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EFFECT OF THE RELATIVE QUANTITY OF FLOUR FRACTIONS ON CAKE QUALITY[1]

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ABSTRACT

An unbleached, commercially milled 48% extraction soft wheat flour was fractionated by a batter method into water-solubles, gluten, starch tailings, and prime starch. Flour blends using various proportions of the fractions were prepared and bleached. White layer cakes were baked using a lean formulation. A batter-mixing schedule incorporating a preliminary doughing step was necessary in order to obtain layers comparable in volume and internal structure to cakes baked from the parent flour.

The baking quality of these reconstituted flours appeared to be strongly influenced by their composition. By means of a central composite statistical design, a multiple regression equation was derived relating layer volume to the relative proportions of the fractions making up the flours. Because of interaction, responses of fractions varied significantly at different concentrations of the fractions. It was found that, in general, the water-soluble fraction tended to decrease cake volume, although not greatly, and that tailings had a marked effect in increasing volume and improving internal appearance. Small changes of concentration of gluten or of prime starch above or below the normal amounts had little effect on volume, but much greater or smaller than normal concentrations of either resulted in much smaller cakes.

It was concluded that the relative proportions or balance of flour components conditioned the contribution to cake structure of each component and had a significant effect upon the quality of the cake.

At this laboratory one of the general approaches to the investigation of cake flour quality has been by baking cakes from reconstituted flours. Such flours are produced by combination of four flour components: water-solubles, gluten, starch tailings, and prime starch, ob-

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tained by a process of fractionation.

Sollars (11), by means of a reconstitution technique, investigated the effect of chlorine bleaching on flour fractions in cakes and cookies. The properties of baking-powder biscuits were studied by interchanging flour components from two sources of flour and in two compositions by Zaehringer *et al.* (13). Yamazaki studied the effect of starch tailings on cookie diameter (12). This paper reports an investigation of the variation of white layer cake quality with changes in the proportions of the component flour fractions. In this case, the measure of quality was chosen to be cake volume, with due consideration of internal appearance and contour. Since the effect of a given fraction might depend upon the specific levels of the other components, it was necessary to utilize a multifactor experimental design.

Materials and Methods

Flour. An unbleached 48% extraction commercially milled soft wheat cake flour was used as the source of all the flour fractions. The percentages of the components and their protein content as found by fractionation are shown in Table I.

TABLE I

PERCENTAGE COMPOSITION AND PROTEIN CONTENT OF FLOUR FRACTIONS

MATERIAL	COMPOSITION [a]	PROTEIN CONTENT [b]
	%	%
Unbleached flour	100.0	7.6
Water-solubles	3.6	22.2
Gluten	10.0	60.7
Starch tailings	10.7	3.53
Prime starch	75.7	0.35

[a] Adjusted to 14% moisture basis; fraction percentages adjusted to 100%.
[b] 14% moisture basis. Protein = N × 5.7.

Flour Fractionation. Sixty-five pounds of the unbleached flour was fractionated by a batter method adapted from the process reported by Adams (1). A batter, or slack dough, was formed by mixing 500 g. flour and 380 ml. distilled water in a Hobart C-10 laboratory cake mixer with a paddle at medium speed to optimum gluten development (about 10 minutes). This dough was then whipped for 2 minutes at low speed with 950 ml. distilled water to form a slurry in which the gluten was aggregated as chunks. All the mix was run on a vibrating 25 standard silk bolting-cloth screen. Gluten was collected from the surface of the screen as large pieces and washed by hand-kneading with three 50-ml. portions of water. The washings were added back to the screen. The filtrate from the screening was centrifuged for 15 minutes at 1,800 r.p.m. in an International centrifuge. The supernatant, which contained the water-soluble fraction, was decanted and the layered residue was separated with a knife into starch tailings (top layer) and prime starch (bottom layer). A small residue of highly hydrated material was retained on the screen and this was added to the tailings fraction. Each fraction was then frozen to the inner walls of 4,000-ml. jars, lyophilized, and ground at the fine setting of a Hobart coffee mill. This method of fractionation gave a 97.5% recovery of materials and reasonably complete separation. The procedure has been used successfully to fractionate several low-protein soft wheat flours. The amount of water required in the batter-forming step, and the batter mixing time, are both rather critical and must be adjusted according to the requirements of each flour.

Flour Reconstitution. Flour blends were prepared by mixing the dry components in the proportions needed for each treatment combination of the experimental design. The blends were hydrated to approximately the moisture content of the original flour (12%), by exposure on stainless-steel trays to a high humidity atmosphere in a closed cabinet. Each flour was then bleached with chlorine gas in laboratory equipment to a pH of 4.8, the optimum level found for the original flour.

Cake Baking. The cake formula used in testing these cake flours was a modification of the lean white layer formula developed by Kissell (9). This formula was developed as a test of the baking capacity of cake flours and contains only flour, water, shortening, sugar, and baking powder. The omission of milk and eggs eliminates all structure-forming elements except the flour, and the very high sugar content places additional stress upon the flour. The method of testing is very sensitive to the liquid-carrying capacity of the flour, to the extent of bleaching, and to varietal differences. The formula is summarized in Table II.

The cake batter mixing schedule for reconstituted flours required a preliminary dough mixing operation, as described by Sollars (10). The flour and about 75% of the water required were mixed in a pin-type bread mixer to optimum gluten development. The dough was then transferred to a Hobart C-100 cake mixer, and shortening, blended sugar and baking powder, and additional water were added. These ingredients were mixed 0.5 minute at low speed, then 1.5 minute at medium speed. The balance of the water required was added to the mass and the batter mixed 0.5 minute at low speed, then 1.5 minute at medium speed.

TABLE II

LEAN WHITE LAYER CAKE FORMULA (MODIFIED)

INGREDIENT	QUANTITY	FLOUR BASIS
	g	%
Flour	150.0 (14% m.b.)	100.0
Sugar (Bakers' Special)[a]	195.0	130.0
Shortening (high ratio, emulsified)	41.8	27.9
Baking powder (double action)	7.05	4.7
	ml	
Water (to optimum level)	145.5–163.5	97–109

[a] In baking cakes from whole flours, 212 ml. of 69% sucrose solution are used to supply the sugar and part of the water.

The preliminary dough step seemed to be necessary because the reconstituted flours were merely mechanical mixtures of ground fractions. Apparently an intimate recombination of components was required, and attempts to obtain cakes directly from reconstituted blends by standard full formula or by the regular one-step lean formula were unsuccessful. Attempts to obtain cakes directly from flours produced by lyophilizing a dough made up from the reconstituted blends (12) were also unsuccessful. The batters appeared curdled, the shortening was not well dispersed, and the baked products were of very low volume and relatively structureless. The two-step dough and batter method apparently permitted the organization of a protein matrix strong enough to disperse the shortening and yield a smooth batter, and to provide a basic matrix within which the final cake structure developed, without being so well defined and cohesive as to give a breadlike structure. Reconstituted cakes baked during a 2-year period with this two-step method were comparable in volume and contour to those baked from the corresponding whole flours. Internal structure, flour bleach optima, optimum liquid level, etc., were similar to those of cakes baked from the whole flour, although the over-all texture was somewhat coarser and cell-wall thickness was slightly greater. It seems likely that the gluten development in the batters of reconstituted flours is greater than that in batters using whole flours, where a dough step is not necessary.

An indication of the importance of the dough step in forming an organized or structured batter can be gained from the fact that variation of dough mixing times and liquid level both affected final cake volume. In preliminary bakes, any combination of absorption and mixing time that did not permit optimum gluten development in a firm dough was associated with lowered cake volume. With respect to total liquid level, the lean formulation is rather sensitive. For this study trial bakes determined the amount of water that would yield

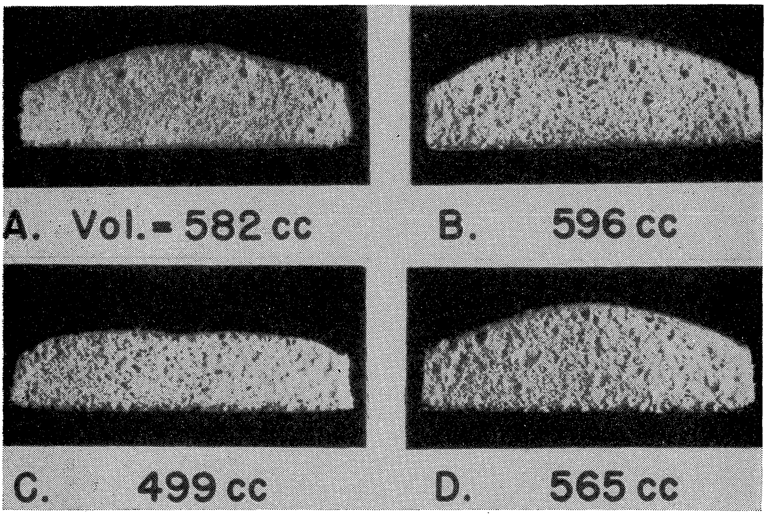

Fig. 1. Cross-section of lean-formula cakes. A, baked with whole flour; B, C, and D, baked with reconstituted flours, treatments No. 1, 3, and 10 respectively.

the maximum volume and optimum top contour (rounded, with this formula) for each treatment combination. Most bakes required 103% liquid level, the optimum level of the whole flour, although absorption throughout the whole series ranged from 97 to 109% for different flour compositions.

Each batter was scaled at 240 g. into two 6-in. bottom-lined, greased-wall steel cake pans and baked at 375°F. for 21 minutes. Cake volumes were measured by seed displacement and taken as the mean between two layers. The internal structure and contour scores were determined by the system of Kissell (9). Generally, the internal appearance was slightly coarser than that of cakes baked from the bleached whole flour and of cakes baked from a commercial control flour. Figure 1 shows sections of cakes baked from the whole flour and from several treatments of the reconstituted flours.

Experimental Design. A preliminary baking study suggested that observed differences in cake volumes might be ascribed to interactions among flour components, so an experimental procedure in which the amount of one fraction at a time was varied, with the other three held at fixed levels, would yield rather restricted information. The effect of one fraction at fixed levels of the other three might be rather different from its effect at other levels of the rest of the components, a quite familiar situation in chemical synthesis. Indeed, holding all fractions but one at fixed levels introduces a logical *non sequitur.* Any alteration made to the composition of a flour, either by recombining fractions in different proportions or by enriching a whole flour by addition of a fraction, is bound by the condition that the sum of the percentages of the components must equal 100%. For example, if a series of baking tests is made using flour enriched with gluten, the gluten additions effect not only an increase in the percentage of gluten, but a decrease in the percentage of the other flour components. Any result ascribed to the change in gluten concentration is confounded with change possibly due to decrease in concentration of the other flour components. It is questionable whether experimentation in which one factor at a time is varied yields any straightforward result independent of this confounding. For a study such as this, where the aim of the experiment is to follow the effect on cake quality of alterations of the proportions of flour components, which is in part just an attempt to investigate whether the confounding mentioned is important or not, this constraint becomes a major concern.

It was hypothesized that, in part, cake quality is a function of the relative concentrations of flour components used. That is, two cakes baked from the same flour fractions might be of rather different quality if the proportions of fractions used in each were different. It appeared possible to do a series of test bakes using flour fractions from a single flour recombined in a variety of proportions, in order to obtain some rational estimate whether the concentration aspect of these quality differences was significant, apart from any question concerning the inherent quality of flour components.

It seemed appropriate to attempt to fit a multiple regression equation as an estimate of the quality-concentration response. Within the concentration constraint mentioned, the independent variables, whether expressed as amounts, percentages, or ratios of flour fractions, were capable of being varied continuously and could be taken at required levels with essentially only random error, in order to obtain the quality response. The response selected as the measure of quality was layer volume, since this is straightforwardly amenable to quantitative treatment, does not entail many arbitrary judgments on the part of the experimenter, and is not therefore biased to the extent that cake-scoring procedures might be. Indeed, layer volume is a fairly good measure of quality, both commercially and in the laboratory, since most rating methods give it great weight, and with the lean-formula baking test, volume is a rather good index of flour quality. It was felt that use of this criterion, in conjunction with scores as a supplement, would give a fairly satisfactory measure of baking quality, so long as the flour fractions used in the treatments were all from the same source.

We can postulate a functional relationship:

$$y = \psi(\xi_1, \xi_2, \xi_3, \xi_4),$$

where y is cake volume and the ξ_i are the amounts of water solubles, gluten, tailings, and prime starch. With all other baking conditions, such as amount of reconstituted flour and other batter ingredients, equal for each treatment, or else arranged by preliminary tests of factors such as liquid level and dough mixing time so as to yield the best layer obtainable for each treatment, the functional relation derived should be an acceptable approximation. It was thought that a satisfactory first approximation to the form of this functional relation would be a polynomial of second order in the four independent variables. The mixed terms would allow some estimate of interaction. However, the subsidiary condition of this experiment, that the sum of the percentages of the four components must be equal to 100%, would lead to indeterminate normal equations in the estimation of the coefficients of the polynomial if the percentages were used directly as the independent variables, because of linear dependence of these variables. In order to obtain a set of variables such that each could be changed independently of the others, ratios of the percentages of flour fractions were selected for a transformation of the regression equation. These ratios were:

x_1 = water solubles/(gluten + tailings + starch)
x_2 + gluten/(tailings + starch)
x_3 = tailings/starch

Each of these ratios could be varied independently of the other two, but specification of all three uniquely determined the amounts of all four components, and vice versa. Admittedly, such a transformation makes interpretation of data rather awkward, but it affords a solution to the mathematical problem involved. An approximation to the transformed functional relation between cake volume and composition was made by fitting a second-order polynomial in the three variables; i.e., the familiar Taylor series expansion in three variables with all terms beyond second order considered as a negligible remainder, $R(x_i)$:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 \\ + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + R(x_i)$$

The cross product terms would afford some estimate of interaction, the remainder term would show the adequacy of the second-order approximation, and statistical analysis would indicate the degree and location of significance of various factors.

Such a mathematical apparatus is, of course, a common way to set up a multiple regression problem. The major statistical and experimental problem of fitting a regression equation is the *rational selection* of treatment combinations to use; i.e., the design, on the basis of compromise among the desired goodness of fit of the derived equation, the amount of experimental material available, the ability to solve the coefficient matrix, etc. A complete factorial design, for example, in the three variables at a minimum of three levels of each would require 27 treatments, and such a design might be considered as the traditional way of selecting treatment combinations to test. But, as pointed out by Hader *et al.* (8), when a polynomial approximation is used, more precise estimates of the coefficients are available by use of designs other than factorial.

A design of the Box-Wilson multiple response surface type was chosen as the best available means of gaining a test of the hypothesis and to obtain a measure of the relative effect of the four flour fractions. The treatment combinations were selected to form a central composite second-order design, comprising 22 treatments, each replicated. These comprised five levels of each variable. Hackler *et al.* (7), Hader *et al.* (8), and Box (2) discuss the advantage of this type of design for multilevel multifactor evaluation; Cochran and Cox (5) present typical forms, and Box (3,4) and Davies (6) present several discussions concerning interpretation of experimental data. In general, the basic design provides a rational way to estimate the joint effect of several factors simultaneously, with a minimum number of experimental tests, to solve the coefficient matrices straightforwardly and to obtain statistical data conveniently.

When the experiment was planned, it was decided to select ranges of flour composition that seemed at the time likely to give the maximum information, although some of the compositions were rather abnormal. The ranges of flour component percentages were as follows: 1 to 7%, water-solubles; 5 to 17%, gluten; 3 to 20%, starch tailings; and 65 to 82%, prime starch. Such a wide range of variation would show whether cake volume did indeed depend to any appreciable extent on the composition of the reconstituted flour and might show how each factor contributed to cake volume, although for a given number of treatments there might be only a fair fit of the regression equation. In case one should require a better approximation, it would be possible to take narrower ranges in an extension of the experiment, or increase the number of treatments or add additional terms to the fitted polynomial expression. The center point of the Box-Wilson design was taken as the reconstituted flour composition:

4.1% water-solubles; 11.4% gluten; 12.0% tailings; and 72.5% prime starch; a composition rather typical of soft red winter patent flours. Of the points taken for treatment combinations, this center point was closest to the proportions actually found by fractionation of the flour (Table I).

The range for each ratio was divided into five equally spaced levels, in the absence of any reason for scaling otherwise. To facilitate calculation of the coefficients in the matrix solution, the ratios were coded as follows:

$$X_1 = \frac{-0.0430 + x_1}{0.0165}$$

$$X_2 = \frac{-0.135 + x_2}{0.040}$$

$$X_3 = \frac{-0.166 + x_3}{0.063}$$

Table III lists the compositions, coded values of the ratios, cake volumes, and scores of all treatments. The volumes and scores were

TABLE III

TREATMENT COMBINATIONS WITH CORRESPONDING FLOUR COMPOSITIONS, CAKE VOLUMES, AND SCORES

TREATMENT No.	VARIABLE CODED VALUE			FLOUR COMPOSITION [a]				CAKE VOLUME AVERAGE	CAKE SCORE AVERAGE
	X_1	X_2	X_3	Water Solubles	Gluten	Starch Tailings	Prime Starch		
				%	%	%	%	cc	
1	0	0	0	4.1	11.4	12.0	72.5	596	5.0
2	0	0	0	4.1	11.4	12.0	72.5	587	6.5
3	−1	−1	−1	2.6	8.5	8.3	80.6	499	5.3
4	−1	−1	+1	2.6	8.5	16.6	72.3	595	7.5
5	−1	+1	−1	2.6	14.5	7.7	75.2	566	5.8
6	−1	+1	+1	2.6	14.5	15.5	67.4	585	7.0
7	+1	−1	−1	5.6	8.2	8.1	78.1	583	3.8
8	+1	−1	+1	5.6	8.2	16.1	70.1	596	5.3
9	+1	+1	−1	5.6	14.1	7.5	72.8	583	5.8
10	+1	+1	+1	5.6	14.1	15.0	65.3	565	6.5
11	0	0	−2	4.1	11.4	3.3	81.2	544	4.5
12	0	0	+2	4.1	11.4	19.1	65.4	574	7.5
13	0	−2	0	4.1	5.0	12.9	78.0	546	5.5
14	0	+2	0	4.1	17.0	11.2	67.7	562	6.3
15	−2	0	0	1.0	11.8	12.4	74.8	631	5.5
16	+2	0	0	7.1	11.1	11.7	70.1	575	6.5
17	0	0	−1	4.1	11.4	7.9	76.6	561	5.5
18	0	0	+1	4.1	11.4	15.7	68.8	607	7.0
19	0	−1	0	4.1	8.3	12.5	75.1	604	4.8
20	0	+1	0	4.1	14.3	11.6	70.0	613	6.5
21	−1	0	0	2.6	11.6	12.2	73.6	629	5.8
22	+1	0	0	5.6	11.2	11.8	71.4	594	5.5

[a] 14% moisture basis.

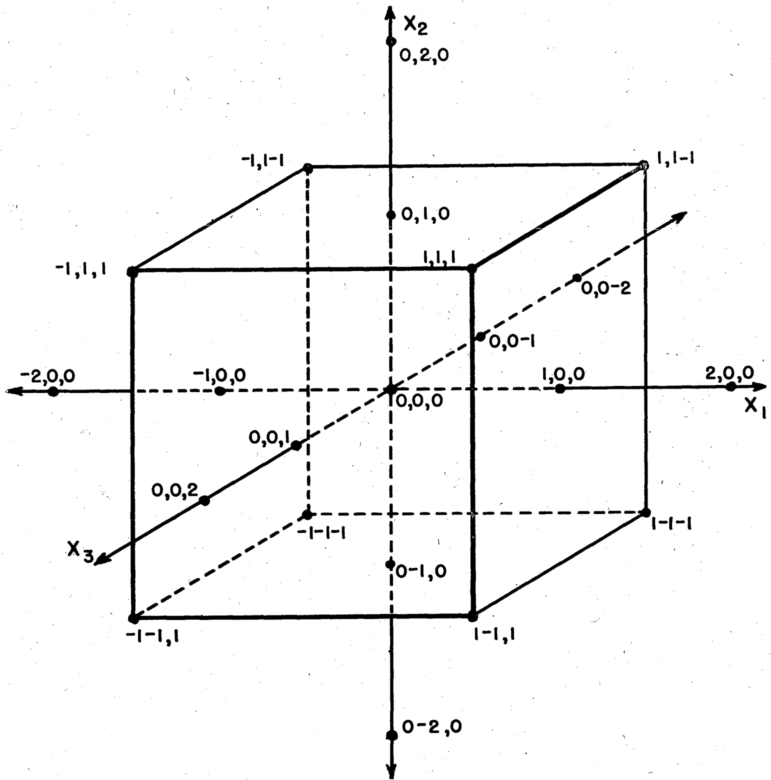

Fig. 2. Spatial layout of composite design in three variables, with five levels. Coded values.

the mean values of two replicates of each treatment, and each replicate was the mean of duplicate cakes prepared from each batter.

Figure 2 illustrates the spatial arrangement of the design. The first two treatments lay at the center, making four replicates altogether of the center point. The next eight treatments formed a three-variable, two-level factorial, the points being located at the vertices of a cube. The next six treatments were placed at a distance of one code unit along the axes, being located at the faces of the cube, and the last six treatments were placed at a distance of two code units along the axes.

Experimental Results

The regression equation obtained from the cake volume data was:

$$\begin{gathered} Y = 602.487 - 3.556\ X_1 + 3.722\ X_2 + 12.028\ X_3 \\ -0.709\ X_1^2 - 12.356\ X_2^2 - 12.724\ X_3^2 - 11.063\ X_1\ X_2 \\ -14.813\ X_1X_3 - 13.438\ X_2X_3, \end{gathered}$$

where Y is estimated cake volume, and the values of the independent variables are the coded values of each. Note that in the use of this equation, such as estimating volume for some composition of the reconstituted flour, it is necessary first to compute the ratios from the percentages of fractions, then code the ratios and use the coded values in the equation. The equation may be decoded by inserting code values and collecting terms, but it is more convenient to use it in the form given. The coding simply transfers the origin of coordinates to the center of the design pattern of Fig. 2. We can then note what happens in the volume-concentration relation as departures from the normal are made. The equation may be considered to define a response surface in a four-dimensional space; as flour composition varies continuously, a continuous surface is generated. The regression equation summarizes the experimental volume results and provides the best-fitting second-degree approximation to the true response surface in terms of the experimental values. It may be used to estimate the volumes for compositions not actually included in the study, so long as they are in the ranges actually used and, one might add, not too close to the edges of the ranges. Or, as illustrated below, it may be used to construct model response surfaces as visual aids for examining the volume-concentration changes observed.

Statistical analysis was made by analysis of variance (Table IV). The null hypothesis formulated was that there was no functional variation of cake volume with flour composition. It is evident that the hypothesis must be rejected at the 1% probability level. In the analysis, the error mean square is the random error derived from the

TABLE IV

Analysis of Variance for Cake Volume Data of Reconstituted Cake Flours

Source of Variance	Degrees of Freedom	Mean Squares
Due to regression	9	
Linear		
X_1	1	455
X_2	1	499
X_3	1	5,208**
Quadratic		
X_1^2	1	23
X_2^2	1	6,982**
X_3^2	1	7,404**
Interaction		
X_1 by X_2	1	1,958**
X_1 by X_3	1	3,511**
X_2 by X_3	1	2,889**
Deviations from regression	11	893**
Error	23	151

replication of treatments. The linear mean squares are measures of the variation accounted for by the linear part of the approximation, and of these only the tailings/starch ratio is highly significant. The quadratic mean squares are the additional variation accounted for by the squared terms in the approximation, and of these only the ratio of water-solubles to the other fractions is not highly significant. The interaction mean squares, all highly significant, are the additional variation accounted for by interaction among flour fractions. The deviation from regression (lack of fit) is a measure of the success of the second-order polynomial to adequately describe the experimental results. The polynomial expansion of the function accounts for 73% of the variation ($R = 0.856$), which is fairly good for a second-order approximation for which no prior evidence was available concerning ranges and scaling of the variables and connected with which there were procedural approximations such as determining optimum liquid levels for each treatment combination. Actually, the random error was satisfactorily small, for cake-baking, with standard deviation ± 12 cc. The smallness of the experimental error increases the significance of the lack of fit. As mentioned above, a better fit might be obtained by using narrower ranges of the variables or by fitting the data with an equation of third or higher order and taking more experimental points. However, the main contention is demonstrated, that there appears to be variation of cake volume dependent upon the flour composition used.

From the significance of the analysis of variance and the magnitude of the partial regression coefficients, it may be inferred that the response of the X_1 variable is essentially linear, and that as the proportion of water-solubles is increased there is in general a slight decrease in cake volume. The greatest effect of water-solubles lies in conditioning (interaction) the response of the other variables at their extreme values. The responses of the X_2 and X_3 variables are essentially curvilinear; i.e., each tends to have a maximum value. Further, the response of each variable depends upon the levels of the other two. In terms of flour composition this means that there are a number of different compositions which give the same volume, that some compositions yield far larger cakes than others, that the volume obtained depends markedly upon the proportions of the flour fractions, and that some ratios of fractions give volumes very different from others because of interaction among the fractions. In general, the effect of varying composition about the normal percentages is rather small, and very large changes of volume occur only when extreme compositions are used.

Demonstration of these conclusions is a trifle awkward because of the necessity of using ratios which is an unfortunate but apparently necessary limitation. If we differentiate the regression equation with respect to X_1,

$$\frac{\partial Y}{\partial X_1} = -3.556 - 1.418X_1 - 11.063X_2 - 14.813X_3,$$

the expression is an indication of how rapidly the volume is changing with unit change of X_1 at specific levels of X_1, X_2, and X_3. The effect of X_1 depends upon the levels of X_2 and X_3, as indicated by the magnitude of the coefficients of the variables, and quite obviously there is a band of values near the normal composition where the effect of X_1 is very small. with respect to X_2,

$$\frac{\partial Y}{\partial X_2} = 3.722 - 11.063X_1 - 24.712X_2 - 13.438X_3$$

shows how rapidly the surface changes along the X_2 axis for specific values of the three ratios. The change is least at values near the normal composition, and the change of sign as one ranges from low to high values of the ratios indicates that the rate of change of X_2 goes through a minimum near the center values. That is, the volume itself goes through a maximum here. With respect to X_3,

$$\frac{\partial Y}{\partial X_3} = 12.028 - 14.813X_1 - 13.438X_2 - 25.448X_3,$$

and the rate of change of volume with respect to X_3 depends very much on the specific values of the three ratios. As the ratio of tailings to starch increases from the lowest value, the rate of increase of volume, initially very rapid, begins to taper off, although near the normal composition the volume is still rising, and doesn't reach a maximum until the X_3 ratio is larger than normal. Beyond this, as the percentage of tailings increases, the slope falls off. These considerations illustrate that the general volume response surface tends to a maximum and that in general the curvature of the surface is greatest along the axis of the tailings/starch variable. If these three partial derivatives are set equal to zero, and the equations solved simultaneously for the values of the ratios, we find a composition: 6.1% water-solubles, 10.0% gluten, 11.6% tailings, 72.3% prime starch, and a volume of 599 cc. At this point, the slope of the surface is zero, but it is easy to show that there are compositions for which the estimated volume is larger—e.g., 1.0% water-solubles, 12.4% gluten, 18.0% tailings, and 68.6% prime starch. Consequently, the point at which the slope is

TABLE V

CHANGE IN SLOPE OF RESPONSE SURFACE AND CAKE VOLUME ALONG X_3 COORDINATE FOR SETS OF VALUES OF X_1 AND X_2

X_1	X_2	X_3	$\left(\frac{\partial X_3}{\partial Y}\right)_{X_1, X_2}$	FLOUR COMPOSITION[a]				VOLUME CALCULATED	VOLUME ACTUAL	CAKE SCORE
				Water Solubles	Gluten	Tailings	Prime Starch			
				%	%	%	%	cc	cc	
−1	−1	−1	54.7	2.6	8.5	8.3	80.6	525	499	5.3
−1	−1	+1	13.8	2.6	8.5	16.6	72.3	606	595	7.5
0	0	−1	37.5	4.1	11.4	7.9	76.6	578	561	5.5
0	0	+1	−13.4	4.1	11.4	15.7	68.8	602	607	7.0
+1	+1	−1	9.2	5.6	14.1	7.5	72.8	582	583	5.8
+1	+1	+1	−41.7	5.6	14.1	15.0	65.3	550	565	6.5
−1	+1	−1	38.9	2.6	14.5	7.7	75.2	582	566	5.8
−1	+1	+1	−12.0	2.6	14.5	15.5	67.4	608	585	7.0
+1	−1	−1	36.1	5.6	8.2	8.1	78.1	570	583	3.8
+1	−1	+1	−11.8	5.6	8.2	16.1	70.1	591	596	5.3
Comparison:									(Mean)	
0	0	0	12.0	4.1	11.4	12.0	72.5	602	592	5.8

[a] 14% moisture basis.

zero is not a true maximum, but a stationary point—in some directions it is a maximum, in others not. It is then the high point of a pass through a ridge, and the general surface is thus a skewed saddle, with the steepest slope downward along the axis of tailings/starch ratio, with a less steep downward slope along the axis of gluten/(tailings + starch) and a mild upward slope along or near to the axis of the ratio of water-solubles to the other fractions.

This rough analysis indicated also that the mode of change of cake volume depended very much upon the actual composition and that some combinations of fractions produced significantly greater degrees of change than did others; i.e., interaction was involved. The relative effect of interaction can be assessed from the magnitude of the partial regression coefficients; the relative effect of each ratio can be similarly assessed, and the compositions at which interaction becomes great can be determined by trying values in the regression equation. It is apparent that the tailings-to-starch ratio had the greatest effect on cake volume, that the ratio of gluten to tailings and starch had considerable effect, that the water-solubles ratio had little effect, and that interaction became greater as compositions deviated from near the normal one.

We are most interested in what the response is like near the center of the design, in the coded region $-1 \leq X_i \leq +1$. It would be expected, perhaps, that peculiar compositions at the extremes of the composition ranges would be associated with cakes of substandard volume. As an illustration, if we investigate changes in the X_3 ratio,

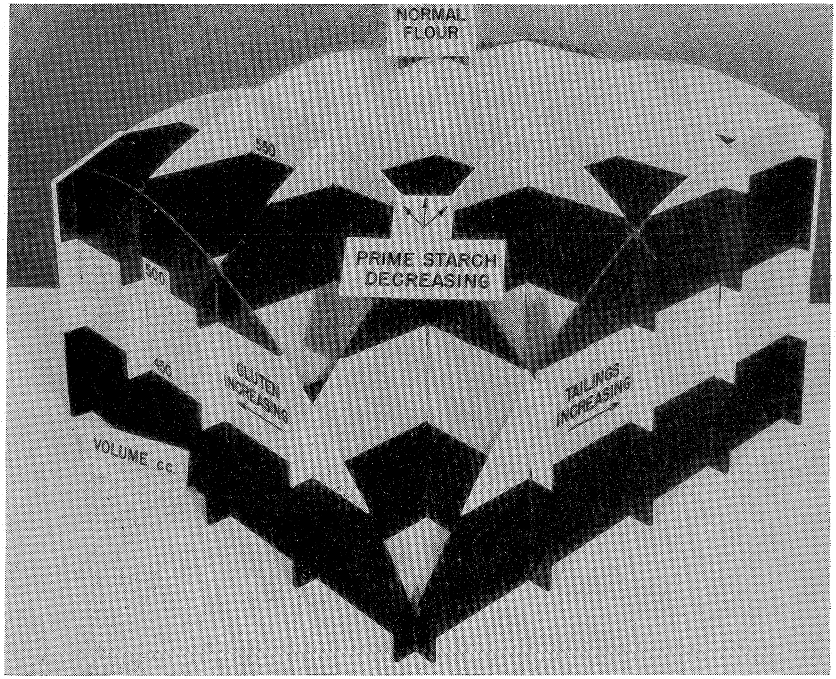

Fig. 3. Three-dimensional model showing changes in cake volume with changes in variables X_2 (indicated as gluten increasing) and X_3 (indicated as tailings increasing). Variable X_1 is constant at the median value of its range. Variables X_2 and X_3 extend from -2 to $+2$ (coded values).

for successive sets of fixed values of X_1 and X_2, this will show the effect of tailings and starch on cake volume for particular flour compositions. Table V is a tabulation of volume changes, cake scores, and values of the slopes of the surface with respect to the tailings-to-starch ratio for a number of treatment combinations in the range in question. These are ranges of composition well among those typical of soft wheat flours. It is noticeable, though not always the case, that relatively large volumes and high scores (good internal structure) are associated with an increased percentage of tailings. The magnitude and sign of the slope in the X_3 direction for each treatment indicates how rapidly the surface is changing in the tailings direction at that composition.

As mentioned above, the regression equation can be interpreted as defining a volume response surface in a four-dimensional space. Figure 3 illustrates a model constructed as a sample surface, to show the effect of varying two ratios at a time (in order to permit three-dimensional representation) and to show the accompanying effects. In this case, the ratio of water-solubles to the other fractions was set at the normal value of its range, since the water-solubles ratio was the one having the least effect. The tailings-to-starch ratio is plotted as "Tailings Increasing" against the gluten-to-tailings-and-starch ratio plotted as "Gluten Increasing." The vertical direction is cake volume in cc. It will be noted that as gluten or tailings or both increase, the amount of prime starch decreases. In most of the planes taken at right angles to the axes across the surface, the volume goes through a maximum, and in fact the surface itself has a maximum. The point of largest volume on this particular surface, 606 cc., occurs where the composition is: 4.1% water-solubles, 11.0% gluten, 14.2% tailings, and 70.7% prime starch. Note that the percentage of tailings is somewhat greater and the percentages of gluten and starch are slightly less than normal. The model illustrates the necessity of specifying the values of the other variables when we wish to discuss the effect of a particular component. For example, if the gluten is maintained at a high level, and the tailings are increased, the volume increases only slightly, then declines rapidly (down the back of the figure), but if gluten is maintained at a low level and the tailings are increased, volume increases steadily to a maximum. Tables VI and VII incorporate the association of cake volume and compositions corresponding to points along the median planes to this surface.

Table VI shows cake volumes obtained with five combinations of fractions taken with the ratio of gluten to total starch variable. The other two ratios are constant. The composition of the middle column is that of the "normal" flour. The amount of gluten varies from a smaller than normal to a larger than normal amount. Although the ratio of tailings to starch is constant, the actual amounts present change somewhat as the gluten changes. As percent gluten increases,

TABLE VI

ACTUAL AND ESTIMATED CAKE VOLUMES FOR SEVERAL TREATMENT COMBINATIONS, WITH GLUTEN-TO-TOTAL-STARCH RATIO VARIABLE

Cake volume, cc.					
Actual	546	604	596	613	562
Estimated	546	586	602	594	560
Flour protein, %[a]	4.7	6.7	8.5	10.3	11.9
Treatment No.	13	19	1	20	14
Composition, %[a]					
Water-solubles	4.1	4.1	4.1	4.1	4.1
Gluten	5.0	8.3	11.4	14.3	17.0
Tailings	12.9	12.5	12.0	11.6	11.2
Prime starch	78.0	75.1	72.5	70.0	67.7

[a] 14% moisture basis.

TABLE VII

ACTUAL AND ESTIMATED CAKE VOLUMES FOR SEVERAL TREATMENT COMBINATIONS, WITH TAILINGS-TO-PRIME-STARCH RATIO VARIABLE

Cake volume, cc.					
Actual	544	561	596	607	574
Estimated	528	578	602	602	576
Flour protein, %[a]	8.3	8.4	8.5	8.7	8.8
Treatment No.	11	17	1	18	12
Composition, %[a]					
Water-solubles	4.1	4.1	4.1	4.1	4.1
Gluten	11.4	11.4	11.4	11.4	11.4
Tailings	3.3	7.9	12.0	15.7	19.1
Prime starch	81.2	76.6	72.5	68.8	65.4

[a] 14% moisture basis.

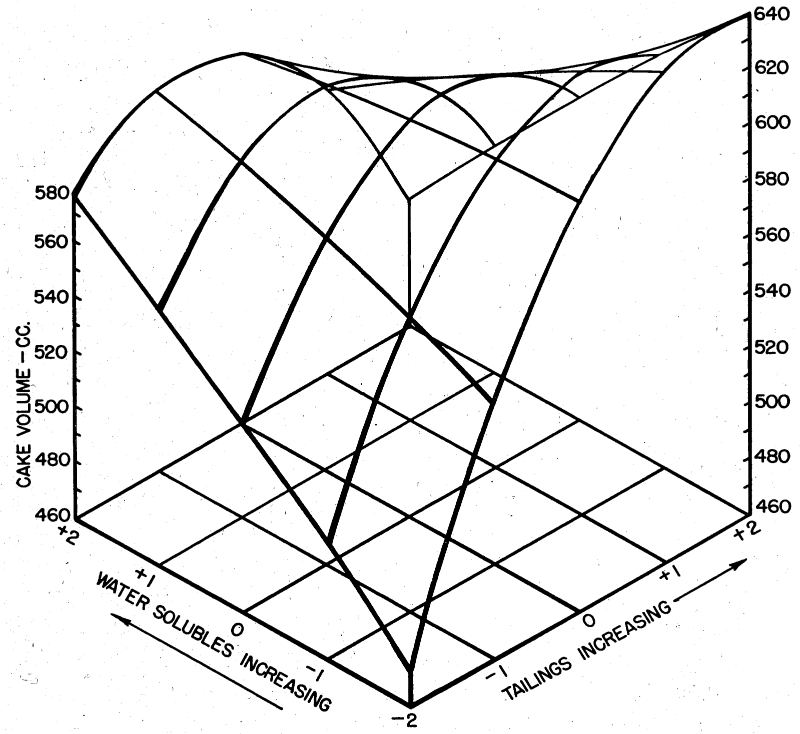

Fig. 4. Drawing of response surface showing cake volume changes with changes in variables X_1 (indicated as water-solubles increasing) and X_3 (indicated as tailings increasing). Variable X_2 is fixed at the median value of its range. Coded values of the variables are shown.

the cake volume increases to a maximum of 602 cc. predicted value, then decreases. Since the protein content increases with increasing concentration of gluten, there would *appear* to be no simple association between protein level and cake volume.

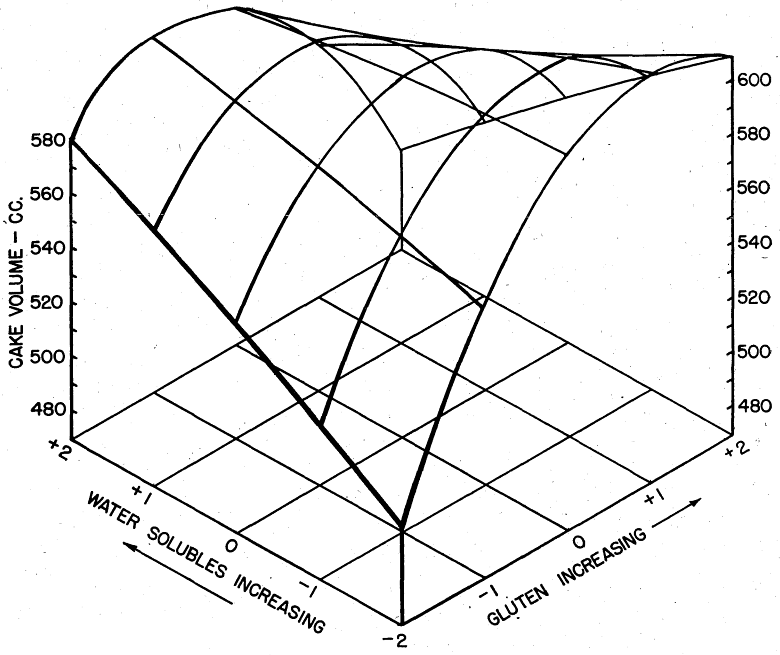

Fig. 5. Drawing of response surface showing cake volume changes with changes in variables X_1 (indicated as water solubles increasing) and X_2 (indicated as gluten increasing). Variable X_3 is fixed at the median value of its range. Coded values of the variables are shown.

Table VII shows volumes of the set of cakes baked with the ratio of starch tailings to prime starch variable and the other two ratios fixed at their median values. That is, water-solubles and gluten are constant and in the normal percentages. The starch tailings and prime starch vary over a rather wide range. Here again the cake volume increases to a maximum, then falls off sharply. Note that the largest estimated value of this series has somewhat more tailings and less starch than the normal amounts. Although the protein levels of the flours change only slightly, the cake volumes change considerably.

The experimental results recorded in Tables VI and VII show that there did not seem to be much association between cake volume and the level of any one component. There must have been complex interaction among the components that accounted for volume changes.

Figure 4 illustrates another example of a three-dimensional surface; this is a saddle type of surface generated if the gluten-to-total-starch ratio is held constant and the ratios of tailings to starch and of water-solubles to gluten, tailings, and starch are varied. Changes in the amount of water-solubles with tailings/starch at a fixed value lead to an essentially linear volume change, although with the tailings/starch near the normal value (along the ridge of the surface) there is a negligible change in volume. However, if the water-solubles ratio is fixed, the change in volume due to changing tailings and starch is markedly curvilinear.

A similar saddle surface is shown in Fig. 5. In this plot the tailings-to-starch ratio is held constant. The water-solubles and gluten ratios are varied. It may be noted that here, also, the effect of water-solubles is essentially linear, and with nearly normal amounts of gluten, the effect on volume is small. However, at the extremes of the amount of gluten, change in the quantity of water-solubles produces rather large changes in volume. Change due to the variation of the gluten ratio is markedly curvilinear.

Figure 6 was drawn to show typical effects of altering the proportions of two fractions at a time. In Fig. 6, A, where tailings and starch were fixed at the normal values and water-solubles and gluten were varied, the small decrease in volume as water-solubles increased is shown. For *these* compositions there was relatively little change in cake volume, except at the very high gluten, very low water-solubles composition. In Fig. 6, B, where starch and gluten concentrations were fixed and water-solubles and tailings were varied, there was a steady decrease in volume as tailings decreased, or water-solubles increased. In Fig. 6, C, tailings and water-solubles were fixed and starch and gluten were varied. There was a large volume change. Volume was low at both high gluten-low starch and at high starch-low gluten, and the greatest volume was found near the normal amounts of both. In Fig. 6, D, water-solubles and starch were fixed at the normal amounts and gluten and tailings were varied. Here also, volume was greatest near the normal amounts and fell at extreme compositions.

It was apparently not possible to obtain quantitative measures of the magnitude of response of each component, because of the presence of significant interactions. But it was possible to generalize concerning the direction and relative magnitude of response of the components. Water-solubles tended to decrease layer volume, and the extent of decrease, although small, was approximately linear with the concentrations used. Variation of gluten and prime starch concentration had a rather complex and nonlinear effect on cake volume. A small increase in gluten or a small decrease in prime starch concentration increased layer volume slightly, but substantially greater or smaller amounts of either resulted in much smaller cakes. Tailings acted to increase vol-

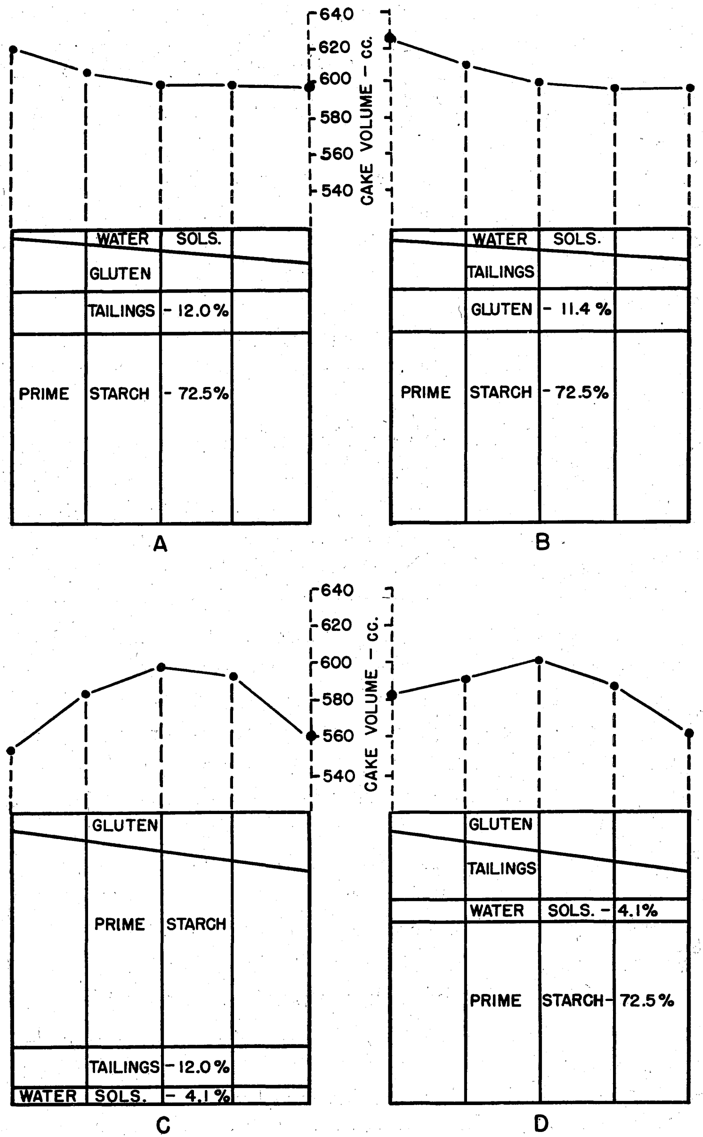

Fig. 6. Graphs of calculated cake volumes for various flour compositions. Relative amounts of flour components are indicated by lengths of vertical intercepts on the bar graph below each graph. A, water-solubles vary from 1.0 to 7.2%; gluten from 14.5 to 8.3%. B, water-solubles vary from 1.0 to 7.2%; tailings from 15.1 to 8.9%. C: gluten varies from 6.0 to 16.8%; prime starch from 77.9 to 67.1%. D: gluten varies from 6.0 to 16.8%; tailings from 17.4 to 6.6%.

ume and to produce a finer internal structure, and generally the larger cakes contained large amounts of tailings. But for any specific change in concentration, it is not possible to point out the effect of altering the quantity of one component without concomitantly taking into account the levels and changes of levels of the other three, since the response depends upon the concentrations of all the fractions. For example, if one were to increase the tailings concentration considerably at the expense of the prime starch, the resultant cake might be rather different from that obtained if one increased the tailings concentration by spreading the adjustment in ratios over all the other fractions. In particular it was shown that, for the materials utilized, reconstituted flours with compositions not very different from the normal composition could yield cakes with volumes significantly different from layers baked from the normal flour. These results bring into question laboratory analytical techniques such as enriching a flour with an added component, since the result of such treatment may be occasioned by the effect of the change in composition as well as by the "inherent" effect of the added component.

Such differences as were found from one treatment to another cannot be ascribed to differences in quality in its usual sense, since all treatment combinations were drawn from a common source with respect to inherent chemical makeup. Nor can such differences be attributed to protein content, for the results of the experiment indicate that protein *per se* had little association with the responses of treatment combinations used. Some of the better cakes contained 10.0 to 10.5% protein, yet cakes of equal volumes were very low in protein. (Compare Tables VI and VII.) Apparently the balance of the fractions was the main factor determining volume, and total protein content depended merely upon the protein distribution of the fractions. Similarly, gluten protein content cannot be considered, for these materials, as the major cause for volume differences, since all the series of cakes presented in Table VII contained the same amount of gluten. Evidently, given a particular set of flour fractions, the proportioning of these fractions was the limiting factor involved in the production of a superior cake, at least when good-quality flour components were used. Consequently, one may infer that one aspect of some importance in the analysis of cake flour quality is the balance of flour components in the flour.

Acknowledgments

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