BREADMAKING PROPERTIES OF FOUR CONCENTRATED PLANT PROTEINS

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ABSTRACT

The breadmaking characteristics of the four concentrated plant proteins—soy flour, sunflower concentrate, fababean concentrate, and field-pea concentrate—used as additions to wheat flour, were investigated. Each plant protein caused deterioration in breadmaking characteristics, compared with the wheat-flour control, as measured by loaf volume, specific volume, crumb grain, crumb compressibility, and loaf shape. However, by formula alteration, acceptable bread was produced from all concentrated proteins investigated. Breads containing proteins from sunflower, fababean, and field pea had lower loaf volumes than from soy, but fababean and field-pea breads showed more desirable crumb grain. Since a high protein content in the bread was required, flour blends containing 12% sunflower concentrate or 15% fababean concentrate, field-pea concentrate, or soy flour were investigated further. It was necessary to add 2% vital gluten and about 1 g of dough conditioner per 100 g flour to restore bread quality. The glycolipids, and in particular sucrose monolaurate and Emulsifier-845 (polyoxyethylene-8-stearate), were the most effective conditioners. The loaf-volume improvement resulting from the addition of dough conditioners indicated that they functioned, in part, to strengthen the structural framework. This was demonstrated by the ability of the high-protein blends (without conditioner) to produce gassing power at least equivalent to the wheat-flour control. Correlation analysis showed little relation between breadmaking characteristics and mixograph parameters, but showed highly significant correlations with viscoamylograph measurements.

Many reports have been published documenting the needs for larger quantities of edible protein in the developing countries and for less expensive proteinaceous foods for the entire population. Wheat is a common cereal crop in much of the world, and products prepared from wheat such as yeast-leavened bread and unleavened chapatties are staple food products (1). Because they are widely consumed, wheat-based foods may be good products to be considered for supplementation with complementary proteins that have minimal adverse effects on product quality.

Protein efficiency ratios (PER) of 1.81, 1.47, and 0.52 have been reported (2) for soybean, field pea, and fababean, respectively, but when combined with wheat flour in equal proportions the PER ranged from 2.02 to 1.80. Improvements in the balance of essential amino acids were largely responsible for the high nutritive value of the cereal-legume blends. In addition, the protein quality of bread has been improved by supplementation with essential amino acids and concentrated plant proteins (3,4).

If a high-protein bread is intended to have a significant influence on the supply of protein and the protein quality of a diet, this bread must be both visually and organoleptically acceptable. Without these qualities, the product would neither be purchased nor consumed. Acceptable bread can be made with 5–8% soy flour (5), sunflower (6), fababean concentrate (7), and field-pea concentrate (4). However, loaf volumes and crumb-grain ratings of bread showed deterioration when higher levels of concentrated plant proteins were incorporated. These

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characteristics in soy and fababean bread have been improved by the use of dough conditioners such as lactylate esters (7,8) and glycolipids (9,10). However, Rooney *et al.* (11) reported that a sunflower-flour:wheat-flour blend produced an unacceptable bread with a low specific volume even in the presence of sodium stearoyl-2-lactylate (SSL). Fleming and Sosulski (12) used vital gluten in combination with various dough conditioners for preparing acceptable soy bread with a high protein content.

In order to evaluate the nutritional value of a diet, Campbell (13) proposed a protein rating for foods based on the quantity and quality of protein in a reasonable daily intake of that food. White bread has been given low ratings of 9.6 (13) and 13.0 (14) due to the low protein content and nutritive value as compared to ratings of over 40 for eggs, meat, and milk. By increasing either the quantity or quality of protein in bread, this rating could be improved.

The objective of this study was to evaluate the potential for preparing high-protein breads from Canadian grown plant proteins including sunflower concentrate, fababean concentrate, and field-pea concentrate. In addition, soy flour was evaluated for purposes of comparison. Vital gluten and eight dough conditioners were included in the formulations to improve breadmaking characteristics. It was desirable to prepare an organoleptically acceptable bread which could be rated as an excellent dietary source of protein. Therefore, based on PER of 1.8–2.0, bread containing 13.5 to 14.8%% protein (N × 6.25, 36% moisture basis) was required. Mixograph and viscoamylograph properties and gassing power of the composite-flour blends were determined and these results were used to interpret the effects of nonwheat plant proteins on breadmaking characteristics.

MATERIALS AND METHODS

Wheat-Flour and Protein Supplements

The wheat flour used in the present study was an untreated baker's straight-grade flour, commercially milled from hard red spring wheat. The vital gluten was obtained from Industrial Grain Products Ltd., Montreal, and the defatted soy flour (*Glycine max*) was obtained from a local supplier. The fababean (*Vicia faba*) and field-pea (*Pisum sativum*) concentrates were prepared by pin milling and air classification at the Prairie Regional Laboratory, National Research Council. These concentrates were chosen for this study in preference to the flours because of their high protein content (4,7). Dehulled sunflower kernels were purchased from Gardenland Packers Ltd., Altona, Manitoba. Preliminary studies showed that baked bread made with defatted sunflower flour acquired a green-brown coloration, presumably caused by the phenolic acid, chlorogenic acid (15). This problem was overcome by using the sunflower concentrate prepared according to the method described by Sosulski *et al.* (16). The chlorogenic acid was removed by diffusing cracked kernels in aqueous medium (pH 4.5) for 4 hr at 60° C. The dried seed was extracted with Skellysolve F (petroleum ether), desolventized, and ground to pass through a 100-mesh Tyler sieve. The chemical compositions of these samples were determined according to AOAC methods (17). The nitrogen-to-protein factor of 6.25 was used for all products.

Dough Conditioners

Eight dough conditioners were evaluated in this study. Emulsifiers-500 (mono- and diglycerides) and -845 (polyoxyethylene-8-stearate) were obtained from Germantown Mfg. Co. Glyceryl monostearate (GMS) and sucrose monolaurate (SML) were obtained from K & K Laboratories, Inc., while polyoxyethylene sorbitan monolaurate (Tween 20) and polyoxyethylene sorbitan monostearate (Tween 60) were purchased from Sigma Chemical Co. In addition, the lactylate esters, sodium stearoyl-2-lactylate (SSL) and calcium stearoyl-2-lactylate (CSL) which were obtained from Patco Products, Inc. were tested. The dough conditioners were added to the dry ingredients in their original physical state with the exception of SML which was diluted 1:5 (w/v) with distilled water. Each conditioner was added at 0.5, 1.0, and 1.5 g/100 g wheat flour or composite flour.

Breadmaking Procedure

The breadmaking formula included 100 g flour (14% moisture basis), 4 g nonfat dry milk, 3 g shortening, 3 g wet yeast, 5 g sucrose, 1.75 g salt, 0.1 g ammonium phosphate monobasic, 10 ppm potassium bromate, 0.3 g malt syrup, and water as needed. Wheat flour was replaced by the concentrated plant protein (CPP) sources so that the total blend was 100 g. The dough was mixed by the straight-dough procedure (18) and baked 25 min at 220° C in an experimental rotary oven. Baking tests were replicated at least twice.

Weights and volumes of loaves were determined 1 hr after the bread was taken from the oven. Loaf volumes of baked breads were determined by rapeseed displacement. Specific volumes were determined from the weight and volume data and are reported as cc/g. When cool, the loaves were cut and the crust and crumb color, crumb grain, and loaf shape were estimated using a numerical rating of 0–10 (optimum = 10, very poor = 0).

Crumb compressibility was measured with a Food Technology Corporation texturometer. Four pieces of bread measuring $3 \times 5 \times 1.5$ cm were cut from each loaf and tested with the shear-compression cell operated by the 100-lb ring at 95 psi. A range of 3000 was used on the chart recorder. The peak areas were measured with a planimeter and the averages for the compressibility values were reported in planimeter units.

The data on water absorption, loaf volume, specific volume, loaf shape, crumb grain, and crumb compressibility were statistically analyzed by three-way analysis of variance. The influences of four CPP, eight dough conditioners, three levels of conditioners and their interactions were evaluated. Significant differences were analyzed by Duncan's multiple range test (19).

The gas-producing abilities of the composite-flour blends were determined according to AACC method 22-11 (18). Ten grams flour (14% moisture basis) and 7 ml water containing 0.3 g yeast in suspension were placed in a pressure vessel, which had been previously warmed to 30° C, and mixed. The gas produced was expressed as mm Hg pressure after 4 and 6 hr of fermentation. The results were analyzed by analysis of variance and Duncan's multiple range test.

Rheology Measurements

Gelatinization studies were conducted according to AACC method 22-10 (18) in which 14.1% flour-water slurries (buffered) were heated in a Brabender viscoamylograph. The slurries were heated from 30° to 97.5° C at 1.5° C per min, held at 97.5° C for 15 min, then cooled at 1.5° C per min to 30° .

Mixograph studies were conducted according to AACC method 54-40 (18). The water level used was based on optimum baking absorption. Peak heights (cm) and peak times (min) were recorded and, in addition, the areas under the curve (cm^2) were determined. A measure of dough-strength stability was reported by taking the curve heights after a 5-min mixing period.

The influences of CPP and dough conditioners on the rheology measures were analyzed in single determinations on the wheat-flour control and 4 CPP blends with 0 and 1.0 g of each of the eight dough conditioners. Two-way analysis of variance and Duncan's multiple range test were used to determine significant differences. Simple correlation coefficients were calculated between rheological measures and breadmaking data.

RESULTS

The proximate compositions of wheat flour and CPP are shown in Table I. While the protein content of wheat flour was only 15.4%, vital gluten had 89.4% protein, and the CPP ranged from 50 to 76%. The fat levels were fairly constant, but wheat flour and vital gluten contained lower levels of crude fiber and ash than the CPP.

Supplementation of Bread with CPP

Soy flour and, to a lesser extent, sunflower flour increased the water required for optimum breadmaking absorption (Table II). However, when 25% wheat flour was replaced by fababean or field pea, the optimum water absorption was reduced by more than 15 percentage units. Similar effects have been previously reported (4,5,7,20).

Each CPP caused deterioration in loaf volume, specific volume, crumb grain, and loaf shape in proportion to the quantity of CPP used to replace wheat flour (Table II). Soy breads had larger loaf volumes and specific volumes than the other fortified breads, whereas sunflower breads were rated lowest in all characteristics. Fababean and field-pea breads were intermediate in volume

TABLE I
Average Proximate Composition of Wheat Flour and CPP

	Crude Protein[a] Dry Basis %	Crude Fat Dry Basis %	Crude Fiber Dry Basis %	Ash Dry Basis %
Wheat flour	15.4	1.9	0.3	0.6
Vital gluten	89.4	1.8	0.6	0.9
Soy flour	50.5	2.1	2.7	6.4
Sunflower	76.0	1.7	5.2	5.4
Fababean	61.1	2.5	2.6	5.6
Field pea	56.5	3.2	2.8	6.0

[a]N × 6.25.

measures but showed relatively high crumb-grain and loaf-shape ratings. Other workers had reported similar changes in loaf characteristics of bread containing soy flour (20,21), fababean (7), and field pea (4).

The protein content of the breads was increased by supplementation with CPP but, in order to obtain bread with at least 13.5 to 14.8% protein, blends of 80:20 for soy and field pea, 88:12 for sunflower, and 85:15 for fababean were required. The characteristics of these blends were shown to be clearly unacceptable.

Sunflower caused no detectable change in crust color but imparted a grey tone to the crumb when used at more than 7% replacement. The other CPP caused excessive crust and crumb browning and the intensity increased in the order: soy, field pea, fababean. The brown coloration is reportedly due to the Maillard reaction (22) which occurs between free carbohydrates and amino acid residues in the presence of heat and low moisture levels. The intensity of browning was reduced by lowering the temperature of baking, or by eliminating the malt extract, sugar, or nonfat dry milk from the formula. However, these alterations caused further deterioration in loaf volume.

Supplementation of Bread with CPP and Vital Gluten

Fleming and Sosulski (12) showed that the addition of vital gluten to soy breads increased loaf volumes but that levels of only 5% resulted in coarse and

TABLE II
Influence of CPP on Breadmaking Properties

Bread Type	Supplementation Level %	Water Absorption %	Loaf vol cc	Loaf sp vol cc/g	Crumb Grain 0–10	Loaf Shape 0–10	Protein Content[a] %
Control	0	61.0	865	6.04	10.0	9.5	10.2
Soy	5	62.0	830	5.83	8.0	9.0	10.6
	10	64.0	740	5.24	7.0	7.0	11.4
	15	67.0	650	4.32	5.0	6.0	13.3
	20	68.0	600	4.03	5.0	4.0	14.2
	25	72.0	550	3.70	2.0	2.0	15.5
Sunflower	5	62.0	730	4.48	7.5	8.0	10.8
	10	63.5	665	4.20	7.0	6.0	12.1
	12	64.5	610	3.98	5.0	4.0	14.2
	15	65.5	520	3.54	4.0	2.5	15.9
	17	65.5	440	3.04	3.0	2.0	17.3
Fababean	5	60.5	705	4.96	8.0	8.0	10.9
	10	55.0	685	4.81	7.0	7.0	11.6
	15	53.5	635	4.64	4.0	5.0	13.7
	20	48.5	535	3.91	4.0	4.0	15.5
	25	45.5	475	3.45	3.0	3.5	17.4
Field pea	5	58.5	785	5.54	8.0	9.0	10.7
	10	55.0	705	5.12	7.0	7.0	11.6
	15	53.5	620	4.17	6.0	7.0	12.8
	20	49.0	550	4.09	4.0	7.0	14.5
	25	44.0	525	3.56	2.0	6.0	16.8

[a]N × 6.25.

TABLE III
Influence of Vital Gluten on CPP Bread Characteristics

		Water Absorption %			Loaf vol cc			sp vol cc/g			Crumb Grain 0–10			Loaf Shape 0–10			Protein[a] %		
Vital gluten, %		0	2	5	0	2	5	0	2	5	0	2	5	0	2	5	0	2	5
CPP, %																			
Control	0	61.0			865			6.01			10.0			9.5			10.2		
Soy	10	64.0	66.0	68.0	740	750	780	5.24	5.43	5.67	7.0	8.0	8.0	7.0	8.0	8.0	11.4	12.8	14.3
	15	67.0	68.0	69.5	650	715	730	4.32	4.68	4.74	5.0	7.0	5.0	6.0	6.0	7.0	13.3	14.0	15.4
	20	68.0	69.0	70.5	600	615	645	4.03	4.28	4.21	5.0	5.0	5.0	4.0	4.0	5.0	14.2	15.2	16.4
Sunflower	10	63.5	65.0	68.0	665	700	725	4.20	4.42	4.54	7.0	7.0	7.0	6.0	6.0	6.0	12.1	13.2	15.8
	12	64.5	66.5	70.0	610	650	720	3.98	4.38	4.40	5.0	6.0	6.0	4.0	6.0	7.0	14.2	14.8	17.3
	15	65.5	65.5	70.5	520	610	640	3.54	3.85	3.88	4.0	5.0	5.0	2.5	4.0	4.0	15.9	16.8	18.2
Fababean	10	55.0	58.5	59.5	685	715	730	4.81	4.83	5.16	7.0	7.0	7.0	7.0	7.0	8.0	11.6	13.8	15.1
	15	53.5	55.0	54.0	635	645	675	4.64	4.59	4.83	4.0	7.0	7.0	5.0	5.0	5.0	13.7	14.9	15.8
	20	48.5	49.5	50.5	535	540	575	3.91	3.91	4.14	4.0	5.0	5.0	4.0	4.0	4.5	15.5	16.3	17.3
Field pea	10	55.0	57.0	58.5	705	740	790	5.12	5.23	5.79	7.0	8.0	7.0	7.0	8.0	7.0	11.6	13.5	14.3
	15	53.5	55.0	56.5	620	685	730	4.17	4.85	5.23	6.0	7.0	7.0	7.0	5.0	5.0	12.8	14.2	15.8
	20	49.0	48.5	50.0	550	570	575	4.09	4.23	4.44	4.0	5.0	7.0	7.0	5.0	5.0	14.5	15.9	17.2

[a]N × 6.25, 36% moisture basis.

porous textures. Therefore, 2 and 5% vital gluten were used in this study. The addition of vital gluten to wheat-flour:CPP blends increased water absorption and partially counteracted the influences of fababean and field pea (Table III). Loaf volumes and specific volumes were increased with each addition of vital gluten but even 5% did not restore the characteristics of breads containing 10% CPP to the level of the wheat-flour control. Generally, vital gluten improved crumb-grain and loaf-shape ratings for all CPP breads, but the 2% level was often as effective as the 5% level. Due to the high protein content of vital gluten, its addition increased the protein content of the breads. Breads with at least 14% protein (36% moisture basis) were prepared in blends of wheat flour:CPP:vital gluten of 83:15:2 for soy, fababean, and field pea and 86:12:2 for sunflower. Based on their high protein contents and acceptable crumb grains, these composite-flour blends were used for further evaluation with dough conditioners.

A test for gassing power was conducted on these blends to determine their potential for loaf-volume improvement. Statistical analysis of the results showed significant differences between the average of pressures measured after 4 and 6 hr of fermentation, and the values were shown to increase with time (Table IV). All CPP blends, with the exception of sunflower, gave higher gassing power values than the wheat-flour control, which indicates an adequate supply of fermentable carbohydrate. The values showed the following order in decreasing value: field pea > fababean > soy > control > sunflower. Since these values showed no significant correlation with loaf volume, it can be concluded that the CPP blends can produce sufficient gas for loaf expansion but that this gas is retained to varying degrees by the structural frameworks.

Use of Dough Conditioners in Composite-Flour Blends

All dough conditioners except CSL increased the loaf volumes of wheat-flour bread, but Tween 20, Tween 60, Emulsifier-845, and SML had the most pronounced effects (Table V). The latter conditioners also increased loaf volumes of the CPP breads at low levels of 0.5 g/100 g and the loaf volume of soy bread was made nearly equivalent to the wheat-flour control by adding at least 1.0 g Tween 20 or Tween 60. However, only Emulsifier-845 and SML produced large volumes ranging from 820 to 875 cc for sunflower, fababean, and field-pea bread which are in the range of the control value of 865 cc.

TABLE IV
Influence of CPP on Gas Production

Blend	4 hr mm Hg	6 hr mm Hg	$\overline{X}(s_{\bar{x}} = 32{,}410)$ mm Hg
Control	282	314	298[d]
Soy	309	339	324[c]
Sunflower	233	261	247[e]
Fababean	381	460	421[b]
Field pea	416	516	466[a]
$\overline{X}(s_{\bar{x}} = 14{,}472)$	324[a]	378[b]	

[a–e]Lower case letters denote significant differences at 0.05.

The dough conditioners were not entirely consistent in beneficial effects on the crumb-grain ratings of wheat-flour bread and this may be due to the large increases in loaf volumes (Table VI). Soy bread had a crumb-grain rating of 7.0. When supplemented with 1.0 g CSL, the value was increased to 8.5, but higher levels of CSL had a deleterious effect. Each level of Emulsifier-500 gave a crumb-grain rating of 8.0 and 1.5 g Emulsifier-845 gave a value of 9.0, which was nearly equivalent to the wheat-flour control. Sunflower breads had low ratings due to a coarse and porous appearance, but CSL (1.5 g) or GMS (1.0 g) gave the most improvement to ratings of 7.5. Even without conditioners, both fababean and field-pea breads were fine and evenly grained, which contributed to their high crumb-grain ratings. These ratings were further improved by all conditioners except GMS. The 1.0 g levels of Tween 20, Emulsifier-845, and SML, and the 1.5 g level of Emulsifier-500, when added to fababean bread, showed excellent ratings of 8.5 or more. Field-pea bread received similar ratings with at least 0.5 g SML or 1.0 g SSL and Emulsifier-845.

The control bread had a soft crumb and measured 20 units (Table VII). This value was reduced due to the softening influence of all conditioners except SSL, which caused a marginal increase to 22 units. The CPP breads showed restricted crumb compressibility. Soy bread was softer than sunflower, whereas fababean and field pea were particularly firm. The effects of low (0.5 g) levels of

TABLE V
Average Effects of CPP, Dough Conditioners, and Levels of Conditioner on Loaf Volume

CPP[a]	Level	Dough Conditioners								
		None cc	SSL cc	CSL cc	Tween 20 cc	Tween 60 cc	845 cc	500 cc	GMS cc	SML cc
Control	0.0	865								
	1.0		890	850	950	945	935	890	875	905
Soy	0.0	715								
	0.5		730	720	805	810	760	735	730	800
	1.0		755	745	825	820	810	730	740	840
	1.5		765	740	840	825	845	730	710	875
Sunflower	0.0	650								
	0.5		655	675	735	735	685	685	660	730
	1.0		670	680	765	765	780	680	660	825
	1.5		675	675	730	770	820	700	665	845
Fababean	0.0	645								
	0.5		690	680	730	745	700	675	665	730
	1.0		725	675	750	760	800	655	680	755
	1.5		735	670	750	780	845	650	690	795
Field pea	0.0	685								
	0.5		675	650	725	740	720	640	655	700
	1.0		680	655	795	765	750	690	675	785
	1.5		660	650	750	795	850	685	690	875

[a]The blends of wheat flour:CPP:vital gluten were as follows—83:15:2 for soy, fababean, and field pea; 86:12:2 for sunflower.

conditioners were variable and 1.5 g Emulsifier-845 or SML was required in most cases to give ratings equal to the wheat-flour control. Tweens 20 and 60 gave intermediate values but were most effective in soy bread.

The influences of CPP, dough conditioners, levels of conditioner, and their interactions on breadmaking characteristics were statistically analyzed. The variance ratios indicated that highly significant differences due to the CPP existed for all baking characteristics (Table VIII). Highly significant differences due to the dough conditioners and their levels are shown for all measurements, but crumb-texture differences were significant at only the 5% level of probability. The CPP × conditioner interaction was significant for loaf volume and specific volume, and highly significant for water absorption and crumb compressibility. Interactions were significant but generally lower in magnitude than the main effects for all characteristics except water absorption.

Further analyses of the differences among the CPP were conducted using Duncan's multiple range test. When averaged over all dough conditioner treatments and levels, the soy blend was shown to require the most water to give optimum breadmaking absorption, and averaged more than 2.5% higher than the sunflower blend (Table IX). The fababean and field-pea blends required only 54.8 and 55.8% water, respectively, for optimum absorption and were about 14% lower than the soy blend. The soy blend also showed significantly higher loaf volumes and specific volumes. The high water-absorption values shown for

TABLE VI
Average Effects of CPP, Dough Conditioners, and Levels of Conditioner on Crumb-Grain Rating

		Dough Conditioner[a]								
CPP	**Level**	**None**	**SSL**	**CSL**	**Tween 20**	**Tween 60**	**845**	**500**	**GMS**	**SML**
Control	0.0	10.0								
	1.0		7.5	5.0	9.0	9.0	9.0	9.0	8.0	8.0
Soy	0.0	7.0								
	0.5		6.0	6.0	7.5	6.5	7.0	8.0	7.5	6.5
	1.0		6.5	8.5	5.5	6.0	7.0	8.0	7.0	6.5
	1.5		5.0	5.0	6.0	6.0	9.0	8.0	6.0	7.0
Sunflower	0.0	6.0								
	0.5		5.0	4.5	4.0	5.5	5.0	4.5	5.0	4.5
	1.0		5.5	6.0	6.5	6.5	7.0	6.5	7.5	5.5
	1.5		5.5	7.5	5.0	6.5	6.5	5.5	5.0	4.5
Fababean	0.0	8.0								
	0.5		7.0	7.0	8.0	7.5	7.5	6.0	7.0	7.0
	1.0		7.0	6.5	8.5	7.5	9.0	7.5	7.0	8.5
	1.5		8.0	8.0	7.5	8.0	8.0	9.0	7.0	8.0
Field pea	0.0	7.0								
	0.5		7.5	7.5	7.0	7.5	7.5	7.0	7.0	8.5
	1.0		8.5	7.0	8.0	6.0	8.5	7.0	7.0	9.0
	1.5		7.0	6.0	6.0	8.0	9.0	7.5	7.0	9.0

[a]Rated from 1 to 10.

sunflower were responsible for the low specific volumes of this blend. The loaf-shape ratings for the CPP breads decreased in the following order: soy, sunflower, fababean, and field pea. Fababean and field pea showed the highest crumb-grain ratings followed by soy and sunflower. Compared to the value of 20 units for wheat flour (Table VII), soy breads, on the average, had the softest crumb. Fababean caused a very firm crumb while sunflower and field pea gave intermediate ratings.

Despite highly significant differences, the mean water absorptions were very similar for all conditioners and levels (Table IX). SML had an exceptionally favorable effect on loaf volume as well as specific volume, loaf shape, and crumb compressibility. Emulsifier-845, Tween 20, and Tween 60 were also higher than other dough conditioners in these bread characteristics. Emulsifiers-845 and -500 and SML gave high ratings for crumb grain. It appeared that SML and Emulsifier-845 were the best dough conditioners for general use in CPP-blended breads.

Rheology Measurements

The treatment means for the flour blends showed highly significant differences for mixograph measurements. The soy blend required the longest time to reach mixograph peak height while fababean and field pea reached maximum peak in the shortest time (Fig. 1). The area under the mixograph curve, a measure of

TABLE VII
Average Effects of CPP, Dough Conditioners and Levels of Conditioner on Crumb Compressibility

		Dough Conditioners[a]								
CPP	Level	None	SSL	CSL	Tween 20	Tween 60	845	500	GMS	SML
Control	0.0	20								
	1.0		22	17	15	12	14	18	17	16
Soy	0.0	32								
	0.5		35	50	24	32	34	31	34	30
	1.0		22	31	14	14	18	22	37	19
	1.5		18	20	13	14	14	16	24	13
Sunflower	0.0	39								
	0.5		40	48	35	30	28	39	46	43
	1.0		41	37	30	25	24	34	30	26
	1.5		33	26	30	25	22	29	31	22
Fababean	0.0	55								
	0.5		55	73	31	48	49	55	56	59
	1.0		38	53	35	32	27	54	59	36
	1.5		34	39	25	19	23	31	44	25
Field pea	0.0	46								
	0.5		31	41	34	26	26	39	52	39
	1.0		40	41	25	24	27	39	48	25
	1.5		35	36	25	25	22	38	36	20

[a]Expressed in planimeter units.

TABLE VIII
Variance Ratios (F) of the CPP, Dough Conditioners, Levels of Conditioner, and their Interactions for Water Absorption, Loaf Volume, Specific Volume, Loaf Shape, Crumb Grain, and Crumb Compressibility

Source of Variation	Degrees of Freedom	Water Absorption	Loaf vol	sp vol	Loaf Shape	Crumb Grain	Crumb Compressibility
CPP	3	7609.51**	70.11**	18.46**	30.03**	32.26**	60.30**
Conditioner	7	5.64**	98.92**	86.80**	19.41**	2.36*	24.54**
Level of conditioner	2	41.11**	48.24**	42.17**	19.30**	4.67*	83.46**
CPP × conditioner	21	3.28**	2.16*	2.00*	1.28	1.63	1.72*
CPP × level	6	10.90**	0.96	2.31	5.74**	2.83*	5.63**
Conditioner × level	14	2.64**	7.92**	9.92**	2.41**	1.01	1.98**
Error	42						

dough strength and stability, showed highly significant differences among blends and appeared to be inversely related to dough development time.

All CPP blends showed lower viscoamylograph viscosities than the wheat-flour control (Fig. 1). The differences among CPP at peak, 60 min (including a holding treatment at 97.5°C for 15 min), and after subsequent cooling to 30°C gave similar rankings. Sunflower blends were higher and field-pea blends were lower than other CPP blends at each stage, but some differences were not significant.

The dough conditioners caused significant differences in mixograph and viscoamylograph properties. SSL, Tween 20, Tween 60, GMS, and SML showed short mixing times and strong mixograph curves similar to the control (Fig. 2). Emulsifiers-845, -500, and CSL increased mixograph peak time and, in the case of -845 and -500, decreased mixograph area. The viscoamylograph data indicated that Tweens 20 and 60, Emulsifier-845, and SML gave the highest peak viscosities, whereas CSL, Emulsifier-500, and GMS showed no difference from the treatments without conditioner. Only Emulsifier-845 retained the high viscosity at 60 min. SSL, CSL, and Emulsifier-500 significantly reduced cold-paste viscosity, whereas all other treatments showed no significant change.

TABLE IX
Average Effects of CPP, Dough Conditioners, and Levels of Conditioners on Breadmaking Characteristics

Source of Variation	Water Absorption %	Loaf vol cc	sp vol cc/g	Loaf Shape 0–10	Crumb Grain 0–10	Crumb Compressibility planimeter units
CPP						
Control	(61.0)[a]	(865)	(6.01)	(10.0)	(10.0)	(20)
Soy	69.1^{b}	778.5^{b}	5.18^{b}	7.0^{b}	6.8^{c}	24.1^{d}
Sunflower	66.3^{c}	719.4^{c}	4.89^{d}	6.4^{c}	5.6^{d}	32.3^{c}
Fababean	54.5^{e}	722.1^{c}	5.06^{c}	5.9^{d}	7.6^{b}	41.7^{b}
Field pea	55.8^{d}	719.0^{c}	5.01^{c}	5.3^{e}	7.5^{b}	33.1^{c}
Dough conditioners						
None	(61.3)	(673.8)	(4.65)	(5.5)	(7.0)	(43.0)
SSL	61.9^{b}	701.3^{d}	4.80^{d}	5.3^{d}	6.5^{c}	35.2^{c}
CSL	61.7^{bc}	684.6^{e}	4.65^{d}	5.6^{d}	6.6^{c}	41.3^{b}
Tween 20	61.2^{d}	766.7^{c}	5.27^{c}	6.3^{c}	6.6^{c}	26.8^{d}
Tween 60	61.5^{bcd}	775.8^{c}	5.36^{c}	7.3^{b}	6.8^{c}	26.2^{d}
Emulsifier-845	61.3^{d}	780.4^{c}	5.32^{c}	7.0^{b}	7.6^{b}	26.2^{d}
Emulsifier-500	61.5^{bcd}	687.9^{de}	4.67^{de}	5.4^{d}	7.0^{bc}	35.6^{c}
GMS	61.4^{cd}	685.0^{e}	4.68^{de}	5.6^{d}	6.7^{c}	41.4^{b}
SML	60.9^{d}	796.3^{b}	5.54^{b}	6.9^{b}	7.0^{bc}	29.8^{d}
Levels						
0	(61.3)	(673.8)	(4.63)	(5.5)	(7.0)	(43.0)
0.5	61.0^{d}	711.6^{d}	4.86^{b}	5.7^{d}	6.6^{c}	40.4^{b}
1.0	61.3^{c}	740.2^{c}	5.08^{c}	6.1^{c}	7.1^{b}	32.1^{c}
1.5	61.9^{b}	752.5^{b}	5.17^{b}	6.7^{b}	6.9^{bc}	25.8^{d}

[a]Values in parentheses were not included in statistical analyses.
[b–e]Lower case letters denote significant differences at 0.05.

Correlations among Breadmaking and Rheology Characteristics

The high negative correlations of loaf and specific volumes with crumb compressibility (Table X) indicated that large loaves had softer crumbs. In addition, loaf shapes improved along with loaf and specific volumes. Although significant in some cases, only low correlations were obtained among crumb grain and loaf volume, specific volume, and water absorption.

Mixograph characteristics gave significant but low correlations with water absorption and crumb compressibility (Table X). Similarly, dough viscosities gave low correlations with loaf and specific volumes, crumb compressibility, and loaf shape.

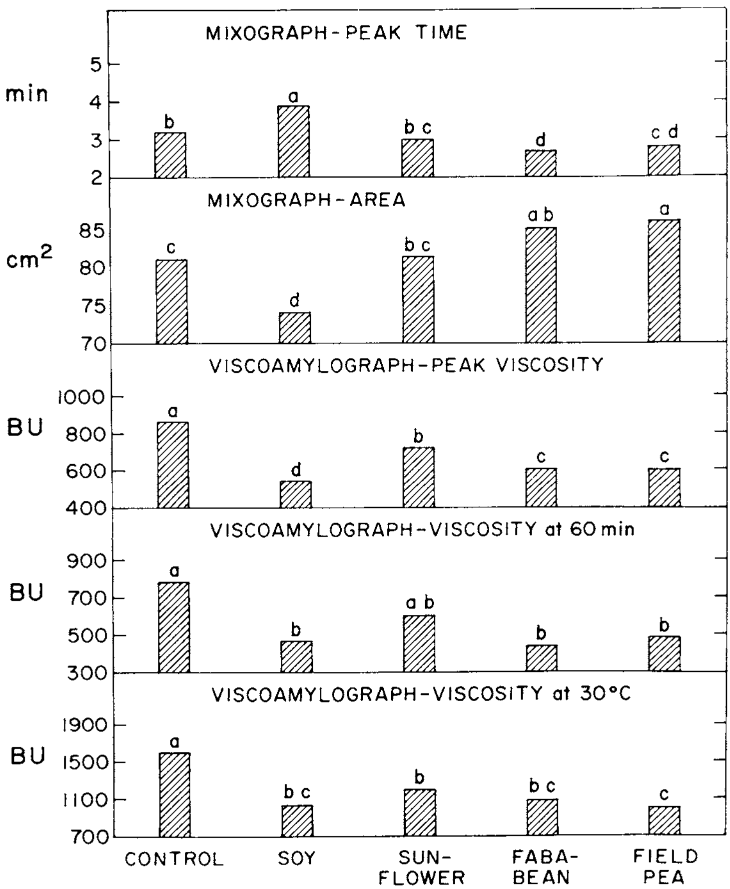

Fig. 1. Effects of CPP blends on mixograph and viscoamylograph characteristics.

DISCUSSION

Each CPP caused deterioration in breadmaking characteristics as measured by loaf volume, crumb texture, crumb compressibility, and loaf shape. Sunflower, fababean, and field-pea bread had lower loaf volumes than did soy bread, but fababean and field-pea bread showed more desirable crumb textures. Dough conditioners and vital gluten were effective in restoring some of these characteristics to the level of the wheat-flour control. Since a high protein content in the bread was required, blends containing 12% sunflower or 15% soy, fababean, and field pea were used. It was necessary to add 2% vital gluten, and 1.0–1.5 g dough conditioner per 100 g composite flour, to restore bread quality. SML and Emulsifier-845 were the most effective conditioners.

Generally, the mono- and diglycerides (Emulsifier-500 and GMS) were not

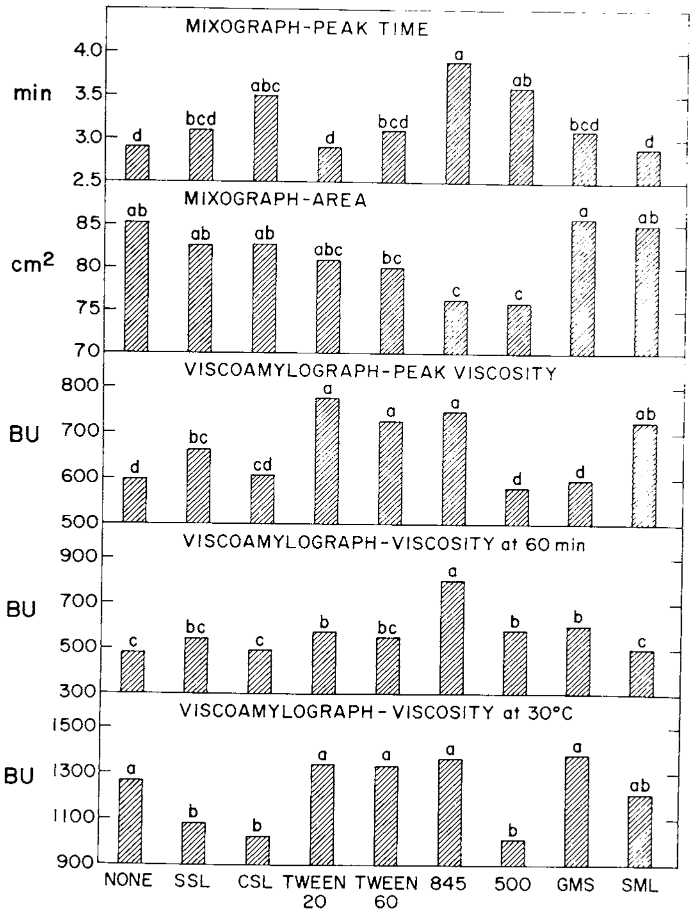

Fig. 2. Effects of dough conditioners on mixograph and viscoamylograph characteristics.

TABLE X
Correlation Coefficients of Breadmaking, Mixograph, and Viscoamylograph Characteristics

	Loaf vol	sp vol	Crumb Grain	Water Absorption	Crumb Compress-ibility	Loaf Shape	Mixograph		Viscoamylograph	
							Peak time	Area	Peak time	Peak viscosity
sp vol	0.967**									
Crumb grain	0.343*	0.469**								
Water absorption	0.149	−0.042	−0.395**							
Crumb compress-ibility	−0.848**	−0.751**	−0.155	−0.444**						
Loaf shape	0.832**	0.766**	0.208	0.341	−0.743**					
Mixograph										
Peak time	0.194	0.036	−0.108	0.634**	−0.343**	0.218				
Area	−0.259	−0.148	0.122	−0.598**	0.431**	−0.216	−0.546**			
Viscoamylograph										
Time	0.252	0.251	0.176	0.103	−0.304*	0.109	0.177	−0.420**		
Peak viscosity	0.694**	0.709**	0.183	0.059	−0.575**	0.640**	−0.171	0.035	0.264	
Viscosity at 30° C	0.764**	0.800**	0.414**	0.093	−0.592**	0.685**	0.033	−0.087	0.281	0.816**

effective at improving breadmaking characteristics, but the glycolipid SML proved more effective. Monoglycerides have been reported to have both amylose- and amylopectin-complexing abilities which soften the crumb and retard staling (23,24). In this study, however, neither Emulsifier-500 nor GMS showed significant softening influences. The polyoxyethylene esters, Tween 20, Tween 60, and Emulsifier-845, showed similar beneficial effects on loaf volume, specific volume, loaf shape, and crumb compressibility. However, Emulsifier-845 was most effective at improving the crumb-grain ratings. All conditioners used in this study had been shown by other workers to be beneficial in starch or wheat-flour breads. However, the present results did not always show beneficial effects, possibly due to the very high levels of CPP used herein.

The influence of the conditioners appeared to be related to their potential emulsification ability as measured by the hydrophilic-lipophilic balance (HLB) number. Emulsifier-500 and GMS have been reported to have HLB values of approximately 3.5 (25,26) and caused only minor improvements in breadmaking characteristics. Tween 20, Tween 60, Emulsifier-845, and SML have HLB numbers of 12–17 (26) and were effective at improving volume, grain, and compressibility characteristics. In addition, Tenney and Schmidt (27) reported that CSL has very little hydrophilic character, in comparison to SSL, due to the Ca^{+2} ions. The present results showed that SSL was more effective than CSL. Therefore, it appears that dough conditioners with an emulsifier-like effect are beneficial to breadmaking. A high HLB number, *i.e.*, lipophilic nature, is required for best results.

Hoseney *et al.* (28) proposed that glycolipid was simultaneously bound to gliadin and glutenin and, in addition, also bound starch into the complex. It is possible that the beneficial conditioners add to the complex. In addition, the lipophilic conditioners may act to lubricate and emulsify this system and reduce repulsive forces which may occur when CPP are added. The significant correlations noted between various breadmaking characteristics and viscoamylograph measures imply that the pasting qualities caused by the CPP blends and conditioners also account for some of the quality changes in the bread system. Since all CPP blends but sunflower produced more gas than the wheat-flour control, the conditioners functioned to strengthen the gas-retaining structural framework.

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Literature Cited

1. POMERANZ, Y., and SHELLENBERGER, J. A. Bread science and technology, p. 1-3. AVI Pub. Co., Ltd.: Westport, Connecticut.
2. SARWAR, G., SOSULSKI, F. W., and BELL, J. M. Nutritive value of field pea and fababean proteins in rat diets. Can. Inst. Food Sci. Technol. J. 8: 109 (1975).
3. JANSEN, G. R. Total protein value of protein- and amino acid-supplemented bread. Amer. J. Clin. Nutr. 22: 38 (1969).
4. ANONYMOUS. Pea flour and pea protein concentrate. PFPS Bulletin No. 1. Prairie Regional Laboratory, National Research Council, and College of Home Economics, Univ. of Saskatchewan, Saskatoon, Canada (1974).

5. OFELT, C. W., SMITH, A. K., and MILLS, J. M. Baking behavior and oxidation requirements of soy flour. II. Commercial defatted soy flours. Cereal Chem. 31: 23 (1954).
6. ROONEY, L. W., GUSTAFSON, C. B., CLARK, S. P., and CATER, C. M. Comparison of the baking properties of several oilseed flours. J. Food Sci. 37: 14 (1972).
7. McCONNELL, L. M., SIMMONDS, D. H., and BUSHUK, W. High-protein bread from wheat-fababean composite flours. Cereal Sci. Today 19: 517 (1974).
8. TSEN, C. C., HOOVER, W. J., and PHILLIPS, D. High-protein breads. Use of sodium stearoyl-2 lactylate and calcium stearoyl-2 lactylate in their production. Baker's Dig. 45(2): 20 (1971).
9. POMERANZ, Y., SHOGREN, M. D., and FINNEY, K. F. Improving breadmaking properties with glycolipids. I. Improving soy products with sucroesters. Cereal Chem. 46: 503 (1969).
10. POMERANZ, Y., SHOGREN, M. D., and FINNEY, K. F. Improving breadmaking properties with glycolipids. II. Various protein-enriched products. Cereal Chem. 46: 512 (1969).
11. ROONEY, L. W., GUSTAFSON, C. B., CATER, C. M., and MATTIL, K. M. Influence of sodium stearoyl-2-lactylate on bread baking properties of several oilseed flours. Presented at the 32nd Annual Meeting of the Institute of Food Technologists, May 22-24, Minneapolis, Minn. (1972).
12. FLEMING, S. E., and SOSULSKI, F. W. Dough conditioners in wheat-soy-gluten breads. Can. Inst. Food Sci. Technol. J. 7: 51 (1974).
13. CAMPBELL, J. A. Evaluation of protein in foods for regulatory purposes. J. Agr. Food Chem. 8: 323 (1960).
14. STILLINGS, B. R., SIDWELL, V. D., and HAMMERLE, O. A. Nutritive quality of wheat flour and bread supplemented with either fish protein concentrate or lysine. Cereal Chem. 48: 292 (1971).
15. CLANDININ, D. R. Sunflower seed oil meal. In: Processed plant protein foodstuffs, ed. by A. M. Altschul, p. 557. Academic Press: New York (1958).
16. SOSULSKI, F. W., SABIR, M. A., and FLEMING, S. E. Continuous diffusion of chlorogenic acid from sunflower kernels. J. Food Sci. 38: 468 (1973).
17. ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. Methods of analysis (11th ed.). The Association: Washington, D.C. (1970).
18. AMERICAN ASSOCIATION OF CEREAL CHEMISTS. Approved methods of the AACC (7th ed.). Method 22-11, approved April 1961; Method 22-10, approved May 1960; and Method 54-40, approved April, 1961. The Association: St. Paul, Minn.
19. DUNCAN, B. D. Multiple range and multiple F tests. Biometrics 11: 1 (1955).
20. MARNETT, L. F., TENNEY, R. J., and BARRY, V. D. Methods of producing soy-fortified breads. Cereal Sci. Today 18: 38 (1973).
21. OFELT, C. W., SMITH, A. K., EVANS, C. D., and MESER, H. A. Soy flour wins its place. Food Eng. 24: 145 (1952).
22. BERTRAM, G. L. Studies on crust color. I. The importance of the browning reaction in determining the crust color of bread. Cereal Chem. 30: 127 (1953).
23. LAGENDIJK, J., and PENNINGS, H. J. Relation between complex formation of starch with monoglycerides and the firmness of bread. Cereal Sci. Today 15: 354 (1970).
24. KROG, N. Amylose complexing effect of food grade emulsifiers. Staerke 23: 206 (1971).
25. DEL VECCHIO, A. J. Emulsifiers and their use in soft wheat products. Baker's Dig. 49(8): 28 (1975).
26. GRIFFIN, W. C., and LYNCH, M. J. Surface active agents. In: CRC Handbook of Food Additives, 2nd ed., ed. by T. E. Furia. CRC Press, Inc.: Cleveland, Ohio (1973).
27. TENNEY, R. J., and SCHMIDT, D. M. Sodium stearoyl-2 lactylate-its functions in yeast-leavened bakery products. Baker's Dig. 42(6): 38 (1968).
28. HOSENEY, R. C., FINNEY, K. F., and POMERANZ, Y. Functional (breadmaking) and biochemical properties of wheat flour components. VI. Gliadin - lipid - glutenin - interactions in wheat gluten. Cereal Chem. 47: 135 (1970).

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