SOY-FORTIFIED WHEAT-FLOUR BLENDS. IV. STORAGE STABILITY WITH SEVERAL SURFACTANT ADDITIVES[1]

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ABSTRACT

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Blends containing 94% wheat flour, 6% defatted, lightly heated soy flour, 0.28% surfactant, and 12.7% moisture were stored at 90° and 100°F. Blends containing 88% wheat flour, 12% soy flour, 0.50% surfactant, and 12.4% moisture were stored at 100°F. Similar control blends were stored at −10°F. Bread was baked from stored samples without added shortening. With both levels of soy addition, loaf volume of samples containing sodium stearoyl-2-lactylate (SSL) decreased in 6 months to 58–75% of that of −10°F controls; crumb structure also deteriorated. Changes were significantly slower with ethoxylated monoglycerides (EMG) as the additive, with 80–90% of loaf volume retained. Polysorbate-60 (PS-60) also gave a more stable blend, but the original loaf volume was less than those given by SSL or EMG. In one experiment, two sucrose esters and an experimental sample of stearic acid esters of polyethoxylated glycerol glycosides maintained loaf volume above 89% of the −10°F control. Panel evaluations of the odor of blends showed differences between samples stored at −10° and 100°F. Odors of SSL and EMG blends stored at the same temperature did not differ significantly. In flavor evaluations after 6 months storage, breads from EMG blends were ranked above those of PS-60 and SSL. After 12 months storage, EMG and PS-60 blends retained satisfactory flavor and were ranked above those of SSL. When blends were dried to 10% moisture, SSL blends retained satisfactory baking performance for 6 months at 100°F (>90% of control-loaf volume). No significant differences in baking performance or storage stability were found among three commercial defatted, lightly heated soy flours present in blends.

Soy-fortified wheat-flour (SFF) blends have been used in overseas aid programs since 1972 (1,2). Storage studies have indicated that, in blends containing 12.4 to 13.0% moisture and at 100°F, the added surfactant sodium stearoyl-2-lactylate (SSL) becomes less effective in maintaining loaf volume within a few weeks and, upon longer storage, the wheat flour loses baking strength and develops off-flavors (3,4).

In practice, unsatisfactory baking performance of blends has been observed occasionally when the SFF blend has been stored under adverse conditions of temperature and humidity, and distribution time has exceeded 6 months. To obviate such difficulties, at least three alternatives can be suggested. 1) The SSL might be omitted from the blend and added at the time of dough-mixing; but previous work (4) suggested that SSL may not be effective with storage-deteriorated flours. Also, additional inventory problems would be created at all points in the supply line. 2) The maximum moisture in the complete blend might be set considerably lower than the present 12.7 and 12.4% for the 6 and 12% SFF blends, respectively, because the stability of SFF blends is increased by lowering their moisture content (3). This would require that wheat flour be produced or dried below 13% moisture. However, this is not common practice in the U.S. and would increase costs. 3) A surfactant might be used which is more effective

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Reference to a company or product name does not imply approval or recommendation of the product by the U.S. Department of Agriculture to the exclusion of others that may also be suitable.

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than SSL in stored blends, assuming that off-flavors did not develop so rapidly as to make the blend unacceptable while bread of good volume and texture could still be produced.

The effectiveness of several materials with potential as loaf-volume improvers in wheat-soy-flour blends was pointed out at about the same time (5–8). In addition to SSL, the group includes ethoxylated monoglycerides (EMG), polysorbate-60 (PS-60), sucrose esters (SE), and the glycolipids from wheat flour or other plants. Fatty esters of polyalkoxylated polyol glycosides also have been found effective (9). SSL has received most attention because it is a commercially available dry powder, has international acceptance as a food additive, and performs well in freshly prepared blends, particularly with respect to crumb structure. Because of questions of stability, however, comparisons with some of the other surfactants were made.

MATERIALS AND METHODS

Flours

The wheat flours were samples from lots purchased by the Agricultural Stabilization and Conservation Service (ASCS) as export all-purpose and bread flours, or were supplied as typical of flours produced for use in soy-fortified wheat-flour blends. Mills located in various areas of the U.S. are represented.

TABLE I
Composition of Wheat and Soy Flours[a]

	Moisture %	Protein[b] %	Ash %	Crude Fat %	Falling Number
Wheat flour					
Experiment A[c]	13.3	10.2	0.48	1.2	496
Experiment B	12.9	11.7	0.72[d]	...	258
Experiment C	11.6	11.4	0.81[d]	...	266
Experiment D	13.7	11.1	0.38	1.3	289
Experiment E	13.4	12.1	0.44	1.2	285
Soy flour					
Experiment A	8.1	52.9	5.3	1.5	
Experiment B	8.5	53.8	6.2	2.3	
Experiment C					
I	8.5	53.8	6.2	2.3	
II	6.0	52.1	6.2	1.4	
III	7.0	52.4	6.0	1.8	
Experiment D	7.9	53.5	6.6	1.7	
Experiment E	5.7	51.8	6.9	1.3	

[a]As-is moisture basis.
[b]N × 5.7 for wheat flours; N × 6.25 for soy flours.
[c]The all-purpose wheat flour of Experiment A did not meet the 11% protein minimum adopted later in purchase specifications.
[d]Calcium carbonate included in these flours as obtained.

The soy flours were defatted, lightly heated products purchased as the type supplied to bakers or obtained as samples from processors as representative of that type. Properties of the flours and designation of the storage experiment in which each one was used are given in Table I.

Surfactants

Commercial dough conditioners and experimental compounds were included in the study. The commercially available products and their compositions were the following:

SSL =sodium stearoyl-2-lactylate (Emplex from Patco Products).
EMG =32% ethoxylated monoglycerides and 33–37% α-monoglycerides, remainder di- and triglycerides (Tally 100 Plus from Durkee Div., SCM Corporation).
PS-60 =25% polysorbate-60 and 75% mono- and diglycerides (Tandem 9 from Atlas Chemical Industries). The dry-flake form supplied was ground to a powder in a Wiley mill in the presence of Dry Ice to prevent softening.
MSSL =physically modified SSL to increase its stability in flour blends (Patco Products).

TABLE II
Composition of Blends in Storage Experiments

	Soy Flour %	Moisture %	Surfactant %	Surfactant Type[a]	Loaf Volume[b] ml
Blend for					
Experiment A[c]	6	12.7, 10.0	0.28	SSL	676, 670
				EMG	657, 661
Experiment B	6	12.7, 10.0	0.28	SSL	689, 664
				EMG	685, 681
Experiment C I, II, III,	12	12.4	0.50	SSL	672, 656, 650[d]
				EMG	665, 662, 631[d]
Experiment D	12	12.4	0.50	SSL	665
				MSSL	671
				EMG	640
				PS-60	592
Experiment E	12	12.4	0.50	SSL	667
				PGGM	668
				SE-F-140	661
				SE-F-160	666

[a]SSL, sodium stearoyl-2-lactylate; EMG, ethoxylated monoglycerides; MSSL, a modified SSL; PS-60, polysorbate-60; PGGM, polyoxyethylene glycerol glycoside monostearate; SE-F-140 and SE-F-160, sucrose esters.
[b]Initial pup-loaf volume of blends at zero-time storage.
[c]The experiment letter identifies the wheat and soy flours used; see Table I.
[d]Values for blends with soy flours I, II, and III, respectively.

The experimental compounds included the following:

SE =sucrose esters, identified as F-140 and F-160, produced by Dai-ichi Kogyo Seiyaku, Japan; supplied by Department of Economic Development, Box 94666, State Capitol, Lincoln, NE 68509.

PGGM =POE (9.6) glycerol glycoside monostearate prepared at the Northern Regional Research Laboratory, ARS, U.S. Department of Agriculture, Peoria, IL 61604.

For preparation of PGGM, glycerol, starch, and sulfuric acid were heated together and the resulting glycosides were treated with 9.6 mol ethylene oxide/mol to form polyethers, followed by esterification of the products with 1 mol stearic acid. The emulsifier so obtained was blended with an equal weight of starch, and 1% tricalcium phosphate was added. Additional information on compounds of this type is available (10,11).

Preparation, Storage, and Baking of Blends

Blends were prepared according to ASCS specifications (1,2) except that test surfactants were substituted for SSL where experiment indicated. Moisture adjustment to required levels, storage, and removal from storage were as

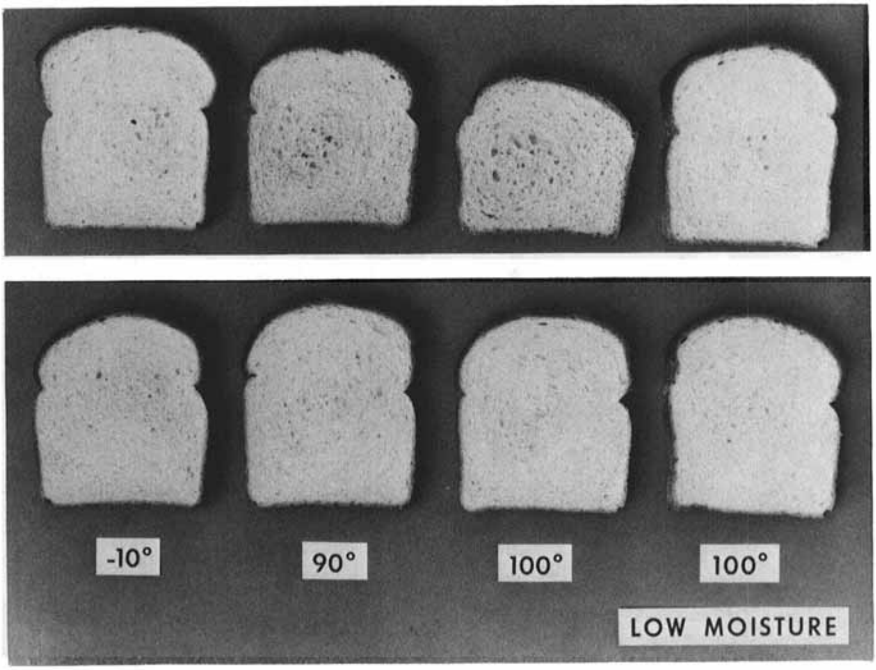

Fig. 1. Experiment A: Breads baked from 6% soy-fortified all-purpose-flour blend that was stored 3 months with either SSL (upper row) or EMG (lower row). The low-moisture samples at 100° F were 10.0%; the other blends had 12.7% moisture.

previously described (3). Duplicate moisture determinations were made in a forced-air oven at 130° C for 1 hr. Blends containing 6% soy flour were stored at −10°, 90°, and 100° F. Those containing 12% soy were stored at −10° and 100° F. All were evaluated at intervals up to 12 months.

Baking tests were carried out as described earlier (3) except that shortening was not added to doughs in baking, and pound loaves were given 30 revolutions under pressure on a three-roll dough molder (National Mfg. Co.) after the sheeted doughs were curled by hand. Blend compositions and initial pup-loaf volumes are shown in Table II. Loaf volumes of stored samples are expressed as per cent change from −10° F controls containing SSL and baked at the same time.

Odor and Flavor Evaluation

For evaluation of odor changes, flour blends were placed in 4-oz screw-cap jars (half full) and submitted to a panel of 18 to 21 judges. The samples were presented as a duo-trio, and the judges were asked to match the odor of one of the two coded samples to that of the labeled control, state their preference, and identify any rancid or other off-odor samples. Each comparison was replicated twice, and the position of control samples in the coded pair was balanced. Evaluation of taste changes in bread was carried out as previously described (4).

RESULTS

Baking Tests—SSL and EMG Blends

A blend of 6 parts soy flour, 94 parts wheat flour, and 0.28 parts surfactant (Experiment A) gave the results shown in Figs. 1 and 2. In these blends, the

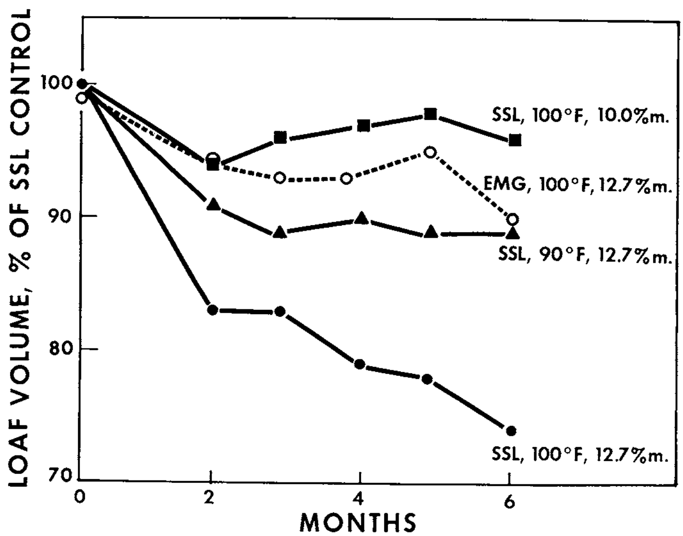

Fig. 2. Experiment A: Loaf-volume changes from a −10° F SSL control for 6% soy-fortified all-purpose-flour blends containing either SSL or EMG, stored at indicated temperatures and moisture content. Standard deviation is 1.88%; standard error is 0.94%.

protein content of the all-purpose wheat flour was 10.2%, so the relatively rapid deterioration of the 12.7% moisture SSL sample may reflect marginal flour strength as well as decreased effectiveness of SSL. Nevertheless, it is noteworthy that the SSL blend at 10% moisture was little affected by 100° F storage. The EMG samples retained reasonably good baking properties, even at 100° F and 12.7% moisture (the only EMG blend shown in Fig. 2). This blend, when held at a lower temperature (90° F) or lower moisture (10%), retained 95% of the control volume throughout storage. Then, at 6 months, the 90° sample dropped to 93.4%. As shown in Fig. 1, internal characteristics of the bread reflected as marked differences as loaf volume, *e.g.*, coarse, open grain with decreased volume.

In Experiment B, a stronger bread wheat flour was used with 6% soy flour. The initial rate of loss of loaf volume (Fig. 3) was less than Experiment A. However, deterioration continued until, at 6 months, the percentage of loss of loaf volume was almost the same with the bread-flour blends as found with the corresponding all-purpose-flour blends of Experiment A. The SSL blends stored at −10° F gave loaf volumes averaging 684 ml for the export bread-flour blend and 683 ml for the all-purpose-flour blend, so the comparison between flours is not affected by expressing the results on a percentage basis.

A third comparison was made with blends containing 12% soy flour (Experiment C, Fig. 4). Storage conditions were limited to 100° F and 12.4% moisture. Soy flours from three processors were used; loaf volumes differed only slightly among them. The soy flour giving the largest loaf volume (the 100% value at zero time, Fig. 4) was used in the blend stored at −10° F as the SSL control. With the increased proportion of soy flour (12%), the loss of loaf volume with storage of the SSL blends was quite rapid, averaging 25% in 2 months. The less rapid loss observed in earlier work (3) (about 12% of loaf volume in 6 months) probably reflects the addition of 3% shortening to doughs and its omission in the present work. This difference has been confirmed in later work (unpublished data). The blends containing EMG maintained their loaf-volume potential relatively well, again illustrating the greater stability of baking performance of such blends (*vs.* SSL) after storage at high moistures and temperatures. The three soy flours gave blends with similar baking properties. The maximum spreads in loaf volume of 4% among blends containing EMG and of 6% with SSL are not large enough to indicate differences among the soy flours. Accordingly, the range as well as average values have been shown on the two curves of Fig. 4. It may be noteworthy that, in the 2- to 4-month storage period, loaf volumes for blends containing SSL stabilized and increased slightly. The change is too small to be considered significant on the basis of one experiment, but a similar trend appears to be present in Figs. 2 and 3. It also supports the suggestion made in a previous paper (4) that the baking performance of defatted, lightly heated soy flours actually improves for a few months at 100° F and 13% moisture.

Baking Tests—Other Surfactants

The above results suggested comparison of blends containing other surfactants, to identify any (including EMG) that might serve as satisfactory alternatives to SSL in soy-fortified flours. Results with blends containing products commercially available in the U.S. and stored up to 12 months are shown in Fig. 5 (Experiment D). The 12% soy blend containing EMG again

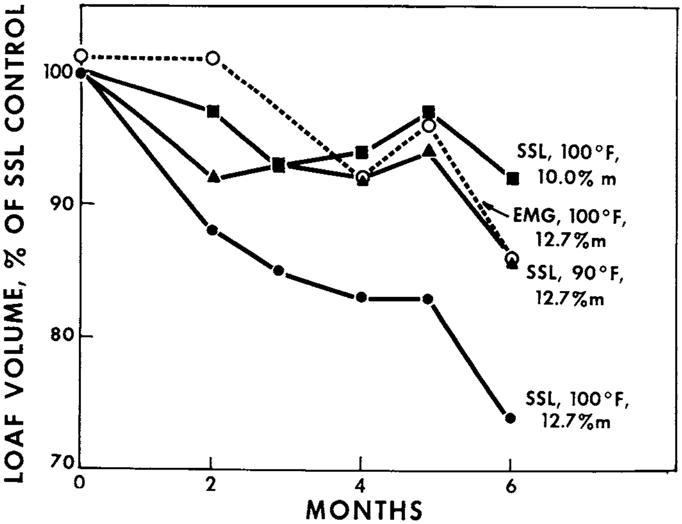

Fig. 3. Experiment B: Same as Fig. 2 except a bread flour was used in the blend. Standard deviation is 1.72%; standard error is 0.86%.

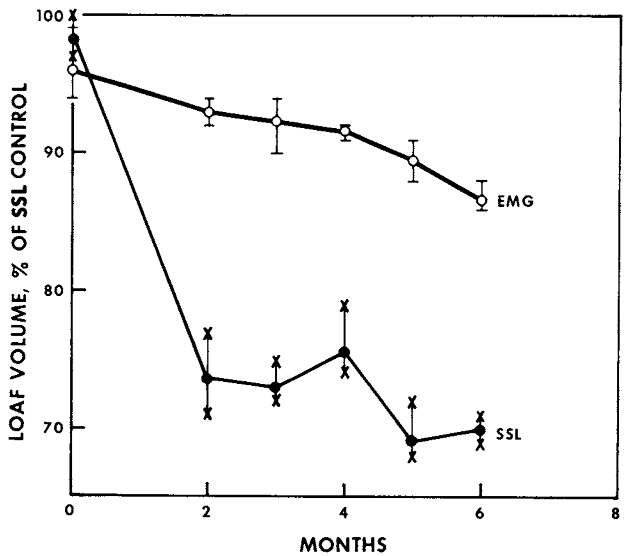

Fig. 4. Experiment C: Loaf-volume changes from a −10° F SSL control for 12% soy-fortified bread flour containing either SSL or EMG and 12.4% moisture; stored at 100° F. The spread obtained for the three soy flours used is indicated at each average point.

retained relatively good loaf-volume potential through 6 months at 100° F. The PS-60 blend changed little in loaf volume during the first 6 months of storage, but was only 90% of the SSL control blend before storage. This may be due to the significantly lower content (25%) of the loaf-volume-improving component in the commercial preparation used. Products containing higher levels of polysorbate are available but their physical state (plastic or hydrate) eliminates them from consideration in dry-flour blends. The modified SSL gave appreciably higher loaf volumes through about 3 months but then began to approach more closely the performance of the unmodified SSL blend.

Results with SE and PGGM are compared with SSL results in Fig. 6 (Experiment E). The three materials were much alike in their effectiveness in the freshly prepared 12% soy blends, and maintained better than 95% of the loaf volume of the SSL control blend through 4 months storage. Loaf volumes then gradually declined on longer storage.

Odor and Taste Evaluations

Odors of samples in Experiment A (using a 6% SFF blend) were compared after storage for 6 months (Table III). Holding blends at either 100° or 90° F produced significant differences in odor compared with storage at −10° F. However, none of the comparisons between an SSL and an EMG sample stored

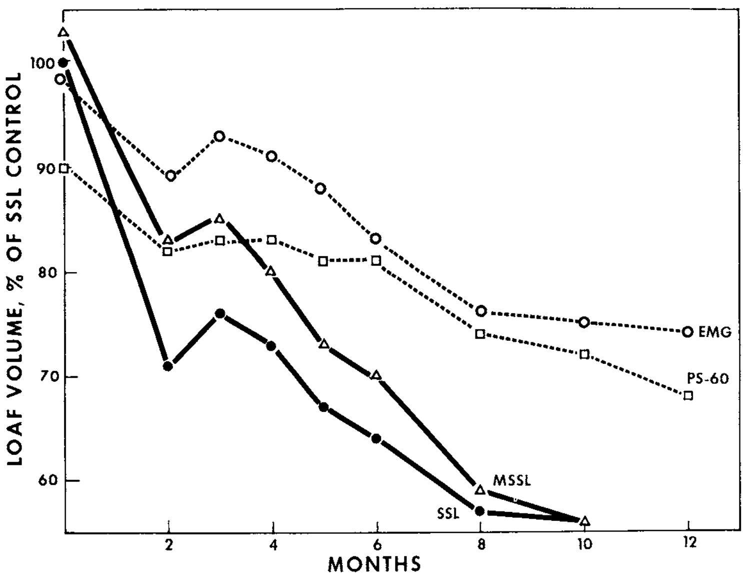

Fig. 5. Experiment D: Loaf-volume changes from a −10° F control for 12% soy-fortified bread flour containing various surfactants. Blends contained 12.4% moisture and were stored at 100° F. Standard deviation is 2.15%; standard error is 1.08%. EMG, ethoxylated monoglycerides; PS-60, polyoxyethylene (20) sorbitan monostearate; MSSL, modified sodium stearoyl-2-lactylate; and SSL, sodium stearoyl-2-lactylate.

under the same conditions showed a significant difference or preference.

With samples of Experiment C (using a 12% SFF blend), the effect of 100° F storage for 6 months on odor appeared to be less pronounced (Table III). Preferences were in favor of the −10° F samples but only at the 13% probability level, not normally considered significant. The results suggest that the increased soy level with the resulting slightly lower moisture content (12.4 *vs.* 12.7%) may help prevent off-odor development, although greater stability of the different wheat flour used in the 12% blend could also be responsible. Again, no significant difference was found between EMG and SSL with regard to odor development during storage.

The taste of bread baked from the 6% soy flour blend (Experiment A) was evaluated by a ranking procedure. The results indicated that the 100° F SSL samples were least like the −10° F SSL control, the difference in score being at the borderline of significance. Rankings of the 100° F EMG, −10° F EMG, and −10° F SSL samples were very close. In direct comparisons of pairs, the only statistically significant result was obtained between −10° F EMG and 100° F SSL samples. Thus it was indicated that the SSL 100° F sample was inferior to the EMG −10° F sample but not to the EMG 100° F or the SSL −10° F sample.

Bread was baked from the samples of Experiment D after 6 months storage; and flavors were scored by a ranking procedure and also rated hedonically on a

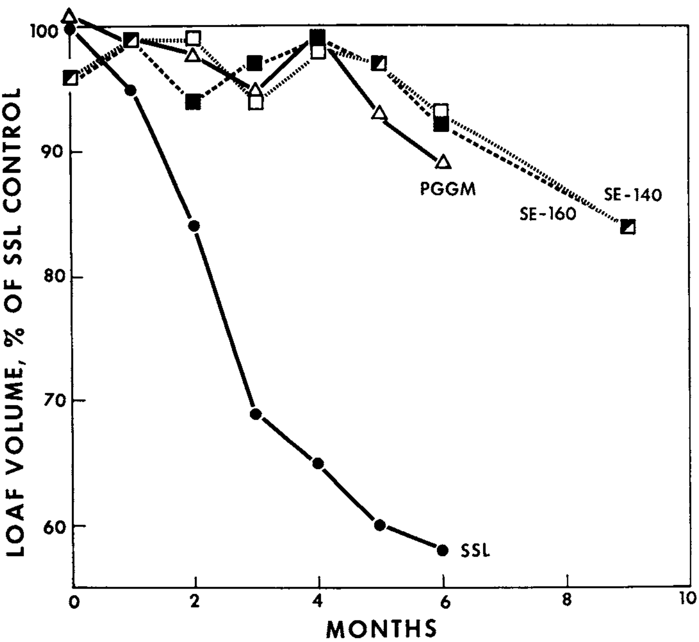

Fig. 6. Experiment E: Same as Fig. 5 except different surfactants were used in stored blends. Standard deviation is 3.10%; standard error is 1.55%. SE-140, sucrose ester, F-140; SE-160, sucrose ester, F-160; PGGM, polyoxyethylene glycerol glycoside monostearate; and SSL, sodium stearoyl-2-lactylate.

TABLE III
Odor Evaluations of Soy-Fortified Flours Stored 6 Months

Surfactant	Storage Temperature	N[a]	Correct Response	Probability
Experiment A				
EMG	−10° F *vs.* 100° F	42	37	0.000003
EMG	−10° F *vs.* 90° F	36	23	0.13
EMG	90° F *vs.* 100° F	36	25	0.028
SSL	−10° F *vs.* 100° F	42	33	0.00027
SSL	−10° F *vs.* 90° F	36	27	0.004
SSL	90° F *vs.* 100° F	36	31	0.000013
EMG *vs.* SSL	−10° F	42	20	...
EMG *vs.* SSL	90° F	36	18	...
EMG *vs.* SSL	100° F	42	24	...
Experiment C				
EMG	−10° F *vs.* 100° F	36	25	0.028
SSL	−10° F *vs.* 100° F	36	21	...
EMG *vs.* SSL	−10° F	36	18	...
EMG *vs.* SSL	100° F	36	18	...

[a]N = Number of responses.

TABLE IV
Flavor Evaluations of Stored 12% Soy-Fortified Flours Containing Various Surfactants (Experiment D)

Surfactant	Storage Temperature	Total Rank Sums[a]		Average Hedonic Rating[b]	
	°F	6 Months	12 Months	6 Months	12 Months
EMG	−10	41		6.0	
	100	57		5.3	
SSL	−10	45		5.8	
	100	67		4.5	
PS-60	−10	34		6.4	
	100	53		5.4	
MSSL	−10	49		6.4	
	100	64		4.6	
EMG	100	79	67	5.7	5.9
PS-60	100	105	76	4.7	5.6
SSL	100	121	109	4.7	4.6
MSSL	100	105	118	4.5	4.7

[a]Rank 1 = least off-flavor; 4 = most off-flavor (number of judgments totaled). Rank Sums: 6 months nonsignificant range P̄c 0.01 = 86–119 (N = 41); 12 months nonsignificant range P̄c 0.01 = 77–108 (N = 37).
[b]Rating 4 = dislike slightly; 5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; etc. (number of judgments averaged).

like-dislike scale. The $-10°$ F and $100°$ F samples were judged in groups of four as shown in Table IV. In addition, all samples held at $100°$ F were judged together in a separate evaluation (Table IV, also). As expected, the $-10°$ F samples were ranked as having less off-flavor than the corresponding $100°$ F samples. The hedonic rating also indicated significant differences between samples held at the two temperatures for all the surfactants except EMG. When all the $100°$ F samples were compared in one set, the EMG sample was ranked as having the least off-flavor. Hedonic ratings also indicated that the EMG sample was liked significantly better than those samples containing the other surfactants. A second evaluation after 1 year of storage differed principally in that the PS sample was given scores quite close to those of the EMG, with the SSL and MSSL samples again ranked lowest and given lower hedonic ratings. Taste testing was not permitted for SE and PGGM because they are not accepted food additives in the U.S.

DISCUSSION

The loss of bread loaf-volume potential in stored blends containing EMG, rather than SSL, was much slower than expected. The direct comparisons reported here, together with the observations reported earlier regarding changes in the soy and wheat flours (4), suggest that EMG does not undergo a change early in storage under adverse conditions such as SSL seems to undergo. The increased stability of SSL blends at 10% moisture continues to suggest that moisture content of blends is a critical factor in the effectiveness of SSL. Hydrolysis of this compound at normal flour moisture has been suspected but not confirmed in any published reports. However, changes in SSL do not account for the large losses in loaf volume observed over a longer time. As previously indicated (4), deterioration in wheat flour also occurs such that lost volume is not regained with SSL added when doughs are mixed. Consequently, the present results suggest that EMG may exert an improving effect on storage-deteriorated wheat-soy blends. This will be reported upon in a subsequent paper.

SE and PGGM were tested in only one experiment, but the results indicated somewhat greater retention of loaf-volume potential with these additives than with EMG or PS-60. Neither of the latter was included in the experiment, so direct comparisons were not made; however, the results can be compared to those with SSL in the two experiments. The flour blend used with SE and PGGM was somewhat less stable with SSL than the blend used with EMG and PS-60 (Fig. 5 *vs.* Fig. 6). Consequently, the latter may have been the more demanding test and the performance of SE and PGGM, therefore, is more impressive.

The large losses in loaf volume after 6 months storage (without shortening added to doughs) raise the question of acceptability of the blends regardless of the flavor of bread they produced. However, the hedonic ratings at worst did not reach the "dislike slightly" level, and the lack of change in rating from 6 months to 12 months storage seems particularly significant in view of the continued decrease in loaf volume. Storage at 12.4% or less moisture content then was relatively slow to produce off-flavors; and loss of loaf-volume potential led more quickly to unacceptable quality than did development of off-flavors.

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Literature Cited

1. AGRICULTURAL STABILIZATION AND CONSERVATION SERVICE. U.S. Department of Agriculture, Announcement WF-9. Purchase of soy-fortified bread flour for use in export programs, September 27, 1972. (ASCS Commodity Office, P.O. Box 8377, Shawnee Mission, Kansas 66208.)
2. FELLERS, D. A., MECHAM, D. K., BEAN, M. M., and HANAMOTO, M. M. Soy-fortified wheat flour blends. I. Composition and properties. Cereal Foods World 21: 75 (1976).
3. BEAN, M. M., HANAMOTO, M. M., MECHAM, D. K., GUADAGNI, D. G., and FELLERS, D. A. Soy-fortified wheat flour blends. II. Storage stability of complete blends. Cereal Chem. 53: 397 (1976).
4. MECHAM, D. K., HANAMOTO, M. M., BEAN, M. M., FELLERS, D. A., and GUADAGNI, D. G. Soy-fortified wheat flour blends. III. Storage stability of ingredients and incomplete blends. Cereal Chem. 53: 405 (1976).
5. 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).
6. FINNEY, K. F., and SHOGREN, M. D. Surfactants supplement each other, make foreign proteins compatible in breadmaking. Baker's Dig. 45(1): 40 (1971).
7. TSEN, C. C., HOOVER, W. J., and PHILLIPS, D. High-protein blends. Use of sodium stearoyl-2-lactylate and calcium stearoyl-2-lactylate in their production. Baker's Dig. 45(2): 20 (1971).
8. TSEN, C. C. New concepts for use of soy flour in baking: Preparation of high-protein bread. In: Soy: The wonder bean. Amer. Ass. Cereal Chem.: St. Paul, Minn. (1971).
9. BEAN, M. M., MEHLTRETTER, C. L., WILHAM, C. A., and McGUIRE, T. A. Fatty esters of polyalkoxylated polyol glycosides as bread additives. Food Prod. Dev. 7(3): 30 (1973).
10. OTEY, F. H., MEHLTRETTER, C. L., and RIST, C. E. Starch-derived polyol glycosides. Cereal Sci. Today 13: 199 (1968).
11. BOOKWALTER, G. N., and MEHLTRETTER, C. L. Dough conditioners for 12% soy-fortified bread mixes. J. Food Sci. 41: 67 (1976).

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