Optimization of the Fat-Emulsifier System and the Gum-Egg White-Water System for a Laboratory-Scale Single-Stage Cake Mix[1]

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ABSTRACT

Several techniques for measuring cake batter viscosity were evaluated. A modification of the amylograph procedure gave the most reproducible results. Response surface methodology was used to optimize the formulation of single-stage cake mixes for white layer cakes. A study having three variables (shortening, propylene glycol monostearate, and mono- and diglycerides) at five levels was used to optimize the fat-surfactant system. A second response surface methodology study, also with three variables at five levels, was used to optimize the xanthan gum, egg whites, and water levels. Data were obtained for batter viscosity, batter specific gravity, cake volume, contour, shrinkage, and internal score. Batter specific gravity, viscosity, and cake crumb grain were all highly correlated and affected mainly by the level of propylene glycol monostearate. Optimum values for the fat-emulsifier system were 25% shortening, 4% propylene glycol monostearate, and 3% mono- and diglycerides. Xanthan increased viscosity and decreased shrinkage. Cake volume increased when xanthan level was increased and water level was decreased.

The use of response surface methodology (RSM) for optimizing conditions is becoming increasingly popular in industry. The RSM technique has been applied to cake formulations (Donelson and Wilson 1960, Kissell 1967, Kissell and Marshall 1962, Wilson and Donelson 1965).

Our objective was to use RSM for optimizing ingredient levels in the recently developed procedure to produce single-stage, white layer-cake mixes (Lee et al 1982). In one study, we examined levels of shortening and two emulsifiers (propylene glycol monostearate [PGMS] and mono- and diglycerides [MONODI]. In another, we examined water, xanthan gum, and dry egg whites.

MATERIALS AND METHODS

The materials used and their sources were: PGMS (PROMOPAN SP), Grindsted Co.; MONODI, Durkee Co.; shortening, D10 (a partially hydrogenated mixture of soybean, palm, and cottonseed oils), Durkee Co.; lecithin (UF 250), Paniplus Co.; xanthan gum, Kelco Co.; dry egg white (White-n-Lite), Monark Co.; cake flour (protein 8.27%, ash 0.37%, pH 4.72), Mennel Milling; powdered sugar 6X, baking powder ($NaHCO_3$ and SALP), and salt were of the best grade available.

Cake Procedure

For response surface analysis of white layer cakes, we used a previously established and optimized (one variable at a time) formula (Lee et al 1982) as the design center point (Table I).

Using mixing and baking procedures outlined previously (Lee et al 1982), we heated shortening (D10) and/or emulsifiers (PGMS and MONODI) in an aluminum dish on a hot plate until clear; it was then cooled in a cold room (10° C) overnight. After lecithin was weighed into the aluminum dish containing the cooled mixture of fat and emulsifiers, the mixture was placed with sugar in a Stein mill cup and ground for 2 min. The remaining dry ingredients were added to the cup containing the mixture, and grinding was continued for an additional 2 min to form the cake premix. Cake batters were prepared by mixing water and cake premix with a Sunbeam household mixer at speed 8 for 3 min; the batter was scraped from the sides of the bowl and mixed for 3 more min. Batter specific gravity and viscosity were then measured. Cakes (200 g of batter in a 6 × 1½-in. pan) were baked at 375° F for 25 min in a National reel oven. Volume, top contour, grain quality, and shrinkage of the cakes were determined. Data reported were based on a minimum of three replications.

TABLE I
Cake Formula at the Design Center Point

Ingredient[a]	Quantity (g)	Flour Weight Basis (%)	Total Weight Basis (%)
Flour	60.00	100.00	24.37
Sugar (6X)	66.00	110.00	26.80
Shortening (D10)	15.00	25.00	6.09
PGMS	2.40	4.00	0.97
MONODI	1.80	3.00	0.73
Lecithin	0.49	0.82	0.20
$NaHCO_3$	1.80	3.00	0.73
SALP	1.98	3.30	0.80
Dry egg white	2.10	3.50	0.85
Salt	0.90	1.50	0.37
Xanthan gum	0.78	1.30	0.32
Water	93.00	155.00	37.77
Total	246.25		100.00

[a]PGMS = propylene glycol monostearate, MONODI = mono- and diglycerides, $NaHCO_3$ = sodium bicarbonate, and SALP = sodium aluminum phosphate.

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Measuring Batter and Cake Characteristics

Specific Gravity. Specific gravity (expressed as grams per milliliter) of the batter was determined by comparing the weight of a glass cup filled with batter with the weight of the same cup filled with water (specific gravity of water expressed as 1.0 g/ml). Standard deviation was 0.017 g/ml.

Amylograph. Viscosity of the batter was measured with a Brabender Amylograph-Viscograph. Cake batter (200 g) was poured into the amylograph bowl, temperature set at 25°C, and rotational speed adjusted to 25 rpm. Viscosity was read after 20 min and expressed as Brabender units (BU). If the cake batter was too viscous, extra weight was added.

Cakes. All cake measurements were determined after the cakes had cooled for 60 min. Cake volume was measured by rapeseed displacement, with a standard deviation of 19 cc. Top contour was determined by AACC Method 10-91 (1976). Cake grain quality was judged for fineness, moistness, and uniformity of crumb cell distribution. The factors were evaluated on a scale of one to five. Shrinkage, calculated as the width of the cake 1.6 cm above the pan subtracted from the width of the pan, was reported in centimeters.

Experimental Design

A central composite, rotatable design of the Box-Wilson multiple response surface type was chosen to systematically study the relative contribution of six ingredients and to determine the most desirable cake formulation. The six independent variables selected after a series of preliminary trials were shortening (D10), two emulsifiers (PGMS and MONODI), water, xanthan gum, and dry egg white. To simplify the problem, we used two three-variable, five-level, central composite rotatable designs; one for the D10-PGMS-MONODI fat systems, the other for the water-xanthan gum-dry egg white systems (Cochran and Cox 1957).

To increase the precision, we randomized the complete design, which required 20 cakes baked on three different days. Six dependent variables or responses were measured for each treatment: specific gravity and viscosity of batters, and volume, top contour, shrinkage, and grain quality of cakes, designated as Y_1, Y_2, Y_3, Y_4, Y_5, and Y_6 for the D10-PGMS-MONODI system and Y'_1, Y'_2, Y'_3, Y'_4, Y'_5, and Y'_6 for water-xanthan gum-dry egg white system, respectively.

The data obtained from the batters and the cakes were treated by multiple regression analysis using least squares methodology (Cochran and Cox 1957). For most dependent variables examined, the possible subset models contained linear, quadratic, and interaction terms with three independent variables. The best final subset of variables was found by eliminating variables of poor significance, ie, using the backward elimination procedure to improve the standard error of the estimates, the coefficient of multiple determination (R^2), and the sum of squares of the residuals, simultaneously.

RESULTS AND DISCUSSION

Measuring Cake-Batter Viscosity

The viscosity of food materials is a complex quantity to determine, mainly because of the complex nature of foods. Little information is available on cake batter viscosity.

For preliminary tests, we considered six methods for measuring viscosity: capillary flow, MacMichael, amylograph, Brookfield, falling ball, and spreading. Because of the opaqueness of cake batter, the capillary method could not be used. The high viscosity of cake emulsion was beyond the range of the MacMichael viscometer. Therefore, only four methods were tested. We found that viscosity measured by the amylograph was the most reproducible.

RSM to Study White Layer-Cake Formulations

Fat-Emulsifier System. Significant terms from the analyses of variance are summarized in Table II. The prediction equations (Table III) for the batter and cake parameters were generated by multiple regression techniques, with decimals rounded to two places. The measure-of-fit for data of specific gravity, viscosity, top contour, and grain quality to the response surface was high (ranging from 87–96%) as shown by the R^2 in Table III. The R^2 of cake volume was fairly good (69%). Only 39% of the variation in cake shrinkage was explained by the prediction equation, showing that other ingredients not under manipulation also affect that parameter. The standard errors of the estimates also are shown in Table III.

In this study, specific gravity and viscosity were highly correlated ($r = -0.947$), and both affected grain quality (viscosity versus grain quality, $r = 0.65$; specific gravity versus grain quality, $r = -0.795$). All were affected by the fats and emulsifiers and particularily by the level of PGMS and its interactions. Cake volume and top contour were less affected by the fat-emulsifier system.

In Fig. 1, specific gravity is displayed as a function of both PGMS and MONODI, with shortening held constant at 25%. The effect of MONODI was much less pronounced than that of PGMS. A contour plot of batter viscosity as a function of PGMS and MONODI concentration, with shortening held constant at 25%, was very similar (data not shown).

Limits of acceptability can be assigned to the dependent variables and area of optimum performance obtained by superimposing two or more contour plots of the quality factors

TABLE II
Significant Terms from Analysis of Variance for Fat-Emulsifier System

Independent[b] Variable	F-Test for Significance[a]: Specific Gravity	Viscosity	Volume	Top Contour	Shrinkage	Grain Quality
Linear						
X_1	4.88**[c]	16.24***	14.38***	1.74	NS	4.33**
X_2	37.31***	8.74**	NS	0.85	2.19[b]	56.66***
X_3	26.73***	47.14***	0.53[b]	3.45*	5.99**	11.64***
Quadratic						
X_1^2	NS	NS	NS	5.61**	NS	NS
X_2^2	73.89***	46.10***	NS	7.51**	3.35*	39.75***
X_3^2	NS	NS	8.59***	7.51**	5.11**	9.97***
Interaction						
X_1X_2	4.26*	23.83***	NS	3.85*	NS	NS
X_1X_3	NS	NS	5.54**	NS	NS	NS
X_2X_3	16.49***	20.90***	NS	5.54**	NS	3.55*

[a] If any independent variable appeared in a cross product term or square term significant at $P = 0.01$, the main effect was kept in a response surface equation, although not significant.
[b] X_1 = shortening D10, X_2 = propylene glycol monostearate, X_3 = mono- and diglycerides.
[c] *** = significant at $P = 0.01$, ** = significant at $P = 0.05$, * = significant at $P = 0.15$, NS = not significant.

desired. Because the measure-of-fit of data (R^2) for cake shrinkage was poor, only five responses were considered in this fat-emulsifier response surface system to find areas of satisfactory performance within the experimental range. The acceptable region was delineated from the results obtained by baking a commercial cake mix. The limits were batter specific gravity values below 0.700 g/ml, viscosity values ranging from 500 to 800 BU, cake volume values above 520 cc, top contour values from 1.5 to 2.5 cm, and grain quality values above 3.50. Under these restrictions, the striped area in Fig. 2 contains for each independent variable the values that are expected to yield cakes of acceptable quality. For moderate levels of PGMS, the optimum region was localized with low-to-moderate levels of D10 (31% and below) and low to moderate levels of MONODI (0.83–4.00%). Thus, the center point

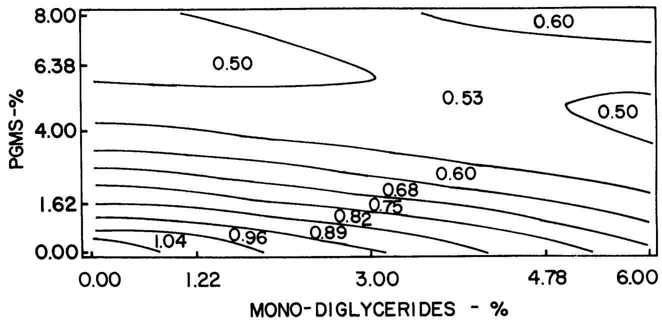

Fig. 1. Contour plot of cake batter specific gravity (g/ml) as a function of propylene glycol monostearate and mono- and diglycerides at the center point, 25% of D10. Percentage values are based on flour weight. All other ingredients held constant.

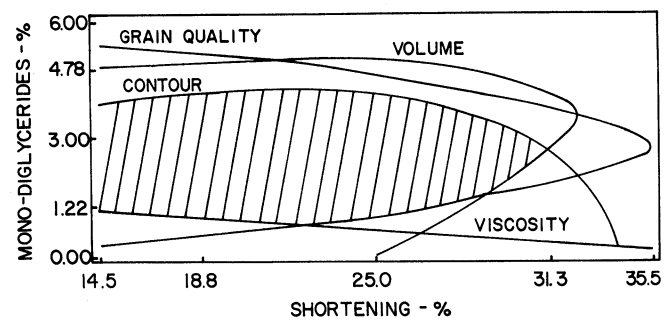

Fig. 2. The acceptable (striped) area obtained by overlapping the contour plots of significant variables as function of D10 and mono- and diglycerides. Percentage values are based on flour weight. Specific gravity not shown as it did not decrease the optimum area.

TABLE III
Best Selected Prediction Equations for Each Response Obtained by Backward-Elimination Procedure, Standard Error of the Estimates, and the Measure-of-Fit of Data to the Response Surface (R^2) for Fat-Emulsifier System

Characteristic[a]	Equation[b]	s	R^2
Specific gravity***	$Y_1 = 0.9944 + 0.0124\,X_1 - 0.2461\,X_2 - 0.1015\,X_3 + 0.0355\,X^2_2 - 0.0044\,X_1X_2 - 0.0044\,X_1X_2 + 0.0302\,X_2X_3$	0.0322	0.9600
Viscosity***	$Y_2 = 252.92 - 31.98\,X_1 + 168.79\,X_2 + 190.94\,X_3 - 39.68\,X^2_2 + 14.69\,X_1X_2 - 48.20\,X_2X_3$	45.63	0.9587
Volume**	$Y_3 = 708.84 - 12.41\,X_1 - 21.63\,X_3 - 12.54\,X^2_3 + 3.89\,X_1X_3$	18.78	0.6881
Top Contour***	$Y_4 = 1.68 + 0.14\,X_1 - 0.21\,X_2 + 0.34\,X_3 + 0.01\,X^2_1 - 0.06\,X^2_2 - 0.11\,X^2_3 + 0.02\,X_1X_2 - 0.10\,X_2X_3$	0.18	0.9429
Shrinkage	$Y_5 = 1.61 - 0.15\,X_2 - 0.33\,X_3 + 0.04\,X^2_2 + 0.08\,X^2_3$	0.16	0.3900
Grain quality***	$Y_6 = -0.69 - 0.08\,X_1 + 2.90\,X_2 + 1.75\,X_3 + 0.41\,X^2_2 - 0.36\,X^2_3 - 0.22\,X_2X_3$	0.50	0.8723

[a] *** = significant at $P = 0.0005$, ** = significant at $P = 0.0001$, * = significant at $P = 0.005$.
[b] X_1 = shortening D10, X_2 = propylene glycol monostearate, X_3 = mono- and diglycerides.

TABLE IV
Significant Terms from Analysis of Variance for the Water-Gum-Egg White System

Independent[b] Variable	F-Test for Significance[a] Viscosity[c]	Volume	Top Contour	Shrinkage	Grain Quality
Linear					
X'_1	5.27***	3.54*	2.44*	22.73***	32.56***
X'_2	105.16***	11.04***	18.65***	9.13***	5.93***
X'_3	4.48**	0.76[b]	5.38**	5.16**	2.93***
Quadratic					
X'^2_1	4.15**	6.77**	NS	25.99***	40.26***
X'^2_2	NS	NS	15.01***	NS	4.03*
X'^2_3	2.77*	9.65***	NS	6.06**	9.54***
Interaction					
$X'_1X'_2$	NS	7.39**	NS	NS	NS
$X'_1X'_3$	2.44*	5.55**	5.94**	NS	13.70***
$X'_2X'_3$	NS	NS	NS	NS	NS

[a] If any independent variable appeared in a cross product term or square term which is significant at $P = 0.01$, the main effect was kept in a response surface equation, although it is not significant.
[b] X'_1 = water, X'_2 = xanthan gum, X'_3 = dry egg white.
[c] *** = significant at $P = 0.01$, ** = significant at $P = 0.05$, * = significant at $P = 0.15$, NS = not significant.

TABLE V
Best Selected Prediction Equations for Each Response Obtained by Backward-Elimination Procedure, Standard Error of the Estimates, and the Measure-of-Fit of Data to the Response Surface (R^2) for Water-Gum-Egg White System

Characteristic[a]	Equation[b]	s	R^2
Specific gravity***	...	...	...
Viscosity***	$Y'_2 = 2667.78 - 46.47 X'_1 + 350.05 X'_2 + 285.01 X'_3 + 0.22 X'^2_1 - 16.27 X'^2_3 - 2.14 X'_1X'_3$	58.23	0.9316
Volume***	$Y'_3 = 18.89 + 12.91 X'_1 + 388.07 X'_2 + 39.33 X'_3 + 0.09 X'_2 - 10.18 X'^2_3 - 3.20 X'_1X'_2 + 1.08 X'_1X'_3$	19.52	0.9461
Top contour*	$Y'_4 = 3.74 - 0.05 X'_1 + 4.98 X'_2 - 2.97 X'_3 - 2.74 X'^2_2 + 0.03 X'_1X'_3$	0.58	0.6739
Shrinkage***	$Y'_5 = 10.52 - 0.21 X'_1 - 0.23 X'_2 - 0.22 X'_3 + 0.001 X'^2_1 + 0.05 X'^2_3$	0.13	0.8182
Grain quality***	$Y'_6 = -34.20 + 0.82 X'_1 + 2.02 X'_2 - 1.64 X'_3 - 0.01 X'^2_1 - 1.02 X'^2_2 - 0.22 X'^2_3 + 0.04 X'_1X'_3$	0.41	0.9245

[a] *** = significant at $P = 0.0005$, ** = significant at $P = 0.0001$, * = significant at $P = 0.005$.
[b] X'_1 = water, X'_2 = xanthan gum, X'_3 = dry egg white.

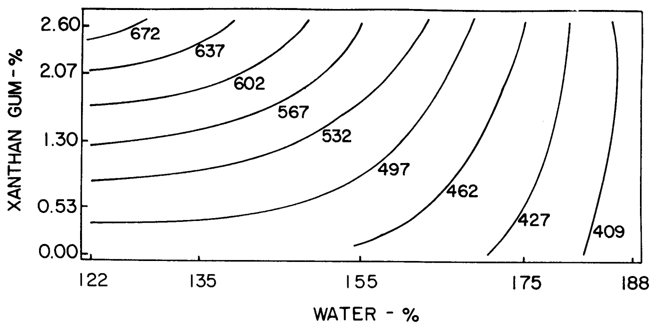

Fig. 3. Contour plot of cake volume (cc) as a function of water and xanthan gum at the center point (3.5%) for dry egg white. Percentage values are based on flour weight. All other ingredients held constant.

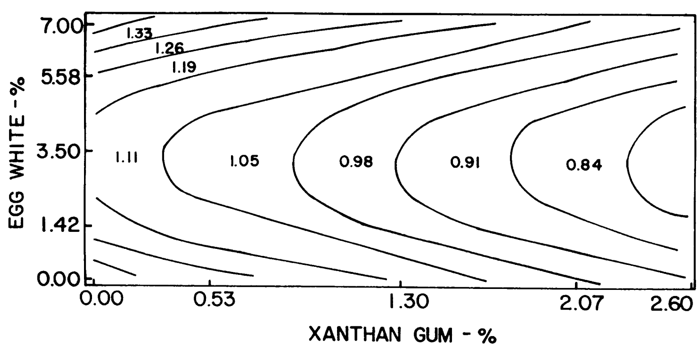

Fig. 4. Contour plot of cake shrinkage (cm) as a function of xanthan gum and dry egg white at the center point (155%) for water. Percentage values are based on flour weight. All other ingredients held constant.

of the experiment (shortening 25%, PGMS 4% and MONODI 3% based on 100 g on flour) was in the optimal area.

Water-Xanthan Gum-Egg White System. Table IV summarizes significant terms from the analysis of variance. Because the effects of water, xanthan gum, and dry egg white on batter specific gravity were not significant from the statistical analysis, we did not include those data. Xanthan gum had a great effect on cake batter viscosity. Increasing the level of xanthan gum thickened the cake batter, seemingly contrary to the results reported by Gunter (1974).

The prediction equations for the batter and cake parameters are shown in Table V. The measure-of-fit of data of viscosity, volume, shrinkage, and grain quality to the response surface was very high as shown by R^2 (ranging from 81 to 95%). The R^2 of cake top contour was fairly good (67%). Standard errors of the estimates also are shown in Table V.

A contour plot of cake volume as a function of water and xanthan gum levels with egg white held constant at 3.5% of flour weight is shown in Fig. 3. This plot shows that the cake volume will increase as xanthan gum level is increased and water level is decreased. Similar results were reported by Spies (1981).

Figure 4 shows the surface attributed to cake shrinkage as a rising ridge generated by a gradual decrease in shrinkage as xanthan gum increases, and by a shrinkage decrease and subsequent increase as dry egg-white level increases. Minimum cake shrinkage values were characterized by high levels of xanthan gum and moderate levels of dry egg white.

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