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9. ABSTRACT

Bread is an ideal food to fortify with protein because it is a staple food in many countries, but fortifiers such as soy flour can induce adverse effects on dough properties and bread quality. In this study three food emulsifiers (sodium stearoyle-2-lactylate, calcium stearoyl-2-lactylate, ethoxylated monoglycerides) were used to improve effectively the baking performance of wheat flour fortified with soy flour or other protein-rich additives, with no adverse effects. Accordingly, acceptable high-protein bread containing a high level of soy flour or other protein-rich additives such as cottonseed flour and fish protein concentration can be made by adding one of these three food emulsifiers.

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THE USE OF EMULSIFIERS FOR PRODUCING PROTEIN - FORTIFIED BREAD*

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Protein malnutrition, a serious problem for people whose diets consist mainly of cereal or starchy products, has aroused interest in fortifying commonly-consumed foods with protein. Because bread is a staple in many countries, it is an ideal food to fortify with protein.

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Of all protein-rich additives now available, soy flour is the most attractive in price and quality. Soy flour (defatted) is a valuable additive for bread, not only because of soy flour's high protein, but also for its 3.2 per cent to 3.8 per cent lysine (1). For example, adding 12 parts soy flour to 100 parts wheat flour could increase total protein content about 30 per cent, depending on the protein content of the wheat flour used. Lysine is the first-limiting amino acid in wheat flour (2). The lysine content of such fortified bread would be about twice that of white (wheat) bread. Thus, the soy-fortified bread can greatly improve human diets nutritionally.

Although fortifying wheat flour with protein-rich additives offers an effective way to combat protein malnutrition, the fortifiers, such as soy flour, can induce adverse effects on dough properties and bread quality (3-8). Improvements in the quality of commercial, defatted and processed soy flour for baking and modifications in breadmaking by increasing bromate and reducing the fermentation period all have alleviated adverse effects of soy flour fortification (4-8). Changes in formulation or mixing time, or both, were examined by Matthews, Sharpe and Clark for making breads containing 25 per cent oilseed flours (9). Although they found that the soft-dough method gave a larger loaf of fortified bread than the straight-dough method, their loaf volumes were far below acceptable standards.

Pomeranz, Shogren, and Finney in 1969 found that adding natural (wheat or Briza spicata) and synthetic glycolipids or sucroesters to wheat flour permitted adding up to 16 per cent soy flour and other protein-rich foodstuffs to bread formulas without a significant loss in physical qualities (10, 11). However, natural glycolipids are uneconomical and approval of sucroesters has not been requested of the US Food and Drug Administration.

Our studies since 1968 on actions of various food emulsifiers, such as sodium stearyl fumarate, calcium stearoyl-2-lactylate (CSL), sodium stearoyl-2-lactylate (SSL), propylene glycerol monostearate, monoglycerides, polyoxyethylene sorbitan monooleate (Tween 60), and succinated monoglycerides in relation to dough strengthening effects show that SSL and CSL can form a complex with gluten to stabilize the gluten network in dough (12, 13). The dough strengthening effect also suggested that SSL and CSL could improve the baking performance of wheat flour fortified with high levels of soy flour or other protein-rich additives. Accordingly, a series of studies were undertaken to examine the improving effects of emulsifiers, particularly SSL, for making high-protein or protein-fortified breads. The keeping quality and nutritive value of such breads were also evaluated. Results of those studies have been reported in detail (14-17), and only the highlights are presented here.

Conditions for making high-protein breads with SSL

Unless otherwise stated, the wheat flour used in our tests was a blend of hard red spring and hard red winter wheat flour milled by a commercial mill and the soy flour was a typical commercial, defatted and chemically-treated product. Defatted cottonseed flour, fish protein concentrate, and nonfat dry milk (NFDM) were commercial products. Chickpea flour was ground by a laboratory mill. Characteristics of the ingredients are given in Table I.

TABLE I. INGREDIENT CHARACTERISTICS

Ingredient	Moisture, %	Protein, %*	Ash, %	Crude lipid, %
Wheat flour	11.4	11.8	0.46	-
Soy flour	6.8	52.6	6.80	-
Nonfat dry milk	6.4	34.9	8.0	-
Fish protein concentrate	4.8	80.0	13.7	0.1
Cottonseed flour	7.0	60.3	7.6	0.7
Chickpea flour	6.7	20.3	2.6	5.6

*Protein content is %N x 6.25, except x 5.7 for wheat flour.

To establish optimum processing conditions for making high-protein breads by our modified sponge-dough method (14), three basic responses were evaluated: mixing, absorption and oxidation.

Mixing response. Dough mixing is critical in determining quality of bread containing 12 per cent soy flour and 0.5 per cent SSL. Optimum mixing time for the soy dough was 2.9 minutes compared with 5.5 minutes for control dough. That is, the mixing requirement is only 45 per cent as long when 12 per cent soy flour is incorporated.

Absorption response. Flour absorption changes when it is fortified with 12 per cent soy flour. Results of our tests showed that optimum absorption of fortified flour ranged from 77 to 79 per cent, an increase of 11 to 13 per cent from the 66 per cent of control flour. Thus about 1 per cent extra water is required for each 1 per cent soy flour added to dough.

Oxidation response. Many deleterious effects of soy flour, as a bread supplement, can be overcome by raising the bromate level, as several workers have observed. We added various levels of bromate (in addition to 0.25 per cent bromate-type yeast food used in the sponge formula) to the dough formula to test bromate response. Twenty ppm bromate was optimum to oxidize the flour fortified with 12 per cent soy flour. As 0.25 per cent of yeast food adequately matured the control flour, it could be estimated that optimum bromate would be approximately 1.7 ppm for each 1 per cent fortified soy flour used. Too much or too little bromate lowers the baking quality of bread containing 12 per cent soy flour and 0.5 per cent SSL.

Improving effects of emulsifiers (SSL, CSL, and ethoxulated monoglycerides (EM)) for making high-protein breads

Under the above optimum conditions, we examined effects of different levels of SSL on the baking performance of fortified flour, with corresponding tests on control flour under its optimum processing conditions (14).

Because calcium stearoyl-2-lactylate (CSL) differs from sodium stearoyl-2-lactylate (SSL) only in the salt form, we conducted a similar set of tests using CSL instead of SSL. Results of these tests (Table II) showed that:

a) SSL is more effective than CSL. SSL's superiority was evident in loaves made from the control flour and became more pronounced for leaves made from the fortified flour. "Specific loaf volume" is an important parameter of bread's marketability. In the United States, specific volume of marketable bread should be at least 6.00 with acceptable appearance, crumb texture, and grain. As shown in Table II, a marketable bread containing 12 per cent soy flour can be made by adding 0.5 per cent SSL but not by adding 0.5 per cent CSL.

b) CSL and SSL can improve overall dough-handling properties during mixing and molding.

Our recent studies show that ethoxylated monoglycerides, like SSL or CSL, also effectively improve the baking performance of wheat flour fortified with various protein-rich additives (17).

TABLE II. EFFECT OF INDICATED TREATMENTS OF SSL OR CSL ON SPECIFIC VOLUMES OF LOAVES MADE FROM WHEAT FLOUR SUPPLEMENTED WITH 12% SOY FLOUR

Agent	Amount added, %	Average loaf volume, cc	Average specific loaf volume, cc/g	Loaf score* I	Loaf score* E
Control	0	2443	5.38	3	4
SSL	0.25	2556	5.63	6	7
SSL	0.50	2835	6.25	7	8
SSL	1.00	2833	6.24	7	7
CSL	0.25	2479	5.46	6	4
CSL	0.50	2561	5.69	7	5
CSL	1.00	2615	5.76	7	6

*Loaf score for external (E) and internal (I) characteristics 18 hours after baking. Finished bread is regarded as unsatisfactory if the score is less than 5.

Effect of different soy flours

Baking performance varies with different wheat flours; to make high-protein breads, the baking quality of various soy flours should be evaluated in addition to that of wheat flours. Defatted and full-fat soy flours are available commercially. From our comparative baking tests with both kinds of soy flour using the Kansas State Process (a no-time dough process), we found from the data listed in Tables III and IV that all breads with 12 to 28 per cent soy flour, defatted or full-fat, had small loaf volumes and poor grain scores. When 0.5 per cent SSL or EM was added, acceptable breads resulted from wheat flour fortified with defatted soy flour up to 12 per cent or with full-fat soy flour up to 24 per cent (17), so the baking quality of full-fat soy flour is superior to that of defatted soy flour. Whether protein quality, fat, and natural emulsifiers (such as glycolipids and lecithin in full-fat soy flour) are responsible for this superiority remains unknown.

TABLE III. EFFECTS ON BAKING QUALITY OF FORTIFYING WHEAT FLOUR WITH INDICATED PERCENTAGES OF FULL-FAT SOY FLOUR

Soy flour, %	SSL, %	Absorption, %	Bromate, ppm	Mix, min.	Av. loaf vol., cc	Av. sp. loaf vol., cc/g	Grain score
12	0	76	70	5.0	2223	4.90	4
16	0	80	70	4.0	2077	4.58	4
20	0	84	70	3.5	1923	4.24	3
24	0	88	70	3.5	1733	3.82	2
28	0	92	70	3.0	1461	3.22	2
12	0.5	76	70	5.0	3003	6.62	9
16	0.5	80	70	4.[illegible]	2876	6.34	8
20	0.5	84	70	3.5	2830	6.24	8
24	0.5	88	70	3.5	2735	6.03	7
28	0.5	92	70	3.0	2640	5.82	7

TABLE IV. EFFECTS ON BAKING QUALITY OF FORTIFYING WHEAT FLOUR WITH INDICATED PERCENTAGES OF DEFATTED SOY FLOUR*

Defatted soy flour, %	SSL, %	Average loaf volume, cc	Average specific loaf volume, cc/g	Grain score
12	0	2059	4.54	4
16	0	1878	4.14	3
20	0	1542	3.40	2
24	0	1438	3.17	2
28	0	1334	2.94	2
12	0.5	2821	6.22	8
16	0.5	2613	5.76	7
20	0.5	2291	5.05	6
24	0.5	1928	4.25	5
28	0.5	1533	3.38	3

*Breadmaking conditions the same as in Table III.

In many poverty areas where diets are deficient in both protein and calories, full-fat soy flour can become an ideal supplement because of its high protein and fat content. Furthermore, facilities for producing full-fat soy flour can easily be set up at much less expense than for defatted soy flour. This should enhance the usefulness of full-fat soy flour for making high-protein bread in poverty areas where both protein and calories are needed most.

Fortifying flour with various protein-rich foodstuffs

Table V summarizes baking results obtained from flour fortified with various protein-rich additives and treated with SSL or CSL. SSL or CSL obviously improve the baking performance of all the fortified flours but SSL is more effective than CSL for other additives, as it is with soy flour.

Each protein-rich additive was added so that its protein contribution was equivalent to that

of 12 per cent soy flour. All except chickpea flour produced acceptable bread with a specific volume above 6.00; apparently we used too much chickpea flour (31g/100g wheat flour). If it could be further purified to raise its protein content, probably no difficulty would be encountered using it to fortify wheat flour.

We used many other protein-rich foodstuffs, such as single cell protein and casein products, to fortify wheat flour. All made acceptable breads when SSL or CSL was added (14).

TABLE V. SPECIFIC VOLUMES OF LOAVES PREPARED FROM FLOUR SUPPLEMENTED WITH INDICATED PROTEIN CONCENTRATES AND TREATED WITH SSL OR CSL

Agent	Amount added, %	Specific loaf volume, cc/g			
		Nonfat dry milk	Fish protein concentrate	Cotton-seed flour	Chick-pea flour
Control	0.0	5.12	4.48	5.23	4.55
SSL	0.25	5.36	5.67	5.55	4.74
	0.50	6.32	5.99	5.70	5.01
	1.00	6.39	-	6.11	5.15
CSL	0.25	5.58	4.99	5.25	4.66
	0.50	5.51	5.14	5.27	4.77
	1.00	5.79	5.24	5.35	5.15

Staleness evaluation

For staleness evaluation, breads were made from wheat flour fortified with 20 per cent full-fat soy flour with or without 0.5 per cent SSL. Control breads with no soy fortification also were prepared with the same processing conditions by the Kansas State Process.

Table VI shows average compressimeter (Bloom gelometer) readings in grams for loaves stored 1, 3, and 5 days. Soy bread without SSL staled rapidly; its crumb became so firm that all compressimeter readings registered more than 500g. SSL effectively helped stored breads (soy and control) retain softness; soy bread with 0.5 per cent SSL compared favorably with the control bread with 0.5 per cent SSL and exceeded the control bread without SSL in softness retention. No soy bread showed any sign of off-flavor after five day's storage (17).

TABLE VI. AVERAGE COMPRESSIMETER READINGS (g) OF STORED CONTROL BREADS AND BREADS CONTAINING 20% FULL-FAT SOY FLOUR

Bread	Days stored		
	1	3	5
Control	101.2	140.1	181.3
Control + 0.5% SSL	68.1	93.8	115.8
Soy	346.6	437.6	>500.0
Soy + 0.5% SSL	76.7	85.1	134.0

Shortening-sparing effect of SSL and CSL

Most commercial bakers in the United States add 3 per cent shortening, generally texturated lard, to produce plain white bread. Shortening is not normally added to white bread in most European countries. Shortening can influence dough mixing, handling, proofing and bread volume; and it imparts desirable eating and keeping properties to the finished bread. Of those functions, the most important is to increase loaf volume substantially.

Adding SSL at 0.25 per cent or CSL at 0.50 per cent to a sponge formula could spare or replace shortening (texturated lard) normally required in plain white bread or bread containing 12 per cent soy flour. SSL was more effective than CSL in replacing shortening. In producing high-protein bread, 0.50 per cent SSL replaced all shortening and gave an acceptable loaf superior to that with 3 per cent shortening in volume and grain score. With SSL or CSL limited to 0.25 per cent and shortening to 1 or 2 per cent, a complementary action appeared between SSL or CSL and shortening, reflected by better volume than with SSL, CSL or shortening alone, as shown in Table VII (15).

TABLE VII. EFFECTS OF SSL, CSL, AND SHORTENING AND COMBINATIONS OF THEM ON QUALITY OF BREAD CONTAINING 12% SOY FLOUR

SSL, %	CSL, %	Shortening, %	Average specific loaf volume, cc/g	Loaf score I	Loaf score E
0	0	0	5.38	3	4
0.25	0	0	5.63	6	7
0.25	0	1.0	6.34	6	7
0.25	0	2.0	6.25	7	6
0.50	0	0	6.25	7	8
0.50	0	1.0	6.22	7	8
0.50	0	2.0	6.26	8	6
0	0.25	0	5.69	7	5
0	0.25	1.0	5.68	6	6
0	0.25	2.0	6.09	8	7
0	0.50	0	5.69	7	5
0	0.50	1.0	5.91	7	7
0	0.50	2.0	6.12	7	8
0	0	3.0	5.75	5	8

It should be emphasized here that the shortening-sparing action of SSL, together with the higher absorption from soy fortification, can substantially lower production costs of high-protein bread. The estimated cost for producing such enriched breads with 12 per cent soy flour is almost the same as for producing white breads in the United States and Japan.

The Kansas State (no-time dough) Process for making high-protein breads

A simple method for making high-protein breads should increase their use in improving man's diet. With a simple method, bakers without much knowledge or experience in breadmaking could easily produce acceptable high-protein breads in poverty areas of the United States or developing countries where such breads are needed most.

In an effort to simplify present methods for making high-protein breads, we found that no-time dough gave large loaf volume of soy bread with better grain score than did the 40- and 75-minute fermented doughs baked by a straight-dough method (16).

No-time dough also exhibited excellent molding properties. Dough fermented for 75 minutes had torn surfaces after proofing, so that the crust of the finished bread wrinkled.

SSL could further improve baking performance of no-time dough containing 12 per cent soy flour. Soy bread made with SSL, added at 0.5 per cent, had an acceptable volume, excellent grain and appearance, and good break and shred compared with control bread and shortening-treated bread. The no-time dough process for making soy bread did not require a specially designed high-speed mixer (as does the Chorleywood process (18)) or use cystine (as does the Reddisponge process (19)) because soy flour reduces both mixing and fermentation requirements. This no-time process, referred to simply as the "Kansas State Process" could be used advantageously to make high-protein breads, particularly for United States schools and institutions and in developing areas. It saves labor and time, and it is a simple process to follow (16).

Nutritional feeding studies with high-protein bread

Shamsuddin (20) has used rats to evaluate the nutritive value of high-protein breads. Male, Charles River 22-day-old albino rats were fed three diets using a completely randomized design, 8 replications per diet. The rats ranged from 50-54 grams at the beginning of the test.

As shown in Table VIII, the enriched bread formula using 12 per cent soy flour significantly increased weight gains above gains from enriched white bread or enriched bread containing 3 per cent nonfat dry milk solids (NFDM). Rats fed high-protein breads ate more than those fed the other breads.

Protein efficiency ratios indicate rats on high-protein bread used protein efficiently. Feed consumption and body weight gain data also indicate that rats on high-protein breads were more efficient in feed conversion, which agrees with the data by Guggenheim et al. (21). They reported higher nutritive value of bread containing soy flour than that of commercial white bread as measured by growth of rats.

TABLE VII. AVERAGE WEIGHT GAIN, FEED CONSUMPTION, PROTEIN EFFICIENCY AND FEED CONVERSION BY RATS FED BREAD DIETS

Diet	Gain,[a] g	Feed consumed,[b] g	Protein efficiency[c]	Feed conversion[d]
Vitamin and mineral enriched white flour	13.6	191.3	0.51	14.0
Vitamin and mineral enriched white flour + 12% soy flour + 0.5% SSL	101.7	384.6	1.56	3.5
Vitamin and mineral enriched flour + 3% nonfat dry milk solids	17.6	171.0	0.66	9.7

[a] Average gain per rat 0-4 weeks, LSD (0.01)

[b] Grams of feed consumed 0-4 weeks, LSD (0.01)

[c] Grams gain per gram of protein consumed, LSD (0.01)

[d] Feed conversion grams feed/gram weight gain

Summary

Bread is an ideal food to fortify with protein because it is a staple food in many countries, but fortifiers such as soy flour can induce adverse effects on dough properties and bread quality. However, we have used three food emulsifiers, sodium stearoyl-2-lactylate (SSL), calcium stearoyl-2-lactylate (CSL), or ethoxylated monoglycerides (EM), to effectively improve baking performance of wheat flour fortified with soy flour or other protein-rich additives, with no adverse effects. Accordingly, acceptable high-protein bread containing a high level of soy flour or other protein-rich additives such as cottonseed flour and fish protein concentrate can be made by adding one of these three food emulsifiers.

Full-fat soy flour can become an ideal supplement in many poverty areas, where diets are deficient in both protein and calories, because of its high protein and fat content. Its baking quality is also superior to that of defatted soy flour.

SSL helps stored breads (soy and control) retain softness (to extend the shelflife of breads).

SSL or CSL, added to a sponge formula at 0.25 and 0.50 per cent, respectively, can replace shortening (texturated lard) normally required in white bread or high-protein bread. Savings on shortening can offset, at least in part, the cost of the emulsifier.

The Kansas State (no-time dough) Process has been developed to make acceptable high-protein breads. It is a simplified process with a great time-saving advantage, and it could be used in expanding production of high-protein breads in poverty areas or for the school lunch program in the United States and in developing countries where such breads are needed most.

The nutritional benefits of high-protein breads have been demonstrated in studies using the breads in diets of experimental rats.

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