FUNCTIONAL PROPERTIES OF SURFACTANTS IN BREADMAKING. I. ROLES OF SURFACTANTS IN RELATION TO FLOUR CONSTITUENTS IN A DOUGH SYSTEM[1,2]

O. K. CHUNG[3,4] and C. C. TSEN[3], Kansas State University, Manhattan, KS 66506

ABSTRACT

In doughs mixed to optimum consistency, sodium stearoyl-2-lactylate (SSL), calcium stearoyl-2-lactylate (CSL), and ethoxylated monoglycerides (EMG) competed with lipids on the binding sites of wheat-flour dough constituents and suppressed lipid binding in this order: EBG $\simeq$ CSL $>$ SSL. The surfactants also complexed with dough constituents, including lipids, in this order: SSL $>$ CSL $>$ EMG. The main reactive sites were in the 0.05*N* acetic acid-soluble proteins (A) for the nonionic EMG and the acid-insoluble starch-lipid-protein fraction C for the ionic SSL and CSL. Dough stability increased with increasing level of the ionic surfactants, apparently due to increase in fraction C stabilized by interaction between surfactants with proteins, lipids, and starch. Maximum stability in the EMG dough was reached with 0.5% of the additive, presumably due to formation of the most stabilized form of complex between EMG and proteins and lipids in the acid-soluble fraction A.

In recent years, the production of acceptable high-protein breads has been made possible by the addition of small amounts of lipids or lipid-related surfactants to the doughs (1,2,3).

Some surfactants complex with the starch moiety (4,5) and interact with wheat-flour proteins (5–10) or with such foreign protein concentrates as soy

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[2]Presented at the 58th Annual Meeting, St. Louis, Mo., Nov. 1973.

[3]Respectively: Postdoctoral Research Associate and Professor, Department of Grain Science and Industry.

[4]Present address: U.S. Grain Marketing Research Center, ARS, USDA, Manhattan, KS 66502.

proteins (6). However, the improving mechanisms of certain surfactants in breadmaking are not well understood.

Previously we studied the functional properties of surfactants by observing how their presence changed protein- and lipid-extractabilities and also dough-mixing characteristics (11,12). We report here on effects of surfactants on lipid binding in an optimally mixed dough system and in dough fractions. Quantitative data on changes in dough fractions and associated lipids, as affected by different levels of surfactants, should provide a better understanding of functional properties of surfactants in breadmaking.

MATERIALS AND METHODS

Materials

Flour sample used for this study was as described previously (13). The surfactants used were sodium stearoyl-2-lactylate (Emplex or SSL), calcium stearoyl-2-lactylate (Verv or CSL), and ethoxylated monoglycerides (EMG) obtained from Patco Products, Kansas City, Mo. Reference materials and chemical reagents used were the same as previously described (11,13).

Preparation of Dough Samples

Surfactant was mixed with wheat flour as described previously (11). They were further blended in a farinograph 300-g mixing bowl. Distilled water was added, and dough with or without added surfactant was mixed to optimum consistency. Mixed doughs were immediately frozen, lyophilized, and ground to pass a 60-

TABLE I
Farinogram Characteristics of Doughs Prepared from Wheat Flour with Surfactants Added[a]

Surfactant Level %	Water Absorption %	Arrival Time min	Peak Time min	Departure Time min	Dough Stability min	M.T.I. BU
0 (Control)	57.2	1.8	4.3	7.0	5.2	70
Emplex (SSL)						
0.25	56.0	1.2	2.5	7.5	6.3	50
0.50	56.7	1.5	2.5	10.0	8.5	50
1.00	55.0	1.3	2.0	12.5	11.2	40
2.00	55.7	1.5	26.5	68.5	67.0	0
Verv (CSL)						
0.25	57.1	1.8	4.3	8.5	6.7	50
0.50	57.0	1.5	4.0	8.3	6.8	50
1.00	56.8	1.3	3.0	8.6	7.3	40
2.00	58.0	1.5	2.8	10.0	8.5	40
Ethoxylated monoglyceride (EMG)						
0.25	56.6	2.5	6.0	9.5	7.0	50
0.50	56.2	2.5	5.5	10.0	7.5	50
1.00	55.5	2.0	5.0	8.0	6.0	60
2.00	52.7	1.8	4.3	7.8	6.0	60

[a]Average of two replicates.

mesh sieve; ground doughs were stored at −18° C between experiments. Moisture contents of the lyophilized and ground doughs were determined according to AOAC Method 14.004 (14).

Fractionation of Lyophilized Doughs

Samples were fractionated, as described previously (13), into "acetic acid-soluble fraction" (A) and acid-insoluble residue; top layer of residue, "gelatinous fraction" (B); middle layer, "starch-lipid-protein fraction" (C); and bottom layer, "starch fraction" (D). Fraction D was discarded because it contained very little proteins, and we were interested mainly in dough fractions containing proteins.

Determination of Proteins

Nitrogen content was determined by the AOAC micro-Kjeldahl method 42.014-42.016 (14), and protein content was calculated using 5.7 as conversion factor.

Extraction of Lipids and Surfactants

Lipids and surfactants were extracted in duplicate as described previously

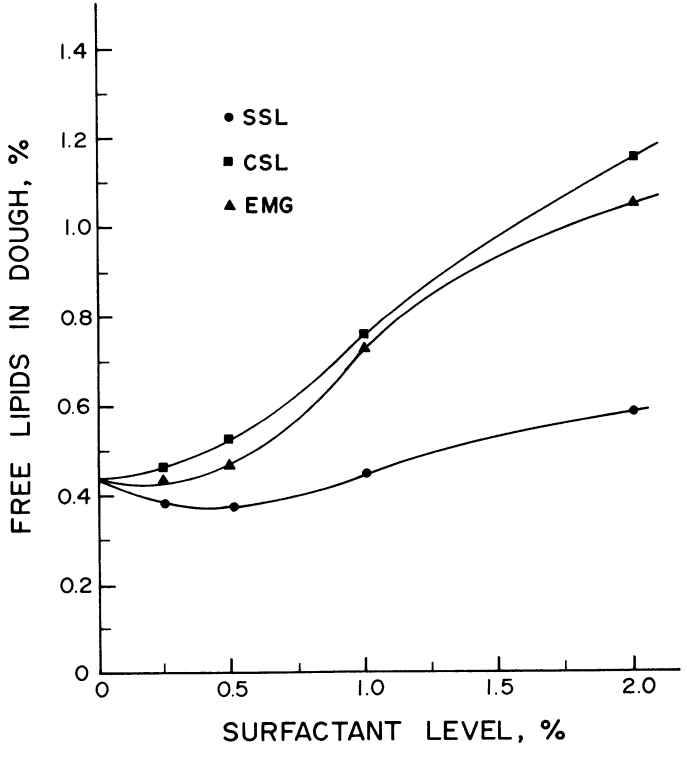

Fig. 1. Free lipids in doughs containing SSL, CSL, and EMG; lipids and surfactants were expressed as percentage of dough weight (dry basis).

(11,13), those extracted by petroleum ether (PE) being defined as free and those by water saturated n-butanol (WSB) (following PE extraction) as bound.

Thin-Layer Chromatography (tlc) and Quantitative tlc

Those methods were as described previously (11,13). Each PE or WSB extract was chromatographed twice. Therefore, the reported value was obtained from an average of quadruplicated chromatogram.

RESULTS AND DISCUSSION

Farinograph Studies

Adding surfactants, except 2% CSL, slightly decreased water absorption; adding 2% EMG decreased absorption most (Table I). Adding any of the three surfactants increased dough stabilities at all levels. Dough stability was highly and positively correlated with increasing level of either ionic surfactant (SSL and CSL), with a product-moment coefficient of linear correlation being 0.921 and 0.937 for SSL and CSL, respectively. When the nonionic surfactant EMG was added, dough stability was highest at the 0.5% level of surfactant addition. Those different effects suggest that ionic and nonionic surfactants have different mechanisms for improving dough properties.

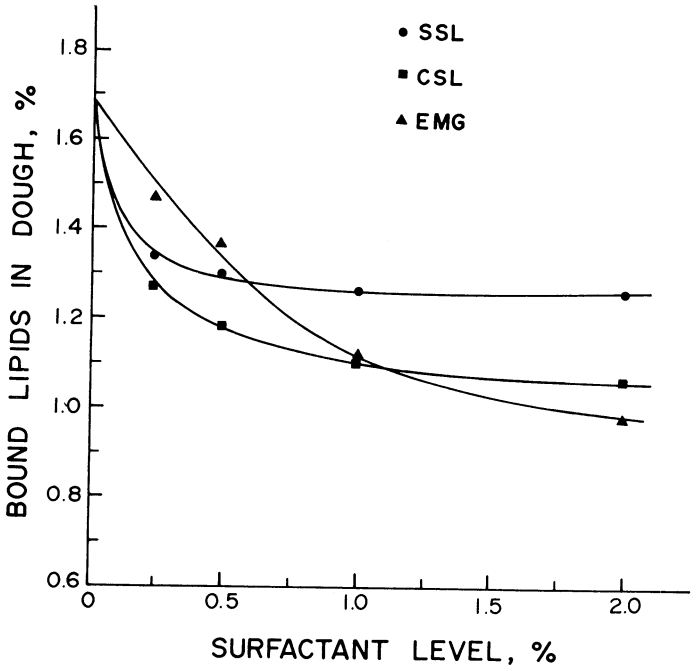

Fig. 2. Bound lipids in doughs containing SSL, CSL, and EMG; lipids and surfactants were expressed as percentage of dough weight (dry basis).

Changes in Lipid Binding Affected by Surfactants

More free lipids were extracted with PE from doughs containing CSL and EMG at all levels and from the SSL doughs at the highest level (2.0%) than from the control dough (Fig. 1). More lipids were present in free form in the EMG and CSL doughs than in the SSL doughs.

Less bound lipids were extracted with WSB from doughs containing any of the three surfactants than from the control dough (Fig. 2).

Different binding capabilities of surfactants were demonstrated (Figs. 3 and 4); much more SSL was present in bound form than the other two surfactants and free SSL, at any level of supplementation, was lowest among the surfactants.

The three surfactants suppressed lipid binding by partially replacing lipids, possibly by competing with lipids on the binding sites of flour dough constituents (Figs. 1–4). That effect was approximately the same by EMG and CSL, and least by SSL. Besides replacing lipids, the surfactants also showed complexing characteristics, SSL demonstrating the greatest and EMG the least such ability.

Changes in Dough Fractions as Affected by Surfactants

Increasing SSL decreased fractions A and B and increased fraction C (Table

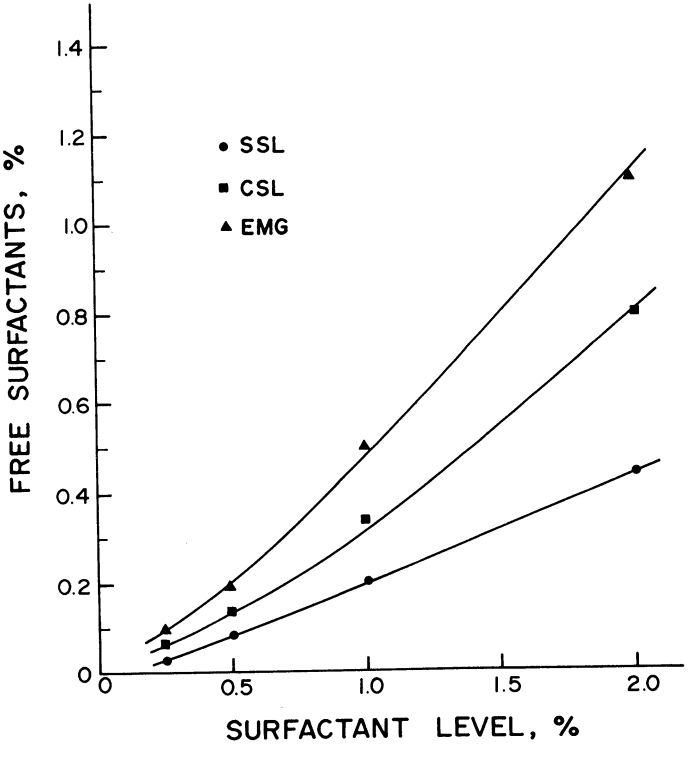

Fig. 3. Free surfactants extracted with petroleum ether from doughs mixed with SSL, CSL, and EMG; surfactants were expressed as percentage of dough weight (dry basis).

II). As SSL increased, the sum total of fractions (A+B+C) increased, indicating a decrease in starch fraction D. Effects of CSL were similar but much less pronounced than those of SSL. The nonionic EMG affected very little on acid-soluble fraction A of which amounts remained nearly constant, regardless of levels of EMG added. However, EMG showed similar but less pronounced effects on B and C with that of ionic surfactants.

As types and levels of surfactants affected amounts of dough fractions (Table II), changes in proteins, lipids, and surfactants are presented in Figs. 5–8 as per cent of total proteins or as per cent of the starting dough weight (dry basis).

As shown in Fig. 5, increasing the surfactant level decreased the amount of proteins present in fractions A and B and increased the amount in fraction C. The ionic surfactants had much more pronounced effects than did the nonionic surfactant, demonstrating the strong ability of the ionic surfactants to enhance the aggregational properties of proteins, thereby decreasing their solubility in 0.05*N* acetic acid. An increase in weight of fraction C by an increasing level of SSL or CSL was substantially larger than a decrease in weight of acid-soluble

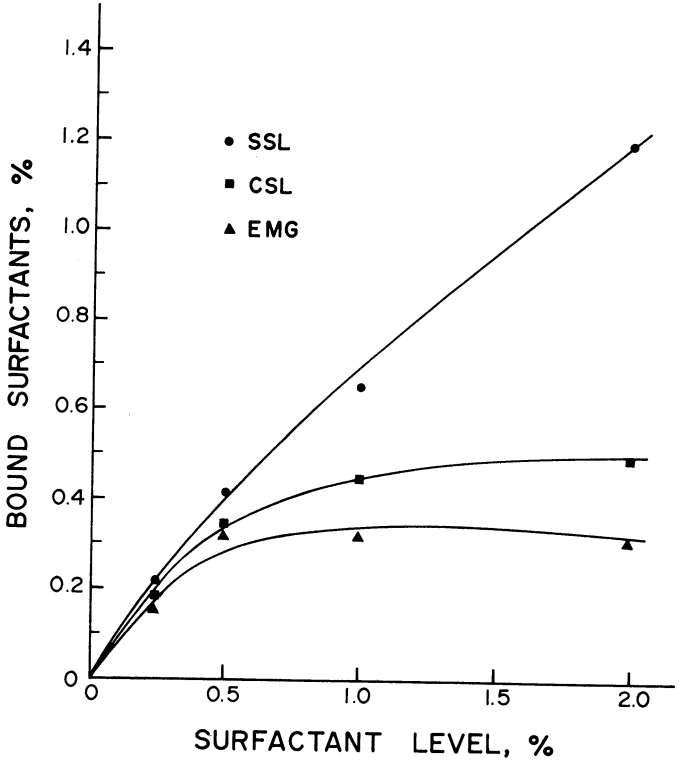

Fig. 4. Bound surfactants extracted with water saturated n-butanol from doughs mixed with SSL, CSL, and EMG; surfactants were expressed as percentage of dough weight (dry basis).

proteins in fraction A, indicating that the ionic surfactants were possibly complexing proteins with the starch moiety.

Amounts of lipids bound to proteins present in fractions A and B also decreased, and lipids in C increased when the supplementation level of the ionic surfactants were increased (Fig. 6). The nonionic surfactant affected lipid binding differently; largest amount of bound lipids in A was at 0.5% level of EMG, and amounts of bound lipids in C were constant at lower level and decreased at higher level. In the ionic surfactant doughs, one-half to two-thirds of WSB-extractable bound lipids were present in C, respectively, at the 0.25 to 2.0% surfactant level. In the EMG doughs, only less than one-third of bound lipids were present in C at all EMG levels.

As the EMG level increased, the surfactant was increasingly bound in fractions A and B and remained constant in C; the amount of SSL bound in both fractions A and B decreased, and substantially increased in C; and CSL showed a similar effect with EMG in fractions A and B but certainly a similar effect with SSL in fraction C (Fig. 7).

Figure 8 shows that the SSL and CSL doughs contained approximately the same amount of PE-extractable lipids and surfactants in fraction A and also in fraction C. In fraction A of the ionic surfactant doughs, PE extracts were small and little affected by surfactant level; and in C of those doughs, substantially more lipids and surfactants were extracted with PE as SSL or CSL level increased. The reverse was shown in the EMG dough system. In gelatinous

TABLE II
Effect of Surfactant Levels on Dough Fraction Distribution[a]

Surfactant Level	Surfactants		
	SSL	CSL	EMG
	% of dough (dry basis)		
(A) Acid-soluble fraction			
0	15.8	15.8	15.8
0.25	15.2	15.0	15.7
0.50	15.9	15.9	16.0
1.00	14.5	14.8	15.7
2.00	11.5	14.8	15.9
(B) Gelatinous fraction			
0	5.5	5.5	5.5
0.25	4.4	4.8	3.8
0.50	2.9	4.3	3.7
1.00	1.8	3.5	3.3
2.00	0	3.0	3.4
(C) Starch-lipid-protein fraction			
0	19.6	19.6	19.6
0.25	39.4	37.0	21.8
0.50	44.4	33.6	23.8
1.00	49.9	31.1	26.8
2.00	61.1	34.9	30.6

[a]Sum total of fractions (A+B+C) was 100-fraction (D); average of two replicates.

fraction B, the three surfactants affected on PE extracts differently.

Although PE-extractable lipids or surfactants were defined as free, they apparently were weakly associated with various dough fractions. More free and bound lipids were associated with proteins in the acid extract A of the nonionic surfactant doughs than with those of the ionic surfactant doughs. The nonionic surfactant, EMG, itself was associated more with A than with the acid-insoluble fractions B and C. In the ionic surfactant doughs, more total lipids (free and bound) and more total SSL or CSL were associated with fraction C than with the fractions A and B.

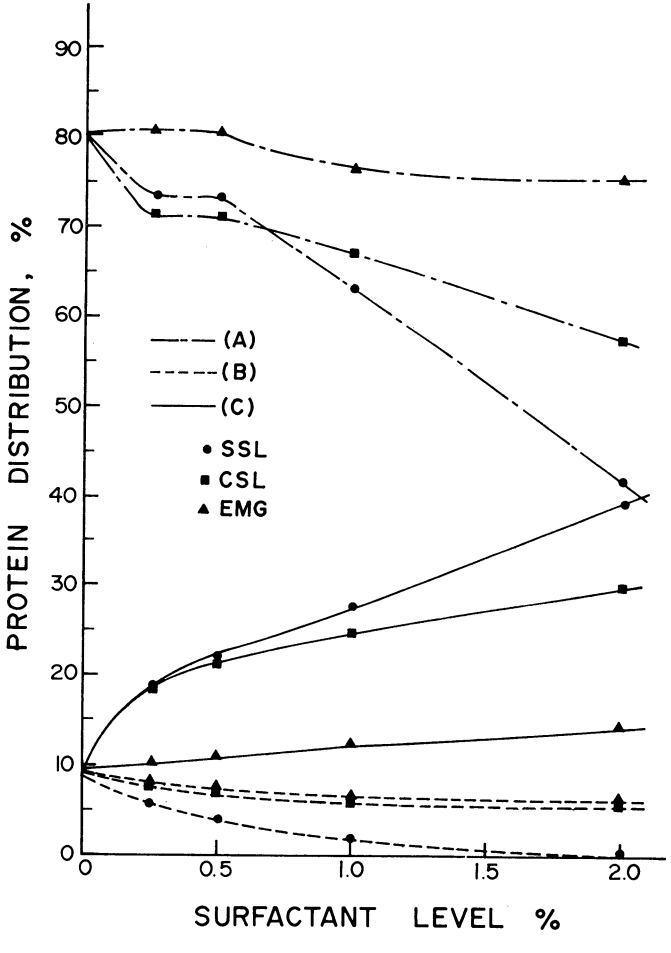

Fig. 5. Protein distribution in doughs containing SSL, CSL, and EMG; distribution was expressed as percentage of total proteins and surfactants were expressed as percentage of dough weight (dry basis). Average of triplicated extracts. (A) Acetic acid-soluble fraction; (B) gelatinous fraction; (C) starch-lipid-protein fraction.

CONCLUSIONS

Results show large differences in functional properties between ionic and nonionic surfactants studied and small differences between SSL and CSL.

The main function of SSL seemed to be to complex flour constituents to form more fraction C. SSL promoted the association of starch-lipids-proteins, leading to reduced amounts of proteins and lipids in the acid-soluble fraction A and to further reduced amounts of acid-insoluble proteins and associated lipids in the gelatinous fraction B. When 2.0% SSL was added to dough, fraction B of the gelatinous aggregate was absent, indicating its possible complexing with starch

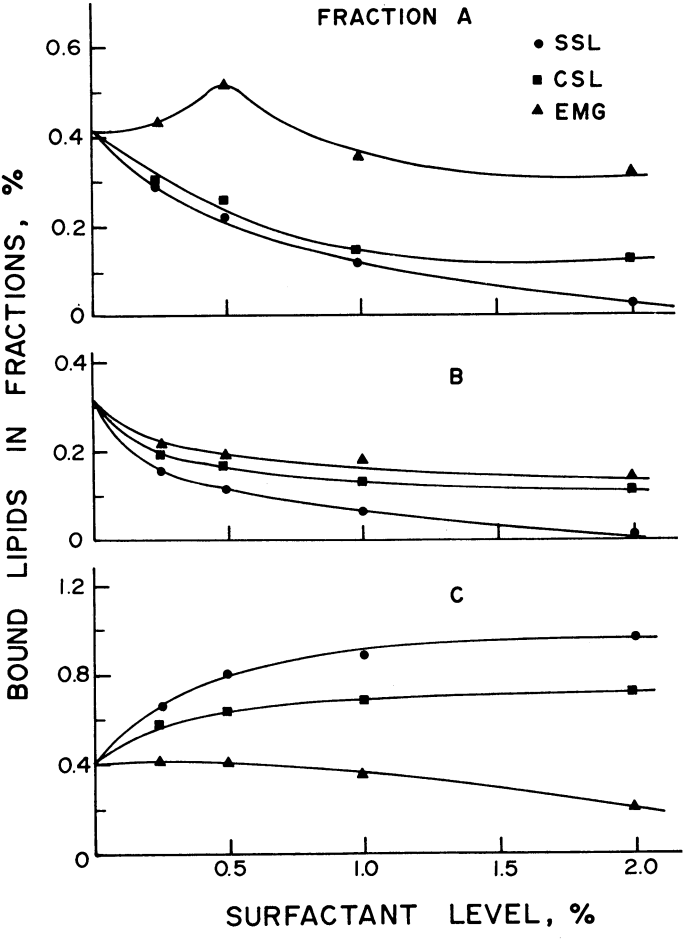

Fig. 6. Lipids bound to various fractions in doughs containing SSL, CSL, and EMG; lipids and surfactants were expressed as percentage of dough weight (dry basis). (A) Acetic acid-soluble fraction; (B) gelatinous fraction; (C) starch-lipid-protein fraction.

to form fraction C in the presence of acetic acid. Apparently, SSL stabilized fraction C by complexing with starch, lipids, and proteins to form a huge aggregate that could not be easily dissociated and extracted by 0.05*N* acetic acid. That huge aggregate of starch-lipids-proteins would be responsible, in part, for an enormous increase in dough stability.

The function of CSL was similar to that of SSL, but its complexing ability to form fraction C seemed to be about one-half that of SSL on the same weight basis. This may have resulted from the fact that the molecular weight of CSL is about twice that of SSL. If surfactants complex with starch on a molar basis

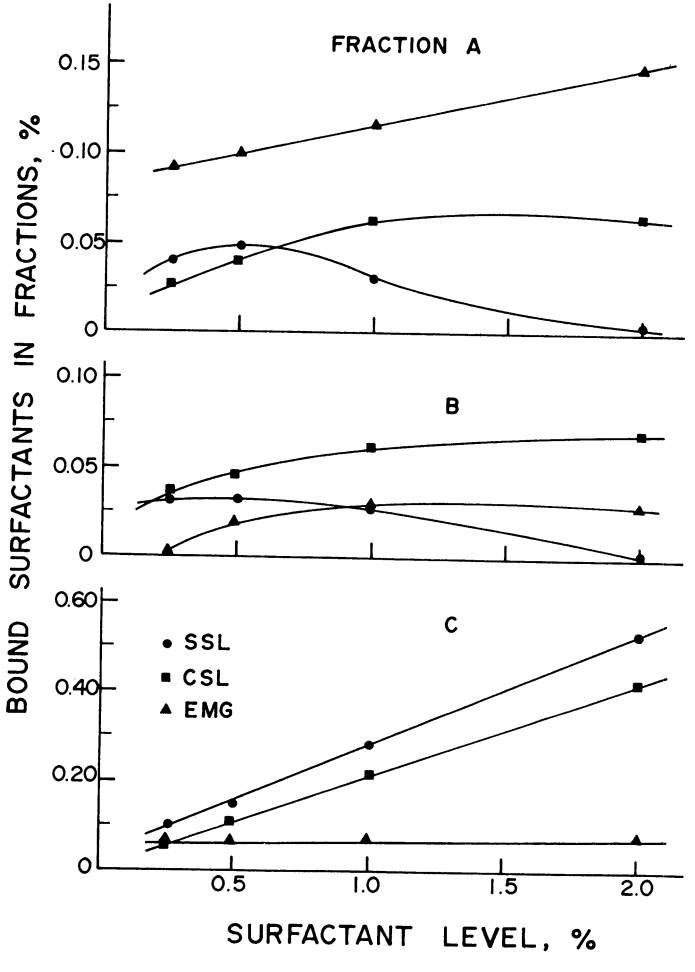

Fig. 7. Surfactants bound to dough fractions containing SSL, CSL, and EMG; surfactants were expressed as percentage of dough weight (dry basis). (A) Acetic acid-soluble fraction; (B) gelatinous fraction; (C) starch-lipid-protein fraction.

rather than according to the number of functional radicals, functionality of CSL would be half of that in SSL. More proteins and bound lipids were dissociated from fraction C, and more were present in both fractions A and B from the CSL dough than from those in the SSL dough.

The nonionic surfactant EMG linked less proteins to starch than did ionic surfactants SSL or CSL. As earlier studies indicated (11,12), EMG interacted primarily with the acid-soluble proteins to form an acid-soluble "protein complex." The optimum level for forming stable "protein complex" seemed to be

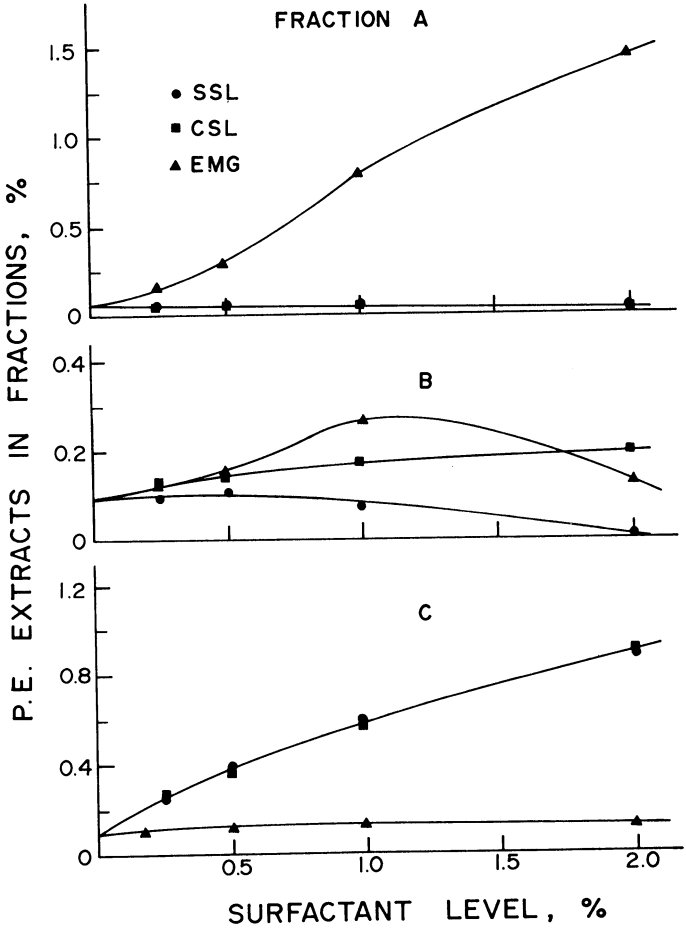

Fig. 8. Petroleum-ether extracts (free lipids and free surfactants) in dough fractions containing SSL, CSL, and EMG; surfactants were expressed as percentage of dough weight (dry basis). Average of triplicated extracts. (A) Acetic acid-soluble fraction; (B) gelatinous fraction; (C) starch-lipid-protein fraction.

at 0.5% EMG. Similarly the largest farinograph dough stability was obtained at 0.5% EMG. Involvement of EMG would be in partially replacing lipids on binding sites of acid-soluble proteins and in interacting with a portion of the lipids to stabilize the association of "glutenins-lipids-gliadins" (12).

Acknowledgments

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