NEW CONCEPTS FOR USE OF SOY FLOUR IN BAKING: PREPARATION OF HIGH-PROTEIN BREAD[1]

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Protein malnutrition, a serious problem of 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 food in many countries, it is an ideal food to fortify with protein. Bread has high consumption, wide acceptability, and low price. Enriching bread with vitamins and minerals already has set a successful example for benefiting public health (1,2). Enriched bread is a common practice in this country and many other countries. The time has now come to fortify wheat flour with protein-rich foodstuffs to raise the protein content and to balance essential amino acids of bread and other baked products to improve the nutritional status of people.

Of all protein-rich foodstuffs now available, soy flour is the most attractive in price, quantity, and quality. It is a valuable additive for bread not only for its high-protein content but also for its 3.2 to 3.8% lysine to enrich wheat flour's about 0.38% lysine (3), the first limiting essential amino acid in wheat flour (4). Fortifying wheat flour with 12% soy flour more than doubles its lysine content, to 0.76 to 0.83%. Finished bread, thus fortified, would greatly improve human diets nutritionally.

Although fortifying wheat flour with soy flour offers an effective way to combat protein malnutrition, adding more than 6% of soy flour to wheat flour can induce adverse effects on absorption, mixing, and fermentation as well as on volume, grain or crumb and color of bread. To alleviate those adverse effects, two approaches are generally taken: (a) selecting properly treated soy flour and good wheat flour, and (b) modifying the processing procedure.

Treatment of Soy Flour

Commercially available soy products include (a) soy flours and grits, (b) soy protein concentrates, and (c) soy protein isolates. Although several workers (Mizrahi et al., 5; Turro and Sipos, 6; Mugler et al., 7; and Kirleis, 8) have used concentrates and isolates for breadmaking, soy flours and grits are the most commonly used by commercial bakers.

Mixing properties and baking performance of soy-fortified flour depend largely on how soy flour is processed.

Heat treatment improves its nutritional value and baking properties. Osborne and Mendel reported that rats grew poorly when fed raw soy meal and that moisted

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Table I. Effect of Heat on Protein Dispersible Index and Relative Protein Efficiency of Defatted Soy Flour

Type	Protein Dispersible Index (PDI)	Relative Protein Efficiency *
Negligible heat	90-95	40-50
Light heat	70-80	50-60
Moderate heat	35-45	75-80
Toasted	8-20	85-90

*Dried skim milk equals 100 percent.

Table II. Enzyme activity in soy protein products

	Uncooked PDI 80-100	Partly cooked PDI 50-80	Fully cooked PDI 20-50	Toasted PDI 0-20
Lipoxidase	+	-	-	-
Urease	+	+	+	-
Diastase	+	+	-	-
Lipase	+	+	-	-
Protease	+	+	-	-

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heat treatment promoted normal growth (9). Why heat improves the nutritional qualities of soy meal still is not understood. Wolf (10) suggested that several soybean components, such as trypsin inhibitors, hemaglutinins, saponins, and isoflavons, may be antinutritional factors; both trypsin inhibitors and hemaglutinins are readily inactivated by heat treatment.

One method, generally used to measure the efficiency of heat-treatment when soy meal is processed, is by determining water-soluble protein content (protein dispersible index (PDI). Table I shows various heat-treated soy flours (defatted), their protein dispersible indexes, and relative nutritional values, as presented by Horan to show heat's effects on nutritional values of soy flour (11). However, as far as this heat and nutrition relationship is concerned, the heat treatment does not seem necessary for soy flour intended to be used in baked foods. Pomeranz suggested that the heat in the baking process may be sufficient to destroy raw soy flour's antinutritional factors (12).

(Table I)

Raw soy flour is rich in many enzymes such as lipoxidase, urease, amylases, lipase, and proteases. Lipoxidase preparations from raw flour long have been used in small quantities to bleach and improve dough and its flavor (13). The improving mechanism, Tsen and Hlynka suggest, involves oxidation of sulfhydryl groups in dough by lipid peroxides formed by lipid peroxidation through the catalyses of lipoxidase (14). Ofelt et al. (15), Finney (16), and Pollock and Geddes (17) have shown that raw soy flour softens bread dough and reduces loaf volume, perhaps by the amylases (18), proteases (15), or some other unidentified enzyme or reducing substance.

Enzymes are readily inactivated by heat. Table II shows heat effects on various enzymic activities in soy flour reported by Hafner (20). Once properly heat-treated, soy flour's enzymatic activities should have little or no effect on dough properties or baking performance.

(Table II)

Two objections to using soy flour in baking, a "beany" odor and bitter taste, can be alleviated by using a toasted product. However, toasting darkens the baked product and often affects other properties, particularly in white bread. But soy flour treated chemically, as with calcium chloride and hydrogen peroxide, improves baking performance (20).

Bookwater et al. (27) found that full-fat soy flours prepared by extrusion and used to fortify wheat flour improved baking performance.

Adding soy flour of various particle sizes to wheat flour affects breadmaking and loaf quality. Doughs, incorporated with finely powdered soy products, required more water and mixing and slightly more bromate than those with coarse soy products or the control (22). Adding coarse soy products gave bread better crumb grain, color, and larger loaf volume than adding less granular soy products. Toasted soy grits gave more appetizing breads and overcame the objectionable brown color of breads containing finely powdered soy flours (12).

Modification of the Processing Practice

Besides treating soy flours for baking use, various efforts have been made to modify processing either by changing processing conditions or using additives.

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Early workers, notably Ofelt et al. (18,23,24), Bohn and Faver (25), Bayfield and Swanson (26), and Finney (16,22), showed that (a) raising absorption (16,23,24), (b) decreasing mixing time (22,25), (c) increasing oxidant (bromate) treatment (16,23,24,26) and (d) reducing fermentation period (25,26), improves baking performance of flours fortified with soy products.

Mathews, Sharpe, and Clark recently studied changes in formulation and mixing time with breads containing oilseed flours, including up to 25% soy flour (27). Although they found that the soft dough method gave a larger volume of fortified bread than the straight-dough method, both loaf volumes were below acceptable standards.

Pomeranz and his associates' series of studies on lipids' role in bread quality showed the importance of the glycolipid component of wheat flour. In 1969, Pomeranz, Shogren, and Finney found that adding natural (wheat or Briza spicata) and synthetic glycolipids or sucroesters to wheat flour permitted adding up to 16% soy flour and other protein-rich foodstuffs to bread formulas without a significant loss in physical qualities (28,29). However, natural glycolipids are uneconomical, and approval of sucroesters has not been requested of the Food and Drug Administration.

During recent years research on how to make acceptable bread or baked products has been intensified through FAO sponsorship. Kim and de Ruiter developed formulas for making breads from nonwheat flours and from wheat and nonwheat flour mixtures, using glyceryl monostearate, calcium stearoyl-2 lactylate, or hydroxyl propylmethylcellulose as an emulsifying agent (30,31). Pringle, Williams, and Hulse showed that acceptable bread could be made with mechanically developed doughs from composite flours (32); further work along that line has been done by Dendy, Clarke and James (33). However, the major objective of the work on composite flour is to replace, at least in part, wheat flour by other indigenous flours and meals in wheat-importing countries, rather than attempting to prepare high-protein breads.

Our studies since 1968 on actions of various surfactants in relation to dough strengthening effects show that sodium stearoyl-2 lactylate (SSL) and calcium stearoyl-2 lactylate (CSL) can form a complex with gluten to stabilize the gluten-network in dough (34,35). Several workers earlier had observed dough-strengthening effects of SSL and CSL: In bread, CSL increased dough tolerances and improved bread quality (36,37,38). SSL imparted strength to dough and permitted the manufacture of yeast-leavened sweet goods with excellent shelf life, good volume, and tenderness (39).

The dough-strengthening effects of CSL and SSL, together with their improvement of bread quality, suggested supplementing wheat flour dough treated with CSL or SSL with high levels of soy flour or other protein-rich foodstuffs. Tsen, Hoover, and their associates extensively examined conditions for preparing soy breads, exploring the effectiveness of CSL or SSL as an additive, and simplifying methods for making soy breads. Part of their results have been published or are in press (40, 41,42). Highlights of their results follow.

Conditions for Preparing Soy Breads

To establish optimum processing conditions for making high-protein bread, three basic responses are evaluated: 1. mixing, 2. absorption and 3. oxidation.

Mixing Response

Dough mixing is particularly critical in determining quality of bread containing soy flour. As shown in Table III, optimum mixing time for soy dough is 2.5

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minutes compared with 5.5 minutes for control dough. That is, the mixing requirement is only 45% so long when 12% soy flour is incorporated (40). The finding that soy dough requires short mixing confirms others' results (22,25).

(Table III)

Absorption Effect

Absorption changes when flour is fortified with soy flour (16,23,24). Table IV shows that optimum absorption of fortified 12% soy flour ranges from 77 to 79%, an increase of 11 to 13%, from the 66% of control flour (40). So, about 1% extra water is required for each 1% soy flour added to dough.

(Table IV)

Oxidation Response

Many adverse effects of soy flour can be overcome by increasing the bromate (16,23,24,26). Table V shows that 20 ppm bromate is optimum to oxidize flour fortified with 12% soy flour. Since 0.25% Arkady (yeast food) oxidized control flour adequately, Tsen et al. estimated optimum bromate would be approximately 1.7 ppm for each 1% soy flour added (40).

Under- or overtreating with bromate lowers baking quality of soy breads.

(Table V)

Effectiveness of SSL and CSL

SSL and CSL can improve baking performance of soy fortified flour Fig. 1 and Table VI (40) .

Although SSL (sodium salt) differs from CSL (calcium salt) in the salt form, SSL improves soy products more than CSL. The difference in solubility may, in part, account for SSL's superiority.

(Table VI) (Fig. 1)

Effect of Different Levels of Soy Flour

Adding soy flour adversely affects loaf volume and score of the finished bread. The adverse effects intensify as soy flour is increased. SSL, CSL, and ethoxylated monoglycerides (EM) all alleviate the adverse effects so high-protein bread can be made from wheat and soy flours (40,43). How much soy fortification may be used depends on the type and quality of soy and wheat flours. For example, with the addition of 0.5% SSL, 12% of a defatted and treated soy flour could be incorporated into wheat flour to produce acceptable bread; while with a full-fat soy flour the percentage could be raised as high as 24% (40,44).

Shortening-sparing Effect of Sodium Stearoyl-2 Lactylate and Calcium Stearoyl-2 Lactylate in Breadmaking

Most United States commercial bakers add 3% shortening, generally texturated lard, to produce white, plain bread. Shortening normally is not added to white bread in most European countries or Australia. Shortening can influence dough mixing, handling, proofing, and bread volume, and it imparts desirable eating and

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Table III. Effect of Mixing Time on the Quality of Bread Containing 12% Soy Flour and 0.5% SSL

Mix time min.	Av. vol./lb. cc	Av. sp. vol. cc/g	Loaf score I	Loaf score E
0.50	2152	4.74	2	2
1.50	2606	5.74	6	5
2.50	2860	6.47	6	8
3.50	2851	6.28	5	7
4.50	2601	5.73	3	6

*Mixing Time: 5.5 min. for control dough.

Table IV. Effect of Absorption on the Quality of Bread Containing 12% Soy Flour and 0.5% SSL

Abs. %	Av. sp. loaf-vol. cc/g	Loaf score I	Loaf score E
73	6.29	5	8
75	6.47	6	8
77	6.59	6	8
79	6.60	7	8
81	6.56	7	6

*Absorption: 66% for control dough.

Table V. Effect of Bromate on the Quality of Bread Containing 12% Soy Flour and 0.5% SSL

Bromate ppm	Av. sp. loaf-vol. cc/g	Loaf score I	Loaf score E
10	5.73	6	5
20	6.42	8	8
30	6.40	7	7
40	6.20	7	7
50	6.10	7	6

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Table VI. Effect of Indicated Treatments of SSL or CSL on Specific Volumes of Loaves Made From Flour Supplemented With 12% Soy Flour

Agent	Amount added %	Av. loaf-vol. cc	Av. sp. loaf-vol. cc/g	Loaf score I	Loaf score E
Control	0	2443	5.38	3	4
SSL	0.25	2556	5.63	6	7
	0.50	2835	6.25	7	8
	1.00	2833	6.24	7	7
CSL	0.25	2479	5.46	6	4
	0.50	2561	5.69	7	5
	1.00	2615	5.76	7	6

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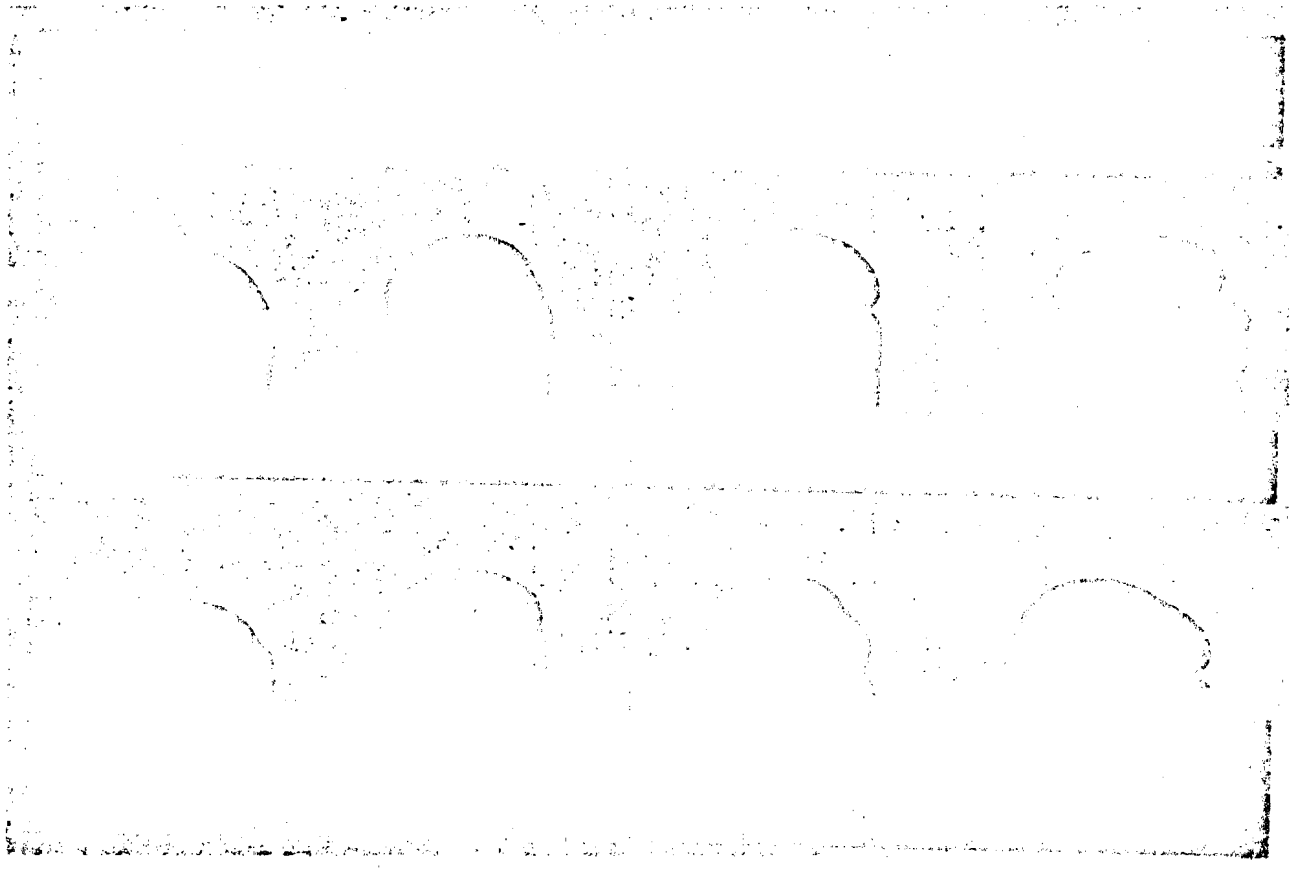

Fig. 1. Effects of SSL and CSL on the quality of bread containing 12% soy flour.

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keeping properties to the finished bread. Of those functions, the most important is to substantially increase loaf volume.

SSL and CSL, added to a sponge formula at 0.25 to 0.50%, could spare or replace shortening (texturated lard) normally required in white (plain) bread or bread containing 12% soy flour. SSL was more effective than CSL in sparing shortening. In producing high-protein bread, 0.50% SSL replaced all shortening and gave an acceptable loaf superior to that with 3% shortening in volume and grain score. With SSL or CSL limited to 0.25% and shortening to 1 or 2%, a complementary action appeared between SSL or CSL and shortening, reflected by better volume than with SSL, CSL, or shortening alone. White breads stored at 25°C up to 5 days were slightly softer when SSL, rather than shortening, was used (41).

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 their effort to simplify present baking methods for making high-protein breads, Tsen and Tang (42) found that no-time dough gave large loaf volume of soy bread with better grain score than did the 40- and 75-min fermented doughs baked with a straight-dough method (Fig. 2, Table VII).

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

SSL could further improve baking performance of no-time dough containing 12% soy flour. Soy bread made with SSL, added at 0.5%, had an acceptable volume, excellent grain and appearance, and good break and shred, when compared with control bread and lard-treated bread (Fig. 3, Table VIII). Tsen and Tang concluded that the no-time dough process did not require a specially designed high-speed mixer (as does the Chorleywood process (45)) or use cysteine (as does the Reddisponge process (46)) because soy flour reduces both mixing and fermentation requirements. The no-time process, referred to, simply, as the "Kansas State Process" could be used advantageously to make high-protein breads.

Conclusion

Of all protein-rich foodstuffs available today, soy flour is the most attractive in price, quality, and quantity for making high-protein breads. Recent advances in soy flour processings, including heat and chemical treatments or cook-extrusion, make soy flour more suitable for baking uses.

Conditions for making soy breads have been well studied in conjunction to absorption, mixing, oxidation, and fermentation requirements. Various agents such as lecithin (47), glyceryl monostearate, natural and synthetic glycolipids, and lactylates (CSL and SSL) have been used to improve the baking performance of soy dough.

Mechanisms concerning the improving action of the agents are still obscure. Pomeranz et al. suggested that sucroesters seemed to improve quality of protein-enriched bread by rendering noncereal proteins functional in breadmaking (28,29). Tsen et al. postulated that SSL and CSL could form a complex with gluten to strengthen or stabilize the gluten-network in dough so that they may enforce soy

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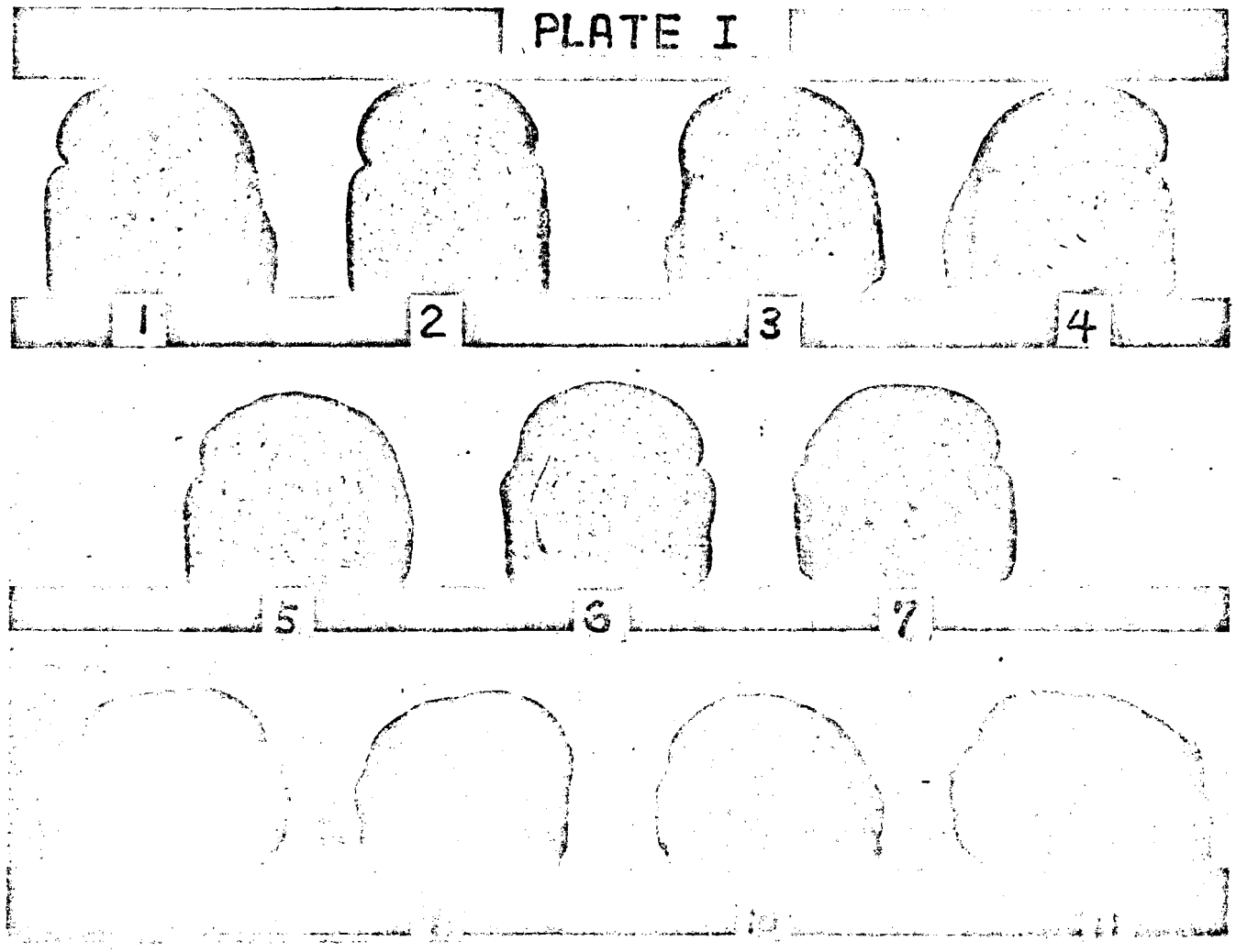

Fig. 2. Effects of fermentation, floor time, and bromate on the c
of breads containing 12% soy flour and 3% Crisco (comme
shortening). (Refer to Table VII for the loaf number.)

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TABLE VII. EFFECT OF FERMENTATION AND FLOOR TIMES AND BROMATE

Floor time min	Bromate ppm	Av. sp. vol. cc/g	Grain score	Loaf No.
30	60	5.90	9	1
40	60	5.95	9	2
50	60	5.85	8	3
40	30	5.90	7	4
20	40	5.20	5	5
30	40	5.70	6	6
40	40	5.55	6	7
20	30	5.05	4	8
30	30	4.95	5	9
40	30	4.90	5	10
30	60	4.95	5	11

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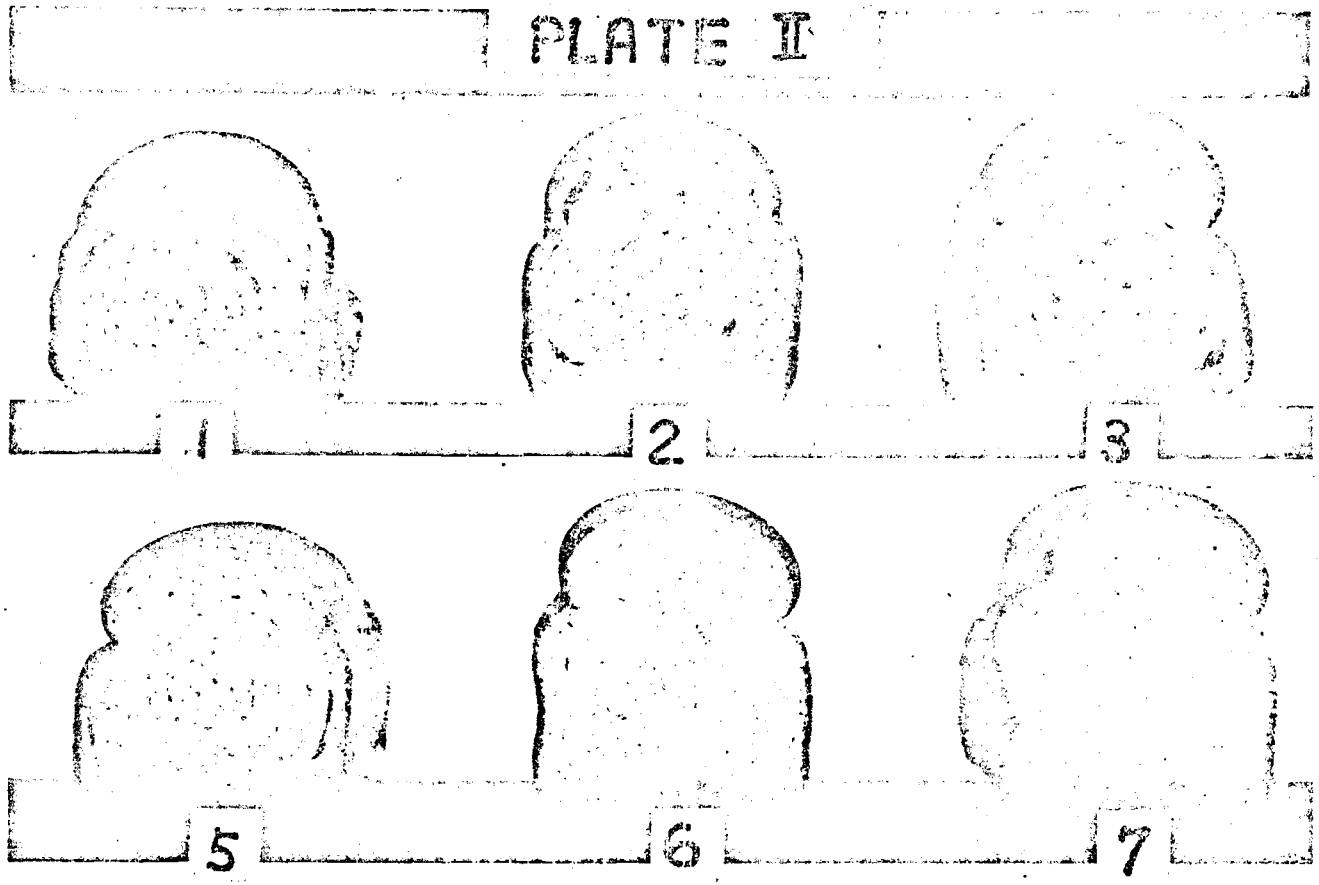

Fig. 3. Effects of sodium stearoyl lactylate (SSL), bromate, and yeast and bromate on the quality of breads containing 12% soy flour but no Crisco (commercial shortening). (Refer to Table the loaf number.)

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TABLE VIII. EFFECTS OF ADDITIVES, YEAST, AND BROMATE

Additive %	Yeast %	Bromate ppm	Av. sp. vol. cc/g	Grain score	Loaf no.
0	3.0	60	4.15	4	1
3% Lard	3.0	60	5.45	5	2
.25% SSL	3.0	60	5.30	5	-
.50% SSL	3.0	60	6.30	9	3
.50% SSL	2.5	60	6.15	7	5
.50% SSL	3.5	60	6.30	8	6
.50% SSL	3.0	40	6.50	9	7
.50% SSL	3.0	80	6.50	8	-

dough to endure the stress of mixing, fermentation, and especially oven spring during early stage of baking (34,35,40,42). Additional studies are needed to elucidate the improving mechanism.

SSL and CSL, added to a sponge formula at 0.25 and 0.50%, can spare or replace shortening (texturated lard) normally required in white bread or bread containing 12% soy flour.

SSL exerts more dough-improving and shortening sparing effects than CSL does. As the lactylates already are being used by commercial bakers and have been approved by the Food and Drug Administration as safe food additives, commercial production of high-protein breads or other baked products with lactylates could start immediately.

A no-time dough process has been developed to make acceptable soy bread with SSL added. The simplified process with a great time-saving advantage could become an asset in expanding production of soy breads in poverty areas of the United States and other countries where such breads are needed most.

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