Fatty Acid Derivatives and Glycolipids in High-Protein Bakery Products[1,2]

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ABSTRACT

High-protein bakery foods, particularly breads, are ideal for alleviating protein malnutrition in poverty areas of the world. Fortifying wheat flour with a high level of protein-rich additives like soy flour can, however, induce adverse effects upon dough properties and bread quality. Several fatty acid derivatives, including sucroesters, fatty esters of polyalkoxylated polyolglycosides, sodium or calcium stearoyl-2 lactylate, and ethoxylated monoglycerides and glycolipids, recently have been shown to improve effectively the baking performance of wheat flour fortified with soy flour. The nutritional benefits of high-protein breads are reported with results from feeding studies using the breads in diets of experimental rats. The possible mechanisms concerning the improving action of fatty acid derivatives are proposed and discussed.

SOY FORTIFYING BREAD

High-protein bakery products, particularly bread, can be used effectively to alleviate protein malnutrition in poverty areas of the world. Bread rapidly is becoming a staple food in many countries, even in rice and corn producing regions. Its high consumption, wide acceptability, and low price make bread an ideal food to fortify for the malnourished and hungry.

A number of protein-rich additives can be used for fortification. Of the additives, probably soy flour has been the most attractive in price, quality, and quantity in the U.S. Defatted soy flour contains ca. 52% protein and 3.6% lysine, an essential amino acid. Wheat flour used for breadmaking generally has 12% protein and 0.38% lysine (1 and unpublished data). Lysine is the first limiting essential amino acid in wheat flour (2). When wheat flour is fortified with 12% soy flour, the soy blend contains ca. 16.8% protein and 0.76% lysine, increasing protein ca. 33% and lysine, 100%. The soy fortification not only increases the protein content but, more importantly, improves the nutritive value of wheat bread and other bakery products by raising the lysine content to balance nutritionally required amino acids.

Although fortifying wheat flour with soy flour offers an effective way to combat protein malnutrition at more than 6% soy flour, it can induce adverse effects upon dough properties and bread quality. The adverse effects include: (A) altered absorption, mixing, and machining properties; (B) changed fermentation rates; (C) poor crumb grain and color; (D) reduced loaf volume; and (E) beany flavor, reported by several workers (3-8). Several approaches have been taken to alleviate the adverse effects, and they are discussed below.

Selecting Properly Treated Soy Flour and Good Wheat Flour

It is well established that heat and chemical treatments improve the nutritive value and baking quality (9,10) of soy flour. Full-fat soy flour outperforms defatted soy flour for producing high-protein bread (11). Adding coarse soy products gives bread better crumb grain, color, and loaf volume than adding less granular soy products. Toasted soy grits give more appetizing breads and overcome the objectionable brown color of breads containing finely powdered soy flour (9,10). Good wheat flour with a high gluten quantity and quality can tolerate soy fortification and produce superior soy bread (12).

Modifying the Processing Practice

Many workers have found that raising absorption, reducing mixing time and fermentation period, and increasing oxidant (bromate) treatment improves the baking performance of wheat flour fortified with soy products (5,7-9,11-15).

Using Fatty Acid Derivatives as Improvers

Although the first two approaches, to a certain extent, alleviate adverse effects, acceptable bread containing more than 6% soy flour could not be prepared successfully until several fatty acid derivatives and glycolipids were found to improve the baking quality of soy fortified flour, as next described.

GLYCOLIPIDS AND SUCROESTERS

In 1969 Pomeranz, et al., (14,15) reported that adding natural glycolipids from wheat or quaking grass (*Briza spicata*) and sucrose esters (such as sucrose tallowate or monopalmitate) to wheat flour permitted fortifying with up to 16% soy flour and other protein-rich additives without a significant loss in the bread's physical properties. Comparing improving effects of various lipids and fatty acid derivatives on loaf volume and crumb grain of soy breads (Table I) led them to the conclusions (14) discussed below.

TABLE I

Loaf Volume and Crumb Grain of Bread Baked at Optimum Bromate Level with 8 g Soy Flour/100 g Wheat Flour, Various Lipids, and Lipid Derivatives[a]

Lipid	Lipid level, g	Loaf volume, cc	Crumb grain[b]
None	None	766	Q-U
Shortening	3.0	933	Q-S
Polar flour	0.5	1015	S
Lecithin	0.5	873	Q
Sucroesters			
Monolaurate	0.5	997	Q-S
Sesquilaurate	0.5	970	Q-S
Dilaurate	0.5	955	Q-S
Monopalmitate	0.5	965	Q-S
Dipalmitate	0.5	840	Q
Monostearate	0.5	915	Q-S
Sesquistearate	0.5	853	Q
Tristearate	0.5	795	Q
Lipid derivatives			
Palmitic acid	0.5	778	Q-U
Glycerol monopalmitate	0.5	815	Q-U
Glycerol dipalmitate	0.5	805	Q-U
Glycerol tripalmitate	0.5	765	Q

[a] See ref. 14.

[b] U = unsatisfactory; Q = questionable; and S = satisfactory.

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[1] One of 12 papers presented in the symposium "Novel Uses of Agricultural Oils" at the AOCS Spring Meeting, New Orleans, April 1973.

[2] Contribution 825 from the Department of Grain Science and Industry, Kansas State University.

TABLE II

Effect of Indicated Treatments of Sodium Stearoyl-2-Lactylate or Calcium Stearoyl-2-Lactylate on Specific Volumes of Loaves Made from Flour Supplemented with 12% Soy Flour[a]

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

[a] See ref. 12.

[b] Score scale for external (E) and internal (I): 1-10. Finished bread scored less than 5 regarded as unsatisfactory.

[c] SSL = sodium stearoyl-2-lactylate and CSL = calcium stearoyl-2-lactylate.

Free polar wheat flour lipids (compared with shortening and lecithin) most effectively improved the baking performance of wheat flour fortified with 8 g defatted soy flour/100 g wheat flour. Lecithin gave a relatively small but significant improving effect. Of the sucrose esters tested, the improving effect was greater from those with fewer and shorter chain lengths of fatty acids attached to the sucrose molecule. Palmitic acid, glycerol monopalmitate, glycerol dipalmitate, and glycerol tripalmitate had little or no improving effect.

The effectiveness of free polar flour lipids in making soy bread substantiate the findings of Daftary, et al., (16) that small amounts of polar wheat flour lipids greatly improved loaf volume and crumb grain of bread and that glycolipids were primarily responsible.

FATTY ESTERS OF POLYALKOXYLATED POLYOLGLYCOSIDES

Bean, et al., (17) recently tested many mono- and difatty esters of polyethoxylated and polypropoxylated propylene glycol and glycerol glycosides as improvers with wheat flour fortified with 6% soy flour. Most fatty esters tested showed promise for improving loaf volume and crumb grain of soy bread. Monostearoyl glycerol glycosides containing 8 moles of ethylene oxide and 3.8 moles of propylene oxide gave particularly good loaf value and grain score.

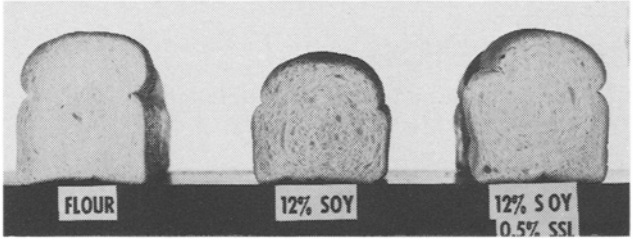


FIG. 1. Effects of soy flour (12%) and sodium stearoyl-2 lactylate (SSL) (0.5%) on the baking performance of wheat flour. Loaf volume (cc); flour, 2788; 12% soy flour, 2443; 12% soy flour + 0.5% SSL, 2835. See ref. 12.

TABLE III

Protein and Amino Acid Composition of Bread Samples[a]

	Identification of bread		
	White regular	12% soy flour + 0.5% SSL[b]	14% NFDM[b]
Protein %[c]	14.3	19.0	17.7
Amino acid[d]			
Lysine	1.72	3.29	3.05
Histidine	1.73	2.18	2.07
Arginine	3.09	4.69	3.13
Aspartic acid	4.08	7.25	7.94
Threonine	2.62	3.14	3.28
Serine	4.58	4.95	4.80
Glutamic acid	33.00	30.91	32.26
Proline	10.48	9.71	10.88
Glycine	3.30	3.76	3.26
Alanine	2.78	3.46	3.31
Cystine[e]	2.79	1.59	1.38
Valine	3.75	4.51	4.29
Methionine[e]	1.21	1.15	1.18
Isoleucine	3.25	3.84	3.93
Leucine	6.44	7.31	7.84
Tyrosine	2.69	1.52	3.33
Phenylalanine	4.39	4.83	4.82
Recovery	94.43	101.81	105.14

[a] See ref. 21.

[b] SSL = sodium stearoyl-2-lactylate and NFDM = nonfat dry milk.

[c] Percent protein (N x 6.25).

[d] Grams amino acid/100 g Kjeldahl protein.

[e] Cystine and methionine values determined by performic acid oxidation, following procedure of Moore.

However, the fatty esters of polyalkoxylated polyolglycosides are all in liquid or plastic (wax) form. Additional study is required to develop dry, free-flowing, powder form fatty ester to use in flour blends and baking processes. None of the fatty esters, sucrose esters, or glycolipids have been cleared by the Food and Drug Administration. Appropriate studies, including feeding and toxicity tests, must be made to determine their acceptability in human food.

SODIUM OR CALCIUM STEAROYL-2 LACTYLATE AND ETHOXYLATED MONOGLYCERIDES

Tsen, et al., (11-12,17-20) found that sodium stearoyl-2-lactylate (SSL) and calcium stearoyl-2-lactylate (CSL) could form a complex with gluten to stabilize the gluten network in dough. The dough strengthening effect led them to find that SSL and CSL could improve the baking performance of wheat flour fortified with high levels of soy flour or other protein-rich additives, including fish protein concentrate, cottonseed flour, chickpea flour, and nonfat dry milk (NFDM).

Fortifying wheat flour with 12% defatted soy flour not only depressed the loaf volume but also impaired the grain score; adding 0.5% SSL greatly improved the volume. In fact, the volume of soy bread with 0.5% SSL was slightly larger than that of regular bread (Fig. 1). The improvement in loaf volume was enhanced as added SSL and CSL were increased. SSL was more effective than CSL (Table II).

Tsen, et al., (19,20) further found with the no-time dough method that acceptable bread could be made from wheat flour fortified with full-fat soy flour up to 24% with 0.5% SSL added. The bread containing 28% full-fat soy flour had an acceptable grain score, although its loaf volume was slightly below the U.S. standard.

Later, ethoxylated monoglycerides (EMG) were found effective in improving the baking quality of soy-fortified flour. In general, the EMG-treated soy bread was a little larger than the SSL soy bread. However, grain and texture of EMG-treated breads were slightly inferior to those of SSL-treated soy breads (20).

NUTRITIVE VALUE OF HIGH-PROTEIN BREADS

Shamsuddin (21) has undertaken extensive evaluations of the nutritive value of high-protein breads (Table III). Protein content was increased from 14.3% for regular bread to 19.0% and 17.7% for wheat flour fortified with 12% defatted soy flour and for wheat flour fortified with 14% NFDM, respectively. The figures represent 33% and 24% increases for soy- and NFDM-fortified breads over regular bread. The increase was higher for soy-fortified bread than for NFDM-fortified bread because defatted soy flour contained 17.7% more protein than NFDM did. In addition, as shown in Table III, adding 12% soy flour or 14% NFDM in the bread formula could raise the lysine content of regular bread from 1.72 to 3.29 or 3.05% on protein basis.

Using the breads in experimental diets for rats, Shamsuddin found that protein efficiency ratio values were 1.26, 1.93, and 1.65 for regular, soy-, and NFDM-fortified breads, respectively (21). Obviously, the fortification of wheat flour with soy flour or NFDM can improve the nutritive value of bread.

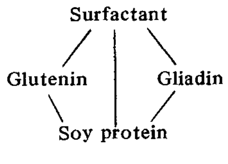
IMPROVING MECHANISM

Although the improving effect of various agents has been established for making high-protein bread and nutritional enhancement of high-protein bread has been observed, the mechanism concerning the action of these agents still is not understood fully.

Pomeranz, et al., (14) suggested that sucrose esters seemed to improve quality of high-protein bread by rendering noncereal proteins functional in breadmaking. Tsen, et al., (12,18,22) postulated that SSL and CSL could form a complex with gluten, in addition to starch, to strengthen or stabilize the gluten network in dough so that dough could carry soy flour or other protein-rich additives and endure the stress of mixing, fermentation, and especially oven-spring during early stages of baking.

The unique property of wheat flour for yeast leavened products is attributable to the ability of flour gluten to retain gases, mainly carbon dioxide, produced during fermentation. That ability, according to Daftary, et al. (16), is impaired when the free lipids are extracted by petroleum ether or similar nonpolar solvents, but is restored completely when the extracted polar fraction, rich in glycolipids, is added back to the flour. Glycolipids in the free polar lipids can be bound to the gliadin fraction of gluten by hydrophilic bonds and to the glutenin fraction of gluten by hydrophobic bonds. In unfractionated gluten, the glycolipid is simultaneously bound to both protein groups forming a gliadin-glycolipid-glutenin complex, as Hoseney, et al., (23) proposed. Such a complex would explain the relatively large effect of small amounts of glycolipids on gas-retaining properties of flour gluten (or baking performance), particularly loaf volume, of wheat flour.

In the presence of soy flour, the interactions of wheat proteins and soy proteins with various improving agents in soy-fortified dough are, of course, much more complicated than those in wheat flour dough. Aidoo and Tsen (unpublished data) recently have shown interactions between: (A) wheat proteins and soy proteins, (B) wheat proteins and surfactants, and (C) soy proteins and surfactants in doughs and in model systems. Of the wheat proteins, glutenin and gliadin were most involved in the interactions. The mechanism of the relative improving action of surfactants, including various fatty acid derivatives, such as sucroesters, SSL, and EMG, appears to depend, in part, upon two major complexes forming: glutenin-soy protein-gliadin and glutenin-surfactant-gliadin. The multiple interaction is depicted in the model below.



It is conceivable that a glutenin-surfactant-gliadin complex enhances, while a glutenin-soy protein-gliadin impairs the functional potential of gluten. Thus, the relative improving effect of surfactants in the system would depend upon the strength of association between the surfactant and the gluten proteins compared with that of soy proteins and the gluten proteins or on the relative stabilities of the glutenin-surfactant-gliadin complex and the glutenin-soy protein gliadin complex. The relative stabilities or strengths of such associations would be decided by individual surfactants' molecular structure. Surfactants, like fatty acid derivatives with the improving effect, all contain one or more fatty acid groups to provide hydrophobic bonding sites along with polyols, such as sucrose, galactose, and lactylate, to provide hydrogen-bonding sites. Availability of the sites may be the factor that determines the relative improving effects of surfactants. Furthermore, the ionic nature of surfactants recently has been found by Chung and Tsen (unpublished data) also to affect stability of the complex, as evidenced by actions of SSL (an ionic surfactant) and EMG (a nonionic surfactant) varying on proteins, lipids, and starch in dough. That lets us postulate that a stabler glutenin-surfactant-gliadin complex in such a multiple system should be better than a stable glutenin-soy protein-gliadin complex. In other words, a surfactant that shows an improving effect in the multiple interacting system probably can maintain or enhance the integrity of the wheat flour proteins in the complex so that the gluten proteins can either accommodate the soy proteins in the gluten matrix or overcome the concomitant deleterious effects of soy flour and still yield an acceptable bread.

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