Fatty-Acid Esters of Alkoxylated Polyol Glycosides as Emulsifiers in White Layer Cake[1]

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ABSTRACT

Functional emulsification properties were determined for a series of products prepared by direct reaction of glycerol or propylene glycol with starch or lactose in acid media, followed by alkoxylation with ethylene oxide and propylene oxide, and esterification to introduce one or two fatty acid residues. All materials were tested in white layer cake batters prepared according to AACC Methods. Most effective, and comparing favorably with commercial mono- and diglyceride emulsifiers, were mono- and dipalmitates of moderately ethoxylated propylene glycol and glycerol glycosides. Next in effectual order were the distearate and mono- and dioleate esters. Many of the emulsifiers were too powerful for the high sugar: shortening ratio cake formulation. All surfactants were re-evaluated at reduced levels of total added fat. With the emulsifiers held constant at 2% of the fat, improvement was noted in volume, contour, and grain of cakes by reduction of shortening from 50% (flour basis) to the 35 to 25% range. Preliminary studies to determine the safety of these materials as food additives are underway.

The functional emulsification properties of 27 alkoxylated polyol glycoside esters were tested in high-ratio white layer cakes, and were evaluated for

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effectiveness at reduced levels of shortening. This general series of surfactants was studied independently as emulsifiers in French dressing by Wilham et al. (1), and as volume improvers in bread dough systems by Bean et al. (2). Wilham et al. (3) also described the surfactant properties of the fatty acid esters in this series.

MATERIALS AND METHODS

The emulsifiers were prepared at the Northern Regional Research Laboratory by direct reaction of glycerol or propylene glycol with starch (4) or lactose in acid media. After random substitution of the resultant glycosides with amounts of ethylene oxide ranging from 5.0 to 19.9 moles, or with a mixture of 8.0 moles ethylene oxide plus 3.8 moles propylene oxide, the polyethers were esterfied to contain one or two fatty-acid residues, including laurate, oleate, stearate, and palmitate.

All surfactants were tested for performance and optimum concentration according to the AACC Method for Baking Quality of Cake Flour (10-90) (5). This formulation is based upon a flour-sugar-shortening ratio of 100:140:50, designed for sensitivity to flour quality and treatment, as well as ingredient differences. The basic formulation is given as follows:

		Ingredient Ratios	
Ingredient	*Weight, g.*	*Flour Weight Basis, %*	*Batter Weight Basis, %*
Patent Cake Flour	200	100.0	21.82
Sugar (Baker's Special)	280	140.0	30.58
Dry Milk Solids (non-fat)	24	12.0	2.62
Dry Egg Albumin	18	9.0	1.96
Leavening (Double Acting)	13	6.5	1.42
Sodium Chloride	6	3.0	0.65
Shortening (Emulsified)	100	50.0	10.90
Water (Distilled)	270	135.0	29.50
Vanilla Extract	5	2.5	0.55
Total Batter	916		100.0

Two commercial cake flours from the same mill, differing in crop year and analysis, were selected for the baking study. The control fat was a commercial high-ratio cake shortening, containing mono- and diglycerides. A second, nonemulsified triglyceride shortening served as a base for incorporation of the experimental surfactants. Baking performance was determined first over a range of emulsifier levels (percentage in the shortening) to determine optimum concentration under test conditions. In the second phase, performance was evaluated at reduced levels of total shortening containing 2% surfactant (fat basis).

As anticipated from the varying degrees of etherification and from the chain lengths and configuration of fatty acid residues, the surfactants had widely different melting points, solubilities in the fat phase, and functional responses in the baked product tested. All the laurates and mono- and dioleate additives were fluid at room temperature (20° C.). All mono- and distearates, monopalmitates at low degrees of ethylene oxide substitution, and all dipalmitates were waxy or plastic solids at 20° C.

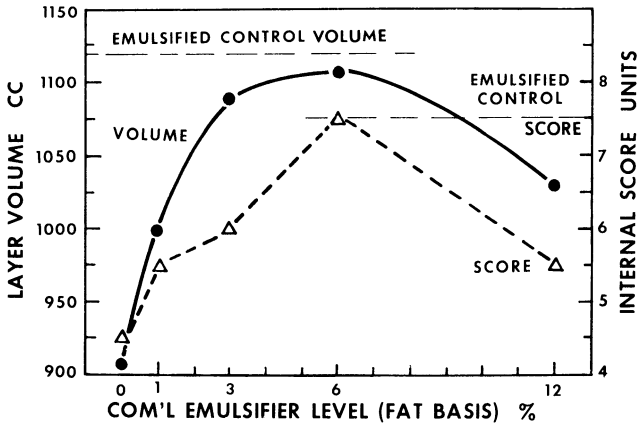

Fig. 1. Volume and internal score responses of AACC white layer cake to increasing concentrations of commercial mono- and diglyceride shortening, using control flour 1.

Low-melting surfactants were blended with plastic triglyceride shortening by direct mixing at high speed in the bowl subsequently used for batter preparation. Blending efficiency was improved by placing 3-mm. plastic shims on the mixer registration pins to reduce the paddle-to-bowl clearance. Solid surfactants were blended similarly after first melting the requisite quantity with 5 to 10% of the total shortening at 95° to 105°C. Shims were removed after blending to restore standard clearance for batter mixing.

Batters were scaled at 425 g. into two 8-in. layer pans and baked for 25 min. at 190°C. (375°F.). After cooling, the plastic template included with AACC

TABLE I. RELATIVE PERFORMANCE OF POLYOXYETHYLENE POLYOL GLYCOSIDE FATTY ACID ESTERS AS EMULSIFIERS IN CAKE BATTERS CONTAINING 50% SHORTENING (FLOUR BASIS). CONTROL FLOUR 1

Rank	Lab. Code	Triglyceride plus Surfactant[1]	Optimum[2] Level %	Layer Volume cc.	Volume[3] Index %
1	H3	POE (7.4) PGL dipalmitate	2.0	1,113	102
2	H1	POE (10.0) GL dipalmitate	1.0	1,110	100
3	F4	POE (5.0) PGG monopalmitate	2.0	1,110	100
4	H2	POE (5.0) GL dipalmitate	2.0	1,099	95
5	E5	POE (19.6) GG distearate	2.0	1,098	94
6	B2	POE (5.2) GG monooleate	1.0	1,090	90
7	B4	POE (5.2) GG dioleate	2.0	1,090	90
8	E4	POE (19.6) GG dioleate	0.5	1,086	89
9	H4	POE (13.2) PGL dipalmitate	2.0	1,081	87
	A	Emulsified Control (commercial)	6.0[4]	1,110	100
	B	Triglyceride Control (commercial)	0.0	890	0

[1]POE (n) = polyoxyethylene substituents totaling *n*-ethylene oxide residues per mole; PGL = propylene glycol glycoside from lactose; GL = glycerol glycoside from lactose; PGG = propylene glycol glycoside from starch; GG = glycerol glycoside from starch.

[2]Percent of shortening.

[3]Volume increase given by experimental surfactant over that of triglyceride control expressed as percent of that given by emulsified control.

[4]Approximate concentration of mono- and diglycerides.

Method 10-90 (5) was used to measure cross-sections of layers for height and radius. Layer volumes were computed by the formula: Volume = $\pi r^2 h$, where r is measured at the midpoint of the side walls and h is the mean of five height measurements across both layers from each batter. Numerical scores for relative batter viscosity and appearance, and for cake contour and internal cell structure were also recorded for each treatment.

RESULTS AND DISCUSSION

To test the suitability of the AACC Cake Method and the triglyceride shortening as a base, a preliminary series of cakes was baked to incorporate a commercial mono- and diglyceride emulsifier at levels ranging from 1 to 12% (fat basis). Figure 1 shows layer volume and internal score response curves obtained with flour 1. Horizontal dashed lines indicate the volume and score levels of

TABLE II. CAKE BAKING PERFORMANCE OF ALKOXYLATED POLYOL GLYCOSIDE FATTY ACID ESTERS AT REDUCED SHORTENING LEVELS (2% SURFACTANT, FAT BASIS) CONTROL FLOUR NO. 2

Lab. Code	Surfactant[1]			Physical State[2]	Shortening Level (flour weight basis) 35% Vol. cc.	35% Score	30% Vol. cc.	30% Score	25% Vol. cc.	25% Score
B1	POE (5.2)	GG	monolaurate	L	1,100	8.0	1,058	8.0	...	...
B2	POE (5.2)	GG	monooleate	L	1,185	8.5	1,140	7.5	...	...
B3	POE (5.2)	GG	monostearate	W	1,116	7.5	1,125	7.5	1,092	6.0
B4	POE (5.2)	GG	dioleate	L	1,110	6.0	1,126	6.5	1,092	4.5
C1	POE (9.6)	GG	monolaurate	L	1,010	7.5	1,090	8.0	1,040	5.0
C2	POE (9.6)	GG	monoleate	L	1,060	8.0	1,108	9.0	1,125	6.0
C3	POE (9.6)	GG	monostearate	W	1,046	7.5	1,078	7.5	1,120	6.5
C4	POE (9.6)	GG	dioleate	L	1,128	7.5	1,128	7.0	1,134	6.0
D1	POE (8.0) POP (3.8)	GG	monolaurate	L	1,010	8.0	1,095	8.5	1,060	7.0
D2	POE (8.0) POP (3.8)	GG	monooleate	L	1,003	7.5	1,102	8.0	1,072	6.0
D3	POE (8.0) POP (3.8)	GG	monostearate	W	1,028	8.0	1,076	7.5	1,128	6.5
D4	POE (8.0) POP (3.8)	GG	dioleate	L	1,128	9.0	1,110	8.5	1,102	7.0
E1	POE (19.6)	GG	monolaurate	L	935	6.0	1,080	8.0	1,110	9.0
E2	POE (19.6)	GG	monooleate	L	1,012	6.5	1,090	8.5	1,096	6.0
E3	POE (19.6)	GG	monostearate	W	1,040	7.0	1,076	9.0	1,095	6.5
E4	POE (19.6)	GG	dioleate	L	978	7.5	1,044	8.5	1,100	6.5
E5	POE (19.6)	GG	distearate	W	1,014	8.0	1,120	9.0	1,058	7.0
F1	POE (5.0)	PGG	monostearate	W	1,060	7.5	1,100	8.0	1,100	7.5
F2	POE (10.1)	PGG	monostearate	W	1,030	7.5	1,090	8.5	1,110	7.5
F3	POE (19.9)	PGG	monostearate	W	1,018	6.0	1,051	7.5	1,082	7.0
F4	POE (5.0)	PGG	monopalmitate	W	1,125	7.0	1,092	7.0	...	...
F5	POE (10.1)	PGG	monopalmitate	L	1,002	7.5	1,092	8.5	1,094	6.5
F6	POE (19.9)	PGG	monopalmitate	L	920	7.0	1,012	8.0	1,108	7.5
H1	POE (10.0)	GL	dipalmitate	W	1,102	8.0	1,110	7.0	...	...
H2	POE (5.0)	GL	dipalmitate	W	1,100	7.0	1,124	8.0	1,092	9.0
H3	POE (7.5)	PGL	dipalmitate	W	1,150	7.0	1,156	8.0	1,106	8.0
H4	POE (13.2)	PGL	dipalmitate	W	1,130	7.0	1,100	7.5	...	...
A	Emulsified control (commercial)				1,058	7.0	1,042	6.0	...	...
B	Triglyceride control (commercial)				942	5.0	912	4.0	...	...

[1]POE(n) or POP(n) = polyoxyethylene or -propylene substituents totaling *n*-ethylene oxide or propylene oxide residues per mole of surfactant; GG = glycerol glycoside from starch; PGG = propylene glycol glycoside from starch; GL = glycerol glycoside from lactose; PGL = propylene glycol glycoside from lactose.

[2]L = liquid, W = waxy (at 20°C.).

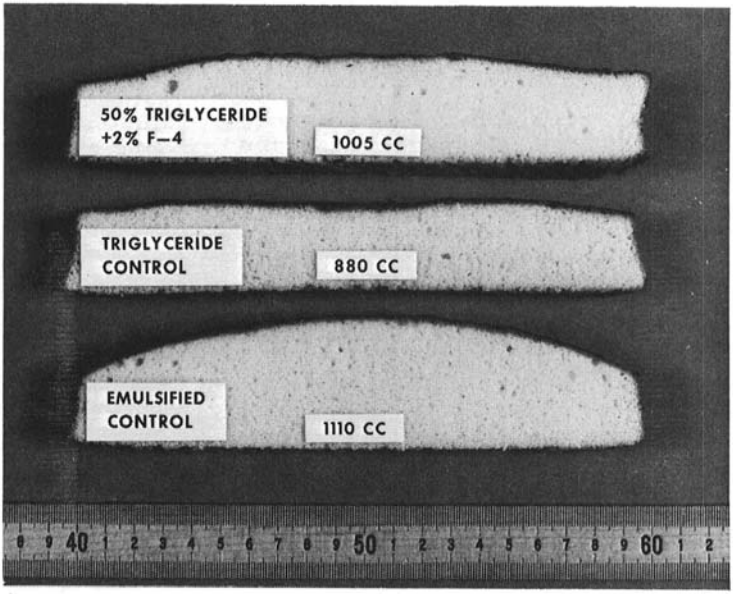

Fig. 2. Top, example of cake from overemulsified batter with experimental surfactant (control flour 2); center, triglyceride shortening (no surfactant); and bottom, commercial shortening containing mono- and diglycerides, both control flour 1.

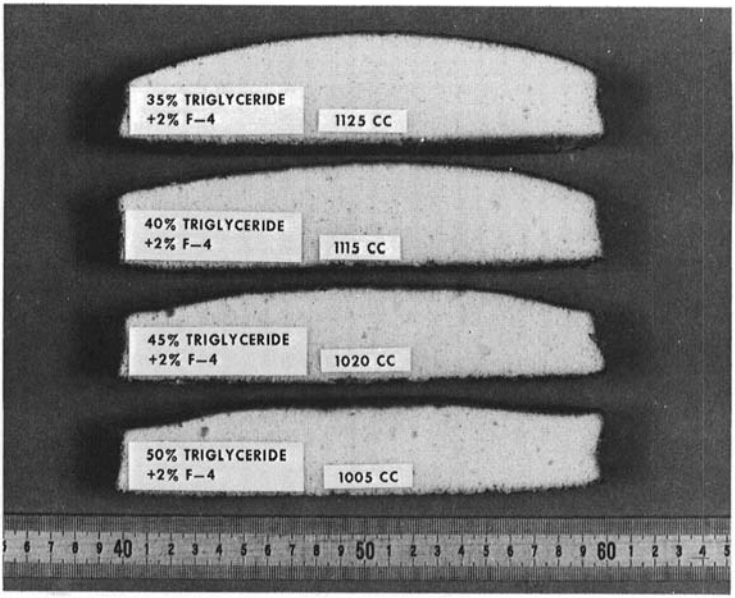

Fig. 3. Cakes showing typical increase in volume and improvement in grain with decrease in level of shortening containing 2% (fat basis) of experimental surfactant, using control flour 2.

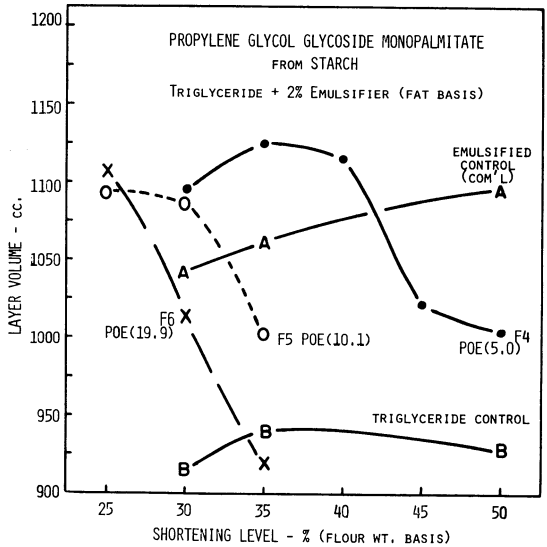

Fig. 4. Layer volume response curves at reduced levels of triglyceride containing 2% (fat basis) of three related experimental surfactants, compared with performance of commercial emulsified and triglyceride control shortening (Control flour 2).

cakes containing commercial emulsified control shortening. The method and materials appeared to be suitable, with sensitivity to both under- and overemulsification and close correspondence of control and experimental products at the optimum (6%) emulsifier level.

Each experimental surfactant was tested for the level yielding maximum layer volume, within the concentration range of 0.25 to 4.0% (fat basis) in batters prepared with flour 1. Table I summarizes for the nine best-performing materials the apparent optimum level, the corresponding layer volume, and a volume index based on performance of nonemulsified triglyceride shortening and expressing the volume increase from experimental surfactants as a percentage of the increase given by the commercial emulsified shortening. The moderately ethoxylated dipalmitates of propylene glycol glycoside and glycerol glycoside from lactose and the monopalmitate of propylene glycol glycoside from starch occupy the top positions. The five most effective esters were in the high-melting category, followed by some fluid oleates.

The 18 materials (omitted from Table I) with performance indices of 85% or below ranged downward to a minimum of 18% or a volume increase of only 40 cc. over the triglyceride control. Among the least effective, under test conditions, was the series of esters substituted with approximately a 2:1 ratio of ethylene oxide: propylene oxide. Throughout the study overemulsification was evident at most concentrations of the surfactants, often including the level yielding maximum cake volume. Overemulsification was seen as a tendency toward thin, glossy batters which produced high virtual volume during thermal expansion, but which suffered excessive shrinkage during the cooling cycle. This type-response was in contrast to that of the thick, curdled triglyceride batter which,

having little entrained air, expanded only moderately in the oven and also suffered massive shrinkage.

Although some materials gave satisfactory performance with the AACC formula which uses a high sugar-shortening ratio, the method was hypercritical in the presence of highly effective surfactants. Moreover, attempts to reproduce some of the satisfactory treatments, using the second cake patent flour, revealed an apparent interaction with flour quality, illustrated in Fig. 2. The emulsified- and triglyceride-control cakes, each containing 50% fat on a flour-weight basis, are compared with the same level of triglyceride blended with 2% of surfactant F4, POE (5.0) propylene glycol glycoside monopalmitate. The top layer is reduced in volume by 105 cc. with respect to the same treatment using flour 1 (Table I). Asymmetric shrinkage, a symptom of overemulsification, is also evident, along with coarse texture and uneven cell distribution.

Figure 3 illustrates cakes from a series of batters containing progressively lower levels of shortening, while holding the surfactant ratio at 2% and all other ingredients constant, as in the AACC formula. Contour and texture improved at the 45% level; progressive increases in volume and improvements in contour and grain resulted at 40% and 35% shortening levels.

The entire surfactant series was reevaluated at reduced levels of added fat ranging from 40 to 25% (flour basis) at the 2% level of surfactant (fat basis). Figure 4 shows representative volume-response curves at reduced fat levels for propylene glycol glycoside monopalmitates from starch etherified with 5.0, 10.1, and 19.9 moles of ethylene oxide, respectively. Each curve shows the marked volume reduction obtained at higher levels of fat, and the restoration or improvement in volume, with respect to the commercial emulsified control, when total fat levels were reduced to the 35 to 25% range. Although shortening levels below 25% were not tested, extrapolation of the curve for highly ethoxylated No. F6 suggests that even greater reductions in batter fat content may be possible. When, as in curve A, commercial emulsified shortening levels were reduced to 30 to 35% baking performance was significantly impaired.

Table II shows layer volumes and grain scores for each treatment. Most surfactants, at one or more levels of shortening, giving baking performance equal to or greater than that obtained with 50% emulsified control shortening (1,095 cc. with flour 2). In all, 11 entries gave volumes of 1,090 cc. or greater and scores of 6.0 or greater at the 35% added fat level; 19 produced similar results at 30% fat, and 16 at the 25% fat level. On the basis of the measured quality factors, surfactants B2, POE (5.2), glycerol glycoside monooleate, and C4, POE (9.6), glycerol glycoside dioleate from starch, and H3, POE (7.5), propylene glycol glycoside dipalmitate from lactose, were superior as functional surfactants in the present test.

Use of surfactants, which permitted reduction of shortening levels in the batter system from 50 to 25% (flour basis), lowered batter fat concentration from 10.9 to 5.6%. In addition, the level of surfactant reduced from about 6% in commercial shortening to 2.0% (fat basis), with a resultant concentration in the batter of 0.12%. This value is only about one-fifth the batter concentration of commercial mono- and diglyceride in AACC Method 10-90.

As a generic group, all the alkoxylated polyol glycoside esters examined have marked functional responses as emulsifiers in plastic shortening. Their possible

synergistic interactions with Polysorbate-60, sodium stearoyl-2-lactylate, or other current shortening components or improvers remain to be evaluated. Preliminary studies are underway to determine safety for FDA acceptability as surfactants in food.

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