STUDIES ON THE DYNAMICS OF CAKE-BAKING

I. The Role of Water in Formation of Layer Cake Structure[1]

J. T. WILSON AND D. H. DONELSON[2]

ABSTRACT

A study was made of the effect of liquid level in the batter on the volume, crumb structure, and top contour of layer cake, using 1) a standard white layer recipe and 2) a simplified formula which omits milk solids and egg protein. The quantitative data for each response was fitted to a second-degree polynomial. Water concentration had a critical effect on the extent of starch gelatinization during baking, which in turn determined the type of crumb structure found.

With either formula, maximum volume was obtained at the liquid level where layer contour was rounded, but the structure score was highest at a slightly higher liquid level. The optimum level was consistently higher for the full formula than for the simplified one. The change in volume and contour with liquid level was much more abrupt and was greater with the simplified formula. The increased amount of water needed for the full formula demonstrated that milk solids and egg protein have definite absorption requirements, and indicated that water bound by them is not available for starch gelatinization.

The purpose of this investigation was to obtain a better understanding of the dynamics of layer cake-baking by using liquid content as the variable in an otherwise fixed formula. During the baking, certain physical events were measured and attempts were made to relate these data to resultant cake structures. Liquid requirement seems to depend on two factors: flour absorption and specific formula. The

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[2] Research Staff, Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio.

first factor was recognized in the AACC-recommended cake-baking procedure (1). With respect to cake formula, liquid requirement varies considerably with the proportions of the ingredients, and the reasons for this are not fully known.

The recommended liquid level for high-ratio batter-type cakes was stated by Matz (4) as follows: "Total liquid, including the water in the eggs and milk, should exceed the amount of sugar by 25 to 35%." Sufficient liquid is necessary to dissolve the sugar and still provide adequate moisture for starch gelatinization. Relatively little has been published on the effect of water on cake structure. Sundberg *et al.* (6) stated that the fluid requirement was dependent upon flour absorption. Davies (2) noted that a 25% decrease of liquid produced larger volume, coarse, less uniform grain, and dry texture, whereas a 25% increase of liquid led to smaller volume, finer grain, and moist, tender crumb. Kissell (3) developed a simplified layer cake formula wherein each flour tested appeared to have an optimum liquid requirement; too little liquid resulted in a layer with sunken appearance, and too much liquid led to a peaked cake.

The possibility of obtaining some understanding of the dynamics of layer cake baking by using liquid content as the variable in an otherwise fixed formula was explored. The conclusion was reached that standard layer cake formulas might not be altogether suitable for analytical studies. Shellenberger *et al.* (5) have leveled the criticism at traditional layer cake baking tests that they are in general unable to differentiate among flours, because the other ingredients tend to obscure the real differences.

The lean-formula cake method of Kissell (3) omits milk and egg protein, salt, and flavoring. It seems to be a minimal formula in the sense that omission of any of the remaining ingredients precludes formation of crumb with typical cellular appearance and texture.

Comparing a balanced complete formula with a balanced simplified formula on the basis of equal amounts of the common ingredients is not possible, because balancing rules require changes in the amounts of sugar, leavening, and shortening. Consequently, the comparisons in this study are intended to show that the simplified formula yields an acceptable layer cake structure and that it does provide a more sensitive method of evaluating flours.

Materials and Methods

Seven commercially milled and improved cake flours, each designated by a letter, and four laboratory-milled flours, each designated by a number, were used in this study. The laboratory-prepared flours were treated with chlorine gas to pH 4.6–4.8. Analytical data are given in Table I.

TABLE I
ANALYTICAL DATA FOR CAKE FLOURS

FLOUR	MOISTURE	PROTEIN[a]	ASH[a]	pH
A	13.4	8.3	...	4.7
B	13.0	7.7	...	4.5
C	12.2	8.4	...	4.7
D	11.2	7.5	...	4.6
E	11.2	7.7	...	4.8
F	12.2	7.4	...	4.6
G	12.6	7.9	...	4.6
1	12.9	8.5	0.30	4.7
2	12.7	9.1	0.34	4.8
3	12.0	7.7	0.33	4.6
4	12.0	6.6	0.32	4.8

[a] 14% moisture basis.

Simplified layer cake batters were made using Kissell's formula, K, and complete cake batters were prepared according to a typical white layer formula, F. Dry sugar was substituted for concentrated sugar solution in Kissell's formula; thus sugar was used in the same state in both formulas.

Both formulas are listed in Table II and their respective mixing schedules are shown in Table III.

TABLE II
LAYER CAKE FORMULAS

INGREDIENT	MOSITURE	K FORMULA	F FORMULA
	%	g.	g.
Flour (14% m.b.)	variable	150	150
Sugar (Baker's Special)	....	195	180
Baking powder (double-action)	....	7.05	9.38
Nonfat dry milk	5.45	...	15
Salt	....	...	3.75
Shortening	....	41.8	60.0
Egg white (frozen)	87.50	...	60
Flavor (artificial vanilla)	99.9	...	3
Water	....	154.5[a]	128.0[b]
Total water	....	154.5[c]	184.3[d]

[a] Value given is amount of 103% liquid (flour basis).
[b] Value given is amount of 123% liquid (flour basis).
[c] Less moisture of flour; neglecting moisture of sugar, baking powder, and shortening.
[d] Less moisture of flour; neglecting moisture of sugar, baking powder, salt, and shortening.

The mixing action for the two types of batters was similar enough to eliminate mixing as a major factor contributing to differences in the two types of cakes.

TABLE III
CAKE BATTER MIXING SCHEDULE

ACTION	K FORMULA	F FORMULA
Blend by sifting 4×:	Flour, baking powder, sugar	Flour, baking powder, sugar, milk powder, salt
Place dry ingredients in mixing bowl; add:	Shortening, 90.0 ml. water	Shortening, 80 ml. water
Mix 0.5 min. low speed; scrape; mix 2.5 min. 2nd speed; scrape; mix 0.5 min. 2nd speed; scrape;		
Add:	64.5 ml. water[a]	Egg whites, vanilla, 48 ml. water[b]
Mix 0.5 min. low speed; scrape; mix 1.5 min. 2nd speed		
Pan: 240 g. for 6 in. layer		

[a] Value given is amount for 103% liquid (flour basis).
[b] Value given is amount for 123% liquid (flour basis).

Equipment and layer-measuring procedures were the same as reported by Kissell (3). Two 6-in. layers were scaled at 240 g. from each batter; the K cakes were baked 21 min. and the F cakes 19 min., both at 375°F. The longer baking time for K batters appears to be a characteristic requirement which has not yet been explained. Six-inch pans, rather than the customary 8-in. size, were used because only small amounts of the experimentally milled flours were available. Another advantage of the smaller pan was greater sensitivity to liquid level.

In computation of liquid content of batters, moisture corrections were made for flour, milk solids, and frozen egg white. Moisture content of the remaining nonliquid ingredients was neglected; the error thus introduced in total water content of a batter was less than 1% for both interformula and intraformula comparisons. Liquid concentration was reported as baker's absorption.

For each flour, seven equally spaced liquid levels, at 6% intervals (9-ml. increments of water) were selected to bracket the optimum liquid level, as estimated from preliminary bakes or previous knowledge of flour absorption.

Three types of data were collected for each liquid series: 1) *volume*, measured by seed displacement and expressed as the mean of two layers per batter; 2) *layer structure score*, based on the system of Kissell, wherein the total score is the sum of partial scores for cell size, cell-wall thickness, and uniformity in distribution of cell sizes, each partial score assigned on a scale from extremely poor, 0, to excellent, 5; and 3) *layer contour score*. Cakes were scored numerically as follows: 1, sunken very greatly; 2, sunken greatly; 3, sunken; 4, sunken slightly; 5, rounded but sunken slightly in center; 6, rounded, but flat center; 7, rounded; 8, rounded, but peaked slightly in center; 9, peaked; 10, peaked greatly; and 11, peaked very greatly.

Standard curvilinear regression methods were applied to each class of data: volume, structure score, and contour score. Such a procedure offers the distinct advantage that volume, structure, and contour response to liquid can be described quantitatively by the parameters of the empirical equations obtained, and the parameters of the various flours can be readily compared. In addition, estimations of the liquid level at which maximum volume, maximum structure, and optimum contour occur are obtained more precisely by means of a smoothed approximation than by visual inspection of cakes or estimation from tie-line graphs such as those for layer volume which have been published (3).

When results are plotted with liquid level on the X axis, differences between flours or between two formulas appear as translations along the liquid-level axis. Differences in response per unit of change in liquid level or difference in magnitude of response are detected as changes in the coefficients of the fitted regression equations.

The regression equations used were second-order polynomials of the form

$$Y_i = b_{0i} + b_{1i} X + b_{2i} X^2$$

where Y_i is the estimated volume (or structure score, or contour score) and the X's are the values for liquid level.

In all cases regression accounted for well over 90% of the variance and was therefore considered adequate to represent the data.

Values of Xi for maximum scores were readily estimated by setting

$$\frac{dYi}{dX} = b_{1i} + 2b_{2i}X = O.$$

The maximum estimated values of volume or structure score were obtained by substituting the estimated liquid level, X max., in the original equation.

Analysis of variance of each class of data was made on the completely randomized design with equal replications, usually two, per treatment. Standard deviations of coefficients were computed and significance of coefficients assessed by t-test.

Results

Effect of Liquid Level on Layer Structure in K and F Formulas. Figure 1 shows a series of cakes baked with the A flour using the K formula. The liquid level used in the formula was increased by 6%

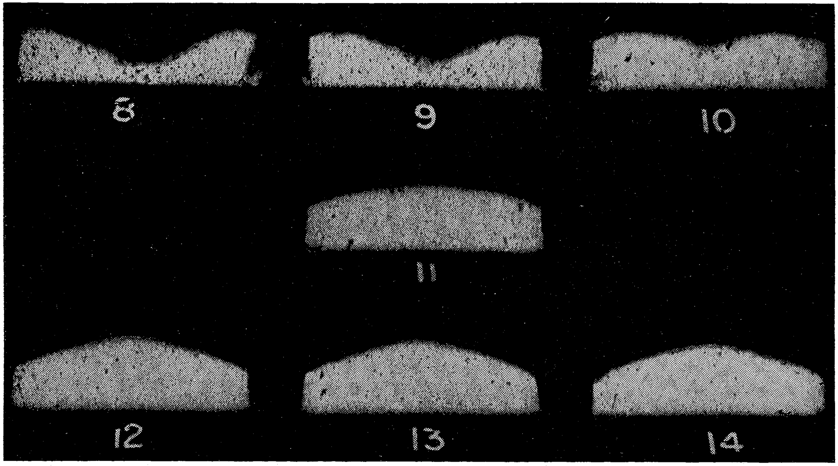

Fig. 1. Effect of liquid level on crumb structure and contour using K formula. Layer No. 8 contained 79% liquid, increased by 6% increments to 115% for layer No. 14.

amounts in the batters from 79% in cake No. 8 to 115% in cake No. 14. Figure 2 presents graphs of averaged experimental values and best-

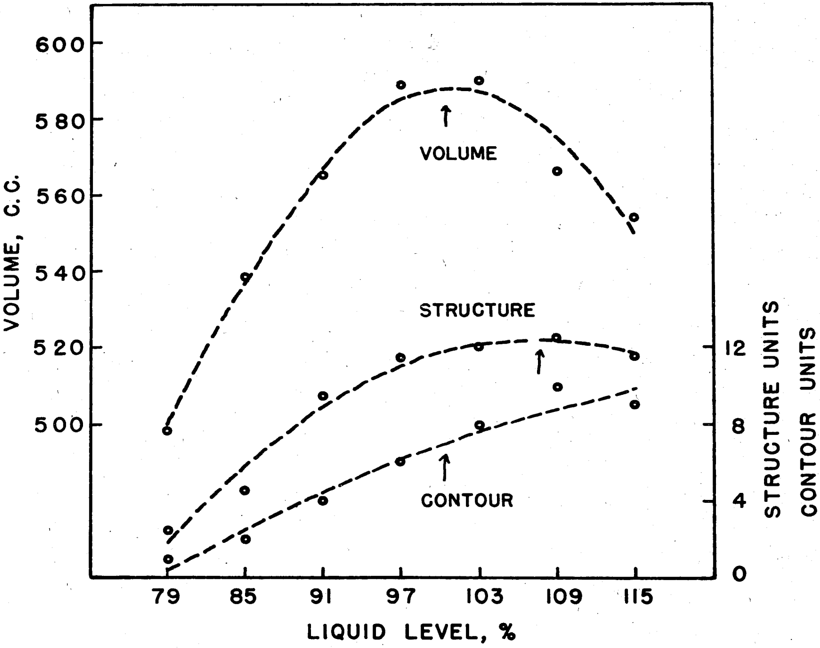

Fig. 2. Graphs of volume, structure score, and contour score for cakes baked using the K formula at different liquid levels. Curves are best-fitting second-order polynomials. Arrow beneath each curve indicates the liquid level for optimum response.

fitting curves for layer volume, structure score, and contour score for this flour and formula. The arrow beneath each curve indicates the liquid level for optimum value of that response. These results showed that crumb structure, contour, and volume changed regularly as functions of liquid. With increasing amounts of water, the top contour changed progessively from deeply sunken to rounded and then to peaked. Concomitantly, crumb structure changed from dry and coarse with thick-walled, open, irregular cells, particularly at the center of the cake, and a broad distribution of cell sizes, to a tight, uniform distribution of small thin-walled cells, and then to a compact, very moist texture. Layer volume increased rapidly with liquid level to a maximum, and then decreased with excess liquid.

Observation during baking proved that the peripheral region of a low-liquid layer rose almost normally in response to leavening action, but that the center never rose above the level finally attained. On the other hand, a batter with high liquid content attained a very large volume and greatly rounded contour during baking, but began to fall around the periphery before the cake was removed from the oven. During cooling, further settling took place to produce the final peaked contour. Layers which possessed rounded contour after baking acquired that top shape during baking, and fell to only a small extent. Thus, over a liquid series there was a regular pattern of increasing response to leavening, but at higher liquid levels this was offset by greater and greater collapse of the annulus of cake toward the periphery of the pan.

None of the cakes baked for these experiments was fallen in the usual sense of that term, i.e., that the center collapsed. Normally this phenomenon has occurred in layer cake only when insufficiently improved flours were used.

Figure 3 shows a series of cakes baked with the A flour using the F formula. The liquid level in this formula was also increased by 6% increments, from 99% in cake No. 1 to 135% in cake No. 7. Figure 4 presents graphs of experimental values and best-fitting curves for volume, structure, and contour. It will be noted that the general pattern of dependence was similar to that for the K-formula cakes, although certain differences were probably significant. The volumes of F-formula cakes were substantially larger, as might be expected of cakes containing egg albumin, despite the smaller amount of flour per layer. Although crumb structure and contour followed responses similar to those of the K cake, the top contour did not become so sunken nor so peaked at extreme liquid values; the response appeared to be tem-

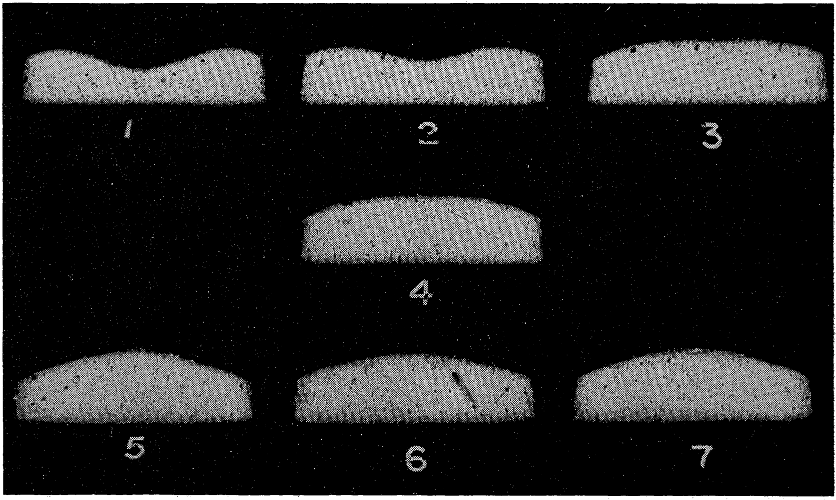

Fig. 3. Effect of liquid level on crumb structure and contour, using F formula. Layer No. 1 contained 99% liquid, increased by 6% increments to 135% for layer No. 7.

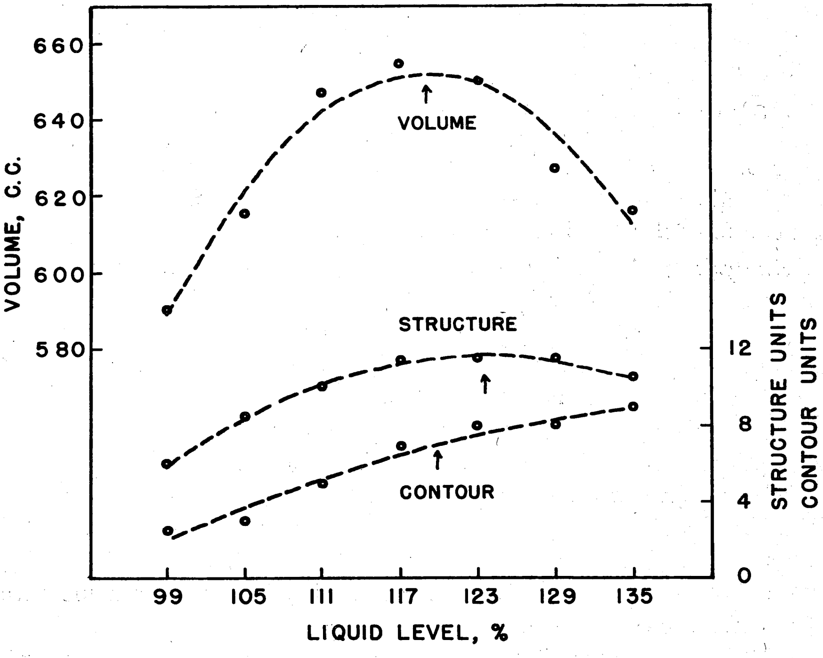

Fig. 4. Graphs of volume, structure score, and contour score for cakes baked using the F formula at different liquid levels. Curves are best-fitting second-order polynomials. Arrow beneath each curve indicates the liquid level for optimum response.

pered by the additional ingredients. Crumb structure was more nearly normal at extreme liquid levels.

Table IV presents results of baking using K and F formulas with flour B. These data show similar patterns to those illustrated in Figs. 2 and 4 and are representative of the differences found for cake flours in the two formulas and in liquid-level series.

TABLE IV

EXPERIMENTAL RESULTS FOR FLOUR B IN K AND F FORMULAS

LIQUID	AV. VOL.	AVERAGE CONTOUR SCORE[a]	AVERAGE STRUCTURE SCORE[a]				CRUMB CHARACTER
			Walls	Size	Distrib.	Total	
%	*cc.*	*units*		*units*			
			K Formula				
85	517	2	2.0	1.0	1.0	4.0	Very dry
91	548	3	2.5	2.0	2.0	6.5	Very dry
97	567	5	3.5	3.0	3.0	9.5	Dry
103	571	7	3.5	3.5	3.5	10.5	Slightly dry
109	557	9	4.0	3.5	3.5	11.0	Normal
115	532	10	4.0	3.5	3.0	10.5	Moist
121	520	11	3.0	3.0	2.5	8.5	Very moist
			F Formula				
105	570	3	2.0	2.0	1.5	5.5	Very dry
111	598	4	3.0	2.5	2.5	8.0	Very dry
117	603	5	3.5	3.5	3.5	10.5	Dry
123	617	7	4.5	4.5	4.0	13.0	Normal
129	609	8	4.5	4.5	4.0	13.0	Moist
135	600	8	4.0	4.0	3.5	11.5	Very moist
141	577	9	3.5	4.0	3.5	11.0	Soggy

[a] For explanation of score system see text.

Analysis of Regression Results. An analysis of the parameters and other derived quantities is presented in Table V. With regard to layer volume, the fitted curve was parabolic downward, and consequently the liquid level where the slope of the curve was zero was the level where maximum volume was attained. This might be called the optimum liquid level for the flour for cake volume. Any deviation from the optimum value led to a smaller cake, and the decrease in volume with liquid level was a measure of the sensitivity of response to liquid. If it had been possible to select the center point of the seven liquid levels to coincide with the optimum liquid level, the coefficient b_{1v} would have been essentially zero. Hence, b_{1v} is primarily a measure of how far the center point chosen deviated from the optimum liquid level. The parameter that was primarily a measure of how the response changed with shift of liquid level away from the optimum values was b_{2v}, the second-order coefficient.

TABLE V

Coefficients of Fitted Volume, Structure, and Contour Equations for Two Flours and Two Baking Formulas. Also Optimum Liquid Level, Maximum or Optimum Values, and Multiple Regression Coefficient

Score [a]	Standard Error of Estimate	Decoded Regression Coefficients			Optimum Liquid Level	Maximum or Optimum Value	R^2
		b_{0i}	$b_{1i} \pm sb_{1i}$	$b_{2i} \pm b_{2i}$			
					%		
Flour A, Formula K							
V	4.86	−1466.75	40.640** ± 3.760	−0.2010** ±0.0147	101.1	587	0.964**
S	0.99	− 141.20	2.869** ± 0.332	−0.01339* ±0.00302	107.1	12.5	0.939**
C	0.88	− 50.32	0.903** ± 0.095	−0.0033 ±0.0027	100.2	7	0.929**
Flour A, Formula F							
V	5.29	−1597.40	37.817* ±10.078	−0.1589** ±0.0160	119.0	653	0.925**
S	0.18	− 130.10	2.292** ± 0.102	−0.0093** ±0.0005	123.8	11.7	0.957**
C	0.60	− 59.12	0.929** ± 0.090	−0.00314 ±0.00180	119.6	7	0.942**
Flour B, Formula K							
V	6.26	−1064.06	31.868 ±31.995	−0.1557** ±0.0190	102.4	567	0.926**
S	0.33	− 147.32	2.929** ± 0.227	−0.0136** ±0.0010	108.0	10.9	0.967**
C	0.30	− 38.17	0.608** ± 0.021	−0.00165 ±0.0009	103.2	7	0.971**
Flour B, Formula F							
V	4.91	−1252.76	30.169 ±25.480	−0.1219** ±0.0149	123.8	614	0.917**
S	0.64	− 206.78	3.408** ± 0.444	−0.01323** ±0.0020	128.9	12.8	0.953**
C	0.45	− 49.62	0.742** ± 0.061	−0.00231 ±0.0014	125.3	7	0.954**

[a] V = volume; S = structure; C = contour.

Similar considerations hold for layer structure score, which also had a parabolic form concave toward the liquid level axis. The liquid level for largest score might be called the optimum liquid level for structure score, and the coefficient b_{2s} was a measure of the sensitivity of response of structure to change of liquid level.

The contour score equation must be considered differently, since it was constrained: that is, the optimum contour value was taken as 7, regardless of the shape of the curve. Since the contour curve was in general monotone increasing without a maximum, the second-order coefficient, b_{2c}, was simply a measure of the deviation of the contour response curve from linearity. The second-order term was not significant for any of the flours used, which indicated that the contour response was not markedly curved. Therefore, with the numerical system applied for contour, the linear coefficient b_{1c} afforded a measure of how rapidly contour changed as liquid level was shifted from the optimum value. Thus the sets of parameters might be considered as measures of three aspects of response: 1) the optimum values of response to liquid, 2) the sensitivity of response to liquid, and 3) the amount of liquid required to obtain the optimum response.

With flour A, for example, comparisons between the parameters in Table V for optimum values in the K and F formulas show that volume was considerably larger for the F formula; the contour optimum scores were the same for both, since rounded contour was selected as being optimum, and the optimal structure scores were practically identical for the two formulas. Also, it is apparent from Figs. 1 and 3 that the general shape of the layers and the internal structure were similar at the optimum liquid level of the two formulas. Comparisons of the coefficients b_{2v}, b_{2s}, and b_{1c} show that liquid had a more marked effect in the K formula. Comparisons of the liquid requirements for optimum values showed that the F formula requires some 16 to 18% greater liquid in order to reach the optimum values.

A study of the parameters in Table V for flour B led to similar conclusions. The F formula not only gave a much larger optimum volume, but volume was less sensitive to changes in liquid level; also, the contour changed less radically with this formula. The maximum structure score was considerably higher for the F formula, but the sensitivity of structural response to liquid was about the same with both. The difference in liquid required for optimum response in each of the three criteria used was about 21 to 23% higher for the F formula.

A comparison of the results for the two flours indicated that flour A yielded larger cakes than flour B, but was more sensitive to the effect of liquid. This was true for both formulas, but the sensitivity was greater for the K formula. This difference in sensitivity must be related to some inherent differences in flour quality, which might be designated as tolerance to liquid. Another aspect of sensitivity was that the F formula was less sensitive to change in liquid level. Hence in addition to flour tolerance, there is also formula tolerance. Although formula tolerance in these baking studies may be associated with the formula difference in protein content due to constitutents other than flour, it seems rather doubtful that the small difference in protein content of flours A and B was sufficient to account for differences between flours.

It is noteworthy that the optimum liquid levels for volume and contour appeared to be nearly identical within each experiment. The result was in agreement with Kissell's observation that maximum layer volume seemed to occur when the top contour was rounded. However, the liquid level for best structure score in these and other sets of data lay at a somewhat higher liquid content than the optimum values for volume or contour, and agreed with the observation that layer crumb in 6-in. cakes was generally slightly better in slightly peaked cakes. It was possible that one reason for the decrease in layer volume at higher liquid levels was the smaller amount of flour in each batter which resulted from scaling at fixed batter weight.

Comparison of Optimum Response of Flours with K and F Formulas. It has been noted that the F formula had about 20% higher liquid absorption than the K formula. To test the validity of this figure, the optimum liquid levels for contour and volume of several flours in the K formula were determined by baking a series of cakes in which the liquid increment was reduced to 3%. F-formula batters were then prepared using the optimum K-formula water content plus 30 ml. (20% liquid) of water. Results are presented in Table VI. It may be

TABLE VI

COMPARISON OF BAKING RESULTS AT OPTIMUM LIQUID LEVELS OF FULL-FORMULA AND SIMPLIFIED-FORMULA CAKES

FLOUR	FORMULA	LIQUID	VOLUME	CONTOUR SCORE	STRUCTURE SCORE			
					Walls	Size	Distribution	Total
		%	*cc.*	*units*		*units*		
A	K	100	590	7	4.0	4.0	3.5	11.5
	F	120	658	7	4.0	4.0	3.5	11.5
B	K	103	565	7	3.5	4.0	3.5	11.0
	F	123	620	7	4.5	4.5	4.0	13.0
C	K	109	549	7	4.0	4.0	4.0	12.0
	F	129	619	7	4.5	4.5	4.5	13.5
D	K	97	602	7	4.0	3.5	3.5	11.0
	F	117	660	7	4.0	4.0	4.0	12.0
E	K	100	575	7	4.0	4.0	3.5	11.5
	F	120	651	7	4.5	4.5	4.0	13.0
F	K	103	595	7	4.0	4.0	3.5	11.5
	F	123	670	7	4.5	4.0	4.0	12.5
G	K	109	580	7	4.0	3.5	3.5	11.0
	F	129	655	6	4.5	4.0	4.0	12.5
1	K	103	548	7	3.5	3.5	3.5	10.5
	F	123	603	6	4.0	4.0	4.0	12.0
2	K	103	576	7	3.5	3.0	3.5	10.0
	F	123	623	7	4.0	3.5	4.0	11.5
3	K	103	565	7	3.5	3.5	3.5	10.5
	F	123	623	7	3.5	3.5	4.0	11.0
4	K	103	549	7	3.5	3.5	3.0	10.0
	F	123	602	7	4.0	3.5	4.0	11.5

concluded that the 20% difference appeared to be correct. Only two of the F layers failed to possess rounded contour, and the contour of the failures, rounded but flat center, indicated that the optimum value was not greatly underestimated. In general those flours with higher structural scores in the one formula carried higher scores in the other, although there were no great differences in score among flours.

There were large volume differences between flours and between formulas, which were tested for significance by analysis of variance. The mean square for formula was 21,630.91**, for flours 895.85**, and for error (interaction) 54.21.

The experiment provided a two-way classification of data: two formulas versus eleven different flours. Individual results were not replicated, but the interaction term of the analysis supplied an error estimate. The standard deviation assumed from this term is 7.36 cc., which compared favorably with independent estimates of 5 to 8 cc. from other baking studies. Consequently, there was negligible interaction between formulas and flours, and it was legitimate to use the interaction mean square as the estimate of error.

The volume difference between the K and F cakes for the flours ranged from 47 to 76 cc.; these differences were significant at the 0.5% level. Since there were just two formula treatments, it might be stated that the F formula yielded cakes significantly larger (1% level) than the K formula. The volume differences among the cakes from the eleven flours were also significant at the 0.5% level, but it was not possible to determine *which* were significantly different.

Application of Duncan's New Multiple Range Test to the volume data for the eleven flours in each formula gave additional information regarding the differences among the flours.

It was shown that the interaction between flours and formulas was negligible. With respect to the *ranking* of flours, the formula used should not have had significant effect. Consequently, the best relative volume estimate for each flour with respect to rank was the mean volume of the two bakes, K and F. Table VII presents each mean ordered with respect to volume. The first set of underlinings summarizes the tests of significance of the range test at the 5% level. Here any flours covered by the same line were not significantly different from one another, but those flours not covered by the same line had significantly different volumes. The least significant ranges for these data ranged from 16.4 cc. for two adjacent means to 18.1 cc. for the extreme-value pair. The second set of underlinings summarizes the tests of significance of the range test at the 1% level. The least significant ranges for

TABLE VII

RESULTS OF RANGE TEST FOR SIGNIFICANT DIFFERENCES AMONG FLOURS: DUNCAN'S NEW MULTIPLE RANGE TEST

(Underlinings: *5% significance; **1% significance)

Flour Designation										
1	4	C	B	3	2	E	G	A	D	F
Mean vol., cc.										
575.5	575.5	584	592.5	594	599.5	613	617.5	624	631	632.5
							———	———	———	——— *
						———	———	——— *		
					———	——— *				
		———	———	———	——— *					
———	———	———	——— *							
						———	———	———	———	——— **
					———	———	———	——— **		
			———	———	———	———	——— **			
———	———	———	———	———	——— **					
K-formula flour (vol., cc.)										
1	4	C	B	3	E	2	G	A	F	D
548	549	549	565	576	575	576	580	590	595	602
F-formula flour (vol., cc.)										
4	1	C	B	3	2	E	G	A	D	F
602	603	619	620	623	623	651	655	658	660	670

the data ranged from 23.3 cc. for each adjacent pair of means to 27.90 cc. for the extreme-value pair. Even at the 1% level, the range of volumes displays real differences.

The rankings of volume for K and for F cakes from each flour set up at the bottom of Table VII are provided for comparison with the statistical results. The ordering in the two formulas was essentially the same. Flours 1 and 4, flours D and F, and flours E and 2 were reversed, but these reversals were entirely within experimental error in the first two pairs and within range error for the third pair. We can, therefore, conclude that the two formulas ranked the flours remarkably near the same. The distribution of values for the K-formula ordering suggested that this formula might provide better discrimination among flours than the F formula.

Discussion

The baking comparisons indicated that the simplified Kissell formula yielded a product with the typical characteristics of white layer cake and had the advantage of greater sensitivity to liquid. Relative to a standard formula, the greater effect of altering liquid level, evidenced by a greater change in volume and a more radical change in top contour per unit change of liquid concentration, should be advantageous in studies on the effect of baking conditions on cake structure, and for comparison of measurements of certain properties during baking.

A method of data treatment by fitting each of three response variables, volume, crumb structure score, and layer top contour score, to second degree polynomials, offered a quantitative approach to flour quality comparisons on the basis of relative differences in liquid requirement, maximum volume obtainable, and relative sensitivity of response to liquid.

The higher liquid requirement of the F formula was undoubtedly attributable to additional water-binding capacity supplied by milk solids and egg albumin, despite the decrease in water-binding capacity entailed by its slightly lower sugar concentration. This moisture requirement, which evidently must be met if a successful cake is to be obtained, indicated that not only must sufficient water be supplied for sorption by flour and association with sugar, but that milk solids and egg protein have characteristic sorption requirements of their own which must be satisfied if the formula is to be in balance. Use of too little water to satisfy these additional ingredients, even though there was enough to take care of the needs of flour and sugar, as judged by the liquid requirement of the K formula, led to sunken contour. If a certain degree of starch gelatinization is necessary for satisfactory crumb formation, starch was in an unfavorable position in competing for water against such strongly hydrophilic ingredients as sugar and protein. If there was insufficient water for very much starch gelatinization, then a dry coarse granular crumb should have resulted. This is actually what happened with suboptimum liquid. On the other hand, if excess water was used, not only would the strongly hydrophilic materials receive adequate water but there would be enough left over for extensive starch gelatinization. This seemed to be the case for high liquid levels, at which the cake crumb begins to assume a certain gel-like character. It appeared, therefore, with respect to the effect of moisture on ingredients, that a satisfactory cake was one which had sufficient but not excessive starch gelatinization. The major problem still to be solved is why the optimum starch gelatinization level coincided with uniform cell size and largest volume.

Since acceptable layer cake structure was obtained from standard cake flours without use of milk and egg protein, these ingredients must have acted as supplementing or reinforcing agents. However, the tempering of response to liquid, as shown by the full-formula results as compared with the simplified-formula data, suggested that milk and egg protein may have acted not only as structural agents in cell walls, perhaps to trap more carbon dioxide generated in the leavening process, but also to act as water reservoirs or buffers to limit and moderate the over-all response of the flour to liquid. This tempering effect suggested a new concept in commercial formulations: that supplementary ingredients minimize individual flour differences in favor of greater product uniformity and greater tolerance to errors in compounding batters. It appears disadvantageous to use such formulations in flour-quality evaluation, since the probability of detecting real differences among flours would be greatly reduced.

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