The Selection of Levels of Canola Oil, Water, and an Emulsifier System in Cake Formulations by Response-Surface Methodology

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ABSTRACT

Cereal Chem. 64(1):50–54

Canola oil successfully replaced hydrogenated shortening in layer cakes when used with appropriate levels of water and an emulsifier system of monoglycerides, polysorbate 60, and sodium stearoyl lactylate. Sixteen formulations representing five levels each of oil, water, and emulsifier were selected for preparation on the basis of a modified Box central composite design. Emulsifier level was a critical component of the regression equations for batter specific gravity, baked volume index, Texturometer firmness, and the sensory features of crumb quality, crumb color, and flavor. Multiple contour maps derived through response-surface methodology showed the acceptability region for various water and oil combinations at different oil levels. Flavor was the limiting factor at all oil levels. Predictions were that cakes containing either 52.5 or 31.5% canola oil would yield acceptable cakes with 8% or more of the emulsifier system in combination with 137% or more water, based on flour weight. However, at the lowest oil level tested (10.5%), higher levels of both emulsifier (9.5%) and water (169%) were required.

Canola oil is a low erucic acid rapeseed oil (LEAR oil) characterized by a high content of oleic acid (55–65%) and a substantial quantity of linolenic acid (9–15%) (Daun 1984). Canola and its parent rapeseed oil are major oilseed crops of northern countries such as Canada, Sweden, Poland, and parts of China and India. In 1985 canola accounted for 77% of the salad oil, 38% of the margarine oil, and 38% of the shortening oil deodorized in Canada (Statistics Canada 1986) and has recently been awarded GRAS status in the United States as LEAR oil with less than 2% erucic acid (U.S. Food and Drug Administration 1985). While canola is an excellent salad and cooking oil, the crystal instability of hydrogenated products has limited its use in baking shortenings and margarine. Replacing plastic fat with oil in bakery goods could further enlarge the market for canola oil.

The emulsified plastic fat used conventionally for layer cake entraps air cells during batter mixing and leads to the development of a fine regular grain, tender texture, and large volume (Painter 1981). A stable structure of beta prime crystals is required for optimum plasticity in a fat (Hoerr and Ziemba 1965). During storage, the crystals forming the structure of hydrogenated canola oil undergo a phase transition from beta prime to the coarser beta form, a property not observed in products of the parent rapeseed oil (Persmark and Bengtsson 1976, Persmark et al 1978). This crystal instability in hydrogenated canola oil has been related to the uniformity in chain length of its triglycerides (Madsen and Als 1968).

The use of emulsifiers in combination with liquid oils was shown in the 1960s to produce very satisfactory layer cakes. The appropriate surfactants reduced the dependence of batter aeration and cake texture on the solids index and crystalline form of the shortening (Ellinger 1962). The total fat content in cake formulations could be reduced substantially when oil-emulsifier combinations replaced plastic fats (Buddemeyer et al 1962, Ellinger 1962, MacDonald and Lensack 1967). In addition to fat reduction, it is possible to pump, meter, and store in bulk, fluid shortening products offering savings to commercial bakers (Hartnett 1977).

The problem in using fluid shortening in cake formulations is that the blend and amount of emulsifier that is required with oil varies with the type of cake. To avoid the large inventories associated with the use of specialty fluid shortenings, Hartnett (1977) suggested the use of hydrated emulsifier systems that can be added directly to batters on a cake-formula-specific basis. For example, a hydrated emulsifier system containing mono- and diglycerides, polysorbate 60, and sodium stearoyl-2-lactylate was effective in producing the desired specific gravity, baked volume, grain, and overall appearance in finished cakes made with soybean oil even at reduced fat levels (Hartnett and Thalheimer 1979). However, adjusting fat levels to suit the amount of emulsifier used also requires manipulation of total batter water. An optimum liquid level is critical to cake volume and crumb structure (Wilson and Donelson 1963). Ellinger (1962) showed that increasing liquid is required as fat level is reduced.

Response-surface methodology (RSM) is an attractive tool for the design of baked product formulations because it affords the detection of optimal levels of several variables coincidentally without the necessity of testing all possible combinations. RSM has been used successfully in cake formulations to define suitable emulsifier levels in rearranged lard (MacDonald and Bly 1966), in fluid shortenings (MacDonald and Lensack 1967), and in cake mixes (Lee and Hoseney 1982). The dependent variables measured in such studies typically include batter specific gravity, baked cake volume, and scores for grain and symmetry. Sensory measurements of eating quality have been less frequently reported.

The objective of this study was to determine if plastic shortening in a white cake formulation could be successfully replaced with canola salad oil if levels of a hydrated emulsifier system and of water were also adjusted. A secondary objective was to demonstrate the convenience of a central composite statistical design in establishing, through RSM, the tolerance of finished cakes to varying levels of emulsifier, water, and oil in the formulations. In addition, the usefulness of certain measurements of sensory quality in designing cake formulas was examined.

MATERIALS AND METHODS

Materials

Canola oil was fully refined and deodorized salad/cooking oil supplied directly from Canbra Foods, Lethbridge, Alberta. The fatty acid composition of refined canola oil from the same crop year (1980) was reported earlier (Vaisey-Genser and Ylimaki 1985). A reference cake was made with a hydrogenated vegetable oil shortening (Crisco) containing mono- and diglycerides. Wheat flour was a commercial cake flour (7.9% protein, dry basis; Maple Leaf Mills). All other ingredients except the emulsifier system were purchased locally in quantities sufficient to prepare all treatments.

The emulsifier system ("Soft Touch" from Paniplus, Olathe, KS), was a blend of fully hydrogenated alpha monoglycerides (13.5% minimum), polysorbate 60 (10–12%), and sodium stearoyl lactylate (SSL, 4.5–6.5%) in hydrated form (up to 70% water).

Experimental Design

RSM was selected as the approach to determine appropriate ingredient levels for canola oil cake formulations. The experimental design was a modification of Box's central composite

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design for three variables at five levels each, as described by Hinchen (1968), where the three independent variables were canola oil, water, and emulsifier system concentration. The complete design consisted of 16 experimental points (Fig. 1), which included duplication of the center point. Thus 16 cakes were required to test the range of combinations that would have required 125 cakes in a traditional factorial arrangement. The 16 cakes were prepared in a randomized order over two adjacent days, and the entire design was duplicated. A reference cake made with hydrogenated emulsified shortening was prepared eight times to provide estimates of the variability of physical measurements. A canola oil cake made with no added emulsifier served as a negative control. Eight dependent variables were measured: batter specific gravity, crumb firmness, baked volume index, crumb color, crumb quality, tenderness, flavor, and moistness.

Cake Procedure

Preliminary baking tests established that a cake formulation adapted from Wootton et al (1967) (Table I) would provide an acceptable reference cake with hydrogenated, emulsified shortening and would also allow for various levels of liquid oil substitution (Table II). Cake batters were prepared by adding oil, the emulsifier system, vanilla, and two-thirds of the water to the sifted dry ingredients and mixing for 30 sec at speed I (Braun kitchen machine model no. 72950). Following scraping of the bowl and mixing at speed III for 4 min, baking powder and the remaining water were added and mixed for 30 sec at speed I. The entire batter was then mixed for 2 min at speed III. Three hundred and eighty grams of batter was poured into a 205 × 40 mm round aluminum cake pan that had been greased and lined with waxed paper. If a formula failed to yield 380 g of batter (e.g., low water and low fat), two identical recipes were prepared and combined. Cakes were baked, four at a time, in a rotary hearth oven (National Manufacturing Company, Toledo, OH) at 180° C for 25 min. After baking, cakes were cooled for 30 min, depanned and cooled an additional 30 min before being wrapped in plastic film and placed in plastic bags for freezing (−15° C). Cakes were held in frozen storage up to 12 weeks before all tests were completed.

Physical Measurements

Batter specific gravity was measured in duplicate by dividing the weight of a sample of batter by the weight of an equal volume of water (Campbell et al 1979). Volume indexes were determined 1 hr after baking using a plastic template as described in AACC method 10-91 (1983).

The General Foods Texturometer was used to determine crumb firmness. It was operated at 2 or 3 V, a chart speed of 750 mm/min, and a low chewing speed (12 chews/min) with a 50-mm diameter nickel plunger that was set at 5 mm clearance from the surface of a cake sample on an aluminum plate. Firmness in Texturometer units (TU) was calculated as the height of the first peak (mm) divided by the volts input. Measurements were made on cake samples (24 × 24 × 12 mm) cut from crust-free center sections of cakes that had been thawed for 3–5 hr after 3–4 weeks of frozen storage. Firmness measurements were made on four samples from each of the 16 treatments per replication.

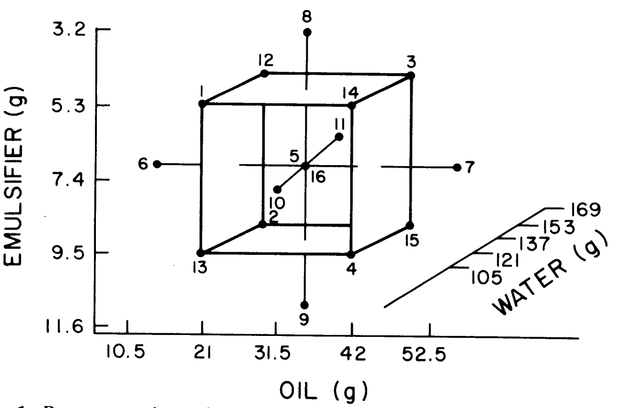

Fig. 1. Representation of points from the modified central composite design (adapted from Hinchen 1968). (For exact combinations of independent variables see Table I. All values are expressed as percentages of flour weight in the cake formula.)

Sensory Measurements

All sensory measurements were made on cakes that had been held frozen for 10–12 weeks after baking. A trained panel of six women judged five parameters of the 16 experimental cakes in comparison to two coded references and the negative control. Six judging sessions over three successive days were required for each replication. A single ballot was used that had separate line scales with end-point descriptors for each parameter. Reference cake scores had been fixed on each line during the training sessions. The ballot included a definition of the ideal for each parameter. Measurements of crumb quality, moistness, and flavor were value judgments (poor to ideal), whereas measurements of crumb color (yellow to white) and tenderness (tough to very tender) were intensity judgments. The maximum score for each parameter was 60. Testing of all responses except color was carried out in individual sensory booths under yellow light.

Statistical Analyses

Data were analyzed by multiple regression to fit second-order equations to all dependent variables. In each case the best-fitting model was chosen on the basis of how closely the R^2 value matched that of the full model and the model significance. Variables were deleted only if they failed to make a significant contribution. If a linear effect was not significant and its squared term or interaction was, the linear effect was included in the model as was the intercept.

Best-fitting models were used to plot the response surfaces (Helwig and Council 1979). For each dependent variable, fat was held constant while water and emulsifier were varied to produce contour plots. This was repeated at all five fat levels if fat proved to have a significant effect. The contour plots for the eight dependent variables were then superimposed to determine the areas of acceptability for water and emulsifier levels at each of the five fat levels.

Acceptability Targets

Limits of acceptability were established from the minimum or maximum measurements for each dependent variable made on the reference cake. Maximal limits were chosen for batter specific gravity and crumb firmness because lower responses are more acceptable. Minimal limits were selected for all other variables because higher values represented greater acceptability. Areas of acceptability were then indicated on the multiple contour map for each fat level by drawing in the response-surface curves that separated the acceptable from unacceptable for each of the eight dependent variables. Thus, the area of acceptability for each canola oil level represented the region where all combinations of water and emulsifier system produced cakes that were acceptable in batter specific gravity, baked volume, crumb firmness, crumb

TABLE I
Reference White Cake Formula[a]

Ingredient	Weight (g)	Flour Weight Basis (%)
Cake flour	95.0	100.0
Sugar	120.0	126.3
Salt	1.5	1.6
Dried egg white	7.0	7.4
Skim milk powder	15.0	15.8
Vanilla extract	2.5	2.6
Water (distilled)[b]	130.0	136.8
Shortening or canola oil[b]	50.0	52.6
Baking powder (double acting)	5.7	6.0
Emulsifier system[b]	0	0

[a] Adapted from Wootton et al (1967).
[b] Levels used in experimental cakes as in Table II.

color, crumb quality, tenderness, flavor, and moistness as determined on the reference cake.

RESULTS AND DISCUSSION

The physical and sensory measurements made on all cakes are summarized in Table II. The contrast between the values for the reference cake and the negative control points out the magnitude of improvement targeted in this experiment. The range of values of the experimental cakes circumscribed that of the reference for each of the dependent variables except flavor and moistness. In these two cases, one or more of the experimental formulations scored equal to the reference but none scored higher. All oil cakes that contained 5.3% or more emulsifier were substantially less firm than the reference cake and were somewhat more fragile to handle. Anti-firming effects have been shown to be a consequence of the complexing of emulsifiers with amylose (Krog 1971).

The coefficients of multiple determination (R^2) for each of the best-fitting model equations show that they accounted for close to 85% of the variability in six out of eight dependent variables (Table III). Henika (1982), in considering the use of RSM with sensory data, stated that models that explained 85% of the variance were very good. Unexplained variability in crumb quality scores (R^2 = 0.56) may have resulted from the complexity of the judging task, which required an integrated response to cell size, density, cell wall thickness, and cell distribution. As for flavor (R^2 = 0.73), some panelists noted an aftertaste in 13 of the 16 experimental cakes and in one of the coded references. While these complaints were neither consistent nor universal, their perception is likely to have increased the variability in flavor scoring.

Best-fitting multiple regression equations illustrate which terms best explained the variability that was estimated (Table III). The level of emulsifier (X_3) was the only one of the three main effects that was required in the best-fitting model for all eight qualities. Canola oil level (X_1) had no effect on crumb quality, and water level (X_2) had no effect on crumb color.

The signs of the regression coefficients within each equation show the direction of the effect of each independent variable, the squared products, or the interactions (Table III). Considering this information together with the F ratios in Table IV provides certain insights. Increasing the emulsifier system (X_3) was evidently the most important single influence in improving batter specific

TABLE II
Responses of Dependent Variables to the Test Formulations (mean of two replications)

	Independent Variables (% flour weight basis)			Dependent Variables								
				Physical[a]			Sensory[b]					
Design Point	Canola Oil X_1	Water X_2	Emulsifier X_3	Batter Specific Gravity Y_1	Crumb Firmness (TU)[c] Y_2	Volume Index (mm) Y_3	Crumb Color Y_4	Crumb Quality Y_5	Tenderness Y_6	Flavor Y_7	Moistness Y_8
1	21.0	121	5.3	0.89	6.6	121	48	40	39	45	44
2	21.0	153	9.5	0.78	4.2	113	48	42	45	41	41
3	42.0	153	5.3	0.89	6.1	102	48	40	44	43	43
4	42.0	121	9.5	0.79	4.6	126	48	38	43	44	42
5	31.5	137	7.4	0.82	4.5	116	49	42	44	43	43
6	10.5	137	7.4	0.80	4.4	122	48	40	42	44	44
7	52.5	137	7.4	0.84	4.7	110	48	40	48	40	38
8	31.5	137	3.2	1.01	11.2	101	42	25	34	43	42
9	31.5	137	11.6	0.74	3.8	123	46	40	47	40	39
10	31.5	105	7.4	0.84	5.7	127	49	38	40	40	44
11	31.5	169	7.4	0.80	5.3	102	49	43	50	39	39
12	21.0	153	5.3	0.88	5.9	106	45	43	43	45	45
13	21.0	121	9.5	0.78	3.2	132	48	36	41	46	45
14	42.0	121	5.3	0.90	4.6	114	49	42	42	44	45
15	42.0	153	9.5	0.78	5.4	104	46	40	49	39	36
16	31.5	137	7.4	0.82	4.1	118	49	42	46	44	44
Reference cake[d]	52.5	137	...	0.84[e]	9.4[e]	108[f]	49[f]	42[f]	38[f]	46[f]	45[f]
Negative control[g]	52.5	137	0	1.06	17.0	84	39	23	18	40	38

[a] For batter specific gravity, n = 4; crumb firmness, n = 8; and volume index, n = 2.
[b] Sensory evaluations from two replications by six panelists.
[c] TU = Texturometer units.
[d] Emulsified hydrogenated shortening; measurements are mean values from eight cakes.
[e] Lower values in test cakes were considered more acceptable.
[f] Higher values in test cakes were considered more acceptable.
[g] Made with canola oil; measurements are mean values from two cakes.

TABLE III
Best-Fitting Models for All Dependent Variables

Dependent Variable	Best Equation[a]	Probability of F	R^2
Specific gravity	$Y_1 = 1.230 + 0.001X_1 - 0.00004X_2 - 0.077X_3 + 0.003X_3^2$	0.0001	0.983
Crumb firmness	$Y_2 = 42.245 - 0.181X_1 - 0.296X_2 - 4.123X_3 + 0.001X_2^2 + 0.191X_3^2 + 0.027X_1X_3$	0.0038	0.837
Volume index	$Y_3 = 106.745 - 0.309X_1 - 0.079X_2 + 13.630X_3 - 0.240X_3^2 - 0.060X_2X_3$	0.0001	0.973
Crumb color	$Y_4 = 22.539 + 0.320X_1 + 5.754X_3 - 0.295X_3^2 - 0.044X_1X_3$	0.0002	0.853
Crumb quality	$Y_5 = 0.221 + 0.089X_2 + 7.970X_3 - 0.523X_3^2$	0.016	0.565
Tenderness	$Y_6 = -1.259 + 0.138X_1 + 0.148X_2 + 5.355X_3 - 0.301X_3^2$	0.0001	0.891
Flavor	$Y_7 = -25.566 - 0.091X_1 + 0.963X_2 + 3.981X_3 - 0.003X_2^2 - 0.034X_2X_3$	0.012	0.728
Moistness	$Y_8 = 2.356 + 0.924X_1 + 0.259X_2 + 5.777X_3 - 0.004X_1^2 - 0.106X_3^2 - 0.005X_1X_2 - 0.032X_1X_3 - 0.031X_2X_3$	0.008	0.895

[a] Full model, where X_1 = canola oil, X_2 = water, and X_3 = emulsifier, is: $Y_i = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3$.

gravity, crumb firmness, crumb color, crumb quality, and moistness and also improved volume and tenderness. On the other hand, increasing canola oil level (X_1) had the disadvantages of decreasing volume, increasing batter specific gravity, and decreasing flavor scores, even though it improved crumb color and tenderness. Increasing water level (X_2) proved to be as important as emulsifier level in increasing tenderness and significantly improved batter specific gravity and flavor. All three of the independent variables significantly influenced batter specific gravity, volume, and tenderness.

The acceptability limits for all cake characteristics are shown in multiple contour maps for each of three canola oil levels (Fig. 2). The response-surface plots were essentially vertical or diagonal. The lack of curvature in these lines reflected the absence of strong quadratic effects and the limited number of significant interactions between the independent variables (Table IV). Values to the left of a line are inferior to the reference cake. The shaded areas in the upper right segment of each map represent the region where all characteristics are equal to or better than the reference cake. Higher emulsifier levels are required for satisfactory layer cakes

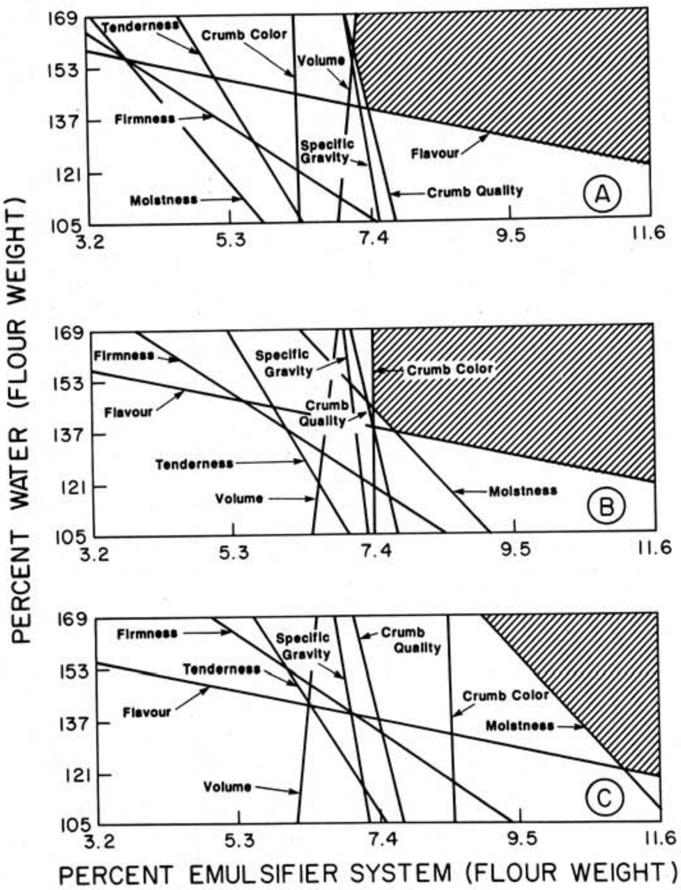

Fig. 2. Multiple contour maps showing the region of acceptability (shaded) for combinations of ingredients that would be expected to meet the acceptability limits for all dependent variables (canola oil level: **A** = 52.5%, **B** = 31.5%, and **C** = 10.5%).

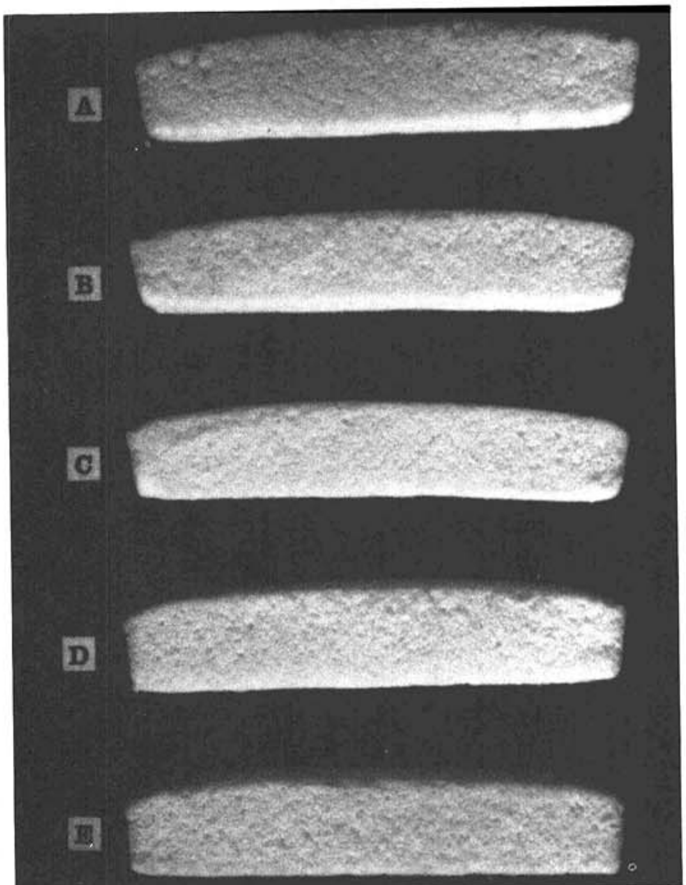

Fig. 3. Cross sections of cakes with: hydrogenated shortening, 52.5%; water, 137% (**A**), and with canola oil at: 42% (**B**), 31.5% (**C**), 21% (**D**), and 10.5% (**E**) of flour weight. All canola oil cake batters contained 169% water and 9.5% emulsifier system based on flour weight.

TABLE IV
***F* Ratio for the Effects Included in the Best-Fitting Models**[a]

Effects of Independent Variables[b]	**Batter Specific Gravity** Y_1	**Crumb Firmness** Y_2	**Volume** Y_3	**Crumb Color** Y_4	**Crumb Quality** Y_5	**Tenderness** Y_6	**Flavor** Y_7	**Moistness** Y_8
	Dependent Variables[c]							
Linear								
X_1	9.2*	2.3	36.7***	8.9*	...	12.0**	6.4*	3.9
X_2	5.9*	1.6	0.2	...	2.7	31.3***	7.2*	3.2
X_3	106.8***	22.0***	16.6**	57.4***	11.7**	21.5***	3.2	6.0***
Quadratic								
X_1^2	...	...	...	...	...	...	...	1.9
X_2^2	...	1.6	...	...	...	...	5.3*	...
X_3^2	40.1***	14.0***	5.3*	46.8***	10.2**	13.7**	...	2.2
Interaction								
X_1X_2	...	...	...	...	...	...	...	2.2
X_1X_3	...	2.6	...	8.8*	...	...	...	1.9
X_2X_3	...	...	6.3*	...	...	...	4.0	3.9

[a] Any variable significant at $P = 0.25$ was included in the model. If an independent variable appeared in a significant quadratic or interaction effect, the linear effect was retained in the model.
[b] X_1 = Canola oil level, X_2 = water level, and X_3 = emulsifier level.
[c] F Value significant at $P = 0.05$, *; 0.01, **; and 0.001, ***, respectively.

when canola oil is restricted to 10.5% of the flour weight than when higher levels of oil are used (Fig. 2C vs. 2A and B). Flavor is a limiting factor at all oil levels, followed by crumb quality at 52.5% oil, crumb color at 31.5% oil, and moistness at 10.5% oil. All three of these limiting factors were measured by sensory methods. Had the measurements been confined to the physical ones of volume, specific gravity, and crumb firmness, an inappropriate expansion of the regions of acceptability at all canola oil levels would have resulted.

Figure 2 predicts that an 8% emulsifier system in combination with 137% or more water will yield cakes as acceptable as the reference when canola oil levels are either 52.5 or 31.5% (Fig. 2A and B). However, at 10.5% canola oil (Fig. 2C), higher levels of both emulsifier and water would be required, 9.5 and 169%, respectively. This confirms the earlier observation that decreasing the fat in cakes increases the liquid requirement (Ellinger 1962).

The cake cross sections in Figure 3 illustrate that products comparable in appearance to the reference cake could be prepared from various oil levels when water and emulsifier levels were within the regions of acceptability that are defined in Figure 2. In this instance all canola oil cakes were prepared with 169% water and 9.5% emulsifier to accommodate the restrictions of the 10.5% oil formulation. The 9.5% level of the emulsifier system in its hydrated form represents 3.0–3.6% of the dry weight of the recipe. Kamel and Washnuik (1983) stated the maximum legal limit under present Canadian legislation for a similar emulsifier hydrate (Atmos 1069) as 5.6%, on a dry basis.

CONCLUSIONS

An emulsifier hydrate containing monoglycerides, polysorbate 60, and sodium stearoyl lactylate is effective in correcting the poor qualities of cakes made from oil by a quick-mix method. A central composite design of only 16 treatments is sufficient to afford predictions of appropriate combinations of oil, water, and the emulsifier system from the response surfaces of dependent variables. Sensory features of cakes such as flavor, crumb quality, crumb color, and moistness are necessary adjuncts to the physical measurements of batter specific gravity, volume index, and crumb firmness in defining acceptable cake formulations.

Canola oil can be used successfully in white layer cakes if appropriate adjustments are made in water levels and the levels and type of emulsifier. The reduction in total fat level permitted by emulsifiers without loss of quality can be of economic value. Additionally, the 10.5% oil cake was calculated to contain only 75% of the calories of the 52.5% oil cake.

ACKNOWLEDGMENTS

The support of the Canola Council of Canada in the conduct of this work is gratefully acknowledged. The authors express appreciation to Canbra Foods, Lethbridge, Alberta for providing the canola salad oil.

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[Received May 28, 1986. Accepted September 12, 1986.]