EFFECTS OF FLOUR FRACTION COMPOSITION ON COOKIE DIAMETER[1]

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ABSTRACT

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Three pure-variety straight-grade untreated flours were fractionated into five fractions: free lipids, starch, gluten, tailings, and water-solubles. For each variety, blends were prepared according to McLean and Anderson's extreme vertices experimental design, with various proportions of the last four fractions. The blends (with restored lipids) were baked into cookies and the effects of fraction composition on cookie diameter were noted. The functions of fractions were similar for Thorne and Blackhawk and different for Shawnee. Within the "valid area" of compositional variation, and at high starch levels, high water-solubles content was associated with small cookie diameter for Shawnee but with large diameter for Thorne and Blackhawk. High tailings content was associated with poorer cookies in Shawnee blends. The starch fraction did not show varietal differences. For all three varieties, fraction effect on diameter was associated with alkaline water-retention capacities of the fractions gluten, starch, and tailings, and the effect was additive.

Fractionation has been used as a technique to study the roles of flour components in the cookie-baking mechanism (1–3). Those efforts involved wet fractionation without prior treatment of the flour and reconstitution of fractions into a "flour." Yamazaki and Donelson (4) extracted lipids from flour with hexane first, then separated the flour into four fractions. They found that reconstitution of these fractions was not necessary to produce cookies; a blend of fractions with restored lipids was adequate. In addition to the obvious advantage in preparing fractions for experimental cookie-baking, the results indicated the independence of the fractions in contributing to cookie quality.

We now describe the effects on cookie spread of altering the fraction levels of gluten, starch, tailings, and water-solubles for each of three pure-variety wheat flours.

MATERIALS AND METHODS

We tested straight-grade, laboratory-milled, untreated flours from three pure-variety wheats: Shawnee, a hard red winter, and Thorne and Blackhawk, soft red winter wheats, all grown at Wooster, Ohio, in 1974. Shawnee is known to bake poor cookies. Thorne is a finely granulating variety of moderately good cookie quality, while Blackhawk is a coarser granulating variety of excellent cookie quality. Each flour was fractionated, by a modified version of the procedure described (4), into five fractions: free lipids, gluten, starch, tailings, and water-

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solubles, the first as a solution in hexane and the others in dried and ground form (Table I). For each flour, the lipids were extracted in bulk and the other four fractions were obtained by fractionating defatted flour in batches. The procedure (4) was modified as follows: a flour-water slurry (1:2), prepared by diluting a dough, was mixed in a blender for 1 min at high speed and centrifuged for 15 min at 1000 × *g*. The supernatant containing the water-solubles was decanted,

TABLE I
Yield, Protein Content, and Alkaline Water-Retention Capacity (AWRC) Values for Four Fractions Obtained by Fractionation of Defatted Shawnee, Thorne, and Blackhawk Flours (All Data on 14% Moisture Basis), and Free Lipid Yields from Parent Flours

	Shawnee			**Thorne**			**Blackhawk**		
Fraction	**Yield**[a] %	**Protein**[b] %	**AWRC** %	**Yield**[a] %	**Protein**[b] %	**AWRC** %	**Yield**[a] %	**Protein**[b] %	**AWRC** %
Free lipids	0.83	...	...	0.86	...	...	0.92	...	...
Starch	76.4	0.30	63.7	71.8	0.29	59.5	73.9	0.30	58.6
Tailings	11.1	4.97	266.1	13.5	3.46	165.9	9.1	4.29	193.4
Gluten	9.8	73.05	157.3	11.2	65.34	145.5	13.7	60.60	145.6
Water-solubles	2.7	17.29	...	3.5	20.33	...	3.3	22.48	...

[a] Calculated to total 100% for the four fractions (excluding lipids).
[b] Based on N content × 5.7.

TABLE II
Compositions of Blends for Cookie Bakes[a]

Treatment No.	**Starch** %	**Tailings** %	**Gluten** %	**Water-Solubles** %
Vertex points				
1	88	5	6	1
2	84	5	6	5
3	76	5	18	1
4	72	5	18	5
5	78	15	6	1
6	74	15	6	5
7	66	15	18	1
8	62	15	18	5
Face points				
9	81	10	6	3
10	69	10	18	3
11	80	5	12	3
12	70	15	12	3
13	77	10	12	1
14	73	10	12	5
Center point				
15	75	10	12	3
Original composition point				
16	(Different for each flour. See Table I)			

[a] Based on redefined total of 100% for the four fractions, omitting flour lipids.

shelled, and freeze-dried. The sedimented tailings, gluten, and starch were separated by hand using a spatula. The gluten was washed with 0.1% sodium chloride solution and rinsed with distilled water. The wash water (but not the separated starch and tailings) was discarded. The gluten was chilled and freeze-dried, and the other fractions were recovered as described previously (4).

We used the extreme vertices experimental design of McLean and Anderson for the study of mixtures (5). The design problems are similar to those used when testing several factors; however, compositional constraints are also introduced into the design. Briefly, compositions to be tested are defined by these constraints which are viewed as the vertices of a polyhedron enclosing the experimental factor space. Additional compositional points are obtained as face points and a center point. A total of 16 experimental compositions of four components (eight vertex points, six face points, one center point, plus the original composition point) were thus determined for each variety. The following arbitrary limited ranges were designated for fractions: for tailings, a minimum of 5% of blend weight and maximum of 15%; for gluten, 6–18%; and for water-solubles, 1–5%. The quantity of starch in each blend was the difference between the sum of weights of the other three fractions and 100%. The center point of the composition was thus defined as 10% tailings, 12% gluten, and 3% water-solubles, and therefore 75% starch, which approximated the mean yields of fractions (Table I). Table II presents the mixture compositions.

For preparation of fraction blends, appropriate quantities of the four fractions to total 60 g were thoroughly mixed, the extracted quantity of free lipids was

TABLE III
Mean Cookie Diameter and AWRC Values for Parent Flours and Fraction Blends from Three Wheat Varieties

	Shawnee		**Thorne**		**Blackhawk**	
Treatment	**Diameter cm**	**AWRC %**	**Diameter cm**	**AWRC %**	**Diameter cm**	**AWRC %**
Parent flour	15.59[a]	62.1	17.13	53.9	17.62	49.0
1	17.34	70.9	18.32	64.7	18.56	65.0
2	16.17	68.5	18.48	58.5	18.49	59.2
3	16.47	79.6	17.59	70.6	17.74	71.0
4	15.44	77.4	17.56	66.3	17.58	64.2
5	15.46	86.0	17.19	72.3	17.14	73.3
6	14.66	84.4	16.81	67.0	16.92	67.9
7	14.72	94.3	16.62	80.7	16.49	81.8
8	14.34	91.8	16.17	76.6	16.07	76.1
9	15.85	76.0	17.82	66.6	17.78	65.7
10	14.91	85.3	16.81	73.4	16.94	73.1
11	16.28	74.0	18.10	65.5	18.09	64.6
12	14.63	91.9	16.62	73.5	16.70	76.5
13	15.87	81.6	17.23	72.3	17.29	73.0
14	14.96	80.5	17.16	66.4	17.27	67.6
15	15.28	82.3	17.45	68.7	17.40	70.6
Orig. comp.	15.56	81.0	16.94	69.4	17.38	70.5

[a] Standard error of a mean diameter is 0.085 cm.

restored, the solvent was evaporated, and the blend was rehydrated as required. A previous study (6) had shown that neither varietal source nor small differences in quantity of free lipids significantly affected cookie spread. Therefore, lipids were considered to be a constant in all blends. The moisture content of the well-mixed blend was determined, and the quantity equivalent to 40 g of blend (with lipids) at 14% moisture was used per cookie bake in accordance with micro method III of Finney *et al.* (7). Replicate blends were made for each treatment. The average diameter values for such replicates were subjected to statistical analysis.

RESULTS AND DISCUSSION

Mean diameters of cookies baked according to compositions given in Table II, as well as alkaline water-retention capacity (AWRC) values of the blends, are given in Table III.

The cookie diameter data were subjected to least squares computation. Transformations of the independent variables as recommended by Gorman (8) for improving accuracy were also used. The following quadratic equations for diameter prediction were obtained:

For Shawnee: $Y = 19.838X_1 + 30.859X_2 + 16.900X_3 + 111.685X_4$

$$-41.322X_1X_2 - 9.256X_1X_3 - 141.433X_1X_4$$

$$-29.289X_2X_3 - 55.883X_2X_4 - 92.879X_3X_4,$$

For Thorne: $Y = 19.506X_1 + 33.393X_2 + 16.944X_3 - 196.829X_4$

$$-32.225X_1X_2 - 6.549X_1X_3 + 242.139X_1X_4$$

$$-19.988X_2X_3 + 90.536X_2X_4 + 209.026X_3X_4,$$

For Blackhawk: $Y = 19.752X_1 + 23.296X_2 + 17.603X_3 - 118.939X_4$

$$-21.763X_1X_2 - 6.216X_1X_3 + 152.144X_1X_4$$

$$-18.432X_2X_3 + 77.883X_2X_4 + 116.763X_3X_4,$$

where Y = predicted cookie diameter,
X_1 = fraction of starch in blend,
X_2 = fraction of tailings in blend,
X_3 = fraction of gluten in blend,
X_4 = fraction of water-solubles in blend, and
$X_1 + X_2 + X_3 + X_4 = 1.00$.

Equations were also computed for the two replicate bakes of each variety. Differences between replicates were significant for Blackhawk but not for Shawnee or Thorne. The results for Blackhawk may have been due to day-to-day variations which at times can influence diameter, and inspection of the data indicated that the mean diameters differed for the two bakes.

When the deviations of diameters from the models were pooled, the standard deviation (s) per bake was 0.127 cm with 36 d.f. The 3-way interaction of treatment by replicate by variety from a 3-way analysis of variance table gave an s value of 0.119 cm. Variation explained by the models was highly significant for all varieties with multiple correlations R exceeding 0.999. In addition, the models showed good agreement between the two replicates. After determining the model, unexplained variation as estimated by s of 0.127 was similar to that observed in previous baking experiments.

The models presented above were used to prepare contour response curves at fixed starch levels of 66, 74, and 82% for each variety. Figure 1 presents the locations of the treatments with respect to proportions of tailings, gluten, and water-solubles at the several starch levels. The inset polygon outlines the extremes in composition and suggests the limits of validity for surface response projections in the figures that follow. The inset is only a suggestion of valid limits with components other than starch normalized to 100%. The factor space is actually an irregular parallelepiped of which the surface generated by its sectioning at each of several starch levels comprises the "valid area." Figures 2, 3, and 4 present surface responses for cookie diameters at three starch levels each for Shawnee, Thorne, and Blackhawk, respectively. In these figures, X_2 refers to the tailings, X_3 to gluten, and X_4 to water-solubles, where $X_2 + X_3 + X_4 = 1.0 - X_1$, and X_2, X_3, and X_4 are normalized to total 100% to facilitate plotting on triangular coordinate graph paper. Isodiametric contour lines, with cookie diameters in cm, are drawn as solid lines within the factor space and as dotted lines elsewhere. The figures shown are drawn to the same size, although the three components other than starch vary from 34 to 18% of the composition. Thus as starch increases, the total area for experimentation with the other components decreases. It is useful to remember this when examining the figures.

Inspection of the equations shows that the signs of the coefficients of the X_4

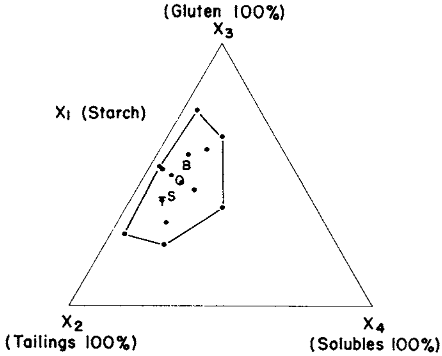
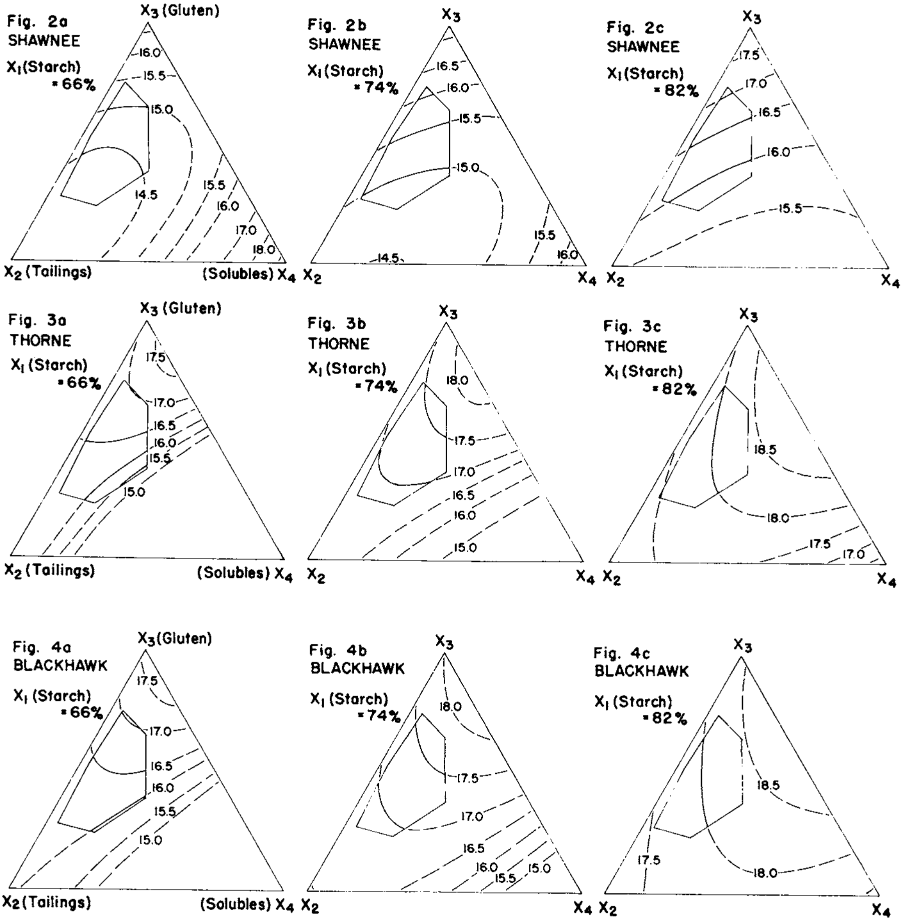


Fig. 1. Treatment locations for fraction mixtures. The hexagonal figure (inset) outlines the "valid area." The center point of the treatments is denoted by 0 and the original compositions for Shawnee, Thorne, and Blackhawk by S, T, and B, respectively. Fractions X_2, X_3, and X_4 are normalized to total 100% at each X_1 (starch) level.

terms are opposite for Thorne and Blackhawk *vs.* Shawnee. The first derivatives of Y with respect to X_4 generally indicate that as the X_4 vertex is approached, the diameter tends to increase for Thorne and Blackhawk, and decrease with Shawnee. This tendency is particularly true at the high starch levels (X_1). The figures also show that, at high starch levels, increasing X_2 generally has little effect on diameter for Thorne (Fig. 3c) and Blackhawk (Fig. 4c) but has considerable effect for Shawnee (Fig. 2c). At equal starch levels, moreover, the diameters in all parts of the "valid area" are significantly smaller for Shawnee than for Thorne. Also the contour lines, relative to the X_2 vertex, are concave for



Figs. 2–4. Contour lines of predicted cookie diameter (in cm) based on mixtures where X_2 (tailings) + X_3 (gluten) + X_4 (water-solubles) are normalized to 100% for Shawnee at X_1 (starch) = 66% (Fig. 2a), X_1 = 74% (Fig. 2b), and X_1 = 82% (Fig. 2c); for Thorne at X_1 (starch) = 66% (Fig. 3a), X_1 = 74% (Fig. 3b), and X_1 = 82% (Fig. 3c); and for Blackhawk at X_1 (starch) = 66% (Fig. 4a), X_1 = 74% (Fig. 4b), and X_1 = 82% (Fig. 4c).

Shawnee and convex for Thorne and Blackhawk.

Inspection of the diameter differences between Shawnee and Thorne at equal starch levels suggests that starch is the primary fraction determining diameter. This relation, however, is more apparent than real. A plot of calculated cookie

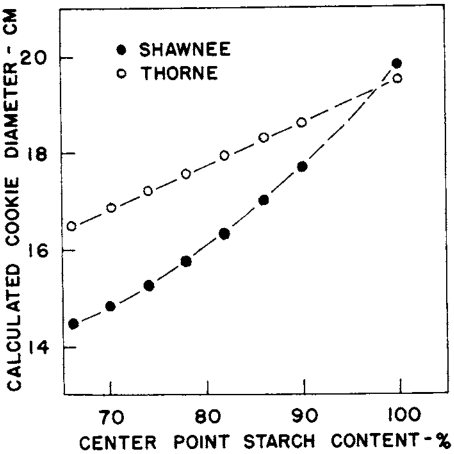


Fig. 5. Center point starch content *vs.* cookie diameter calculated from models for Shawnee and Thorne fraction mixtures.

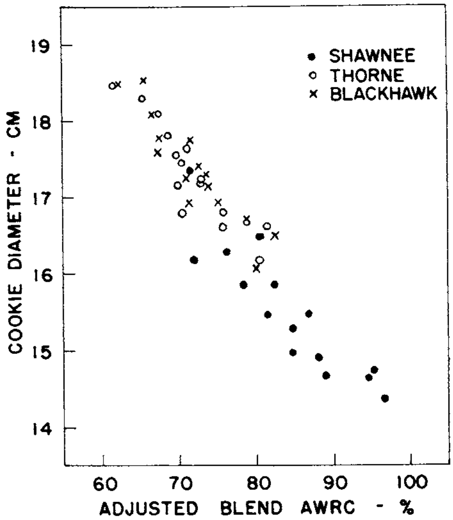


Fig. 6. Scattergram for fraction blend AWRC adjusted for water-solubles content *vs.* observed cookie diameters for blends from Shawnee, Thorne, and Blackhawk fractions.

diameter *vs.* starch content of blend center points (Fig. 5) shows that the predicted diameter increases linearly with starch content for Thorne, but that the relation is curvilinear for Shawnee. The lines projected to 100% starch appear to meet, which indicates (as predicted by the equations) that the starch fraction has little varietal effect on cookie diameter.

The form of the isodiametric contours is determined by the relative contributions of fractions. For example, surface projections in Fig. 2a indicate that for Shawnee at 66% starch, gluten and water-solubles interact to reduce diameter, which is further decreased with inclusion of increasing quantities of tailings, leading to a sloping convex isodiametric surface. On the other hand, Fig. 3a shows that at 66% starch content, Thorne gluten and water-solubles interact to maximize diameter, with tailings again contributing to diameter decrease, resulting in a sloping concave isodiametric surface. Thus the gluten-water-solubles combinations apparently determine surface form (but not necessarily diameter, since starch and tailings apparently also participate in the interaction). Those conclusions are based partly on projections of compositions to unrealistic proportions. Nevertheless, the projections are useful in proposing a possible reason for differences in diameter contour surfaces which have been determined within the factor space.

The spread-depressing effect of the tailings fraction *vis à vis* the gluten, as the quantity of tailings is increased at the expense of gluten, was evident for all three varieties at all starch levels investigated. At comparable starch levels, the spread-depressing effect of tailings was greater for Shawnee than for Thorne, a reflection of Shawnee's higher AWRC value (3).

Flour AWRC is highly correlated with cookie spread (9). Correlations between the AWRC values of blends prepared for baking in the present study and diameter were significant and negative for each of the three varieties and for the pooled population (r = −0.83*** for Shawnee, −0.84*** for Thorne, −0.84*** for Blackhawk, and −0.91*** for the pooled population). From the data in Table I, AWRC values of the blends were also computed as the sums of weighted AWRC values of the insoluble fractions gluten, starch, and tailings for each composition. These AWRC values correlated highly with blend AWRC data (r = 0.98***, n = 45). When the blend AWRC values were adjusted for the nonparticipation of water-solubles, the coefficients of correlation between the adjusted values and cookie diameter were raised to −0.91*** for Shawnee, to −0.92*** for Thorne and Blackhawk, and to −0.95*** for the pooled data (Fig. 6).

Thus, the spread potential of a blend may be expressed in terms of the water-retentive properties of the three insoluble fractions, and the effect is additive. However, the fractions have inherent and perhaps unique physical properties, including those of water sorption, cohesion, and adhesion, that must also be considered.

Our data confirm the efficacy of flour dilution with starch in increasing cookie spread. They also show the spread-depressing effect of increasing the relative quantity of hydrophilic—as measured by AWRC—flour components, or, by implication, by introducing a hydrophilic additive into cookie dough. All of these effects are part of the same mechanism, that is, the control of cookie spread through the adjustment of the water-retentive capacity of flour components and additives.

Literature Cited

1. SOLLARS, W. F. Effects of the water-soluble constituents of wheat flour on cookie diameter. Cereal Chem. 36: 498 (1959).
2. SOLLARS, W. F. Evaluation of flour fractions for their importance to cookie quality. Cereal Chem. 33: 121 (1956).
3. YAMAZAKI, W. T. The concentration of a factor in soft wheat flours affecting cookie quality. Cereal Chem. 32: 26 (1955).
4. YAMAZAKI, W. T., and DONELSON, J. R. Effects of interactions among flour lipids, flour fractions, and water on cookie quality. Cereal Chem. 53: 998 (1976).
5. McLEAN, R. A., and ANDERSON, V. L. Extreme vertices design of mixture experiments. Technometrics 8: 447 (1966).
6. KISSELL, L. T., POMERANZ, Y., and YAMAZAKI, W. T. Effects of flour lipids on cookie quality. Cereal Chem. 48: 655 (1971).
7. FINNEY, K. F., MORRIS, V. H., and YAMAZAKI, W. T. Micro versus macro cookie baking procedures for evaluating the cookie quality of wheat varieties. Cereal Chem. 27: 42 (1950).
8. GORMAN, J. W. Fitting equations to mixture data with restraints on composition. J. Qual. Tech. 2: 186 (1970).
9. YAMAZAKI, W. T. An alkaline water retention capacity test for the evaluation of cookie baking potentialities of soft winter wheat flours. Cereal Chem. 30: 242 (1953).

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