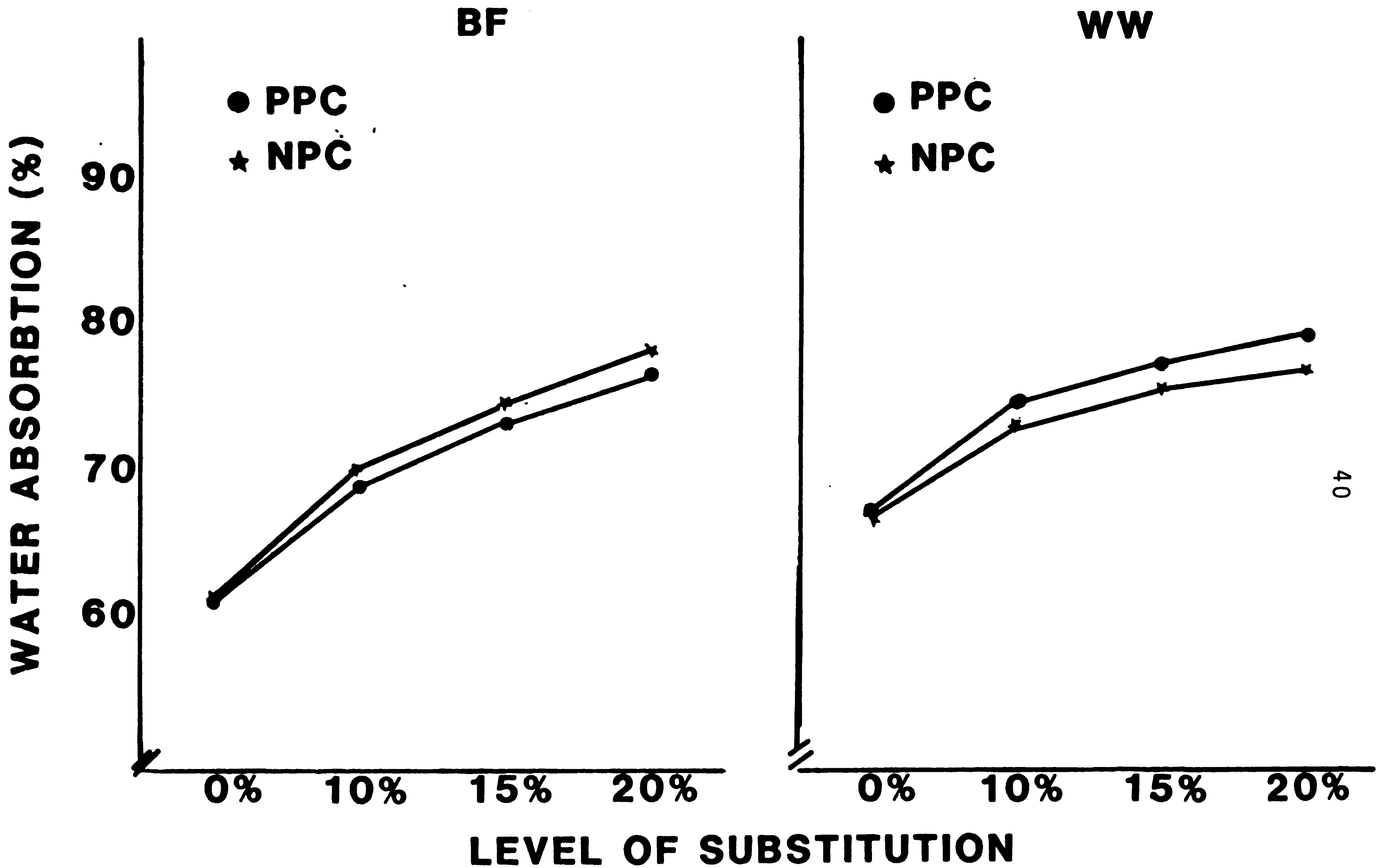

Figure 2. Influence of substituting with pinto protein concentrate (PPC) or navy protein concentrate (NPC) on water uptake as measured by the farinograph.

concentrates and heat treatment of bean flours resulted in higher absorptions. This agrees with previous research studies (D'Appolonia, 1977, 1978; Sathe et al., 1981; Deshpande et al., 1983). Knorr and Betschart (1981) observed that in composite flour systems it was necessary to increase the amount of water 8-12 percent above the farinograph absorption to obtain optimum volume. Bread flour and whole wheat flour had lower absorptions per gram 65 and 72 percent respectively than pinto and navy beans concentrates which had absorptions of 115 and 116 percent per gram respectively. These physical properties explained the observed increase in water absorption as the level of pinto or navy bean protein concentrate increased. There were differences in water absorption among substitution levels for both types of bean protein concentrates (Figure 2). Moreover actual percentages of water absorption varied for both flour systems.

Arrival time is a measure of the rate of complete hydration of flour particles. Substituting and increasing the level of pinto protein concentrates resulted in significant increases in arrival time among levels of substitution for both bread flour and whole wheat flour samples (Tables 6, 7 and 8; Figures 3 and 4). For navy bean protein concentrate blends, arrival time increased significantly for each increased level of concentrate in the blend up to 10% for the bread flour (Table 6), and up

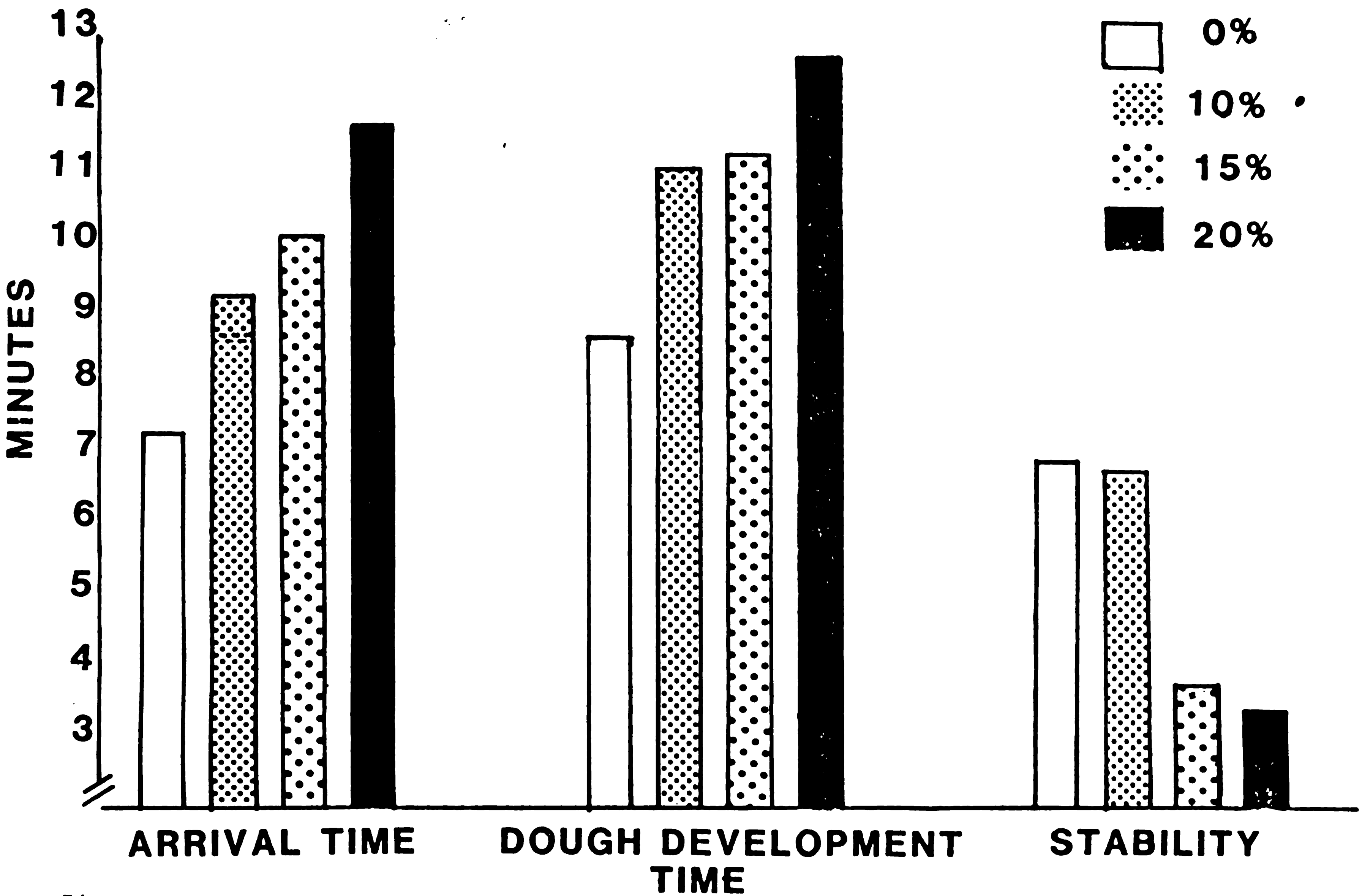

Figure 3. Effect of incorporating pinto protein concentrate (PPC) up to 20% substitution level into bread flour dough's arrival time, dough development time, and stability.

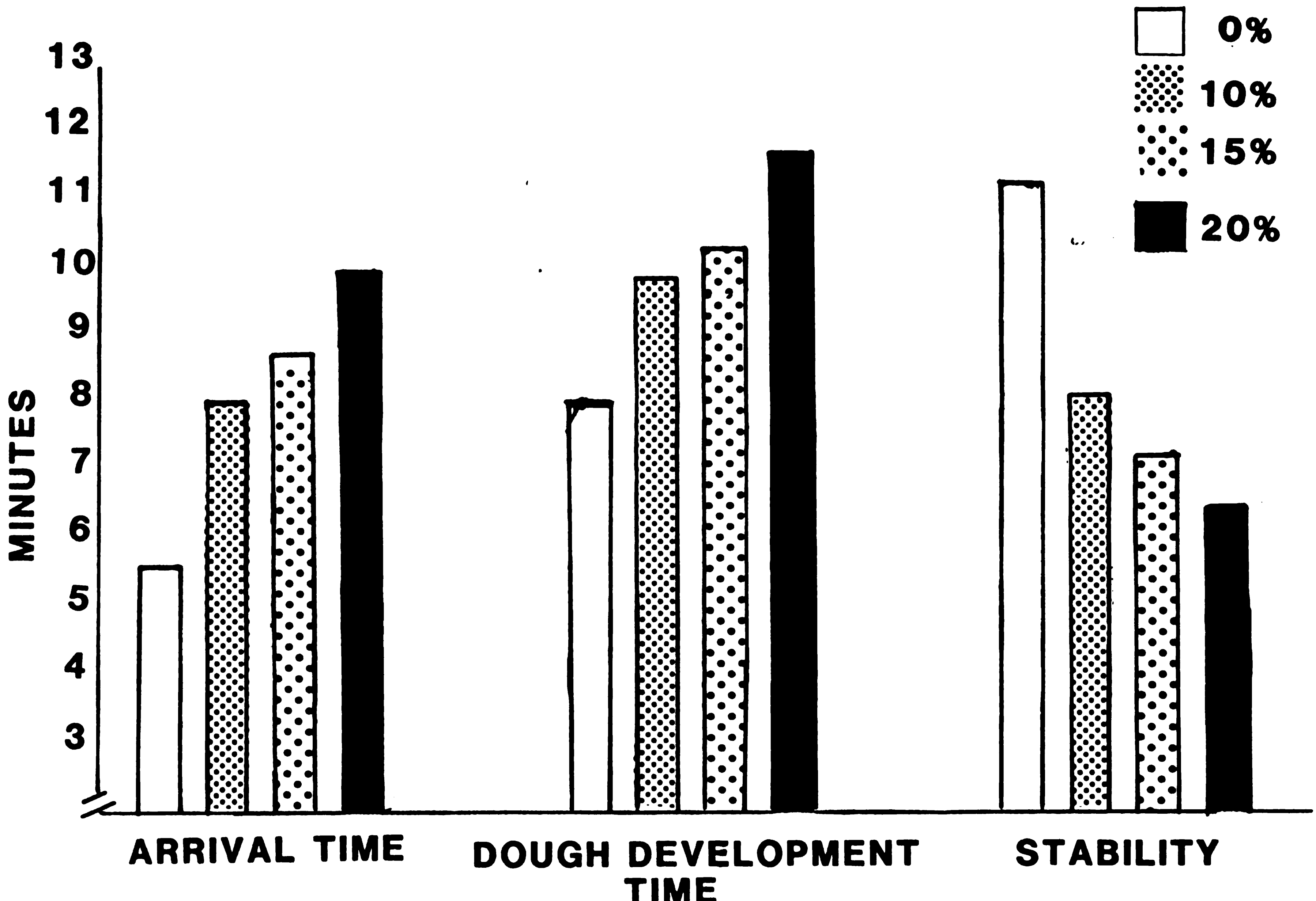

Figure 4. Effect of incorporating pinto protein concentrate (PPC) up to 20% substitution level into whole wheat dough's arrival time, dough development time, and stability.

to 15% for whole wheat flour (Table 7). Findings were in agreement with those of El-Minyawi (1980), who reported an increase in arrival time as the concentration of cottonseed in the dough system increased. Bushuk et al. (1968) also reported that there was a decrease in the rate of hydration with increasing protein content in the system.

Dough development time is the time it takes the dough to reach optimum consistency. Results shown in Tables 6 and 7 and Figure 3 show that generally there was a linear relationship between dough development time and increasing the level of navy or pinto protein concentrate in both flour systems. Nevertheless there were no significant differences ($p \geq 0.05$) between the 10% and 15% PPC substitution and among the 10, 15 and 20% NPC blends in the bread flour system (Tables 6 and 8). For whole wheat flour there were significant ($p \leq 0.05$) differences between all levels of substitution with PPC but no significant difference was observed between the 0 and 10% NPC substitution levels (Table 7). Results agree with El-Minyawi (1980) findings who used cottonseed flour blends and Hoojjat (1981), who used navy bean flour blends. These authors reported an increase in peak time with increasing levels of protein flour fortification. D'Appolonia (1977) found no significant differences as the level of pinto and navy bean flour increased from 10-20%. Inspection of results show that the pinto bean flour blend had higher dough development times than the navy bean flour blend. D'Appolonia (1977) using the pinto and navy bean flours reported a similar trend.

Stability measures the mixing strength of a flour. It is defined as the difference in time between the point where the top of the curve first intercepts the 500 B.U. line (arrival time) and the point where the top of the curve leaves the 500 B.U. line (departure line). It measures dough resistence to mechanical shear as a function of continuous mixing. As indicated in Tables 6 and 7, and Figures 3 and 4, there was a progressive decrease in the strength of the dough (stability) with an increase in pinto or navy bean protein concentrate. These results confirm findings from previous researchers (D'Appolonia, 1977; Deshpande et al., 1983; Sathe et al., 1981; Luciano and Pompei, 1981; McConnell et al., 1974). Substituting with and increasing the concentration of pinto or navy bean protein concentrates generally caused significantly ($p \leq 0.05$) decreased dough stability. Hence increasing the level of pinto or navy bean concentrate by 10, 15 and 20% was inversely related to dough stability.

Possible reasons for the weakening of dough due to the addition of bean flour include: an effective decrease in wheat gluten content (dilution effect); competition between dry bean protein and wheat flour proteins for water. It was reported further that adding soy flour, sunflower protein concentrate and field pea protein concentrate disrupted the well defined protein - starch complex in wheat flour suggesting a weakening of dough (Fleming and Sosulski, 1978). Knorr and Betschart (1978) reported that the dilution effect may be functioning in combination with one or more additional factors.

Whole wheat flour doughs substituted with pinto or navy bean protein concentrate had higher stabilities than bread flour composite doughs because of the different strengths of the two types of flours. At the 95% level of probability there were no significant differences in stabilities of 0 and 10% PPC or NPC substituted bread flour doughs (Table 6). In contrast, for the whole wheat flour blends (Table 7) there were no significant differences between stability of 15 and 20% pinto substituted doughs while a significant difference was observed between the 10 and 20% substitution with navy bean protein concentrate in whole wheat flour doughs (Table 7). In whole wheat - pinto blends no significant differences ($p \geq 0.05$) occurred between the 10 and 15% levels and 15 and 20% levels (Table 7). In addition no significant ($p \leq 0.05$) differences occurred between the 15 and 20% navy protein substituted whole wheat flour doughs. Stability of bread flour doughs was not significantly affected with 15% of the bread flour was replaced with navy bean concentrate (Table 6) while all levels of substitution significantly reduced dough stability for whole wheat flour blends (Table 7).

Extensigraph Studies for Bread Flour and Whole Wheat Flour Prepared with Pinto or Navy Bean Protein Concentrates

Extensibility measured in (mm) on the extensigraph is the only rheological property understood to relate to baking quality (Pomeranz, 1966). Previous studies have shown that using legume flour as a substitute for bread or whole wheat flour resulted in doughs that did not have as much strength when stretched, this was indicated by a decreasing resistance to extension values as the percentage of legume flour in the dough system increased (Volpe, 1976; Sathe et al., 1981). Weak, less extensible doughs will show lengthy but low extensigram curves, while tight doughs yield a high but narrow curve. Dough conditioners and/or oxidizers are often added, particularly to composite flour doughs, to minimize these extremes of dough. Dough conditioners and/or oxidizers may act to stabilize and strengthen the bonding system within the dough properties. A good extensigram curve, however, is the one that achieves a good balance between extensibility and resistance to extension as a function of time. It is this curve that can be used to determine fermentation time of a particular dough. Data showing the effect of salt, oxidant and dough conditioner on extensibility, resistance to extension and proportional number of doughs substituted with 0, 10, 15 and 20% pinto or navy bean protein concentrate are presented in Tables 9, 10 and 11. A series of two-way

Table 9. Means[1] of extensibility (mm) and resistance to extension (B.U.) measurements for bread flour doughs prepared with 0, 10, 15 and 20% pinto or navy bean protein concentrate[2] under varied treatments.

Treatment	Time of Measurement (min)	Extensibility (mm)								Resistance to Extension (B.U.)							
		0 %		10 %		15 %		20 %		0 %		10 %		15 %		20 %	
		PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC
Salt	45	212	212	192	198	159	162	151	171	490	490	400	435	325	340	265	277
	90	151	151	186	165	150	150	152	162	755	755	575	550	510	510	450	450
	135	146	146	170	186	146	161	145	156	720	720	645	802	737	630	567	490
Salt + .5% SSL	45	209	209	194	178	182	195	176	162	520	520	387	402	305	255	225	238
	90	145	145	178	164	166	156	155	150	807	807	657	760	607	545	557	475
	135	139	139	161	145	141	151	132	145	927	927	860	820	780	662	662	600
Salt + 1% SSL	45	188	188	175	183	155	160	142	150	422	422	415	440	285	272	237	243
	90	116	116	151	139	136	142	118	135	820	820	820	820	645	562	535	515
	135	110	110	124	126	118	132	85	118	935	935	943	840	775	680	670	610
Salt + 10 ppm $KBrO_3$	45	172	172	135	108	121	128	118	130	525	525	352	580	220	243	245	185
	90	101	101	98	88	104	95	94	85	825	825	670	716	370	610	485	475
	135	105	105	98	92	114	86	106	80	800	800	742	786	472	595	575	485
Salt + 20 ppm $KBrO_3$	45	200	200	155	96	158	135	141	100	295	295	262	493	180	150	250	243
	90	121	121	138	98	102	90	105	71	620	620	475	573	355	448	352	475
	135	125	125	109	70	112	85	109	76	592	592	502	490	425	495	480	518
Salt + 10 ppm $KBrO_3$ + .5% SSL	45	159	159	124	116	115	102	118	95	282	282	300	380	332	303	225	320
	90	112	112	92	87	101	76	105	71	660	660	617	530	447	480	205	505
	135	115	115	105	92	98	85	72	82	600	600	610	555	505	530	315	495
Salt + 10 ppm $KBrO_3$ + 1% SSL	45	119	119	108	-	120	-	91	-	323	323	388	-	265	-	248	-
	90	80	80	81	106	85	100	76	92	663	663	700	485	503	505	400	423
	135	80	80	84	97	98	99	65	82	643	643	658	545	620	490	395	450
Salt + 20 ppm $KBrO_3$ + .5% SSL	45	154	154	89	-	101	-	112	-	145	145	350	-	405	-	258	-
	90	102	102	66	110	81	96	94	96	360	360	483	493	685	585	483	478
	135	95	95	86	96	100	95	96	102	433	433	575	545	665	585	483	503
Salt + 20 ppm $KBrO_3$ + 1% SSL	45	154	154	110	-	152	-	95	-	278	278	315	-	288	-	320	-
	90	98	98	76	96	94	105	71	84	448	448	613	510	550	566	493	483
	135	101	101	84	94	96	86	84	91	488	488	480	503	605	648	495	545

[1] n=2

[2] PPC = Pinto Protein Concentrate; NPC = Navy Protein Concentrate.

Table 10. Means[1] of extensibility (mm) and resistance to extension (B.U.) measurements for whole wheat doughs prepared with 0, 10, 15 and 20% pinto or navy bean protein concentrate[2] under varied treatments.

Treatment	Time of Measurement (min)	Extensibility (mm)								Resistance to Extension (B.U.)							
		0%		10%		15%		20%		0 %		10 %		15 %		20 %	
		PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC
Salt	45	110	110	114	105	103	162	111	98	505	505	455	360	345	340	400	323
	90	84	84	82	92	102	150	98	99	900	900	710	685	584	510	613	588
	135	80	80	75	84	87	161	81	81	830	830	690	775	649	630	670	645
Salt +	45	111	111	109	102	100	92	92	84	420	420	485	273	303	260	360	325
5% SSL	90	76	76	86	71	79	74	90	68	806	806	955	483	650	520	775	675
	135	61	61	79	75	75	65	84	70	805	805	923	610	845	620	860	675
Salt +	45	114	114	115	82	92	92	95	88	405	405	518	538	310	360	360	335
1% SSL	90	74	74	80	68	86	69	91	76	800	800	870	840	640	590	760	603
	135	66	66	62	62	75	71	68	65	770	770	920	660	745	690	610	665
Salt +	45	152	152	128	116	96	101	95	-	240	240	228	275	280	270	233	-
10 ppm	90	114	114	99	101	85	91	78	-	525	525	460	485	480	500	400	-
$KBrO_3$	135	105	105	84	84	80	68	78	-	555	555	470	480	470	670	413	-
Salt +	45	144	144	124	115	100	92	92	-	210	210	290	295	260	255	178	-
20 ppm	90	126	126	94	96	88	74	74	-	448	448	508	505	495	510	280	-
$KBrO_3$	135	118	118	85	81	84	64	76	-	483	483	565	520	550	640	363	-
Salt +	45	151	151	124	126	98	99	106	-	180	180	270	265	303	380	250	-
5% SSL +	90	112	112	95	109	85	84	88	-	455	455	600	575	578	490	413	-
10 ppm	135	104	105	86	92	82	71	80	-	508	508	575	615	553	570	415	-
$KBrO_3$																	
Salt +	45	119	119	110	112	88	82	96	-	485	485	395	380	315	290	240	-
1% SSL +	90	91	91	91	96	80	70	80	-	950	950	560	620	513	495	405	-
20 ppm	135	88	88	78	80	74	65	76	-	978	978	573	570	568	570	473	-
$KBrO_3$																	
Salt +	45	122	122	102	99	85	80	82	-	298	298	335	385	463	407	215	-
.5% SSL +	90	105	105	91	95	78	74	72	-	513	513	595	535	645	480	355	-
20 ppm	135	100	100	91	81	76	66	86	-	495	495	550	595	583	515	415	-
$KBrO_3$																	
Salt +	45	129	129	112	115	98	84	93	-	288	288	250	335	343	330	203	-
1% SSL +	90	102	102	92	88	84	81	80	-	588	588	460	503	490	505	315	-
20 ppm	135	96	96	92	84	74	78	85	-	605	605	478	600	478	605	375	-
$KBrO_3$																	

[1] n=2

[2] PPC = Pinto Protein Concentrate; NPC = Navy Protein Concentrate.

Table 11. Proportional number[1] of bread flour and whole wheat flour doughs substituted with pinto or navy bean protein concentrate under various treatments.

Treatment	Time of Measurement (min)	Proportional Number (BF)								Proportional Number (WW)							
		0%		10%		15%		20%		0%		10%		15%		20%	
		PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC
Single Additive																	
Salt	45	2.3	2.3	2.1	2.2	2.0	2.1	1.8	1.6	4.5	4.5	4.0	3.4	3.3	2.1	2.5	3.3
	90	5.0	5.0	3.1	3.4	3.4	3.4	2.9	2.8	10.6	10.6	8.7	7.4	5.7	3.4	6.8	5.9
	135	5.0	5.0	3.8	4.8	5.1	4.0	3.9	3.1	10.5	10.5	9.2	9.2	7.4	3.9	8.2	8.0
Double Additive																	
Salt + .5% SSL	45	2.0	2.0	1.9	2.2	1.7	1.3	1.3	1.4	3.7	3.7	4.5	2.8	3.0	2.8	3.8	3.9
	90	5.5	5.5	3.8	4.6	3.6	3.5	3.6	3.1	10.6	10.6	11.0	6.4	8.4	7.0	8.6	10.1
	135	6.6	6.6	5.3	5.6	5.5	4.4	5.0	4.1	11.5	11.5	11.7	8.1	11.2	9.5	10.3	9.6
Salt + 1% SSL	45	2.2	2.2	2.4	2.4	1.8	1.7	1.7	1.6	3.6	3.6	4.5	6.6	3.4	3.9	3.8	3.8
	90	7.0	7.0	5.4	5.9	4.7	3.9	4.5	4.8	10.8	10.8	10.9	12.4	7.4	8.6	8.4	7.9
	135	8.5	8.5	7.7	6.7	6.5	5.1	8.0	5.1	11.7	11.7	14.8	10.6	9.9	9.7	9.0	10.2
Salt + 10 ppm $KBrO_3$	45	3.0	3.0	2.6	5.3	1.8	1.9	2.1	1.4	1.6	1.6	1.8	2.4	2.9	2.7	2.4	-
	90	8.1	8.1	6.8	8.2	3.5	6.4	5.2	5.6	4.6	4.6	4.6	4.8	5.6	5.5	5.1	-
	135	7.0	7.0	8.2	8.5	4.1	6.9	5.0	6.0	5.3	5.3	5.6	5.7	5.9	9.8	5.3	-
Salt + 20 ppm $KBrO_3$	45	1.5	1.5	1.7	5.1	1.1	1.1	1.7	2.4	1.4	1.4	2.3	2.5	2.6	2.8	1.9	-
	90	5.1	5.1	3.6	5.8	3.4	4.9	3.3	6.7	3.6	3.6	5.4	5.3	5.6	6.9	3.8	-
	135	4.7	4.7	2.7	7.0	3.8	5.8	4.0	6.6	4.1	4.1	6.6	6.4	6.5	10.0	4.8	-
Triple Additive																	
Salt + .5% SSL + 10 ppm $KBrO_3$	45	1.8	1.8	2.4	3.3	2.9	2.9	1.1	3.3	1.2	1.2	2.2	2.1	3.1	3.8	2.4	-
	90	6.0	6.0	6.4	6.1	4.4	6.3	2.5	7.1	4.1	4.1	6.3	5.3	6.8	5.8	4.7	-
	135	5.2	5.2	6.8	6.0	5.1	6.2	4.3	6.0	4.8	4.8	6.7	6.7	6.7	8.0	5.2	-
Salt + 1% SSL + 10 ppm $KBrO_3$	45	2.7	2.7	3.2	-	2.2	-	2.8	-	4.1	4.1	3.6	3.4	3.6	3.5	2.5	
	90	8.3	8.3	6.7	4.5	5.9	5.0	5.2	4.6	10.4	10.4	6.2	6.4	7.7	7.1	5.1	-
	135	8.0	8.0	7.8	5.6	6.3	5.0	6.1	5.5	11.1	11.1	7.3	7.1	7.7	8.8	6.2	-
Salt + .5% SSL + 20 ppm $KBrO_3$	45	0.9	0.9	3.9	-	4.0	-	2.3	-	2.4	2.4	3.3	3.9	5.4	5.1	2.6	-
	90	3.5	3.5	7.3	4.5	8.4	5.1	5.1	5.0	4.9	4.9	6.5	5.6	8.3	6.5	4.9	-
	135	4.5	4.5	6.7	5.6	6.6	6.0	5.0	4.9	5.0	5.0	6.0	7.3	7.7	7.8	4.8	-
Salt + 1% SSL + 20 ppm $KBrO_3$	45	1.8	1.8	2.9	-	1.9	-	3.3	-	2.2	2.2	2.2	2.9	3.8	3.9	2.2	-
	90	4.6	4.6	8.1	5.3	5.8	5.3	7.0	5.7	5.8	5.8	5.0	5.7	5.8	6.2	3.9	-
	135	4.8	4.8	5.7	5.3	6.3	7.5	5.9	6.0	6.3	6.3	5.2	7.1	6.4	7.8	4.4	-

[1] $\frac{\text{Resistance to Extension}}{\text{Extensibility}}$

analyses of variance were calculated to determine the effects salt, oxidant, dough conditioner and resting time had on the legume substituted doughs (Table 12).

Extensibility

The addition of pinto or navy bean protein concentrate up to the 20% substitution level brought about progressive decreases in dough extensibility (Tables 9 and 10). In most cases treatments of salt plus the dough conditioner, oxidant or both significantly ($p \leq 0.05$) reduced extensibility of bread flour doughs with 0, 10, 15 and 20% pinto or navy protein concentrate. However, a few exceptions occurred; extensibility of doughs with 15% pinto or navy bean protein, after the 45 and 90 minute rest period improved considerably when salt (2%) and SSL (.5%) were jointly added. In addition the doughs prepared with 20% pinto bean protein concentrate improved with the same treatment after the 90 and 135 minute rest period. Generally dough extensibility decreased significantly ($p \leq 0.05$) as the resting period increased from 45 minutes to 135 minutes for all levels of substitution with pinto or navy bean protein concentrate (Figure 5). Interactions between treatments and resting time enhanced each other to produce significant ($p \leq 0.05$) differences in the extensibility of doughs prepared with 10 and 20% navy bean protein concentrate (Table 12). For bread flour substituted doughs for both bean types multiple regressional analyses showed that most of the variation in extensibility was

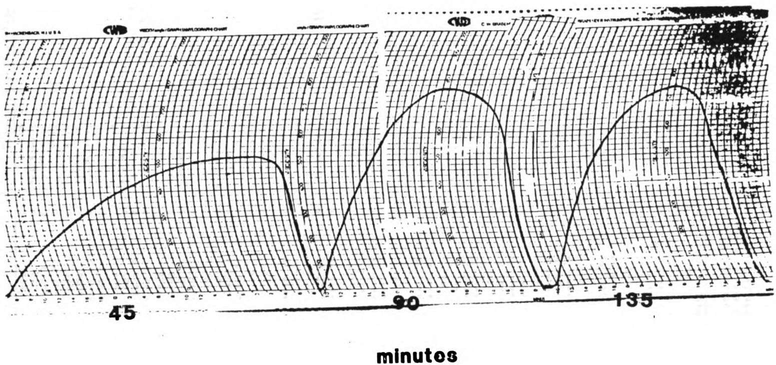

Figure 5. Load extension curves showing the effect of increasing resting time on extensibility and resistance to extension.

Table 12. Mean squares for the effect of single, double and triple additive treatment on each level of pinto or navy bean protein concentrate on extensibility and resistance to extension of bread and whole wheat flour doughs.

Flour Type	Bean Type	Level of Substit.	Source of Variation	Degree of Freedom	Extensibility (mm)	Resistance B.U.	Proportional (R/E)[1]
Bread	Pinto	0	Time	2	220.2***	572118.0***	9367.2***
			Treatment	8	35.8***	142194.8***	895.1***
			Interaction	16	1.2*	6158.7*	110.1**
			Within	27	.592	2607.4	
		10	Time	2	45.9***	526357.4***	7172.0***
			Treatment	8	88.6***	55567.8***	1020.9***
			Interaction	16	1.8	10498.0***	98.7***
			Within	27	.998	1987.0	37.1
		15	Time	2	42.7***	517633.8***	5626.9***
			Treatment	8	33.6***	53846.9***	676.0***
			Interaction	16	2.9***	7822.8***	112.2***
			Within	27	.669	843.9	14.4
		20	Time	2	36.3***	241801.8***	4247.8***
			Treatment	8	42.2***	39336.6**	415.8***
			Interaction	16	2.5**	15169.0	192.4**
			Within	27	.791	9670.8	62.5
Bread	Navy	10	Time	2	27.6***	225803.1***	2958.7***
			Treatment	8	64.8***	60998.6***	856.2***
			Interaction	13	2.4**	14680.1***	59.4
			Within	24	.759	1655.7	64.0
		15	Time	2	34.9***	384017.2***	4426.9***
			Treatment	8	46.1***	13826.1***	407.5***
			Interaction	13	1.7	4125.6**	94.6**
			Within	24	.999	1285.4	23.9
		20	Time	2	21.3***	263328.2***	3487.6***
			Treatment	8	49.6***	3375.7	511.3***
			Interaction	12	1.7***	4297.2	128.9**
			Within	23	.317	1965.2	34.8
Whole Wheat	Pinto	0	Time	2	68.0***	583968.5***	13554.2***
			Treatment	8	18.3***	153614.7***	4101.5***
			Interaction	16	.573*	7823.2***	405.5***
			Within	27	.257	1087.0	9.0
		10	Time	2	55.9***	460743.4***	12509.5***
			Treatment	8	2.2**	134463.9***	2827.9***
			Interaction	16	.832	6140.6***	326.7***
			Within	27	.517	1007.6	19.9
		15	Time	2	11.9***	417876.8***	8968.2***
			Treatment	8	1.8***	24862.9***	562.9***
			Interaction	16	.247	8768.0***	189.6***
			Within	27	.282	773.2	18.2
		20	Time	2	14.6***	306156.0***	6859.4***
			Treatment	8	1.3*	120496.3***	1460.2***
			Interaction	16	.983*	9984.7***	123.6***
			Within	27	.412	2666.2	27.7
Whole Wheat	Navy	10	Time	2	35.2***	360346.3***	8852.5***
			Treatment	8	6.9***	42800.8***	1701.9***
			Interaction	16	.480	7225.9***	115.4***
			Within	27	.275	792.6	22.8
		15	Time	2	17.4***	390806.0***	11040.7***
			Treatment	8	43.1***	4569.2**	825.1***
			Interaction	16	.892*	4804.9***	232.1***
			Within	27	.391	1048.6	23.9
		20	Time	2	4.6**	199801.4***	5136.5***
			Treatment	2	6.2**	2434.7	743.6*
			Interaction	4	.687	1249.3	216.9
			Within	9	.431	2170.8	113.4

*Significant at p≤0.05.
**Significant at p≤0.01.
***Significant at p≤0.001.
[1] $\frac{\text{Resistance to Extension}}{\text{Extensibility}}$

due largely to treatments than to time.

All doughs prepared with whole wheat flour had the expected lower extensibility. For these whole wheat flour doughs, substitution of 0, 10, 15 and 20% pinto or navy protein concentrate significantly ($p \leq 0.05$) decreased dough extensibility as the resting period increased. With salt as the only treatment in the whole wheat flour system, increasing levels of legume protein concentrate had little effect on extensibility, the one exception being the series with 15% substitution of navy bean protein concentrate. In most instances treatments other than combinations of salt and SSL (.5%, 1%) significantly ($p \leq 0.05$) resulted in more extensible doughs for all levels of substitution and at all time intervals. Other treatments had significant ($p \leq 0.05$) negative effects on extensibility (i.e. reduced extensibility) for pinto and navy bean protein concentrate substituted doughs. Noteworthy was the fact that combination treatments of salt and $KBrO_3$ (10 ppm, 20 ppm) had the highest extensibility values at all time intervals for the 0 and 10% substitution levels. This suggested that the whole wheat flour was improved by the addition of oxidant. Doughs with treatment combinations of salt and SSL (.5%, 1%) were shorter, indicating that sodium stearoyl-2-lactylate imparted more strength on the doughs across all levels of substituion. Interaction effects between time and treatments did not produce significant

($p \geq 0.05$) differences on extensibility of whole wheat doughs prepared with 10 and 15% pinto protein concentrate and those with 10 and 20% navy bean protein concentrate (Table 12). Multiple regressional analyses showed that most of the effects accounted for were due largely to time rather than to treatments except for the 15 and 20% navy protein concentrate. Triple additive treatments, salt, oxidant and dough conditioner in the following respective proportions 2%:10 ppm:.5% produced the highest extensibility values for all levels of substitution and at all time intervals when compared to the other triple additive treatment proportions.

Resistance to Extension

Resistance to extension of composite flour doughs progressively decreased as the percentage of pinto or navy bean protein concentrate increased, and increased as the resting period of each blend increased. A similar trend was observed by Sathe et al. (1981). Treatments with salt and both levels of SSL brought about significant ($p \leq 0.05$) increases in doughs resistance to extension for all levels of substitution particularly at the 90 and 135 minute time intervals as compared to the control treatment of salt (2%). Other treatments had varied effects which were scattered (Table 9, 10 and 12) - that is, did not have well-defined trends such that logical documentation was difficult. Increasing the rest period generally brought about significant ($p \leq 0.05$) increases in dough strength for doughs across all levels of legume protein concentrate substitution. Time and treatments worked synergistically to produce significant ($p \leq 0.05$) effects on resistance to extension for all bread flour - legume blends except for doughs with the 20% pinto or navy bean protein concentrate (Table 12). Multiple regressional analyses show that for interaction effects significant ($p \leq 0.05$) differences were largely attributed to time rather than to treatment in most cases. Generally doughs with a resting period of 90 min had higher RE values than either the 45 or 135 min, meaning that for those doughs (Table 9 and 10) 90 minutes was optimum for optimum RE. Doughs which became too tight as indicated by the higher RE values after the 90 minute rest period required shorter fermentation times to prevent breakage.

Effects of treatments on resistance to extension for whole wheat substituted doughs were rather scattered but often followed a similar trend to bread flour - legume protein blends especially with treatments of salt and both levels of SSL. Increasing the rest period had significant ($p \leq 0.05$) effects on resistance to extension for whole wheat flour doughs substituted up to the 20% pinto or navy bean protein concentrate. Treatments, single, double and triple had significant effects on substituted doughs' resistance to extension although triple additive treatments more than often exerted negative effects that is decreased dough strength somewhat. The doughs with 20% navy protein concentrate, however, were not significantly affected by treatment. Both time and treatment enhanced each other to produce significant ($p \leq 0.05$) effects on resistance to extension for all doughs blends except the doughs with 20% navy bean protein concentrate. However more of the effects were caused by the time variable than treatments for doughs substituted with navy bean protein concentrate and the 15% pinto protein substituted dough.

For most dough blends good conditioning which resulted in a good balance between extensibility (mm) and resistance to extension (B.U.) was achieved after the 90 min. rest period when triple additives (salt, $KBrO_3$ and SSL) were administered (Figure 6). This good balance corresponded to proportional numbers 4.5 - 6.5 and 5.0 - 6.5 for the bread flour and whole wheat flour - legume protein concentrate doughs respectively. Furthermore there was an increment in proportional number R/E (Table 11) as the resting period increased from 45 to 135 minutes for all levels of substitution and a reduction in proportional number as the level of pinto or navy bean protein concentrate increased up to 15%. Although doughs prepared with the 20% PPC or NPC did not have low proportional numbers compared to the 15 and 10% they nevertheless had lower proportional numbers compared to control. Although treatments with salt, salt and oxidant, salt and dough conditioner produced varied effects on extensibility and resistance to extension when looked at in isolation,

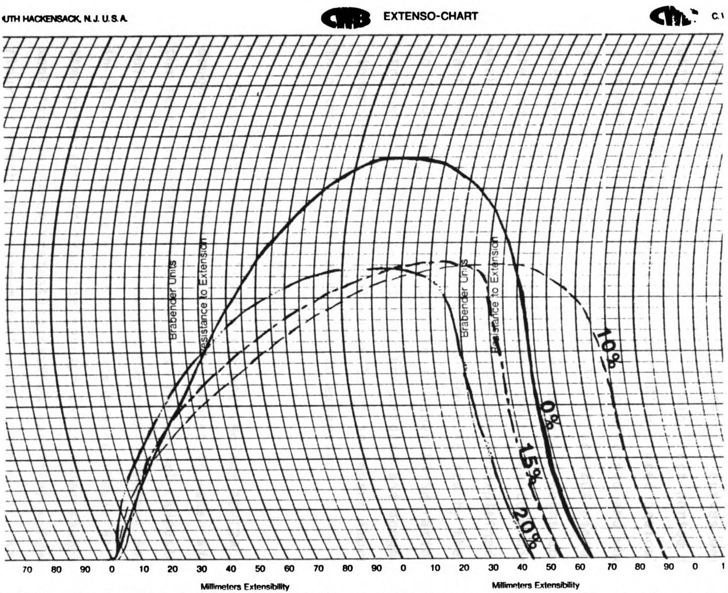

Figure 6. Load extension curves showing good balance after the 90 minute rest period, between extensibility and resistance to extension of bread flour doughs with salt (2%), substituted with 0, 10, 15 and 20% pinto protein concentrate.

triple combination treatments interacted to impart desirable dough properties for both extensibility and resistance to extension and produced load extension curves with good balance. The most desirable load extension curves were obtained in most cases after the 90 min. rest period (Figure 6). Hence this (90 min. rest period) was used basically as a standard index for the fermentation of bread and whole wheat flour doughs substituted with 0, 10, 15 and 20% pinto or navy bean protein concentrate. The improvement brought about by the addition of oxidant and dough conditioner to minimize weak flowy legume substituted doughs may be explained by the fact that free sulfhydryl groups were oxidized by the bromate to disulfide groups resulting in a higher SS:SH ratio , hence stronger bonding; and that both the oxidant and dough conditioner interacted at a molecular level to impart improvements in extensibility and resistance to extension.

Baking Study

Bread was baked following the AACC Method 10-10A straight dough procedure (AACC, 1982). The amount of water added was the farinograph absorption plus an additional (adjusted for moisture on 14% m.b.) 1 percent for each 1 percent increase in pinto or navy bean protein concentrates (Table 5). Mixing time predetermined from farinograph curve under dough development time and from pretesting studies varied as a function of flour strength for optimum loaf volume (Table 5). Noteworthy was the fact that doughs became sticky and more difficult to handle with each percent increment in legume protein. The addition of sodium stearoyl-2-lactylate (SSL), however, minimized dough stickiness. Composite flour blends were treated with combinations of SSL (.5%, 1%) and $KBrO_3$ (10 ppm, 20 ppm) (Table 3). The purpose of treating legume substituted doughs with SSL and $KBrO_3$ was to investigate their effect and extent to which they would minimize deleterious effects exerted by bean protein concentrates on bread characteristics. Fermentation time for wheat flour and composite flour doughs was predetermined from extensigraph and preliminary study data. Fermentation time varied to cater for the different strengths of flour blends (Table 5) and to protect dough exhaustion before baking. Baked breads were evaluated objectively for volume, tenderness, compressibility and color using the control white and whole wheat breads as reference. Breads were also evaluated by taste panelists for crust color, crumb character, crumb color, crumb grain, tenderness, flavor and overall acceptability (Appendix A). Control and untreated composite flour breads were analysed for moisture.

For each flour type, that is, bread or whole wheat the data for each objective and sensory attribute was analysed for variance due to level (0 - 20%) of each of the protein concentrates in the blend. The results of the analysis are given in Table 13, and significant differences ($p \le 0.05$) shown by Duncan's Multiple Range Tests are shown by x - z superscript on Tables 13, 14, 15, 16, 17 and 18. To determine the effect of oxidant and dough conditioner including 0% concentration a series of one-way ANOVAs were calculated separately for each flour type for each level of substitution of each legume protein concentrate as shown in Table 19. The results of Duncan's separation of the means for these latter ANOVA's are shown in Tables 13, 14, 15, 16, 17 and 18 with the following superscript: a - c for 10% legume protein flour blends; d - f for 15% legume protein flour blends; and g - j for 20% legume protein flour blends.

Volume

Volume is an important parameter for consumer bread acceptability. Tsen et al. (1971) reported a specific volume of 6.0 as the acceptable value for marketable bread. The addition of legume flour to bread has been reported to cause a depressed, inferior loaf by several researchers - Great Northern bean (Sathe et al., 1981); faba bean, field pea, sunflower and soy bean concentrate (Fleming and Sosulski, 1978); full-fat soy flour (Tsen and Hoover, 1973); cottonseed (Knorr and Betschart, 1978); untreated and roasted navy bean (D'Appolonia, 1978); pinto and navy bean (D'Appolonia, 1977); faba bean (McConnell et al., 1974; Deshpande et al., 1983). However, Knorr and Betschart (1981) reported that in addition to incorporating SSL to legume fortified breads, the amount of water and mixing time were also critical factors in

Table 13. Means[1] and Standard Deviations of objective measurement volume for untreated and treated bread flour and whole wheat breads substituted with pinto and navy bean protein fractions[2].

Treatment	Volume (cc) BF							Volume (cc) WW						
	Control	10%		15%		20%		Control	10%		15%		20%	
		PPC	NPC	PPC	NPC	PPC	NPC		PPC	NPC	PPC	NPC	PPC	NPC
No SSL, No $KBrO_3$	686^{x}	640^{xc} ±41	677^{xd} ±21	623^{xf} ±31	663^{xe} ±40	648^{xh} ±08	647^{xh} ±50	710^{x} ±44	670^{xa} ±17	690^{xa} ±44	693^{xd} ±15	683^{xe} ±42	693^{xg} ±44	680^{xn} ±44
0.5% SSL, 10 ppm $KBrO_3$		780^{b} ±0	730^{c} ±26	743^{e} ±45	696^{e} ±64	743^{g} ±15	700^{g} ±36		713^{a} ±23	716^{a} ±25	710^{d} ±26	767^{e} ±12	660^{g} ±10	743^{g} ±06
1% SSL, 10 ppm $KBrO_3$		900^{a} ±27	863^{a} ±15	900^{d} ±20	843^{d} ±25	753^{g} ±38	686^{h} ±06		706^{a} ±32	703^{a} ±32	740^{a} ±17	690^{e} ±26	686^{g} ±21	690^{h} ±10
0.5% SSL, 20 ppm $KBrO_3$		886^{a} ±15	793^{b} ±15	806^{e} ±35	807^{d} ±40	756^{g} ±43	823^{g} ±21		743^{a} ±15	733^{a} ±06	690^{d} ±00	783^{d} ±12	683^{g} ±15	770^{g} ±00
1% SSL, 20 ppm $KBrO_3$		753^{b} ±06	743^{c} ±21	790^{e} ±10	783^{d} ±29	766^{g} ±25	810^{g} ±36		733^{a} ±06	753^{a} ±12	723^{d} ±25	747^{d} ±21	753^{h} ±06	770^{g} ±46

[1] n=3.

[2] PPC = Pinto Protein Concentrate; NPC = Navy Protein Concentrate; BF = Bread Flour; WW = Whole Wheat Flour.

Values followed by the same letter are not significantly different at $p \leq 0.05$ Duncan's Multiple Range Test (Duncan's 1957): x...z for levels for individual protein concentrate; for treatment, a...c for individual protein concentrate for 10%, d...f for 15%; g...j for 20%.

Table 14. Means[1] and Standard Deviations showing the influence of $KBrO_3$ and SSL on crumb tenderness (lbs/g) of white bread/whole wheat substituted with 0, 10, 15 and 20% pinto and navy protein concentrate.[2]

Treatment	Tenderness (lbs/g) BF							Tenderness (lbs/g) WW						
	Control	10%		15%		20%		Control	10%		15%		20%	
		PPC	NPC	PPC	NPC	PPC	NPC		PPC	NPC	PPC	NPC	PPC	NPC
No SSL, No $KRrO_3$	09^{x} ±0.02	$.07^{yab}$ ±0.01	$.06^{za}$ ±0.00	$.07^{yf}$ ±0.01	$.06^{ze}$ ±0.01	$.06^{yg}$ ±0.00	$.06^{zg}$ ±0.00	$.10^{x}$ ±0.00	$.07^{ya}$ ±0.00	$.09^{xa}$ ±0.02	$.06^{yd}$ ±0.00	$.08^{xe}$ ±0.01	$.06^{yag}$ ±0.00	$.06^{yg}$ ±0.00
0.5% SSL, 10 ppm $KBrO_3$		$.05^{a}$ ±0.00	$.005^{a}$ ±0.00	$.004^{d}$ ±0.00	$.05^{d}$ ±0.00	$.05^{g}$ ±0.00	$.05^{g}$ ±0.00		$.07^{a}$ ±0.00	$.08^{a}$ ±0.01	$.07^{d}$ ±0.01	$.07^{d}$ ±0.00	$.06^{g}$ ±0.00	$.06^{g}$ ±0.00
1% SSL, 10 ppm $KBrO_3$		$.08^{b}$ ±0.00	$.08^{b}$ ±0.01	$.07^{ef}$ ±0.00	$.06^{de}$ ±0.00	$.06^{g}$ ±0.00	$.06^{g}$ ±0.00		$.08^{b}$ ±0.01	$.09^{a}$ ±0.01	$.06^{a}$ ±0.00	$.08^{e}$ ±0.00	$.06^{g}$ ±0.01	$.06^{g}$ ±0.00
0.5% SSL, 20 ppm $KBrO_3$		$.07^{ab}$ ±0.01	$.06^{a}$ ±0.01	$.06^{e}$ ±0.00	$.06^{d}$ ±0.00	$.07^{g}$ ±0.00	$.06^{g}$ ±0.00		$.10^{c}$ ±0.01	$.09^{a}$ ±0.01	$.07^{d}$ ±0.00	$.08^{e}$ ±0.00	$.07^{g}$ ±0.01	$.08^{h}$ ±0.01
1% SSL, 20 ppm $KBrO_3$		$.10^{c}$ ±0.00	$.08^{b}$ ±0.00	$.09^{f}$ ±0.00	$.08^{e}$ ±0.00	$.06^{g}$ ±0.00	$.06^{g}$ ±0.00		$.08^{b}$ ±0.00	$.08^{a}$ ±0.01	$.06^{d}$ ±0.01	$.07^{d}$ ±0.00	$.07^{g}$ ±0.01	$.06^{g}$ ±0.00

[1] n=3

[2] PPC = Pinto Protein Concentrate; NPC = Navy Protein Concentrate; BF = Bread Flour; WW = Whole Wheat Flour.

Values in each column followed by the same letters are not significantly different at $p \leq 0.05$ Duncan's Multiple Range Test (Duncan's 1957) x...z for levels for individual protein concentrates; a...c for treatment for individual protein concentrate for 10%; d...f for 15%; g...j for 20%.

Table 15. Means[a] and standard deviations showing the effect of substituting white and whole wheat bread with 0, 10, 15 and 20% PPC or NPC and treatment with $KBrO_3$ and SSL on crumb compressibility.

Treatment	Compressibility (lbs/cm) BF							Compressibility (lbs/cm) WW						
	Control	10%		15%		20%		Control	10%		15%		20%	
		PPC	NPC	PPC	NPC	PPC	NPC		PPC	NPC	PPC	NPC	PPC	NPC
No SSL, No $KBrO_3$	$.064^{x}$ ±0.00	$.07^{xa}$ ±0.01	$.06^{xa}$ ±0.00	$.07^{xd}$ ±0.01	$.08^{ye}$ ±0.00	$.06^{xg}$ ±0.00	$.08^{yh}$ ±0.00	$.18^{x}$ ±0.01	$.11^{yc}$ ±0.00	$.13^{yc}$ ±0.00	$.10^{yze}$ ±0.03	$.11^{ze}$ ±0.01	$.07^{zh}$ ±0.01	$.11^{zi}$ ±0.01
0.5% SSL, 10 ppm $KBrO_3$		$.08^{bc}$ ±0.00	$.06^{ab}$ ±0.02	$.07^{a}$ ±0.00	$.04^{d}$ ±0.02	$.05^{g}$ ±0.02	$.08^{h}$ ±0.00		$.09^{b}$ ±0.01	$.08^{b}$ ±0.00	$.09^{de}$ ±0.03	$.12^{e}$ ±0.00	$.07^{h}$ ±0.01	$.08^{h}$ ±0.01
1% SSL, 10 ppm $KBrO_3$		$.06^{a}$ ±0.01	$.04^{a}$ ±0.00	$.07^{d}$ ±0.01	$.08^{e}$ ±0.01	$.04^{g}$ ±0.00	$.07^{h}$ ±0.00		$.07^{b}$ ±0.00	$.09^{b}$ ±0.00	$.08^{de}$ ±0.00	$.15^{g}$ ±0.02	$.07^{h}$ ±0.02	$.10^{i}$ ±0.01
0.5% SSL, 20 ppm $KBrO_3$		$.09^{c}$ ±0.01	$.07^{b}$ ±0.00	$.07^{d}$ ±0.02	$.05^{d}$ ±0.01	$.05^{g}$ ±0.01	$.05^{g}$ ±0.01		$.06^{a}$ ±0.01	$.06^{a}$ ±0.01	$.08^{de}$ ±0.01	$.06^{d}$ ±0.01	$.07^{h}$ ±0.01	$.05^{g}$ ±0.01
1% SSL, 20 ppm $KBrO_3$		$.07^{ab}$ ±0.1	$.08^{b}$ ±0.01	$.06^{d}$ ±0.01	$.07^{e}$ ±0.01	$.05^{g}$ ±0.01	$.05^{g}$ ±0.01		$.05^{a}$ ±0.01	$.05^{a}$ ±0.01	$.06^{d}$ ±0.01	$.04^{a}$ ±0.01	$.04^{a}$ ±0.01	$.05^{g}$ ±0.01

[1]n=3

[2]PPC = Pinto Protein Concentrate; NPC = Navy Protein Concentrate; BF = Bread Flour; WW = Whole Wheat Flour.

Values in each column followed by the same letters are not significantly different at $p \leq 0.05$ Duncan's Multiple Range Test (Duncans, 1957) x...z, for levels for individual protein concentrates; a...c, for treatment for individual protein concentrate for 10%; d...f, for 15%; g...j for 20%.

Table 16. Means[1] and standard deviations of color differences in white bread substituted with pinto and navy bean protein concentrates.[2]

Treatment	Control	10% PPC	10% NPC	15% PPC	15% NPC	20% PPC	20% NPC
				L. Lightness			
No $KBrO_3$, No SSL	68.5^{x} ±1.3	56.5^{y} ±3.8	60.4^{zb} ±1.7	54.2^{ye} ±2.6	55.3^{ze} ±1.2	52.2^{yd} ±2.9	57.0^{zh} ±1.7
10 ppm $KBrO_3$, .5% SSL		53.6^{c} ±1.0	54.7^{d} ±1.2	54.1^{e} ±2.3	54.3^{e} ±1.1	54.6^{ij} ±1.6	53.5^{i} ±3.5
10 ppm $KBrO_3$, 1% SSL		61.7^{a} ±0.6	63.5^{a} ±0.5	62.2^{d} ±4.2	59.5^{d} ±0.9	59.9^{g} ±0.8	61.8^{g} ±0.6
20 ppm $KBrO_3$, .5% SSL		57.4^{ab} ±3.5	57.3^{c} ±1.7	57.3^{e} ±1.0	59.9^{d} ±1.9	56.1^{hi} ±0.8	59.0^{gh} ±0.9
20 ppm $KBrO_3$, 1% SSL		58.7^{ab} ±0.3	57.5^{c} ±0.5	56.1^{e} ±1.0	56.3^{e} ±1.6	58.5^{hi} ±0.4	60.2^{gh} ±0.6
				L_a (-) Greeness (+) Redness			
No $KBrO_3$, No SSL	-1.7^{x} ±0.4	1.7^{y} ±0.6	-0.3^{z} ±0.4	1.5^{yae} ±0.5	1.7^{ye} ±0.1	1.7^{yg} ±0.7	1.0^{zkl} ±0.3
10 ppm $KBrO_3$, .5% SSL		1.8^{a} ±0.2	1.9^{bc} ±0.2	1.9^{e} ±0.2	2.1^{d} ±0.4	2.3^{i} ±0.1	2.2^{j} ±0.2
10 ppm $KBrO_3$, 1% SSL		0.4^{c} ±0.0	0.0^{a} ±0.0	1.1^{d} ±0.2	0.9^{f} ±0.1	1.2^{g} ±0.0	0.7^{k} ±0.0
20 ppm $KBrO_3$, .5% SSL		1.2^{b} ±0.3	0.9^{b} ±0.3	1.8^{e} ±0.1	1.1^{f} ±0.2	2.2^{hi} ±0.5	1.4^{l} ±0.2
20 ppm $KBrO_3$, 1% SSL		1.2^{b} ±0.0	2.0^{c} ±0.1	1.9^{e} ±0.2	1.8^{de} ±0.0	1.5^{gh} ±0.4	1.3^{l} ±0.0
				L_b Yellowness[3]			
No $KBrO_3$, No SSL	15.2^{x} ±0.8	15.6^{xa} ±0.4	16.5^{xb} ±0.2	14.9^{x} ±0.4	16.1^{xd} ±0.4	15.4^{xg} ±0.4	15.9^{xl} ±0.4
10 ppm $KBrO_3$, .5% SSL		16.3^{a} ±0.5	17.1^{a} ±0.4	15.7^{e} ±0.6	16.7^{g} ±0.1	16.7^{g} ±0.1	17.1^{h} ±0.2
10 ppm $KBrO_3$, 1% SSL		15.7^{a} ±0.2	16.4^{b} ±0.0	16.6^{d} ±0.2	16.8^{d} ±0.5	16.7^{g} ±0.0	16.7^{h} ±0.0
20 ppm $KBrO_3$, .5% SSL		16.0^{a} ±0.5	15.9^{b} ±0.4	16.8^{d} ±0.3	16.8^{d} ±0.5	19.9^{g} ±5.6	17.7^{h} ±0.4
20 ppm $KBrO_3$, 1% SSL		16.0^{a} ±0.2	16.1^{b} ±0.2	15.5^{e} ±0.2	16.2^{d} ±0.3	16.6^{g} ±0.0	17.2^{h} ±0.1

[1] n=3

[2] PPC=Pinto Protein Concentrate; NPC=Navy Protein Concentrate.

[3] Standard tile values: L=78.5; L_a=-3.2; L_b=23.4.

Values followed by the same letter are not significantly different at $p \leq 0.05$ Duncan's Multiple Range Test (Duncans, 1957): x...z for level for individual protein concentrate; for treatment, a...c for individual protein concentrate for 10%; d...f, for 15%; g...l for 20%.

Table 17. Means[1] and standard deviations of color differences in whole wheat substituted with pinto and navy bean protein concentrates.[2]

Treatment	0%	10%		15%		20%	
		PPC	NPC	PPC	NPC	PPC	NPC
				L Lightners			
No $KBrO_3$; No SSL	44.5^{x} ±0.9	49.0^{ya} ±2.2	45.0^{x} ±1.0	47.3^{xya} ±1.5	43.2^{x} ±4.0	43.5^{x} ±2.2	47.1^{xyh} ±2.3
10 ppm $KBrO_3$; .5% SSL		50.3^{a} ±2.0	50.1^{b} ±1.5	49.0^{d} ±2.0	51.8^{f} ±0.3	49.8^{g} ±0.2	51.0^{h} ±1.2
10 ppm $KBrO_3$; 1% SSL		51.3^{a} ±0.6	51.5^{c} ±0.8	49.9^{d} ±1.6	50.7^{ef} ±0.7	46.8^{h} ±0.6	49.6^{hi} ±1.4
20 ppm $KBrO_3$; .5% SSL		49.5^{a} ±0.9	48.9^{b} ±0.9	49.3^{d} ±1.4	51.2^{f} ±0.7	49.7^{g} ±0.8	50.4^{h} ±1.0
20 ppm $KBrO_3$; 1% SSL		49.2^{a} ±1.3	49.1^{b} ±0.4	49.5^{d} ±1.5	48.9^{e} ±0.2	49.4^{g} ±0.4	50.0^{hi} ±1.6
			La (-) Greeness	(+) Redness			
No $KBrO_3$; No SSL	5.9^{x} ±0.3	5.0^{ya} ±0.2	5.7^{x} ±0.4	5.4^{yx} ±0.3	5.3^{x} ±0.6	5.6^{zx} ±0.2	5.2^{x} ±0.2
10 ppm $KBrO_3$; .5% SSL		4.8^{a} ±0.4	4.8^{c} ±0.4	4.8^{e} ±0.3	4.6^{f} ±0.2	4.8^{g} ±0.0	4.6^{i} ±0.2
10 ppm $KBrO_3$; 1% SSL		4.7^{a} ±0.1	4.8^{c} ±0.0	4.5^{de} ±0.0	4.5^{f} ±0.1	5.0^{h} ±0.2	4.4^{i} ±0.3
20 ppm $KBrO_3$; .5% SSL		4.2^{b} ±0.2	5.1^{c} ±0.1	4.1^{d} ±0.4	4.7^{f} ±0.0	4.8^{gh} ±0.1	4.7^{i} ±0.1
20 ppm $KBrO_3$; 1% SSL		4.7^{a} ±0.2	4.8^{c} ±0.1	4.7^{e} ±0.2	4.8^{f} ±0.0	4.6^{g} ±0.0	4.5^{i} ±0.3
				Lb Yellowness[3]			
No $KBrO_3$; No SSL	15.4^{x} ±0.4	15.4^{xab} ±0.2	15.7^{xa} ±0.2	15.5^{xc} ±0.2	15.5^{xf} ±0.4	15.4^{xh} ±0.2	15.6^{xj} ±0.2
10 ppm $KBrO_3$; .5% SSL		16.0^{cb} ±0.2	16.3^{b} ±0.2	15.7^{c} ±0.2	16.5^{d} ±0.0	15.9^{g} ±0.2	16.5^{i} ±0.1
10 ppm $KBrO_3$; 1% SSL		15.8^{b} ±0.0	16.1^{b} ±0.1	15.7^{c} ±0.3	16.1^{e} ±0.3	15.6^{h} ±0.2	15.6^{j} ±0.2
20 ppm $KBrO_3$; .5% SSL		15.7^{b} ±0.2	15.9^{ab} ±0.1	15.6^{c} ±0.1	16.1^{de} ±0.3	15.6^{h} ±0.1	15.9^{j} ±0.2
20 ppm $KBrO_3$; 1% SSL		15.0^{a} ±0.4	15.6^{a} ±0.0	15.5^{c} ±0.2	15.5^{f} ±0.2	15.7^{gh} ±0.0	15.6^{j} ±0.2

[1]n=3

[2]PPC=Pinto bean protein concentrate; NPC=Navy bean protein concentrate.

[3]Standard tile values: L=78.5; L_a=-3.2; L_b=23.4.

Values followed by the same letter in each column are not significantly different at p_0.05. Duncan's Multiple Range Test (Duncan's, 1957): x...z for level (across) for individual protein concentrate; for treatment a...c for individual protein concentrate for 10%; d...f, for 15%; g...i, for 20%.

Table 18. Mean squares for the influence of level of each legume protein concentrate on the volume, tenderness, compressibility and Hunter Color values of white or whole wheat flour breads.

Legume Protein Concentrate	Source of Variation	Degrees of Freedom	Volume	Tenderness	Compressibility	Hunter Values L	Hunter Values L_a	Hunter Values L_b
Bread Flour								
Pinto	Level	3	2157.64	.0005	.0001	161.54***	.0231	.2431
	Within	8	1431.25	.0001	.0001	7.74	.2925	.2692
Navy	Level	3	900.00	.0006*	.0004***	103.92***	1.3133***	.7933
	Within	8	1808.33	.0001	.0000	2.23	.0633	.2883
Whole Wheat Flour								
Pinto	Level	3	811.11	.0007***	.0066***	19.187*	.4289*	.003
	Within	8	841.679	.0000	.0003	3.225	.0750	.0567
Navy	Level	3	541.67	.0007***	.0036***	4.303	.3119	.0408
	Within	8	1033.33	.0001	.0001	5.978	.1533	.0983

*Significant at $p \leq 0.05$
***Significant at $p \leq 0.001$

determining loaf volume.

Data for white bread, whole wheat bread and bread with 0, 10, 15 and 20% pinto or navy bean protein fractions is presented in Table 13 and showed no significant differences at the 5% level of probability in volume among control white, whole wheat bread and untreated bread with 10, 15 and 20% pinto or navy bean protein (Table 18 and Figure 7). Substituted breads, however, had slightly lower volumes than control breads (Table 13, Figures 7 and 8). Several factors may have contributed to good comparable loaf volume of breads with pinto and navy bean protein up to the 20% substitution level. For one, varying the amount of water linearly with each percent increase in pinto or navy bean flour concentration in the blend, according to Knorr and Betschart (1981) resulted in a 27 percent increase in loaf volume when breads fortified with 12% soy flour had an additional 8 to 12 percent water above the farinograph absorption. In addition, varying mixing times for composite flour doughs showed that overmixing, determined from preliminary testing studies, resulted in a weakened gluten structure that could not stand the gasing power during fermentation and baking; whereas undermixing resulted in an inadequately developed dough system. Further, varying fermentation time led to the conclusion that doughs of different strengths needed different fermentation time (Table 5). Finally, the use of heated, air-classified bean protein concentrates instead of whole bean flour could have

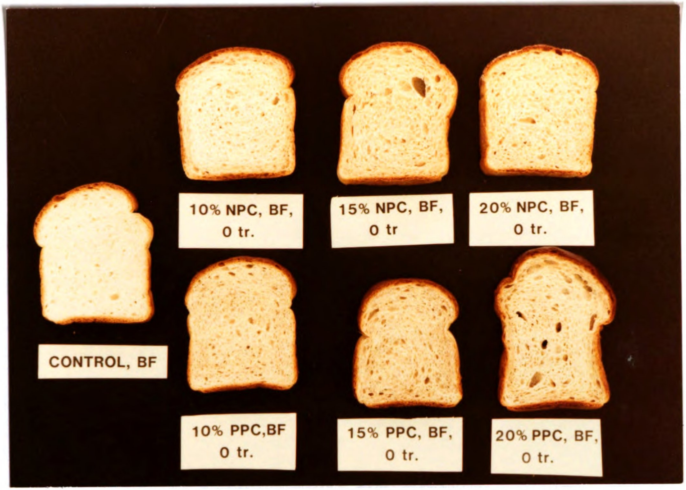

Figure 7. Effect of incorporating 0, 10, 15 and 20% PPC or NPC on white bread volume and crumb grain.

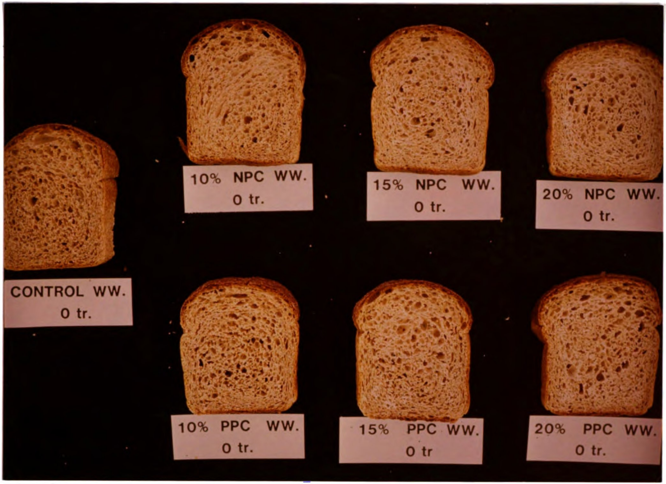

Figure 8. Effect of incorporating 0, 10, 15 and 20% PPC or NPC on whole wheat bread volume and crumb grain.

contributed to the improved loaf volume of pinto and navy bean protein concentrate substituted breads. D'Appolonia (1978) reported superior loaf volumes for breads substituted with roasted as compared to uncroasted navy bean flours in legume - wheat flour blends. McConnell et al. (1974) reported that using the protein fraction of faba bean rather than the whole bean flour resulted in higher loaf volumes.

Results indicate that significant improvements in volume occurred for both navy and pinto protein concentrate at all levels of substitution in bread flour but fewer significant improvements occurred in the whole wheat bread systems with treatments (Table 19, Figure 9 and 10). The treatment combinations of 10 ppm $KBrO_3$ and 1% SSL resulted in the highest volumes for bread flour variables with pinto or navy bean protein concentrate at 10 or 15% levels in the legume flour blend (Table 13, Figure 9). The treatments with 20 ppm $KBrO_3$ improved volume at the higher levels of legume substitution and although actual mean volumes were not as high, they were often not significantly different from the values of the former treatment combination that is 10 ppm $KBrO_3$; 1% SSL at substitution levels of 10 or 15% legume protein concentrate (Table 13). Treatment combinations slightly increased volumes of whole wheat breads but few of these increases were statistically significant. Tsen et al. (1971) reported that increasing bromate in soy fortified breads alleviated adverse effects of soy flour; and that SSL markedly improved

Table 19. Mean squares for the effect of combination of oxidant and dough conditioner on each level of pinto or navy protein concentrate on volume, tenderness, compressibility, and Hunter Color values of white or whole wheat flour breads.

Flour Type	Legume Type	Level	Source of Variation	Degree of Freedom	Volume	Tenderness	Compressibility	Degree of Freedom	Hunter Value L	Hunter Value a_L	Hunter Value b_L
Bread	Pinto	10	Treatment	5	32768.9***	.0010***	.0004*	4	26.469*	.9710**	.2151
			Within	12	950.0	.0001	.0001	10	5.459	.0973	.1467
		15	Treatment	5	28196.7***	.0008***	.0001	4	33.016*	.3723*	1.8983***
			Within	12	1222.2	.0001	.0001	10	6.439	.0647	.1427
		20	Treatment	5	6732.5**	.0005*	.0001	4	28.279***	.6117*	7.8517
			Within	12	1120.8	.0001	.0001	10	2.378	.1173	6.3207
	Navy	10	Treatment	5	14728.9***	.0007**	.0004*	4	33.996***	3.4057***	.6610**
			Within	12	777.8	.0001	.0001	10	1.523	.0387	.0823
		15	Treatment	5	16400.0***	.0006***	.0007*	4	18.898**	.8000***	.3640
			Within	12	1916.7	.0001	.0001	10	1.9991	.0513	.3873
		20	Treatment	5	15955.6***	.0004**	.0008***	4	31.292**	.9357***	1.2923***
			Within	12	1272.2	.0000	.0000	10	3.382	.0367	.0807
Whole Wheat	Pinto	10	Treatment	5	1048.9	.0005***	.0071***	4	2.641	.2773*	.4550**
			Within	12	627.8	.0000	.0001	10	2.301	.0500	.0560
		15	Treatment	5	3008.9*	.0005***	.0057***	4	2.978	.6750***	.0373
			Within	12	605.6	.0000	.0004	10	2.634	.0793	.0400
		20	Treatment	5	3008.9	.0005***	.0075***	4	22.121***	.4527***	.0907*
			Within	12	605.6	.0000	.0001	10	1.267	.0147	.0213
	Navy	10	Treatment	5	1528.9	.0002	.0076***	4	17.333***	.4677**	.2167**
			Within	12	638.9	.0001	.0001	10	.975	.587	.0213
		15	Treatment	5	5186.7**	.0003***	.0088***	4	37.013***	.7457***	.7610***
			Within	12	838.9	.0000	.0001	10	1.132	.0213	.0493
		20	Treatment	5	4698.9**	.0006***	.0072***	4	6.688	.3277**	.4567***
			Within	12	755.6	.0000	.0001	10	2.481	.0513	.0347

*Significant at $p \leq 0.05$.
**Significant at $p \leq 0.01$.
***Significant at $p \leq 0.001$.

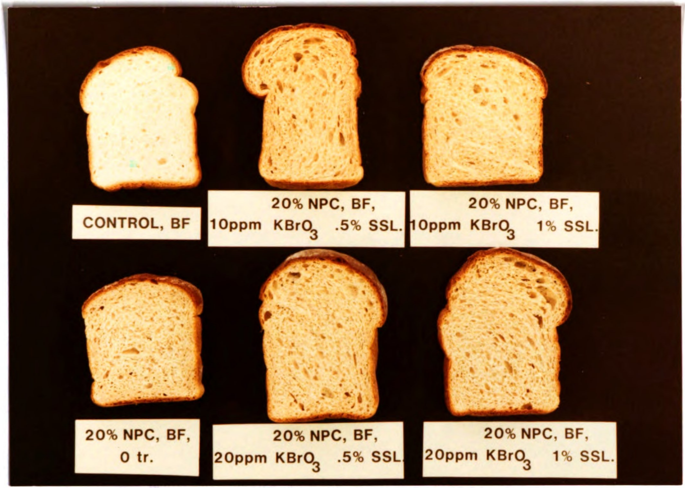

Figure 9. Effect of additive treatments ($KBrO_3$ and SSL) on white bread substituted with 20% PPC and NPC on volume and crumb grain.

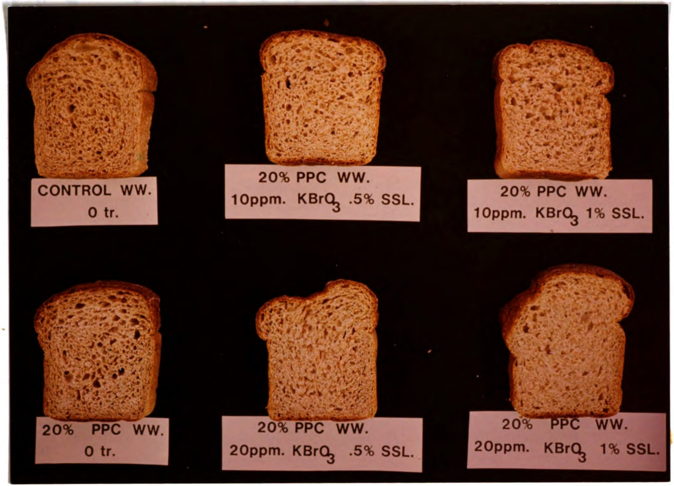

Figure 10. Effect of additive treatments ($KBrO_3$ and SSL) on whole wheat bread substituted with 20% PPC and NPC on volume and crumb grain.

handling qualities of dough, crumb grain, excellent shelf life and tenderness.

Tenderness

Bread tenderness is another desirable characteristic, more important in the United States than in Europe (Tsen and Hoover, 1971). The addition of either pinto or navy bean protein concentrate decreased shear values and all of these decreases were significant except for the addition of pinto protein concentrate up to the 15% substitution level for white breads. All levels of substitution of navy protein concentrate to white bread or pinto protein concentrate to whole wheat bread made the breads significantly ($p \leq 0.05$) more tender than the control but there were no significant differences in tenderness among any of these levels of substitution (Table 14). For the havy bean protein concentrate - whole wheat breads, only the variable with 20% substitution was tender than the control. This data is in agreement with Hoojjat (1981), who reported significantly ($p \leq 0.05$) more tender breads with 20% navy or sesame flour substitution.

Use of combinations of $KBrO_3$ and SSL brought about significant differences in tenderness for all variables except whole wheat bread made from flour blends containing 10% navy bean protein concentrate (Table 19). Although differences were significant, actual differences in force readings were slight (Table 14). For the white bread system use of 1% SSL in the treatment combination for breads made with blends containing either 10% navy or pinto protein concentrate significantly ($p \leq 0.05$) increased the force required to shear the bread. These trends also occurred for 15% blends although differences were not always significant ($p \geq 0.05$) while no significant differences in tenderness were caused by treatment combinations for the white bread made from 20% blends. The treatment combination of 10 ppm $KBrO_3$ and 0.5% SSL significantly ($p \leq 0.05$) increased tenderness of white bread made with the 15% pinto protein concentrate blend.

No treatment combination resulted in significantly more tender whole wheat breads but a few significantly less tender whole wheat breads were found as follows: for whole wheat made with 10% pinto protein concentrate, the untreated bread and the bread with 10 ppm $KBrO_3$, .5% SSL were more tender than both treatments with 1% SSL which were more tender than the bread with 20 ppm $KBrO_3$, 0.5% SSL; for bread with 15% navy bean protein concentrate breads with both the highest and lowest treatment combination were more tender; for the breads with 20% navy bean protein concentrate, use of the treatment combination of 20 ppm $KBrO_3$ and 0.5% SSL caused bread to be less tender than all others.

Compressibility

Increasing the level of protein concentrate brought about significant differences in compressibility for all bread systems except the white bread prepared with pinto protein concentrate in the blend (Table 15). As shown in Table 15 white bread with 15 or 20% navy bean protein concentrate were slightly but significantly ($p \leq 0.05$) less compressible than white bread with 0 or 10% navy protein concentrate. The observed increase in firmness with legume protein substituted breads may be partially explained by the weakened gluten strands which resulted in thicker cell walls and due to concentrated bean proteins disrupting the well defined protein - starch complex (characteristic of control bread) causing a rupture of the cell structure in bread (Fleming and Sosulski, 1978). Firming of crumb as the concentration of legume flour increased was also documented by Tsen and Hoover (1973), Fleming and Sosulski (1978). In contrast, addition of both legume protein concentrate to whole wheat breads reduced the force required for compressibility and the breads with 20% substitution required significantly ($p \leq 0.05$) less force than those with 10% substitution.

More highly significant effects among the treatments were seen in the whole wheat bread system (Table 19). The only significant differences among treatments for the white breads containing pinto protein concentrate occurred at the 10% blend in which all treatments except the combination of

10 ppm $KBrO_3$ and 1% SSL reduced compressibility. In contrast this same treatment combination increased compressibility in white breads with 15% navy protein concentrate. For white breads with 15% navy protein concentrate both treatment combinations with 0.5% SSL resulted in more compressible bread while at the 20% level of navy bean protein concentrate, treatment combinations of 20 ppm $KBrO_3$ resulted in the most easily compressed bread. Significant differences in the whole wheat breads were also somewhat scattered (Table 19) but the treatment combinations with 20 ppm $KBrO_3$ most often had the lowest force values for compression.

Consequently crumb softness of white and whole wheat bread was enhanced when treated with combination treatments with high levels of SSL and/or $KBrO_3$ respectively. Pomeranz et al. (1969) reported that adding .5% synthetic glycolipids produced a soft or even softer crumb than bread baked with 3.0 percent commercial shortening. Tsen and Hoover (1971) observed that the addition of 0.5 percent SSL in addition to the 3.0 percent shortening exerted more shortening power. These dough conditioners can exert a shortening sparing - effect such that because of their higher solubility they may have participated in the gelatinization process reducing the tendency of the starch molecules to retrograde and spared the commercial shortening for crumb softness.

<u>Color</u>

The Hunter color difference meter was standardized with the yellow tile having reference values of 78.5 lightness; -3.2 greeness; 23.4 yellowness. Previous studies have indicated that substituting with legume flour particularly pinto and navy bean flours resulted in grayish crumb colors (D'Appolonia, 1977): Adding pinto bean protein concentrate to white bread significantly affected lightness values while adding navy protein concentrate to white bread significantly affected both lightness and redness (Table 16). On the contrary pinto protein concentrate affected whole wheat bread color and the values significantly ($p \leq 0.05$) changed were lightness and redness (Table 17). Means for lightness values in Table 18 show that white bread crumb color of pinto and navy bean protein concentrate became progressively darker as the concentration of bean protein increased. Adding 10, 15 and 20% pinto or navy bean protein caused a significant ($p \leq 0.05$) decrease in lightness and greeness compared to control white bread. There were few significant differences in color among the 10, 15 and 20% pinto or navy protein concentrate substituted breads. Breads prepared with pinto or navy bean protein fractions were more yellow than the control bread. Due to differences in the color of the pinto and navy bean flours, breads with pinto were grayish and less yellow than white breads with navy bean protein concentrate. Table 19 presents the results of analyses of variance among treatments resulting in significant differences in color values. Significant effects are quite scattered varying for flour type, legume type and level of legume protein in the flour blend. In most cases treating navy and pinto fortified white bread with $KBrO_3$ (10 ppm, 20 ppm) and SSL (0.5%, 1%) at any level of treatment combination improved white bread crumb color (Table 19). Of significant importance was treating breads with 10 ppm $KBrO_3$ and 1% SSL which produced significantly ($p \leq 0.05$) whiter crumbs at all levels of substitution with pinto and navy bean protein. Thus the addition of pinto or navy bean protein flour was inversely related to crumb color. Whole wheat bread on the other hand became progressively whiter as the percent concentration of navy or pinto flour increased. Bread became significantly ($p \leq 0.05$) less red as the substitution level was increased from 0 to 10%. Both the navy and pinto bean flours had significant effects on whole wheat bread crumb yellowness, except for the 15% substitution with pinto bean protein concentrate (Table 19). Treating whole wheat bread containing 10 and 15% pinto flour with 10 ppm $KBrO_3$ and 1% SSL caused crumb color to be lighter and more yellow (Table 17). Bread crumbs were significantly ($p \leq 0.05$) more yellow when 10 ppm $KBrO_3$ and 0.5% SSL were added to breads containing 15 and 20% navy protein flour (Tables 17 and 19). The increase in lightness when pinto or navy bean protein flour was added to whole wheat bread was because the legume flours had higher lightness values than the whole wheat flour.

Sensory Evaluation

To determine consumer acceptability of breads fortified with pinto and navy bean high protein flour, breads were evaluated for crust color, crust character, crumb color, crumb grain, crumb tenderness, flavor and overall acceptability by taste panelists. Analyses of variance showed that adding pinto protein concentrate to white bread significantly affected all sensory characteristics (Table 20) but only crust color, flavor and general acceptability were affected for white bread with navy protein concentrate. Fewer significant differences occurred for the whole wheat breads. The addition of combinations of $KBrO_3$ and SSL also brought about many significant effects on sensory characteristics of these breads (Table 20). Tables 20 and 21 show taste panel scoring for the white bread and whole wheat bread flour blends. McConnell et al. (1974) reported that breads containing 20% faba bean flour were rated inferior to commercially available whole wheat bread and to breads baked in the laboratory by taste panelists. Breads containing faba bean flour were described as flat, tasteless or possessing a bitter aftertaste. Despite these negative attributes, breads were not completely disliked by panelists.

Table 20. Means[1] and standard deviations of sensory evaluation of white untreated and treated bread substituted with pinto and navy bean protein concentrate.

Substitution Level %	Crust Color[2]		Crust Character[3]		Crumb Color[4]		Grain Texture[5]		Tenderness[6]		Flavor[7]		General[8] Acceptability	
	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC
							No $KBrO_3$ No SSL							
Control	5.4^{x} ±.4	5.4^{x} ±.4	4.7^{x} ±.5	4.7^{x} ±.5	5.9^{x} ±.1	5.9^{x} ±.1	5.4^{x} ±.5	5.4^{x} ±.5	5.3^{x} ±.3	5.3^{x} ±.3	5.4^{x} ±.2	5.4^{x} ±.2	5.6^{x} ±.2	5.6^{x} ±.2
10	4.2^{yab} ±.4	4.6^{xabe} ±.5	4.5^{xa} ±.5	4.3^{xa} ±.5	3.7^{yb} ±.1	4.7^{ya} ±.2	4.1^{xya} ±.5	4.8^{xa} ±.6	5.2^{xa} ±.3	4.8^{xb} ±.4	3.9^{xa} ±.1	4.6^{xa} ±.0	4.1^{xa} ±.2	4.7^{ya} ±.1
15	2.7^{zg} ±.4	4.7^{xd} ±.5	2.7^{yf} ±.4	4.4^{xde} ±.2	2.7^{zf} ±.2	4.4^{ze} ±.5	3.7^{xzd} ±.3	4.8^{xd} ±.2	5.2^{xd} ±.4	4.1^{xe} ±.1	3.6^{yzf} ±.2	4.2^{ze} ±.0	3.8^{ye} ±.0	4.3^{ze} ±.1
20	2.1^{zh} ±.4	3.9^{xg} ±.3	3.1^{g} ±.5	4.2^{xg} ±.1	2.7^{zg} ±.4	4.2^{zg} ±.1	3.2^{zhi} ±.2	4.6^{xg} ±.3	4.5^{yij} ±.3	4.5^{xg} ±.3	3.5^{zj} ±.2	4.1^{zh} ±.1	3.4^{zi} ±.0	4.1^{zg} ±.3
							10 ppm $KBrO_3$ .5% SSL							
10	4.4^{ab} ±.6	4.3^{bc} ±.3	4.4^{a} ±.2	4.2^{a} ±.7	3.5^{b} ±.1	3.7^{b} ±.2	3.9^{a} ±.3	3.9^{a} ±.4	4.9^{a} ±.3	5.7^{a} ±.2	4.5^{b} ±.2	4.3^{a} ±.4	4.2^{a} ±.0	4.4^{a} ±.3
15	4.9^{d} ±.6	4.7^{de} ±.5	6.2^{d} ±.2	5.2^{a} ±.4	3.1^{e} ±.3	3.7^{f} ±.1	3.5^{d} ±.5	4.2^{de} ±.2	4.6^{d} ±.4	4.6^{e} ±.2	4.1^{e} ±.1	4.3^{e} ±.2	3.9^{f} ±.4	4.4^{e} ±.2
20	2.1^{h} ±.0	4.4^{g} ±.9	4.3^{g} ±.2	5.0^{g} ±1.2	2.9^{z} ±.5	3.7^{g} ±.2	2.8^{c} ±.6	3.9^{g} ±.3	4.4^{j} ±.1	4.8^{g} ±.4	3.6^{ij} ±.2	4.2^{h} ±.0	2.7^{j} ±.2	4.4^{g} ±.3
							10 ppm $KBrO_3$ 1% SSL							
10	3.0^{c} ±.5	3.8^{c} ±.2	4.4^{a} ±.2	3.6^{a} ±.3	4.3^{a} ±.2	4.5^{a} ±.3	3.9^{a} ±.4	3.8^{a} ±.4	4.9^{a} ±.2	4.9^{b} ±.3	4.6^{b} ±.3	4.6^{a} ±.2	4.6^{a} ±.2	4.5^{a} ±.1
15	3.3^{fg} ±.2	3.8^{e} ±.5	3.9^{e} ±.3	4.8^{d} ±.2	4.0^{d} ±.2	4.9^{d} ±.1	4.1^{d} ±.7	3.3^{f} ±.2	4.8^{d} ±.5	4.9^{de} ±.4	4.7^{d} ±.2	4.9^{d} ±.3	4.5^{d} ±.3	4.7^{d} ±.2
20	3.3^{g} ±.2	3.2^{g} ±.8	4.6^{gh} ±.3	4.2^{g} ±.6	4.4^{d} ±.4	3.8^{g} ±.2	4.1^{g} ±.4	4.2^{g} ±.3	5.0^{hi} ±.5	4.8^{g} ±.2	4.6^{h} ±.1	4.5^{g} ±.2	4.5^{g} ±.0	4.1^{g} ±.3

Table 20 cont.

	20 ppm $KBrO_3$ .5% SSL													
10	4.0^{bc} ±.6	5.2^{a} ±.5	4.4^{a} ±.3	3.6^{a} ±.3	3.7^{b} ±.1	3.6^{b} ±.2	4.0^{a} ±.3	4.5^{a} ±.7	4.8^{a} ±.6	5.0^{b} ±.5	4.8^{b} ±.3	4.4^{a} ±.3	4.4^{a} ±.6	4.4^{a} ±.3
15	3.7^{ef} ±.3	4.3^{de} ±.6	3.9^{e} ±.0	3.8^{e} ±.2	3.5^{d} ±.1	3.7^{f} ±.2	4.4^{d} ±.6	4.7^{d} ±.2	5.3^{d} ±.5	5.4^{d} ±.3	4.3^{e} ±.2	5.0^{d} ±.0	4.2^{de} ±.2	4.6^{d} ±.1
20	3.6^{g} ±.4	3.8^{g} ±.5	4.1^{g} ±.2	3.8^{g} ±.6	3.1^{g} ±.2	3.9^{g} ±.5	3.9^{gh} ±.6	4.7^{g} ±.5	5.1^{h} ±.2	5.2^{g} ±.2	4.1^{h} ±.2	4.5^{g} ±.2	4.1^{h} ±.3	4.5^{g} ±.2
	20 ppm $KBrO_3$ 1% SSL													
10	5.1^{a} ±.4	4.7^{ab} ±.4	4.1^{a} ±.1	3.7^{a} ±.5	4.2^{a} ±.2	3.7 ±.1	5.0^{a} ±.6	4.8^{a} ±.2	4.9^{a} ±.2	4.7^{b} ±.3	4.6^{b} ±.2	4.3^{a} ±.1	4.6^{a} ±.4	4.3^{a} ±.1
15	4.2^{de} ±.5	4.5^{de} ±.8	3.6^{e} ±.2	4.5^{d} ±.6	3.2^{e} ±.2	3.8^{f} ±.2	3.6^{d} ±.2	3.6^{ef} ±.6	4.5^{d} ±.3	4.8^{e} ±.2	4.3^{e} ±.2	4.3^{e} ±.2	4.2^{de} ±.2	4.3^{e} ±.1
20	3.3^{g} ±.2	3.9^{g} ±.9	4.0^{g} ±.4	4.1^{g} ±.8	3.4^{g} ±.8	3.7^{g} ±.2	4.2^{g} ±.2	3.9^{g} ±1.1	4.9^{hij} ±.2	5.2^{g} ±.3	3.9^{hi} ±.2	4.1^{h} ±.0	4.0^{h} ±.1	4.2^{g} ±.2

[1]average of three replications

[2]1-7; 1=darkest, 7=rich golden brown

[3]1-7; 1=tough rubbery, thick; 7=soft and tender

[4]1-7; 1=too grey, 7=bright cream white

[5]1-7; 1=coarse cell structure uneven large wholes, 7=fine cell structure evenly distributed

[6]1-7; 1=tough and dry, 7=tender, soft, moist

[7]1-7; 1=very poor distinct off flavor, 7=excellent

[8]1-7; 1=completely unacceptable, 7=acceptable, excellent

[xyz]Data with same superscript are not significant only different among levels of protein substitution of either PPC or NPC ($p \leq 0.05$, Duncan, 1957).

[a...i]Data with same superscript for one protein substitution level with one protein concentrate, ie either PPC or NPC, are not significantly affected by combination of SSL and $KBrO_3$.

Table 21. Means[1] and standard deviations of sensory evaluation of whole wheat untreated and treated bread substituted with pinto and navy bean protein concentrate.

Substitution Level (%)	Crust Color[2]		Crust Character[3]		Crumb Color[4]		Grain Texture[5]		Tenderness[6]		Flavor[7]		General[8] Acceptability	
	PPC	NPC	PCC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC	PPC	NPC
						No $KBrO_3$ No SSL								
Control	4.5^{x} ±.5	4.5^{x} ±.5	3.2^{x} ±.4	3.2^{x} ±.4	4.0^{x} ±.3	4.0^{x} ±.3	4.0^{x} ±.0	4.0^{x} ±.0	3.4^{x} ±.2	3.4^{x} ±.2	3.9^{x} ±.1	3.9^{x} ±.1	3.9 ±.3	3.9^{x} ±.3
10	3.3^{yb} ±.5	2.4^{ya} ±.4	3.4^{xa} ±.2	2.8^{xc} ±.2	4.5^{xa} ±.5	4.0^{xb} ±.1	4.3^{xa} ±.9	3.6^{xa} ±.3	4.6^{ya} ±.4	3.6^{xa} ±.2	4.1^{xa} ±.4	3.7^{xa} ±.2	4.0^{xyh} ±.2	3.7^{xc} ±.3
15	3.1^{yef} ±.1	4.2^{xde} ±.4	3.9^{xd} ±.2	4.0^{yd} ±.4	4.7^{xe} ±.3	3.9^{xe} ±.7	3.8^{xe} ±.4	3.8^{xef} ±.6	4.7^{yd} ±.5	3.9^{xd} ±.3	4.1^{xe} ±.1	3.7^{xd} ±.5	4.3^{x} ±.1	3.9^{xd} ±.3
20	2.6^{yj} ±.8	2.4^{yg} ±.4	2.9^{xg} ±.7	3.4^{xg} ±.1	4.2^{xg} ±.3	3.7^{xh} ±.2	3.7^{xg} ±.2	3.5^{xj} ±.3	3.7^{xg} ±.6	3.5^{xi} ±.2	3.6^{xg} ±.1	3.6^{xg} ±.1	3.7^{ygh} ±.2	3.7^{xg} ±.0
						10 ppm $KBrO_3$ .5% SSL								
10	4.3^{a} ±.6	3.6^{c} ±.2	3.9^{ab} ±.6	4.0^{b} ±.2	4.1^{a} ±.8	3.7^{b} ±.2	4.4^{a} ±.7	3.9^{a} ±1.1	4.4^{a} ±.6	4.6^{a} ±1.0	4.0^{a} ±.2	4.0^{a} ±.2	3.9^{a} ±.2	3.7^{c} ±.0
15	4.1^{de} ±.6	2.6^{f} ±.4	3.9^{a} ±.6	3.8^{d} ±.4	4.1^{3} ±.4	3.6^{e} ±.3	4.3^{de} ±.2	3.9^{ef} ±.6	4.9^{d} ±.9	4.6^{d} ±1.2	4.2^{e} ±.2	3.8^{d} ±.6	4.2^{de} ±.0	4.1^{d} ±.8
20	3.7^{gij} ±.2	2.7^{g} ±.1	3.5^{gh} ±.1	3.3^{g} ±.7	4.2^{g} ±.3	3.9^{h} ±.1	4.7^{h} ±.4	4.7^{gh} ±.5	5.3^{h} ±.3	4.1^{hi} ±1.0	4.0^{h} ±.2	3.7^{g} ±.3	4.1^{h} ±.2	4.3^{g} ±.3
						10 ppm $KBrO_3$ 1% SSL								
10	3.0^{b} ±.6	4.4^{b} ±.4	4.4^{b} ±.3	3.7^{b} ±.2	3.9^{a} ±.1	3.7^{b} ±.3	4.5^{a} ±.4	4.4^{a} ±.5	5.1^{a} ±.4	4.8^{a} ±.7	3.9^{a} ±.3	4.1^{a} ±.4	4.2^{a} ±.0	4.4^{a} ±.4
15	2.9^{f} ±1.0	2.6^{f} ±.4	4.2^{d} ±.2	4.2^{a} ±.6	3.9^{f} ±.3	4.3^{de} ±.7	3.7^{e} ±.3	3.5^{f} ±.2	4.7^{a} ±.6	5.1^{d} ±.7	3.9^{e} ±.1	4.2^{d} ±.2	3.9^{e} ±.2	4.3^{d} ±.5
20	3.4^{ij} ±1.0	2.9^{g} ±.7	4.2^{h} ±.6	4.1^{g} ±.8	4.2^{g} ±.3	4.4^{h} ±.6	3.8^{g} ±.3	4.3^{hi} ±.3	5.0^{h} ±.3	4.8^{gh} ±.3	4.3^{i} ±.2	3.9^{g} +.2	4.7^{d} ±.3	4.2^{g} ±.2

Table 21 cont.

	20 ppm $KBrO_3$ .5% SSL													
10	3.2^{b} ±.0	2.7^{d} ±.2	4.6^{b} ±.4	4.0^{b} ±.3	5.1^{a} ±.6	4.9^{a} ±.4	4.6^{a} ±.8	4.5^{a} ±.9	4.3^{a} ±.4	4.1^{a} ±.8	4.2^{a} ±.5	3.8^{a} ±.2	4.1^{a} ±.4	3.8^{bc} ±.1
15	2.8^{f} ±.4	3.4^{ef} ±.9	4.5^{d} ±.4	4.4^{d} ±.1	5.4^{d} ±.3	4.9^{d} ±.2	3.8^{e} ±.3	4.5^{de} ±.2	4.7^{d} ±.3	4.8^{d} ±.5	4.8^{d} ±.2	4.4^{a} ±.1	4.5^{d} ±.4	4.4^{d} ±.4
20	4.2^{gi} ±.3	2.9^{g} ±.9	5.3^{i} ±.4	4.3^{g} ±.4	5.2^{h} ±.2	5.1^{g} ±.2	4.7^{h} ±.5	4.0^{ij} ±.2	5.2^{h} ±.5	4.6^{gh} ±.1	5.0^{j} ±.2	4.2^{g} ±.6	4.7^{i} ±.2	4.1^{g} ±.5
	20 ppm $KBrO_3$ 1% SSL													
10	4.5^{a} ±.8	5.6^{a} ±.4	4.3^{b} ±.5	4.9^{a} ±.1	4.5^{a} ±.6	4.9^{a} ±.3	5.1^{a} ±.6	5.1^{a} ±.3	5.1^{a} ±.3	4.9^{a} ±.1	4.1^{a} ±.3	3.8^{a} ±.2	4.3^{a} ±.5	4.2^{abc} ±.2
15	5.1^{d} ±.8	5.0^{d} ±.2	4.7^{d} ±.8	4.3^{d} ±.2	4.5^{e} ±.3	4.5^{de} ±.6	4.8^{d} ±.7	5.1^{d} ±.8	4.5^{d} ±.3	4.7^{d} ±.3	4.2^{3} ±.2	4.3^{d} ±.2	4.5^{d} ±.2	4.3^{d} ±.1
20	4.8^{g} ±.7	3.7^{g} ±.5	3.5^{gh} ±.6	4.5^{g} ±.3	4.5^{g} ±.3	4.4^{h} ±.5	3.9^{g} ±.3	5.1^{g} ±.3	4.8^{h} ±.2	5.3^{g} ±.4	3.6^{g} ±.0	3.7^{g} ±.6	3.5^{g} ±.1	3.7^{g} ±.5

[1] Average of 3 replications (8 member taste panel).

[2] 1-7; 1=darkest, 7=rich; golden brown.

[3] 1-7; 1=tough, rubbery, thick; 7=soft and tender.

[4] 1-7; 1=too pale; 7=bright golden brown.

[5] 1-7; 1=coarse cell structure uneven large wholes; 7=fine cell structure evenly distributed.

[6] 1-7; 1=tough and dry; 7=tender, soft, moist.

[7] 1-7; 1=very poor distinct off flavor; 7=excellent.

[8] 1-7; 1=completely unacceptable; 7=acceptable, excellent.

Crust Color

The color of the crust became significantly ($p \leq 0.05$) darker as the concentration of pinto bean protein concentrate increased for white bread variables (Table 20). However the sensory for crust color of the white bread with 15 or 20% pinto protein concentrate were not significantly different ($p \leq 0.05$). Addition of any level of pinto bean protein concentrate to whole wheat bread significantly ($p \leq 0.05$) darkened crust color and resulted in lower sensory scores for this parameter. Addition of navy bean protein concentrate to white breads did not significantly affect color (Table 20) while data for the whole wheat flour breads had an irregular pattern (Table 21).

Treatments of white bread systems containing navy bean protein concentrate with combinations of $KBrO_3$ and SSL resulted in no significant improvements in crust color (Table 20). Only the whole wheat bread containing 10% NPC and treated with 20 ppm $KBrO_3$ and 1% SSL scored significantly higher for color than the corresponding untreated whole wheat bread. For breads prepared with pinto bean protein concentrate treatments containing 20 ppm $KBrO_3$ lightened crust color of white breads making them to receive significantly ($p \leq 0.05$) higher sensory scores for all variables except the white bread containing 10% PPC with 20 ppm $KBrO_3$ and .5% SSL (Table 20). In addition a few of the variables with 10 ppm $KBrO_3$ also scored significantly higher than the untreated corresponding protein substitution levels. For whole wheat breads all of the breads containing pinto protein concentrate and were treated with 20 ppm $KBrO_3$ and 1% SSL scored significantly higher ($p \leq 0.05$) than the corresponding untreated breads (Table 21). Noteworthy is the fact that other significant differences on this parameter occurred but were rather scattered and thus difficult to logically mention. Thus treatments with high (20 ppm $KBrO_3$) oxidation levels generally produced lighter crust colors, hence one may conclude that potassium bromate was responsible for the improvement in color.

Crust Character

Substituting white bread with navy bean protein up to the 20% level had no significant effects at the 95% level of probability on crust character (Table 20). However, crusts were slightly tougher when navy bean protein was incorporated. No significant differences were noted at the 95% level of probability in crust character (tenderness) between the 0 and 10% pinto substituted white bread. Taste panelists gave slightly higher scores to breads substituted with navy instead of pinto bean protein flour. Untreated white bread with 10% pinto and navy bean flour scored slightly higher than treated breads. Thus treatment did not have significant ($p \geq 0.05$) effects on crust tenderness for breads with 10% legume flour. However, treating breads containing 15 and

20% pinto bean protein with 10 ppm $KBrO_3$ and 1% SSL significantly ($p \leq 0.05$) improved crust tenderness (Table 20). Whole wheat breads with 15% navy bean protein had significantly ($p \leq 0.05$) more tender crusts than 0, 10 and 20% substitution levels (Table 21). In most instances treatments with combinations of SSL and $KBrO_3$ improved crust tenderness of whole wheat bread containing 10, 15 and 20% legume flour. Whole wheat bread with 10 and 20% pinto bean protein flour had significantly better scores than the untreated breads when treated with 20 ppm $KBrO_3$ and .5% SSL (Table 21). Whole wheat breads with 10% navy protein concentrate with all treatments had significantly higher scores than the untreated. A combination effect may have been exerted but combination treatments with high (20 ppm $KBrO_3$) oxidation levels produced better results for legume fortified bread.

Crumb Color

The only significant effect of level of legume protein substitution was for white breads containing pinto bean protein concentrate (Table 20). Increasing levels of substitution resulted in significantly ($p \leq 0.05$) lower sensory scores for crumb color (Table 20). Nevertheless all crumb color scores decreased slightly with the incorporation of legume protein concentrate becoming greyish for the breads with pinto or navy bean protein flour. Treatments with potassium bromate and sodium stearoyl-2-lactylate at any possible combination caused a further impairment in crumb colors of the 10 and 20% navy bean protein substituted white breads (Table 20). In contrast, crumb color for bread with 15% navy bean protein and 10 and 15% pinto bean protein significantly ($p \leq 0.05$) improved with the addition of 10 ppm $KBrO_3$ and 1% SSL. For whole wheat bread containing 10, 15 and 20% pinto or navy bean protein significant improvements occurred with treatments of 20 ppm $KBrO_3$ and .5% SSL (Table 21). Perhaps high levels (1%) of SSL largely contributed to the improvements in crumb color of white bread variables while high (20 ppm $KBrO_3$) oxidation levels may have been primarily responsible for crumb color improvements among whole wheat bread variables. D'Appolonia (1977) reported an improved crumb color for legume fortified loaves with the addition of 1% SSL. Tsen et al. (1971) observed and reported that 20 ppm KBrO was optimum to oxidize flour fortified with 12 percent soy flour.

Crumb Grain

Results indicate that substituting whole wheat breads with 0, 10, 15 and 20% pinto or navy bean protein had no significant effects at the 5% level of probability on crumb grain (Table 21). White bread with 20% pinto bean protein however was scored significantly lower than control bread. Overall crumb grain did not deteriorate significantly ($p \leq 0.05$) with an increasing concentration of navy and pinto flour except for the white bread with 20% pinto bean flour (Figure 7). All treatment combinations except 10 ppm $KBrO_3$ and .5% SSL significantly ($p \leq 0.05$) improved the grain texture scores of white bread containing pinto protein concentrate (Table 20 and Figure 9). No other treatment effects were significantly different for grain texture score of white bread with pinto protein concentrate (Table 20). Although scattered, significant differences occurred for the white bread with navy bean protein concentrate (Table 20); scores given to the treated breads were significantly higher than the corresponding untreated breads. The addition of 20 ppm $KBrO_3$ and 1% SSL to whole wheat bread with 15% pinto or navy bean protein flour as well as bread with 20% navy bean protein flour significantly improved when treated with 10 ppm $KBrO_3$ and .5% SSL. The improvement of crumb grain by the addition of SSL (.5%) to legume fortified breads has been also documented by McConnell et al. (1974), Tsen et al. (1971), Tsen and Hoover (1973). Breads substituted with the navy protein fractions received higher crumb structure scores than their counterparts fortified with pinto bean protein flour. Nothing in the literature was found to substantiate these differences but the reason may be attributed to differences in the micronutrient composition of the two beans. Noteworthy is the point that breads were not scored lower because of a compact structure but rather because of larger cell structure in the formula pores which may have been caused by the increased water.

Crumb Tenderness

White bread was more tender up to the 15% substitution level than the 20% substitution with pinto protein flour (Table 20). Moreover adding potassium bromate and sodium stearoyl-2-lactylate had no significant ($p \geq 0.05$) effects on crumb tenderness of these breads. Adding navy bean protein concentrate at any level did not significantly ($p \geq 0.05$) influence the tenderness of white or whole wheat breads (Table 22). A good score was obtained for bread containing 10% navy bean flour when 10 ppm $KBrO_3$ and .5% SSL was added. White bread containing 15% navy bean protein concentrate was significantly ($p \leq 0.05$) more tender when treated with 20 ppm $KBrO_3$ and .5% SSL than the control bread and untreated bread (Table 20). The addition of 20 ppm $KBrO_3$ and .5% SSL, 20 ppm KBrO3 and 1% SSL significantly improved crumb tenderness of white breads with 20% pinto bean protein and navy protein respectively. For the whole wheat breads, treatments significantly influenced tenderness of breads with either 20% pinto or navy bean protein concentrate (Table 23). In both cases breads containing 20 ppm $KBrO_3$ and 1% SSL scored significantly higher. Generally, taste panel results were consistent with objective evaluation results and with those of previous researchers (Tsen et al., 1971). The softening effects of sodium stearoyl-2-lactylate or similar surfactants

Table 22. Mean squares for the influence of level of legume protein concentrate on sensory characteristics of white or whole wheat flour breads.

Legume Protein	Source of Variation	Degree of Freedom	Crust Color	Crust Character	Crumb Color	Grain Texture	Tenderness	Flavor	General Acceptability
					Bread Flour				
Pinto	Level	3	6.8211***	3.0608***	6.9253***	2.7608***	.4122*	2.2767***	2.9107***
	Within	8	0.2367	.1900	.0717	.1208	.0967	.0408	.0133
Navy	Level	3	1.1524*	.1746	1.7778	.5642	.3056	1.0319***	1.5495***
	Within	8	.1307	.1652	.0254	.2164	.0945	.0271	.0372
					Whole Wheat Flour				
Pinto	Level	3	1.9975**	.4848	.2600	.2017	1.1899*	.1718	.2149*
	Within	8	.2305	.1910	.1427	.2350	.1855	.0447	.0417
Navy	Level	3	4.6372***	.7706**	.0617	.1326	.1280	.0471	.0565
	Within	8	.1704	.0991	.1492	.1455	.0578	.0724	.0651

*Significant at $p \leq 0.05$.
**Significant at $p \leq 0.01$.
***Significant at $p \leq 0.001$.

Table 23. Mean squares for the effect of combination of oxidant and dough condition on each level of pinto or navy protein concentrate on sensory characteristics of white or whole wheat flour breads.

Flour Type	Legume Type	Level	Source of Variance	Degree of Freedom	Sensory Characteristics						
					Crust Color	Crust Character	Crumb Color	Grain Texture	Tenderness	Flavor	General Acceptability
Bread	Pinto	10	Treatment	4	1.6773*	.1443	.4127***	.6023	.0923	.3973**	.1557
			Within	10	.2927	.0687	.0327	.1760	.1067	.0460	.1047
		15	Treatment	4	2.1027***	5.0117***	.6957***	.4217	.3793	.4677***	.2293*
			Within	10	.1593	.0647	.0427	.2473	.1667	.0367	.0580
		20	Treatment	4	1.5623***	.9323**	1.3210*	1.1657*	.2677	.5610***	1.4243***
			Within	10	.0920	.1080	.2700	.2073	.0793	.0300	.0300
	Navy	10	Treatment	4	.7867*	.2433	.7277***	.7283	.4743*	.0610*	.0507
			Within	10	.1707	.2267	.0507	.2300	.1280	.0593	.0553
		15	Treatment	4	.5710	.7977*	.8073***	.9210**	.2723*	.5093***	.1483**
			Within	10	.3073	.1607	.0300	.1473	.0760	.0380	.0160
		20	Treatment	4	.5240	.5883	.1157	.4533	.2277	.0777**	.0890
			Within	10	.5280	.5820	.0813	.3480	.0947	.0127	.0660
Whole Wheat	Pinto	10	Treatment	4	1.3143*	.7150*	.7067	.3177	.3743	.0393	.0673
			Within	10	.2560	.1973	.3173	.4747	.1907	.1320	.0880
		15	Treatment	4	2.8877**	.3810	1.0490**	.6117*	.0860	.3140**	.1867*
			Within	10	.4487	.2600	.1040	.1613	.3033	.3020	.0507
		20	Treatment	4	1.9843*	2.3923**	.4427*	.7860**	1.2707**	1.0510***	.8683***
			Within	10	.4728	.2880	.1127	.1240	.1707	.0320	.0440
	Navy	10	Treatment	4	5.0090***	1.7157***	1.0810***	1.0423	.9383	.0677	.2877*
			Within	10	.1093	.0467	.0760	.4920	.4547	.0673	.0607
		15	Treatment	4	3.3433***	.2777	.8993*	1.4843*	.4877	.3383	.1427
			Within	10	.2340	.1227	.2427	.2627	.5167	.1220	.2027
		20	Treatment	4	.7007	.8257	.9057**	1.0657**	1.3683*	.1517	.1977
			Within	10	.5287	.2847	.1327	.1207	.2600	.1653	.1267

*Significant at $p \leq 0.05$.
**Significant at $p \leq 0.01$.
***Significant at $p \leq 0.001$.

have been well documented (Tsen and Hoover, 1971; Tenney, 1978). Effects may either be by direct action or an indirect action of the shortening - sparing effect of sodium stearoyl-2-lactylate (Tsen and Hoover, 1971).

Flavor and General Acceptability

McConnell et al. (1974) reported a preference for commercially baked bread by panelists in contrast to faba bean concentrate substituted breads which were described as having a bland flavor and slightly gummy crumb. Later it was reported that panelists rated breads with mung bean, pinto and navy bean flour as having pleasant tastes (D'Appolonia, 1977). Similar to the former study current results indicate that untreated white and whole wheat bread substituted with 10, 15 and 20% pinto or navy bean protein flour were rated fair in flavor and were fairly acceptable. Nevertheless there were significant differences at the 5% level of probability in flavor among control white breads and breads fortified with 10, 15 and 20% pinto and navy bean protein. Noteworthy, however, is the fact that often breads containing 10, 15 and 20% pinto and navy bean protein flour scored as high as 5.0 to 6.0 on a 1 to 7 point scale, 7 being the best (Appendix A) but scores were lowered by two panelists who almost always gave low scores to all breads, even the control breads. About 62% of the panelists rated the substituted breads good in flavor. Occasionally white breads with 20%

pinto or navy bean flour were reported as slightly gummy by panelists - a likely characteristic to occur since increasing the concentration of legume flour gave higher water holding capacity values (D'Appolonia, 1977). Baking breads longer at lower temperatures may alleviate this problem. Beaniness and an off flavor was rarely detected in legume protein enriched breads. Some panelists described the whole wheat legume substituted breads as having a molasses flavor. Treating breads with potassium bromate and sodium stearoyl-2-lactylate improved flavor and overall acceptability scores (Table 23). Noteworthy are the strikingly significant improvements at the 5% level of probability in flavor and acceptability when whole wheat bread with 15 and 20% pinto or navy bean protein; white bread with 15 and 20% navy bean protein were treated with 20 ppm $KBrO_3$ and .5% SSL. Whole wheat breads with 15 or 20% pinto bean flour and white bread with 15% navy bean flour were rated good in flavor when treated with 20 ppm $KBrO_3$ and .5% SSL. All other treated white and whole wheat breads containing 10, 15 and 20% pinto or navy bean protein concentrate were rated fair in flavor and fairly acceptable by panelists. The incorporation of SSL (.5%) level and $KBrO_3$ (20 ppm) in most cases further improved dough performance and minimized many deleterious effects of pinto or navy bean protein concentrate. Consequently fairly acceptable bread without treatment was obtained with navy bean protein substitution levels up to

20% and sometimes with pinto bean protein concentrate. Good bread was obtained when treatments of 20 ppm $KBrO_3$ and .5% SSL were added to breads containing 10, 15 and 20% pinto or navy bean protein fractions.

Normally breads are not eaten alone as was the case with experimental breads. Bread condiments such as butter, peanut butter, jelly or honey can markedly mask any off flavors or strong beany flavors that might render the product unacceptable. Bread that has a good balance of amino acids, hence good protein and acceptable to the consumer, can be produced up to the 20% level of substitution with concentrated protein fractions of navy and pinto bean.

Moisture

Moisture for the untreated control and fortified breads was determined (Table 24). Moisture retention increased with percentage increases in pinto or navy bean protein substitution. Moisture values for the 10% and 15% navy bean protein substitution were however very similar for the white bread (Table 24). A somewhat similar trend occurred with the whole wheat pinto or navy bean substituted breads. Moisture values were even higher than in white breads at all levels. The 10% and 15% pinto substituted breads had similar moisture values. This trend was expected since composite flour blends had higher water absorption values than plain bread or whole wheat flours; the legume protein

Table 24. Moisture[1] content of white and whole wheat breads substituted with 0, 10, 15 and 20% pinto and navy bean protein concentrate.[2]

Substitution Level (%)	White Bread		Whole Wheat Bread	
	PPC	NPC	PPC	NPC
0	24.5 ±0.0	24.5 ±0.0	33.1 ±0.1	33.1 ±0.1
10	27.1 ±0.2	34.4 ±0.4	40.5 ±1.1	34.4 ±0.6
15	28.7 ±0.8	34.6 ±0.0	40.6 ±0.4	36.6 ±0.6
20	34.9 ±0.7	35.5 ±0.0	44.3 ±0.4	42.3 ±0.4

[1]n=3

Moisture expressed on 14% m.b.

have higher water retention capacity values (D'Appolonia, 1977).

SUMMARY AND CONCLUSIONS

The objectives of this study were: to observe the effects of substitution with varying levels (0, 10, 15 and 20%) of air-classified pinto or navy bean protein concentrate (PPC or NPC respectively) on dough rheology and bread organoleptic and physical characteristics; to investigate the effect of salt, oxidizer and conditioner in single, double and triple additive treatments on dough rheology particularly extensibility and resistance to extension; to incorporate varied combination treatments of SSL and $KBrO_3$ in legume substituted bread systems; to determine optimum combination of treatments for the various pinto or navy bean protein concentrate substitution levels for white and whole wheat bread; and to therefore provide concrete feasible evidence for future possible food enrichment programs more especially geared to improving the food situation of world populations under marginal nutrition.

Farinograph studies of 0, 10, 15 and 20% PPC or NPC with bread or whole wheat flour showed a progressive increase in water absorption, arrival time and dough development time as the percentage level of bean protein concentrate substitution increased in the dough system. On the contrary dough stability showed a progressive decrease with an increasing concentration of PPC or NPC in the system. Whole wheat - legume protein concentrate doughs had higher absorption values than those with bread flour most probably because of the higher fiber content in the whole wheat system.

According to the chemical composition values of the navy and pinto bean high protein fractions, blends with the pinto protein concentrate should have had higher water absorption values because of the higher protein content, however this was only true with the whole wheat - legume protein variables. Whole wheat composite doughs had shorter arrival times, dough development times and longer stability than their counterparts prepared with bread flour, again this could be attributed to the higher protein content of the whole wheat flour. The longer arrival and dough development times as the percentage of legume protein concentrate increased in the dough system suggested that a delay in inter and intramolecular water distribution occurred.

Extensigraph studies of the 0, 10, 15 and 20% substitution with pinto or navy bean protein concentrate showed a progressive decrease in dough extensibility and resistance to extension suggesting a slackened (more diluted) weaker gluten and consequently a less extensible, less strong dough. The addition of legume protein concentrate perhaps resulted in a decreased SS:SH ratio with increased free sulfhydryl groups in the dough system; this has been documented to be inversely related to dough strength. The addition of potassium bromate however would minimize the number of free sulfhydryl groups by oxidizing them to disulfide groups thus increasing the number of SS groups and thereby strengthening the bonding system. The addition of salt might have contributed to increased dough strength through ionic bonding inter and or intramolecular. The addition of sodium stearoyl-2-lactylate imparted strength to doughs substituted with up to 20% PPC or NPC by stabilizing the gluten framework, although its action at the micromolecular level is poorly understood. Consequently when salt, $KBrO_3$ and salt, or SSL and salt were added stronger doughs with shorter fermentation times were obtained. Treatments with combinations of salt, $KBrO_3$ and SSL, however interacted to produce desirable dough properties - doughs that could be fermented longer and still had good load extension curves (extensibility and resistance to extension).

Although triple additive treatments in most cases seemed to have depressing effects on extensibility and resistance to extension when examined in isolation, they nevertheless imparted controlled, desired dough conditioning which brought about a good balance (proportional number between the extensibility and resistance to extension after the 90 min. rest period). Consequently 90 min. was used as the standard index for fermentation with deviations of minus 5 min. for each level of legume substitution. Noteworthy is the fact that for the higher levels of substitution, that is (15 and 20% with pinto or navy, triple combination treatments with higher (20 ppm) oxidation levels produced more desirable dough extensibility after the 90 min. rest period. This suggested that it was necessary to increase the bromate level with increases in legume protein content. This was somewhat confirmed and consistent with physical and sensory evaluation scores of the corresponding breads. Although closely examining the load extension curves would be a more accurate way to determine a well conditioned dough, proportional numbers of 4.5 - 6.5 and 5.0 - 6.5 for bread and whole wheat flour blends respectively would generally indicate a well conditioned dough. These parameters are invaluable indicators of flour strength and therefore indicate the appropriate fermentation time for various dough blends.

Baking water absorption was increased by 1% (adjusted to 14% m.b.) for 1% increase in PPC or NPC. This enabled adequate hydration of hydrophilic composite flour particles and hence facilitated adequate starch gelatinization and protein coagulation such that the volume of substituted breads was not seriously impaired. Consequently water absorption, mixing time and fermentation time were critical factors to be monitored if optimum loaf volume was to be obtained in pinto or navy bean protein concentrate substituted breads.

Although bread volume of substituted breads was not seriously affected by the addition of 0, 10, 15 and 20% PPC or NPC, treating the 10 and 15% legume protein substituted breads with 10 ppm $KBrO_3$ and 1% SSL improved bread volume while the 20% substitution with PPC or NPC was improved by treatments with higher oxidation levels. Breads became significantly more tender with increasing concentrations of PPC or NPC. This could be attributed to the higher water absorption and water holding capacity of legume protein fractions. As low as .5% SSL improved further crumb tenderness. This was consistent with taste panel results.

For whole wheat breads variable treatments did not have significant effects on tenderness. White substituted breads became less compressible and whole wheat substituted breads more compressible as the concentration of PPC or NPC increased in the bread system. Treatments, however, improved bread softness; particularly the treatments with higher oxidation levels (20 ppm $KBrO_3$) improved the softness of bread with 20% levels of substitution. Substituted white breads became increasingly more yellow or deep creamy white with incorporation of PPC or NPC. In contrast whole wheat breads became more pale as PPC or NPC was increased. This was also consistent with taste panel results. Treatments with SSL and $KBrO_3$ improved crumb color and in some instances crust color. To further minimize crust darkening the amount of added sugar could be decreased or the baking temperature reduced and baking time prolonged or both.

Analyses of variance of taste panel results showed that generally combination treatments of $KBrO_3$ and SSL considerably improved scores of substituted bread characteristics. In most cases substituting white bread with NPC up to 20% resulted in no significant differences and produced breads with characteristics comparable to control bread while substituting with PPC up to 20% level generally resulted in significantly lower bread characteristic scores. For whole wheat bread however substituting with PPC or NPC up to the 15% level and sometimes up to the 20% level and with no treatment had no significant differences on bread characteristics. Combination treatment particularly the 20 ppm $KBrO_3$ and .5% SSL improved bread characteristics considerably (except crust color) of whole wheat substituted breads for all levels of substitution. Optimum characteristics for white bread substituted with 10, 15 and 20% pinto or navy bean protein concentrates were obtained under three conditions. First, 10 ppm $KBrO_3$ and 1% SSL were added. Second, the baking absorption was increased by approximately 11, 13 and 21 percent above the farinograph absorptions. Finally the fermentation time was decreased to 80, 75 and 70 minutes respectively as the percentage of bean protein concentrate increased. For whole wheat bread fortified with 10, 15 and 20% pinto or navy bean protein concentrates, optimum bread characteristics were obtained under these three conditions: First, 20 ppm $KBrO_3$ and .5% SSL were added. Second, baking absorption was raised by 10, 15 and 21 percent above that of the farinograph and finally the fermentation time was decreased to 75, 70 and 65 minutes respectively. Mixing time increased with an increase in the concentration of bean protein concentrate. It was, however, necessary to stop the K-5 mixer occasionally to see if dough was well-developed. Dough was determined to be well-developed when it could no longer break short, White PPC substituted breads were the only ones conspicuously affected in crumb color and overall acceptability. Treatments improved crumb grain, crumb color softness, flavor and overall acceptability of substituted breads such that fair - good, acceptable bread with 20% legume protein substitution was produced. Substitution with legume concentrated protein fractions (40 - 42% d/b protein) should provide increased amounts of lysine and hence result in a bread with better amino acid score. Strong beany flavors that might be detected could be masked by bread condiments such as jam, or jelly. Noteworthy is the fact that taste panelists from other ethnic groups other than American did not detect strong flavors and almost always rated the breads as good or very good.

RECOMMENDATIONS FOR FUTURE RESEARCH

Since bread is consumed worldwide as a staple, convenience or snack food fortifying with concentrated legume protein fractions would ensure consumption of a good quality bread. However the technology required to obtain these high protein fractions from legumes is still beyond the economical capacity of most developing countries. Under current conditions use of high protein bean fractions would result in a high protein bread but this bread would be too costly for the poor. Simplified less costly equipment is required therefore to maximize the benefits of enriching bread with legume protein concentrate.

Future studies could closely control baking water absorption, mixing time and fermentation time to thoroughly document physical and mechanical manipulations of composite flour blends so that minimum amount of additives could be added for optimum dough performance. In addition concise documentation of how SSL imparts strength on the gluten framework is still lacking. Studies aimed at improving the color and/or flavor of legume flours are needed to optimize bread characteristics. Studies to determine the complementarity effect of wheat flour and legume protein concentrate would also aid in establishing a substitution level that would optimize bread quality. Lastly extensive crust darkening could be minimized by reducing the amount of added sugar increasing the α-amylase (from malt extract), increasing the baking time at a reduced temperature or all three could be evaluated at the same time.

APPENDIX

Appendix A. White Bread Score Sheet.

Date:

Name:

Instructions:
1. Evaluate all characteristics of each sample at a time using the descriptive[1] terms assigned as a guideline as much as possible.
2. Rinse your mouth between samples thoroughly.

	CRUST COLOR	CRUST CHARACTER	CRUMB COLOR[2]	GRAIN TEXTURE	GRAIN TENDERNESS	FLAVOR	GENERAL ACCEPTABILITY
1.	Very dark brown	Tough, rubbery & thick	Greyish dark	Compact, thick undistinguishable air cells	Tough & dry	Very poor distinct off flavor	Completely unacceptable
2.	Dark brown	Sl. rubbery tough & thick	Grey	Coarse cell Structure uneven large holes	Tough, gummy, rubbery	Poor off flavor	Unacceptable
3.	Sl. dark brown	Sl. tough, mod. thick, sl. rubbery	Sl. greyish	Mod. coarse cells, thick walls	Sl. tough & dry	About fair. Sl. off flavor	Sl. unacceptable
4.	Sl. dark brown	Mod. tough, mod. thick, mod. rubbery	Deep cream white dull	Coarse & fine cells, thick & thin walls	Sl. tough & moist	Fair	Unacceptable, fair
5.	Brown	Sl. soft, mod. tender, mod. thick	Creamish white moderate bright	S. uneven cell structure, mod. coarse/fine	Sl. tender Soft, moist	Good	Acceptable, good
6.	Rich golden brown, sl. uneven	Mod. soft, mod. tender, mod. thick	Cream white	Mostly fine cells w/ a few coarse fairly even	Tender Soft & moist	Very good	Acceptable Very good
7.	Rich golden brown, even	Soft tender breaks easily sl. thick	Creamish white bright	Fine cells evenly distributed	Tender, soft moist	Excellent	Acceptable Excellent

[1]Hedonic Scale 1-7; 1=least acceptable, 7=most acceptable.

[2]

Appendix A. Whole Wheat Bread Score Sheet.

Date:

Name:

Instructions:

1. Evaluate all characteristics of each sample at a time using the descriptive[1] terms assigned as a guideline as much as possible.
2. Rinse your mouth between samples thoroughly.

	CRUST COLOR	CRUST CHARACTER	CRUMB COLOR[3]	GRAIN TEXTURE	GRAIN TENDERNESS	FLAVOR	GENERAL ACCEPTABILITY
1.	Very dark brown	Tough, rubbery & thick	Too pale brown	Compact, thick undistinguishable air cells	Tough & dry	Very poor distinct off flavor	Completely unacceptable
2.	Dark brown	Sl. rubbery tough & thick	pale brown	Coarse cell structure uneven large holes	Tough, gummy, rubbery	Poor off flavor	Unacceptable
3.	Sl. dark brown	Sl. tough, mod. thick, sl. rubbery	Sl. brown	Mod. coarse cells, thick walls	Sl. tough & dry	About fair. Sl. off flavor	Sl. unacceptable
4.	Sl. dark brown	Mod. tough, mod. thick, mod. rubbery	Neither too brown nor too pale	Coarse & fine cells, thick & thin walls	Sl. tough & moist	Fair	Unacceptable, fair
5.	Brown	Sl. soft, mod. tender, mod. thick	Brown	Sl. uneven cell structure, mod. coarse/fine	Sl. tender Soft, moist	Good	Acceptable, good
6.	Rich, golden brown, sl. uneven	Mod. soft, mod. tender, mod. thick	Brown dull	Mostly fine cells w/ a few coarse fairly even	Tender Soft & moist	Very good	Acceptable Very good
7.	Rich golden brown, even	Soft tender breaks easily sl. thick	Rich, nice brown	Fine cells evenly distributed	Tender, soft moist	Excellent	Acceptable Excellent

[1] Hedonic Scale 1-7; 1=least acceptable, 7=most acceptable.

[2]

Sample #	Crust Color	Crumb Color	Crumb Grain	Tenderness	Flavor	General Acceptability

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