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STUDIES ON THE EFFECT OF FLOUR-FRACTION INTERCHANGE UPON CAKE QUALITY[1]

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

ABSTRACT

A good-quality unbleached cake flour and a poor-quality cake flour were fractionated into water-solubles, gluten, starch tailings, and prime starch. Fractions were combined to form reconstituted flours comprising complete interchanges of the components at the composition of each flour. These reconstituted flours were bleached, and layer cakes were baked using a lean (no milk or eggs, high sugar) formulation.

The contributions to cake volume of the gluten, water-solubles, and tailings fractions obtained from the good flour were significantly greater than, and the effects on gross cake structure with these fractions were superior to, those of the corresponding fractions obtained from the poor flour. The prime starch from the poor flour was significantly superior to that of the good flour. Gluten had the greatest effect on cake volume and structure. Interactions of gluten × composition and water-solubles × tailings × composition were highly significant, which indicated considerable variation of the responses to these flour components with concentration.

It was suggested that the expression of these quality factors may be contingent upon an inherent quality aspect, related to the physical and chemical constitution of each factor, and upon a concentration dependence, related to the percent composition of the flour.

A useful procedure in the investigation of soft wheat quality is that of baking lean-formula cakes from reconstituted test flours. For analytical work, the lean formulation developed at the Wooster laboratory for the baking of white layer cakes has several advantages. The omission of milk and eggs from the formula eliminates all structure-forming elements except the flour, and the high sugar content acts as a tenderizing agent. Consequently, maximum stress is placed upon the flour, and variation found in finished cake may be more readily associated with the treatments used.

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

Previous work (2) demonstrated that white layer cake quality, as measured by volume and appearance, may depend upon the composition or relative proportions of the component flour fractions. The quality of cakes baked from flour fractions obtained from a good soft wheat cake flour could be made to vary considerably simply by altering the proportions of fractions. The effect that each component had depended not only upon the amount of it present, but also upon the amounts of the other fractions used, which suggested that flour quality depends in part upon a balance of its components. For that work, quality of flour fractions was held constant by taking them from the same source, and the proportions of the components were varied by making up synthetic flours containing different amounts of each fraction.

Implicit in such an analytical procedure is the assumption that the quality effect, Q_i, of each fraction is a function of an *inherent quality,* q_i, and a *concentration dependence,* c_i, i.e., $Q_i = f(q_i,c_i)$, analogous to a vector, which has both magnitude and direction. Fraction quality evaluation, then, would require exploration of both inherent quality and concentration. Over-all cake quality, $\overline{Q}$, would be a summation of the quality contributions of all fractions, so that

$\overline{Q} = \sum_i Q_i = \sum_i f(q_i,c_i)$. This is subject to the constraint that $\sum c_i = 100$,

where the c_i are expressed as percentages of the fractions in the flour. For the aforementioned work, all the q_i were held constant and the c_i were varied. Changes in $\overline{Q}$ showed that for the flour used, concentration dependence was significant.

In order to test the other half of this postulate, it would be desirable to hold the flour composition constant and alter or vary the inherent quality of each flour fraction to gain measures of the effect of inherent fraction quality on over-all cake quality. This report is a presentation of data from such an extension of the earlier work, and is concerned, therefore, with the relative quality of flour components.

A systematic substitution of flour fractions obtained from a poor-grade cake flour for those of a good cake flour might allow inferences to be made concerning the contribution of each component to the over-all quality of the cake and indicate how the factors within a flour determine its property of being good or poor. (We select a good and a poor flour for the first experiment in order to ensure that differences in relative quality are bound to be significant.) If we determine by fractionation the good flour composition, C, then by combining good and poor fractions in various ways (all reconstituted flours with the same composition, C), we should obtain measures of the relative inherent quality of the pairs of fractions. However, assuming that the quality expression of each factor is a function of both q and c, the use of a single composition leads to confounding of inherent quality and concentration dependence, since we have no way of estimating concentration dependence from just one composition. If, for composition C, we find that a fraction from the poor flour is poorer than its counterpart, it is entirely possible that for another composition, C′, the positions would be reversed. Lest this appear purely academic, consider that from one point of view, flour milling, especially some of the newer techniques (3), can be considered to be just preparation of products whose components are present in certain concentrations. It becomes a matter of practical importance to discover how greatly flour quality might depend on flour composition.

The smallest number of compositions that might be used to gain some estimate of the effect of concentration on substitutions to test fraction inherent quality is two. A large number, so that one could prepare response surfaces as was done in the previous work (2), would be preferred, but the experimental complications involved in substituting flour fractions at each of a number of compositions are appalling. An experimental design that offers some estimation of concentration dependence and relative inherent quality is one in which substitutions of components from the poor flour into the good one at composition C of the good flour is accompanied by the converse, substitution of good flour fractions into the poor flour at the composition C′ of the poor flour. With such a design, we obtain data on the quality contributions of components from two flours at compositions of both flours, and gain thereby some measure of inherent quality, q_i, of each fraction and an inkling of the effect of concentration, c_i, on its quality at two levels of concentration. We can, if there are differences, at least rank the pairs of fractions for two concentrations and see whether concentration has any effect on their ranking.

An appropriate experimental method is obviously a factorial, especially since we assume that over-all cake quality is, in a broad sense, a summation of flour component contributions to that quality. The experimental procedure would then be a complete interchange of fractions at each composition level. A similar interchange procedure was used by Zaehringer *et al.* (8) for an experiment using biscuits as the baked product.

Materials and Methods

A 48% extraction, unbleached, commercially milled soft wheat flour (hereafter designated for convenience *commercial*) was selected as the good-quality cake flour. An inferior cake flour (designated *Pawnee*) was obtained by milling a sample of Pawnee wheat to 50% extraction. This flour was prepared on Allis-Chalmers laboratory equipment, then Raymond-milled to obtain particle size comparable to that of the commercial flour. The protein content of the commercial flour was 7.6%, and that of the Pawnee flour was 10.1%, on a 14% moisture basis.

Each flour was fractionated into water-solubles, gluten, starch tailings, and prime starch by a batter and screening method modified slightly from that described in the previous report (2). With 1500-g. batches of flour, a small residue remained on the screen after removal of gluten. It appeared to be composed of hydrated tailings particles too large to pass the 25 standard silk bolting cloth (0.0025-in. opening), along with a quantity of dispersed gluten and protein foam. As an additional step, the residues from several batches were pooled, triturated with water, and centrifuged; the supernatant was added to the water-solubles fraction. Gluten was removed from the residue by kneading in a small quantity of water, and added to the main gluten fraction. The remainder of the material was combined with the tailings. All fractions were lyophilized, ground at the fine setting of a Hobart coffee mill (except water-solubles, which were put through at an open setting), and stored under refrigeration.

With the above method, fractions totaling 96.0% of the commercial flour and 97.5% of the Pawnee flour were recovered. Table I reports the relative proportions of fractions, their protein content, and the percentages of total flour protein in each fraction, as found

TABLE I

PERCENTAGE COMPOSITION OF FLOURS WITH PROTEIN CONTENT AND DISTRIBUTION OF TOTAL FLOUR PROTEIN IN FRACTIONS

Fraction	Commercial			Pawnee		
		Protein			Protein	
	Yield [a]	Percent in Fraction [b]	Percent of Total Flour Protein in Fraction	Yield [a]	Percent in Fraction [b]	Percent of Total Flour Protein in Fraction
	%	%	%	%	%	%
Water-solubles	3.6	22.3	10.4	3.7	18.2	6.6
Gluten	11.2	56.4	81.9	17.6	50.2	87.3
Tailings	9.8	3.3	4.2	12.3	2.9	3.6
Prime starch	75.4	0.36	3.5	66.4	0.38	2.5
Total	100.0		100.0	100.0		100.0
Percent recovery	96.0			97.5		

[a] Adjusted to 100%; 14% moisture basis.
[b] 14% moisture basis; factor N × 5.7.

for each flour. Losses were considered as proportionally distributed among all fractions, so the compositions were adjusted to 100% yield and used as the bases for making up treatment combinations required.

Five factors were thus available for interchanging: 1) water-solubles, 2) gluten, 3) starch tailings, 4) prime starch, and 5) composition. Because the relative proportions of components in the two flours differed considerably, it was necessary to include composition as a full-fledged factor, as discussed in the introduction, in order to be able to obtain some measure of the part of the response due to concentration of the other factors. If this composition factor had been omitted, and all the treatment combinations made up at a single composition, the effects of the interchanges would not have been strictly comparable. Perhaps it should be stressed that composition, though a quantity capable of continuous variation, was for this experiment set at two distinct and fixed levels, and was therefore formally equivalent to the qualitative factors comprised by the flour fractions.

The complete set of interchanges was therefore considered as a two-level factorial. Pawnee flour fractions and the composition experimentally found for the Pawnee flour were considered as the Pawnee level, and the commercial fractions and composition were taken as the commercial level. The baking phase of the experiment was arranged as an incomplete block design, set up as a partially confounded 2^5 factorial. The possible combinations of the five factors called for 32 treatments. Three replicate bakes per treatment (with each replicate the average of two cakes per batter) were deemed sufficient for precision with 16 entries per level of every factor. The design was made up of twelve blocks, each containing eight treatments. Since each block comprised the cakes baked on a single day, some comparisons were partially confounded in order to remove error due to daily variation. It was found that the gain in precision of unconfounded comparisons was negligible, which indicated that day-to-day variation in baking results was not an important source of error.

Reconstituted flours for each combination were prepared by blending the lyophilized components in the proportions required for each treatment, as detailed in Tables IIA and IIB. Each blend was then hydrated to a moisture content of approximately 13%, and bleached with chlorine gas to pH 4.7–4.8. Preliminary tests had demonstrated this to be the optimum bleach level for these materials.

The cake formulation was an adaptation of the Soft Wheat Quality Laboratory's lean white layer formula for varietal evaluation (4). The procedure for use with reconstituted flours and the mixing schedule were as reported previously (2). For each flour combination, liquid level was adjusted by trial bakes to give the maximum cake volume and best top contour obtainable from that particular flour. It was expected that using the optimum liquid level, as noted in Tables IIA and IIB, for each treatment would eliminate liquid level as a source of variation.

TABLE IIA

FRACTION INTERCHANGES, LIQUID LEVELS, AND BAKING RESULTS FOR CAKES USING COMMERCIAL COMPOSITION

TREATMENT No.	COMPOSISTION[a] (PERCENT)				AVERAGE CAKE VOLUME	AVERAGE CAKE SCORE	LIQUID LEVEL[b]
	Water-Solubles 3.6	Gluten 11.2	Tailings 9.8	P. Starch 75.4			
					cc		%
1	C	C	C	C	604	6.5	103
2	P	C	C	C	576	5.8	103
3	C	P	C	C	500	3.5	97
4	C	C	P	C	596	7.0	103
5	C	C	C	P	613	6.2	103
6	P	P	C	C	449	3.0	103
7	P	C	P	C	516	4.3	109
8	P	C	C	P	583	5.3	103
9	C	P	P	C	458	3.0	103
10	C	P	C	P	496	3.8	103
11	C	C	P	P	580	5.2	103
12	P	P	P	C	442	3.0	97
13	P	C	P	P	541	4.2	103
14	C	P	P	P	489	3.5	103
15	P	P	C	P	493	3.3	97
16	P	P	P	P	438	3.0	103

[a] C = fractions from commercial flour; P = fractions from Pawnee flour.
[b] Based on flour weight; flour at 14% M.B.

TABLE IIB

FRACTION INTERCHANGES, LIQUID LEVELS, AND BAKING RESULTS FOR CAKES USING PAWNEE COMPOSITION

TREATMENT No.	COMPOSITION[a] (PERCENT)				AVERAGE CAKE VOLUME	AVERAGE CAKE SCORE	LIQUID LEVEL[b]
	Water-Solubles 3.7	Gluten 17.6	Tailings 12.3	P. Starch 66.4			
					cc		%
17	P	P	P	P	483	3.7	115
18	C	P	P	P	484	3.5	109
19	P	C	P	P	557	6.7	115
20	P	P	C	P	511	3.7	115
21	P	P	P	C	478	4.2	115
22	C	C	P	P	522	5.2	121
23	C	P	C	P	523	5.0	115
24	C	P	P	C	481	3.7	121
25	P	C	C	P	539	6.8	115
26	P	C	P	C	519	5.3	115
27	P	P	C	C	470	3.7	115
28	C	C	C	P	556	6.8	115
29	C	P	C	C	493	4.0	121
30	P	C	C	C	502	5.3	121
31	C	C	P	C	500	4.5	121
32	C	C	C	C	538	6.2	121

[a] C= fractions from commercial flour; P = fractions from Pawnee flour.
[b] Based on flour weight; flour at 14% M.B.

The primary measure of cake quality was layer volume, as determined by seed displacement. In the absence of an adequate quantitative cake-scoring procedure, the internal score data were not subjected to analysis. These data are reported in Tables IIA and IIB. Obvious differences in cake structures are apparent from the photographs reproduced in Figs. 2, 3, and 4.

Experimental Results

For ease in making comparisons, the baking results are presented in a bar graph, Fig. 1. Here the upper half of the graph represents all cakes having commercial flour composition and with commercial flour fractions, except as noted in the center row labeled "factions interchanged." The lower half represents the cakes having Pawnee composition and components, with substitutions of commercial fractions as noted. The ordinate for each half represents layer volume in cc.; the hatched area represents the decrease in volume from that

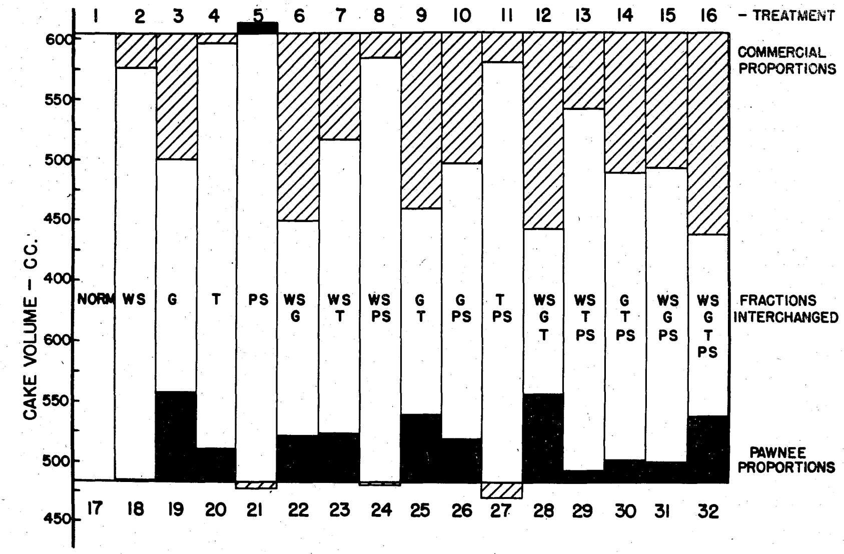

Fig. 1. Variations in volumes of cakes baked with reconstituted flours produced by interchanging four fractions from good- and poor-grade flours. Upper row shows alteration of volumes for flours made up in commercial proportions, and lower row shows changes for those made up in Pawnee proportions. Fractions interchanged are indicated between the rows. Ordinates: layer volume. Lengths of hatched regions 1) in upper row indicate amount of decrease in volume from that of treatment 1 (all commercial fractions in commercial proportions); 2) in lower row, amount of decrease in volume from that of treatment 17 (all Pawnee fractions in Pawnee proportions). The lengths of solid black regions show the volume increase with respect to treatments 1 and 17.

of the normal (standard) reconstituted cake of each kind, treatment 1 in upper row and treatment 17 in lower group, and the black area represents the increase in volume over the respective normal reconstituted cakes. In the commercial cakes, substitution of Pawnee gluten was associated in every case with a decrease in volume of no less than 100 cc. Those cakes of commercial composition containing Pawnee water-solubles and tailings with commercial gluten (no. 7, no. 13) had smaller volumes than the normal cake, and those containing Pawnee water-solubles or tailings, or both, with Pawnee gluten, were very poor indeed. Conversely, cakes of Pawnee composition containing commercial gluten were generally larger than the Pawnee control, although volume differences were not so marked.

Figures 2, 3, and 4 show cross-section photographs of representative layers baked from many of the treatments. In addition, the upper row of Fig. 2 shows sections of cakes prepared from the original commercial and Pawnee flours, bleached to pH 4.8 with chlorine. These were

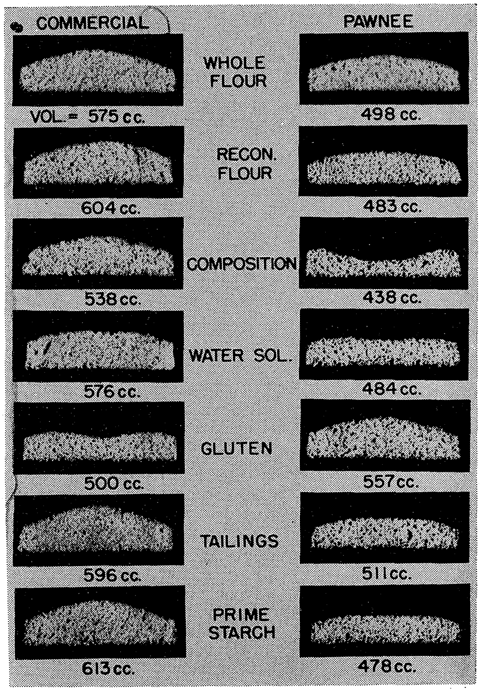

Fig. 2. Rows 1 and 2, comparison of cakes baked from whole and reconstituted flours. Left column commercial, right column Pawnee flour. The reconstituted cakes form treatments 1 and 17 of the treatment combinations. Rows 3 through 7, cakes resulting from single factor interchanges. Factor interchanges noted between the cakes.

obviously of very different baking quality. The second row of cakes in Fig. 2 were prepared from the corresponding normal reconstituted flours; i.e., the commercial reconstituted flour was made up with all commercial fractions combined in the proportions found for that flour (treatment 1), and similarly for the normal reconstituted Pawnee flour (treatment 17). The differences between these reconstituted cakes and their whole-flour counterparts show that, although there was some loss of baking quality attributable to the fractionation, the distinction in quality between commercial and Pawnee was preserved. Consequently, it was felt that whatever damage had occurred to flour factors in fractionation, it was not sufficient to invalidate results obtained from the subsequent interchanges. The other cake sections shown in Fig. 2 were the result of interchanging one factor at a time. For all of these, as well as for Figs. 3 and 4, the column labeled "commercial" comprised layers with all fractions commercial except those interchanged as noted; this was true also for the "Pawnee" column. Interchange of composition (row 3) led to radical decrease of volume in either case, and the layer with Pawnee components was fallen, with very poor internal structure. The "normal reconstituted commercial" cake and the "composition interchanged commercial" cake were both made from all-commercial fractions, i.e., fixed inherent quality, q_i, for each fraction, but the concentrations, c_i, in the two cakes were different; this was true also for the two corresponding Pawnee cakes. Here

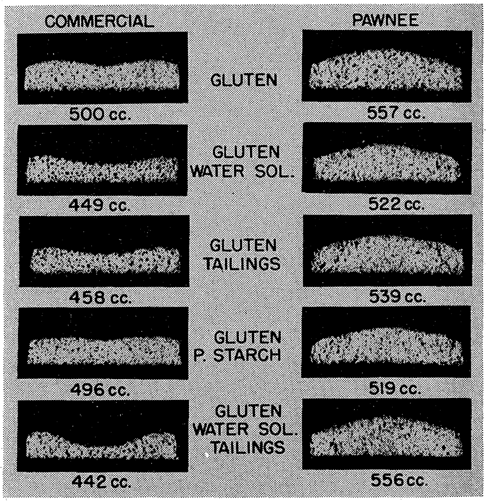

Fig. 3. Effect of gluten and interaction of other flour components with gluten upon cake volume and structure. Left column, all commercial fractions except for interchanges, and all at the commercial proportions. Right column, all Pawnee fractions except for interchanges, and all in Pawnee proportions.

we have direct evidence that composition, in the sense of relative concentrations, of a flour can have a marked effect on the quality of resultant cakes, apart from any effect attributable to inherent fraction quality. It is clear that commercial composition was superior for the commercial components, and Pawnee composition was superior for the Pawnee components. Notable results of the single-fraction interchanges were: 1) decrease in volume of the commercial cake with Pawnee water-solubles; 2) the inferior quality of commercial cake with Pawnee gluten; and 3) the marked improvement in volume and appearance of Pawnee cake obtained by substitution of commercial gluten.

Figure 3 shows some results of interchanging gluten and other fractions at the same time. In each commercial cake, Pawnee gluten was associated with fallen contour, a remarkable decrease in volume, and very coarse structure. The action of Pawnee water-solubles and tailings, singly, was to decrease the volume and structural quality further, and the cake with all three Pawnee factors was extremely poor. Conversely, the presence of commercial gluten in Pawnee cakes was associated with rounded contour and considerable increase in volume, to such an extent that they appeared similar to the normal reconstituted commercial cakes.

Figure 4 illustrates the effect of prime starch, water-solubles, and tailings in various combinations. In general, these components had much less effect on volume and top contour than did gluten. Presence of the commercial components in Pawnee cakes led to a coarsening of structure. It can be seen, by cross-comparison, that the Pawnee prime

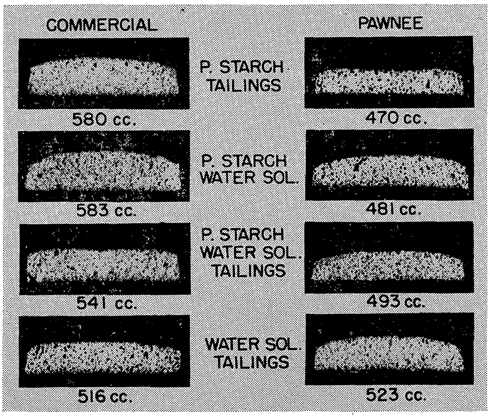

Fig. 4. Effect of prime starch, water-solubles, and tailings interchanges upon cake volume and structure. Left column, all commercial fractions except interchanges, and all at commercial proportions. Right column, all Pawnee fractions except for interchanges, and all at Pawnee proportions.

starch afforded larger volume in both commercial and Pawnee cakes, and that Pawnee water-solubles and tailings together had a greater effect in lowering volume and structural quality of commercial cake than did either component individually.

Analysis

The analysis of variance of the cake volume results is presented in Table III. In the tests of significance, the null hypothesis for each intrafactor comparison was that there was no alteration of volume incident upon changing from the Pawnee to the commercial level of a factor. The basic null hypothesis for the interfactor comparisons was that there was no interaction; that is, any change of volume found for the combination of a set of factors was just the sum of the average responses of each. All five factors were highly significant, but the outstanding result of the analysis was the grouping of factors about three centers: 1) effect of prime starch, 2) effect of gluten and its interaction with composition, and 3) effect of water-solubles and tailings and their interactions with compositions.

TABLE III

Analysis of Variance of Cake Volume Data

Source of Variation	d.f.	Mean Squares
Main effects		
Water-solubles	1	10,626**
Gluten	1	124,704**
Tailings	1	12,331**
Prime starch	1	7,704**
Composition	1	4,428**
Interactions		
Water-solubles × comp.	1	2,513*
Gluten × comp.	1	26,800**
Tailings × comp.	1	1,980*
W.S. × tailings × comp.	1	4,187**
Combined nonsignificant interactions	22	358
Error	53	377

Cross-comparison of the tests indicates that the responses of the prime starches were significantly different, and that starch was not involved in any significant interaction with other factors. A computed average effect would be a direct measurement of the difference in response to the starches. However, it was quite different with the other factors. The responses to the glutens were evidently quite different at different levels of composition. Since the main effect of gluten and its interaction with composition were both highly significant, and since interaction is essentially the failure of the factors to be additive, an average effect of gluten would not be a direct measure of the difference in response between the glutens (1). The situation was quite similar for water-solubles and tailings. The responses to combinations of these flour fractions were variable with different flour compositions. Differences in response were great enough that both the main effects and the interactions were significant.

The effect of the composition factor was complex. Variable responses to changes in gluten, water-solubles, and tailings depended upon the relative proportions of the flour fractions. The simplest cause for such variation would appear to reside in the effect of concentration. That is, the effect of flour composition on fraction response as postulated in the introduction may be equivalent to concentration dependence of that response. It should be noted that this type of experimentation with flour deals with a constrained system. Any alteration made to the composition of a flour is restricted by the subsidiary condition that the sum of the percentages of the constituents must equal 100%. Consequently, the effect of concentration on the response of a factor is confounded with the concomitant change in the concentration of at least one other factor. Some results of such variations in flour composition were reported in a previous experiment (2), from which volume response surfaces were derived for the commercial flour. Alterations of a few percent in flour composition resulted in definite differences in cake volume, and it was shown that it is difficult to abstract from experimental results a simple effect of concentration upon the response of any flour fraction.

In the present experiment, two levels were chosen to fix composition, and interchanges of fractions from two flours of very different baking quality were made at these levels, to investigate primarily the effect of fraction quality. However, the concentration dependence of those fractions was also necessarily involved. As used here, the term concentration is intended to mean the effect of composition upon the response of each flour fraction, with due consideration of the complexity of this effect.

Point plots of the responses of each significant grouping are presented in Figs. 5, 6, and 7, to indicate the magnitudes and difference of the effects of each flour factor and to illustrate the extent of interaction when it was present. In these figures the connecting lines are merely visual aids and do not indicate any linear relationship between volume and composition.

Prime Starch. Figure 5 shows the average volumes of cakes baked with the starches at each composition. Each point represents the average volume of 24 cakes. Within the limits of experimental error, the responses to the starches were nearly independent of the composition

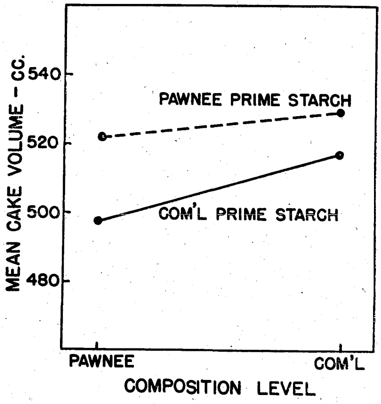

Fig. 5. Effect of prime starch and flour composition upon cake volume.

of the flour, as illustrated by the near parallelism of the connecting lines. The volume change at each concentration was about the same for each starch, averaging 18 cc. in favor of the Pawnee. To that extent Pawnee starch was a better-quality material. Apart from the inherent quality difference, a 9.0% increase in starch concentration (from 66% of Pawnee composition to 75% of commercial composition) effected an increase in volume of about 13 cc. The commercial composition appeared to favor this increase simply because the percentage of starch at this level was higher. The total difference in volume incurred in changing from Pawnee levels of both factors to commercial levels of both was the sum of the responses due to source of starch and concentration, and the net response was negative. It would appear, on the basis of the independence of starch from the other flour fractions, that prime starch quality may be considered as one element in a quality matrix of cake flour. Aside from the question of inherent quality, it appears possible that whatever the role and mode of action of starch may be in the chemistry of baking, it is relatively independent of the quality and amounts of the other flour components, at the levels of concentration studied.

Gluten. Figure 6 is a graph of the average volumes of cakes containing each gluten at each composition. Interaction is evident from the response differences. At Pawnee composition, a change from Pawnee to commercial gluten increased average volume by 38 cc., but at commercial composition, a change from Pawnee to commercial gluten increased average volume by 105 cc. The effect of gluten was undoubtedly the most important item in the entire quality comparison, and it is evident that the degree of response to each gluten was dependent

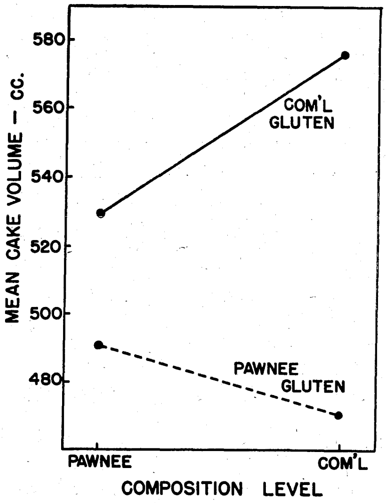

Fig. 6. Effect of interaction of gluten and flour composition upon cake volume.

in some manner upon the amount present. The effect of gluten may be considered from two aspects, 1) layer volume and 2) cake structure. At either concentration, commercial gluten was associated with the better structure and top contour, and the concentration of that gluten affected mainly the volume. But Pawnee gluten was associated with comparable structure only at the Pawnee concentration, and even then layer volume was much smaller. Decrease in concentration led to very poor open crumb and fallen contour, as if the contribution to structural strength had fallen too low. This difference in response between the glutens amounts to a significant inversion, in that the direction of response with respect to concentration for Pawnee gluten was opposite to that of commercial gluten.

We venture to suggest a possible explanation for this inversion, to point up the difference between the glutens and to stress a critical point with respect to the batter-mixing procedure used. Layer specific volume, as a measure of gas-retention capacity and gas phase distribution in crumb, is optimal with small, uniform, thin-walled cells. Any factor tending to produce thick cell walls, holes, or a broad dispersion of cell sizes will impair crumb quality and lower layer volume. For the commercial gluten, granting a basically satisfactory cell formation, the greater response with lower concentration might be associated with decrease in the specific density of gluten in the cellular matrix. That is, with a good-quality gluten, less gluten will do a better job, at least to a point. This corresponds to the practical experience that low-protein, weak-gluten flours bake the best cakes. The peculiar behavior of the Pawnee gluten can be explained from this point of view only if we conclude that the specific density of this poor-quality gluten is basically far lower than that of the commercial gluten. At higher density (Pawnee composition), it is sufficient to allow the formation of a reasonably good cellular structure, but at lower concentration it fails to provide its contribution simply because there is not enough of it. But there is just as much Pawnee gluten at a given concentration. Hence the key factor, which should resolve this paradox, must not be the amount of gluten present, qua gluten, but the state of the gluten.

It was noted that the commercial gluten peptized readily, so it is possible that one criterion of quality for cake flour gluten is ready solubilization. Hence, ultimate structure formation in layer cake may depend upon the state of the gluten in the batter, more as a binder than as a structural element, in contrast to bread, where gluten does make up the basic framework. The whole formulation and mixing procedure for layer cake batter – neutral to slightly alkaline pH, short mixing time, very high sugar concentration – effect minimum gluten development and afford, perhaps, an environment favorable for solubilization. Because for our reconstituted cake-mixing procedure, a dough step, i.e. gluten development, is preliminary to batter mixing, and the dough is then dispersed by adding sugar, shortening, baking powder, and additional water to form a smooth batter, it seems probable that the ability of the dough to disperse is very critical in the formation of an acceptable layer. By this token, the commercial gluten was sufficiently dispersible that it attained ideal solubilized density at low gluten concentration. By the same token, the Pawnee gluten was inferior because of its greater strength. A stronger gluten should be less dispersible under equivalent conditions; consequently, a greater amount of it would need to be present in order to achieve a sufficient density of solubilized gluten to provide the necessary binding function. A lower concentration of this gluten would not provide sufficient material in the requisite state, so the cellular structure would be poorly developed. In addition, the presence of a large proportion of unsolubilized gluten would be expected to lead to abnormally thick cell walls and to a bready crumb, which was the case with the Pawnee gluten.

Whether such considerations be pertinent or not, on the basis of the structure-volume data presented, it appears that gluten must have had a major role in the formation of the over-all structure of these layer cakes. The problem is, whether gluten made a positive contribution, such as a framework, or as a cementing substance for a starch structure, in the finished cake, or acted as a limiting agent in the formation of crumb during baking. In these cakes, the combination of weak commercial gluten and low gluten concentration was in the direction of maximizing the quality of this cake structure. The Pawnee gluten and composition did not fit this pattern. Consequently it is inferred that the effect of gluten depends upon both its concentration and its inherent quality in such a way that the quality of the material is the limiting factor. This suggests the possibility of setting up an index to rate various glutens according to the dependence of their response on concentration, much as flours may be ranked on the basis of liquid-level tolerance and optima. Such an index, using a standard set of the other flour fractions, and three or four compositions, would be useful in studies of the quality characteristics of gluten and in the study of the part gluten and gluten protein have in the formation of cake structure. It is hoped that such a study will provide evidence for the hypothesis that solubilization is a factor of importance.

Water-Solubles and Tailings. A third significant set of factors was the response of cake volume to changes in water-solubles and tailings. A graph of the volume changes involving these is shown in Fig. 7. As with the gluten responses, the effect of each component was dependent upon the levels of other factors. For example, at Pawnee com-

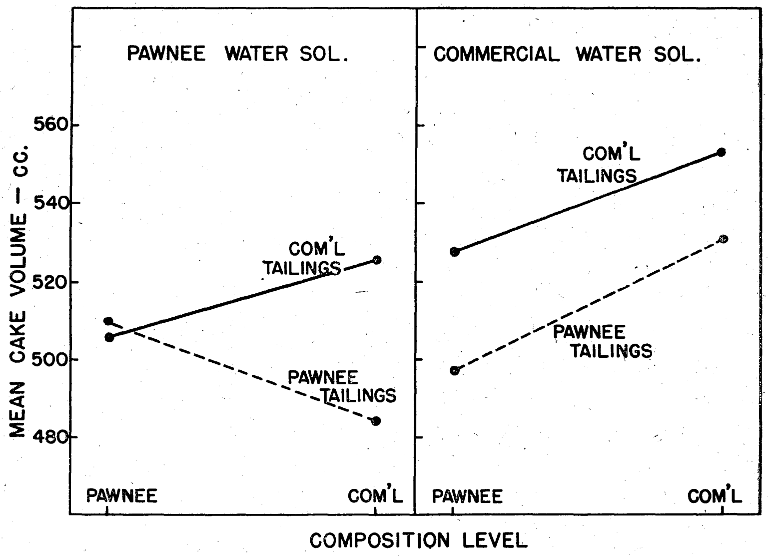

Fig. 7. Effect of interaction of water-solubles, tailings, and composition upon cake volume.

position, change from Pawnee water-solubles and tailings to the commercial components gave an average volume increase of 18 cc., but if the composition were commercial, changing from Pawnee water-solubles and tailings to the commercial components gave an average volume increase of 69 cc. For each of the three factors, the commercial level was in general superior, but the actual volume contribution depended on both the sources of the factors and their relative proportions.

Since the percentage of water-solubles was nearly constant for all treatment combinations, 3.6% in commercial and 3.7% in Pawnee composition, the effect of water-solubles here was not associated with any concentration change. The tailings response, however, was affected by the difference in concentration between the composition levels, amounting to about 20% less tailings for the commercial composition. With commercial water-solubles, tailings response can be attributed to the sum of the effect of tailings concentration and the source, since the response due to the source of tailings was nearly the same at either concentration. With Pawnee water-solubles, the response of commercial tailings was similar to its response with commercial water-solubles, and the lowering of the volume must be a measure of the difference in quality between the two kinds of water-solubles. For these combinations of factors, there was no interaction. But the response of Pawnee tailings with Pawnee water-solubles was opposite to and somewhat lower than its response with commercial water-solubles. This is the interaction shown in the tests of significance.

It will be noted that Pawnee water-solubles, in the presence of commercial tailings, yielded a volume response about 25 cc. lower than did the commercial water-solubles under equivalent conditions. Since Pawnee and commercial composition were about the same with respect to water-solubles, this was a direct measure of the quality difference between the pair. The response attributable to commercial tailings was about 26 cc. greater at the lower tailings concentration afforded by commercial composition, and, under comparable conditions, commercial tailings allowed a 27 cc. greater response than did Pawnee tailings. Consequently, the action of commercial tailings paralleled that of commercial gluten, in that both afforded a greater volume at the lower concentration. With commercial water-solubles, Pawnee tailings had a similar effect; the smaller the amount of tailings, the greater the response, although Pawnee tailings did not allow as much response. The remarkable aspect of this group of factors was the reversal of action of Pawnee tailings when it was used in conjunction with Pawnee water-solubles. The pattern of response involved in this interaction was in the same direction as that of gluten, in that the lowest volume occurred with commercial composition. Figure 3 is a good illustration of the similarity. It is as if a two-factor character of some sort had been separated by the fractionation into a a water-soluble part, W, and a tailings part, T, such that either one had no effect in the presence of its complement, t or w (commercial tailings or water-solubles), or when united in the original proportions WT. But if the amount of T dropped below the original level, as would happen with commercial composition, then the excess of W resulting would act as an inhibitor.

The general effect of water-solubles and tailings appeared to be action on cake structure and volume somewhat similar in type to that of gluten, but not nearly so strong as the gluten effect.

Relative Quality of Flour Fractions and Flour Composition. On the average, over all 32 treatment combinations, the commercial composition was superior to the Pawnee composition. In general, the difficulty in assessing a quantitative measure of the effect of this factor lay in the extent and location of the interactions present, as well as in the confounding of responses due to component quality and component concentration. From analysis of these data it was found that there was negligible interaction of prime-starch response with the other factors. Consequently, it was possible to estimate numerical

TABLE IV

NUMERICAL ESTIMATES OF VOLUME EFFECT OF FLOUR FRACTIONS

FACTOR	INTERACTION	PERCENT CHANGE IN COMPOSITION (COMM.—PAWNEE)	VOLUME EFFECT[a] (COMM. — PAWNEE)	RESTRICTION
			cc	
Prime starch	No	..	−18**	
Gluten	Large	..	Not assignable	
Water-solubles	No	..	+25**	$\bar{c}$ commercial tailings
	Yes	..	Not assignable	$\bar{c}$ Pawnee tailings
Starch tailings	No	..	+27**	$\bar{c}$ commercial water-sol.
	Yes	..	Not assignable	$\bar{c}$ Pawnee water-sol.
Composition				
a) Starch	No	+9	+13	
b) Gluten	Large	−6.4	Not assignable	
c) Water-solubles	No	≃0	....	
d) Tailings	No	−2.5	+26**	Excluding Pawnee water-solubles and tailings
	Yes	−2.5	Not assignable	With Pawnee water-solubles and tailings

[a] Significance by t test.

measures of the difference in starch quality and the concentration effect of starch. With each gluten, the response was greatly modified by concentration, although it was certain that the commercial gluten was far superior to the Pawnee component. With water-solubles and tailings, variability of response was attributable to interaction between Pawnee components and concentration. If this combination were omitted, the experimental data allowed an estimate of the superiority of commercial water-solubles over the Pawnee component, of the superiority of commercial tailings over the Pawnee fraction, and of the difference in response due to concentration. These measures are collected in Table IV. This tabulation, made up by analysis of the data presented in Figs. 5, 6, and 7, shows that by averaging out the difference in concentration of fractions between the two compositions, Pawnee prime starch was slightly but significantly superior to commercial prime starch (−18 cc. volume difference); that commercial water-solubles yielded layers 25 cc. larger, on the average, than did Pawnee water-solubles, for those layers not containing Pawnee tailings; and that commercial tailings produced layers averaging 27 cc. larger than did Pawnee tailings, for those layers not containing Pawnee water-solubles.

Further, although the commercial composition contained 9% more starch, on a total percentage difference, than did the Pawnee composition, the increase in layer volume was not significant with respect to starch, but a decrease in tailings concentration by 2.5%, on a total percentage basis (actually about a 20% change in tailings amount), increased layer volume significantly for all layers except those containing both Pawnee water-solubles and gluten. For all other factors and combinations of factors, explicit values could not be obtained because of the various interactions affecting these combinations.

These data appear to support the main contention of the paper, that flour quality might be categorized into groups located in fractions of that flour, and such that each has two aspects, a concentration dependence, c_i, and an inherent quality aspect, q_i. Even with regard to the interactions, these are clearly tied in with concentration, so that even though we cannot break them down quantitatively, the pattern of interaction appears to be in accord with the postulate.

Discussion

In undertaking analyses of flours in order to determine how quality factors such as those evaluated herein determine cake quality, several variables must be controlled, particularly with a cake formulation such as the one used for these studies, which is quite sensitive. The first of these is liquid level, and Kissell has presented data to show the response of cake volume to change in liquid level (4). Although flour response to liquid level is certainly a major quality factor, usually sufficient to mask the expression of many other factors, we felt that it would be better to attempt to eliminate it as a variable for this work. If the liquid level allowing the optimum response of the flour, in terms of volume, top contour, and internal structure, were selected for each treatment combination, we could discount this aspect of the quality of the flours and perhaps obtain valid comparisons of other factors. For these experiments, liquid level for each reconstituted flour was assigned on the basis of trial bakes. The first trial was made using a liquid level of 103% for flours made up using commercial composition, and of 115% for flours made up using Pawnee composition, these levels being the optima of the respective whole flours, and on the assumption that the percentage of gluten was the determining factor as to liquid level required. If a peaked cake resulted, liquid level was cut back 6% (flour basis) and another trial made. If the layer was fallen, liquid level was increased 6%. For each flour, this procedure was followed until layers of rounded contour, which experience has shown is the optimum configuration, were obtained. The liquid level data presented in Tables IIA and IIB show that some treatments did not require adjustment. This procedure was satisfactory for many of the flours; however, it was not possible to obtain rounded contours for some, notably those which contained Pawnee gluten in commercial proportions, which were all fallen to a greater or lesser degree, and for a few others which were peaked or were flat even though the volume was greater than at another liquid level. For these exceptions, the liquid level which yielded the largest volume and best structure was decided upon.

A correlation analysis of the data, liquid level vs. layer volume, gave a coefficient of correlation of –0.11. The fact that there was negligible correlation indicated that the variable was sufficiently well controlled so that it did not constitute a confounding factor. This was particularly important since the cakes containing Pawnee gluten in commercial proportions were all fallen, and the obvious reason for fallen cake is suboptimal liquid level. Consequently it appears that these failures of Pawnee gluten were occasioned by a deficiency of that gluten which became quite marked at the lower concentration. The data indicate, perhaps, that liquid level depended more upon composition than upon any other factor. The Pawnee composition, requiring high gluten concentration, and therefore high protein content, needed the higher liquid levels. A comparison of flour protein, Tables VA and VB, against liquid level, Tables IIA and IIB, shows that protein content may be the main reason for the higher liquid levels for flours of Pawnee composition. Or the higher liquid level may have been required because of the greater percentage of tailings present at Pawnee composition, since, as shown by Yamazaki (7),

TABLE VA

PROTEIN DISTRIBUTION AND CONTENT IN FLOUR TREATMENT COMBINATIONS AND CHLORINE DOSAGES.
RECONSTITUTED FLOURS MADE WITH COMMERCIAL COMPOSITION

TREAT-MENT No.	PROTEIN CONTENT PER FRACTION				FLOUR PROTEIN	CHLORINE	Δ pH
	Water-Solubles	Gluten	Tailings	Prime Starch			(ml. Chlorine per g.)
	g/100 g flour	*g/100 g flour*	*g/100 g flour*	*g/100 g flour*	*%*	*ml/g flour*	
1	0.80	6.32	0.32	0.27	7.6	0.28	3.0
2	.66	6.32	.32	.27	7.6	.28	2.9
3	.80	5.62	.32	.27	7.0	.28	3.7
4	.80	6.32	.28	.27	7.7	.28	3.3
5	.80	6.32	.32	.29	7.7	.28	3.7
6	.66	5.62	.32	.27	6.9	.28	3.8
7	.66	6.32	.28	.27	7.5	.28	3.9
8	.66	6.32	.32	.29	7.6	.28	3.8
9	.80	5.62	.28	.27	7.0	.28	3.9
10	.80	5.62	.32	.29	7.0	.28	4.0
11	.80	6.32	.28	.29	7.7	.28	4.1
12	.66	5.62	.28	.27	6.8	.28	4.1
13	.66	6.32	.28	.29	7.6	.28	4.3
14	.80	5.62	.28	.29	7.0	.28	4.4
15	.66	5.62	.32	.29	6.9	.28	4.4
16	0.66	5.62	0.28	0.29	6.9	0.32	4.3

TABLE VB

RECONSTITUTED FLOURS MADE UP AT PAWNEE COMPOSITION

TREAT-MENT No.	PROTEIN CONTENT PER FRACTION				FLOUR PROTEIN	CHLORINE PER G. FLOUR	Δ pH
	Water-Solubles	Gluten	Tailings	Prime Starch			(ml. Chlorine per g.)
	g/100 g flour	*g/100 g flour*	*g/100 g flour*	*g/100 g flour*	*%*	*ml.*	
17	0.67	8.84	0.36	0.25	10.1	0.35	3.3
18	.83	8.84	.36	.25	10.3	.35	3.4
19	.67	9.93	.36	.25	11.2	.35	2.9
20	.67	8.84	.41	.25	10.2	.36	3.1
21	.67	8.84	.36	.24	10.1	.36	3.1
22	.83	9.93	.36	.25	11.4	.35	3.0
23	.83	8.84	.41	.25	10.3	.35	3.0
24	.83	8.84	.36	.24	10.3	.35	3.6
25	.67	9.93	.41	.25	11.3	.35	2.9
26	.67	9.93	.36	.24	11.2	.35	2.8
27	.67	8.84	.41	.24	10.2	.35	3.2
28	.83	9.93	.41	.25	11.4	.35	2.6
29	.83	8.84	.41	.24	10.3	.35	2.7
30	.67	9.93	.41	.24	11.3	.35	2.7
31	.83	9.93	.36	.24	11.4	.35	2.8
32	0.83	9.93	0.41	0.24	11.4	0.42	2.5

certain tailings components are extremely hydrophylic.

We must remark, however, that the trials with liquid level cannot be considered to be complete. There was insufficient material available to run full-scale (too low to too high) liquid level series. Nevertheless, we feel that the limited work done, with the compromises enumerated, led to sufficiently close approaches to the optima to be satisfactory.

A second variable involved in baking experiments, not only as a variable to be controlled, but as a quality factor in its own right, is the extent of chlorine treatment, since chlorine is a well-known flour improver. It can be seen from the data listed in Tables VA and VB that in general the chlorine dosage required to obtain the desired flour pH, 4.7–4.8, for the treatment combinations was strongly associated with composition and had no correlation with cake volumes and appearance. It is perhaps reasonable that this association with composition would be present. A flour of high protein content, such as all treatments based on Pawnee composition were, presents a buffer system that will require more chlorine per unit pH change than will a low-protein flour. This bears the implication that in chlorine treatment some alteration of the protein, reflected by the pH of the flour, may be a pertinent reason for the improvement. A report in preparation, however, indicates that chlorine dosage and its effect on the physical structure of prime starch are of great importance in flour improvement by this means, and Sollars (6) has presented evidence that a part of the effect of chlorine can be attributed to the starch fraction. However, there is not necessarily a paradox here as far as pH data are concerned. Chlorine treatment of starch increases its acidity, and the liberated hydrogen ion is then free to be taken up by the protein buffer system. Furthermore, it may well be that the action of chlorine is at least twofold.

A third factor requiring evaluation of its effect on flour quality is protein content. As listed in Tables VA and VB, the protein contents of the reconstituted flours ranged from 6.8 to 11.4%. On the face of it, this might be considered sufficient cause for the quality differences found, but an examination of the results leads to just the opposite conclusion.

In this experiment, with flour fractions combined on two concentration bases, there was no way to equalize protein contents of the treatments if, as here, protein contents of the fractions are different, without discarding composition as a factor. One could, of course, make up a number of reconstituted flours from the fractions, all of equal protein content, but there would necessarily be a variety of flour compositions. A previous report (2) dealt in part with the relation of protein content to cake volume, and it was shown that for several series of compositions, the protein content of those flours presented no clear correlation with cake quality. Here, although we can not equalize protein content without shelving our primary design desideratum, *we can control protein distribution closely*. We have eight starting materials, four commercial and four Pawnee components, each containing a certain percentage of protein. In the make-up of the treatments, the protein is distributed as shown in Tables VA and VB. For the flours based on commercial composition, all eight treatments using, say, commercial gluten have the same amount of commercial gluten protein, 6.32 g. per 100 g. of reconstituted flour, and all eight treatments using Pawnee gluten have the same amount of Pawnee gluten protein, 5.62 g. per 100 g. flour. For the flours based on the Pawnee composition, eight contain 9.93 g. per 100 g. of commercial gluten protein, and eight contain 8.84 g. per 100 g. of Pawnee gluten protein; the data are analogous for all the other fractions in appropriate combinations. The net result is 32 flours with nearly as many protein contents, grouped roughly as high-protein (Pawnee composition) and low-protein (commercial composition).

But note that in the additions and subtractions for the estimates of the volume responses, *these fraction protein contents segregate with their flour fractions*. Hence, the estimates of response to flour fractions are entirely equivalent to the estimates of response to protein content, so volume response and protein content of each factor can be compared directly.

Consider the gluten × composition interaction factor pairs of Table VI. The average increase in volume with the commercial gluten when commercial gluten protein is decreased from 9.93 g. per 100 g. flour to 6.32 g. per 100 g. is 47 cc., which certainly indicates that a lower gluten protein content is better. But the average volume change for decreasing Pawnee gluten protein is a decrease of 20 cc. The table shows that the highest gluten protein content is associated with an intermediate average volume, but the lowest gluten protein content is associated with the lowest average volume. In short, there is no apparent relation between protein content *per se* and the volume response.

The relation shown for gluten × composition interaction is that the responses due to commercial and Pawnee gluten are opposite. Although the factors responsible are located in the gluten, whether the factors are in the protein part or the nonprotein part of the gluten is at this time impossible to say. To locate them precisely would require

TABLE VI

COMPARISON OF FLOUR FRACTION PROTEIN CONTENT WITH AVERAGE CAKE VOLUME

Factor(s)		Protein Content	Average Volume
Fraction(s)	Composition		
		g/100 g flour	*cc*
Pawnee gluten	Commercial	5.62	471
Pawnee gluten	Pawnee	8.84	491
Commercial gluten	Pawnee	9.93	529
Commercial gluten	Commercial	6.32	576
Commercial starch	Pawnee	0.24	498
Commercial starch	Commercial	0.27	518
Pawnee starch	Pawnee	0.25	522
Pawnee starch	Commercial	0.29	529
Commercial water-solubles Commercial tailings	Commercial	1.12	553
Commercial water-solubles Commercial tailings	Pawnee	1.24	528
Commercial water-solubles Pawnee tailings	Commercial	1.08	531
Commercial water-solubles Pawnee tailings	Pawnee	1.19	497
Pawnee water-solubles Commercial tailings	Commercial	0.98	525
Pawnee water-solubles Commercial tailings	Pawnee	1.08	506
Pawnee water-solubles Pawnee tailings	Commercial	0.94	484
Pawnee water-solubles Pawnee tailings	Pawnee	1.03	509

fractionation of the gluten or chemical analysis, and to explain their action would require detailing of a mechanism of gluten action in cake crumb formation. But the point here is that explanation of response on basis of protein determination is inadequate.

This inference is reinforced by evaluation of the water-solubles × tailings × composition interaction. Table VI shows that there is no clear dependence of average volume on protein content. The lowest protein content of the combination of fractions is associated with the lowest volume response, but an intermediate protein level is associated with the greatest volume response. It is of interest to note that if the Pawnee water-solubles and tailings interaction be neglected, and the protein contents of the fractions computed for each combination, then decrease in tailings protein gives larger volume, but decrease in water-solubles protein is associated with smaller volume.

These considerations, taken together with the lack of correlation of flour protein content with cake volume, can only indicate that protein content is not an adequate explanation of the quality differences found. In particular, although protein content was not controllable and so varied from one flour to another, protein distribution was controlled in the design. Hence results were not invalidated by the inequalities of protein content. In fact, the results indicate rather pointedly that protein content can be a poor basis for measuring quality.

It will be noted from the data in Table I that 82–87% of the flour protein of each flour fractionated was found in the gluten, although the protein contents of the glutens were 50–56%. It seemed to us that the best method of fractionation for quality testing by baking experiments would be one which made the least possible modification to the flour components, commensurate with providing, say, four cuts qualitatively and analytically distinguishable. It was considered that a process using distilled water as the sole medium, as small an amount of manipulation of the material as possible, the least loss possible, and batch-to-batch reproducibility of relative proportions and protein analysis of each fraction, was requisite. The batter process developed fulfills these criteria better than any other procedure we have explored. Admittedly, each fraction probably contained a small amount of occluded material properly belonging to other cuts. Except for gluten, which was washed three times in distilled water, and the small refinement detailed above in the "Materials and Methods" section, the fractions were freeze-dried without any further treatment. Qualitatively, the water-solubles obtained were, after drying, very feathery and hygroscopic. The prime starches were low in protein, the tailings cut was quite fibrous and fluffy, and the gluten appeared quite homogeneous and free from prime starch. The boundary between tailings and prime starch, after centrifugation, was well defined.

Although it would certainly be possible to obtain, for example, gluten of much higher protein content, the necessary additional kneading with salt additions (the commercial gluten began to show distressing signs of peptizing after several washings in distilled water) or dispersal in acid and reprecipitation makes it problematical that the gluten would not be further changed by such treatment beyond the development necessary to make the initial separation. Since state of purity of complex mixtures, such as flour fractions are, is a rather arbitrary concept, once one begins to purify, there is always the problem of how to class the new cuts obtained by the refining process. After all, the sort of gluten that one obtains from a fractionation process depends to a considerable extent on how one isolates it. In short, "gluten" is very much an operational definition. There is, to our knowledge, no prior reason, and very few experimental reasons, why gluten should not be half protein and half nonprotein in composition, at least as far as cake-baking is concerned. The distressing similarities of gluten protein amino acid analysis as found in the literature (e.g. 5), may well indicate that the characterization of gluten as a high-protein material is far too restrictive to be useful in evaluating gluten quality in baked goods produced from soft wheats. Indeed, gluten solubilization characteristics may well be the best single criterion of gluten quality. The superiority of the commercial gluten, shown herewith, can certainly be interpreted as evidence for this point of view, although any rational basis for decision as to what constitutes quality must await elucidation of baking mechanisms in terms of chemical or physical processes.

The fact that one can bake from many of these synthetic flours a cake that has volume and appearance similar to the cake made from the original flour, using an extremely lean and consequently very sensitive cake formula, indicates that the fractionation procedure has not altered the starting material too greatly.

We should like to make explicit a methodological assumption implicit in this sort of experimentation. In evaluating data from reconstitution bakes, one is faced with two problems, aside from the questions regarding loss of quality entailed by fractionation itself: 1) evaluating the role of the flour factor or component in the intact flour, since very little is known of the mechanisms of cake baking, and 2) evaluating the action of the component in a reconstituted flour, where even mere physical separation may have altered the function of the component. This is particularly difficult with respect to gluten, since isolation of the material changes its physical state materially. But, if one obtains a layer from a reconstituted flour that is reasonably similar to one obtained from the intact flour, he *must* suppose that whatever the operations performed on the two flours, the end results are occasioned by the same mechanism, so that the state and function of the components are similar in the cakes produced from both the intact and the reconstituted flours, until proved otherwise. The alternative to operating in this way is to discard the analytical approach and try a holistic one, which seems to us to be far less promising.

Conclusions

It may be inferred from the analysis of the data that, with respect to commercial tailings and gluten, the commercial composition, which gave lower concentrations of both factors, was very much superior to the Pawnee composition, and that regarding inherent quality, the commercial gluten and tailings were superior to the Pawnee fractions. With respect to water-solubles, the commercial kind was definitely of superior quality. With respect to starch concentration, a larger quantity was slightly superior, at least in the range of compositions used; and with respect to starch quality, the Pawnee component was slightly better. The marked decrease in cake volume and deterioration of cake structure when Pawnee gluten, water-solubles, and tailings were used in commercial proportions indicated that the inferiority of such components was aggravated by decreasing their concentration, as if the structural strength had fallen below a critical value. The effect of Pawnee tailings was so different with Pawnee and commercial water-solubles that it was inferred that some kind of reinforcement occurs between the Pawnee components, and that this supplements the effect of Pawnee gluten.

The work suggests that fraction responses might be divided into three groups, and that a relative rank can be assigned to each. This division comprises a small prime starch contribution, a very large gluten contribution, and a moderate tailings and water-solubles contribution to cake quality. The analysis indicates that the prime starch contribution is essentially independent of the other two. The gluten, water-solubles, and tailings contributions were related by the presence of concentration effects which were somewhat similar. The implication is rather strong that the gluten, water-solubles, and tailings determine the quality of a basic matrix in the cake structure. A good-quality starch leads to a better cake than a poor-quality starch, other things being equal, but if the basic matrix is of poor quality, it overwhelms the contribution of the starch.

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