Freeze-Dried Wheat Water Solubles from a Starch-Gluten Washing Stream: Functionality in Angel Food Cakes and Nutritional Properties Compared with Oat Bran[1]

B. B. MAZIYA-DIXON,[2] C. F. KLOPFENSTEIN,[2] and C. E. WALKER[2]

Cereal Chem. 71(3):287–291

ABSTRACT

Freeze-dried wheat water solubles (WWS) recovered from a by-product stream of a gluten-starch washing plant could be substituted for 10% of the egg whites in an angel food cake formula. Higher substitution resulted in cakes with reduced volume and poor texture. Whipping time increased as percent of substitution of WWS for egg whites increased. Substitution of WWS for egg whites at all levels decreased batter viscosity. An eight-week rat-feeding study showed no significant differences in overall weight gains, feed efficiencies, and feed intakes in animals fed diets containing WWS, oat bran, or cellulose (control). However, serum cholesterol levels were significantly higher in animals fed the diet containing WWS, in comparison to those fed oat bran or control diets. Animals fed oat bran had a significantly higher percent of serum high-density lipoprotein cholesterol and lower liver cholesterol than did animals fed any other diet. Diet slurry viscosity was inversely related to total serum and liver cholesterol concentrations and directly correlated with percentage of high-density lipoprotein cholesterol. WWS appear to have no potential as a dietary hypocholesterolemic agent.

In the cereal industry, complete utilization of all processing streams is a necessity and a challenge. In recent years, the recovery and modification of wastes has become increasingly important. The ultimate aim is more complete utilization of the raw material, while minimizing pollution and waste (Finley 1981). In commercial wheat starch-gluten production, wheat flour is mixed with water to form a dough. The insoluble starch is carried away by wash water, leaving the gluten as a rubbery mass. The starch is subsequently washed, refined, concentrated, and dried. The excess water, containing most of the soluble portion of the flour and some insoluble solids, is discharged as effluent wastewater (Oomah and Mathieu 1987). Many types of soluble dietary fiber have been shown to have hypocholesterolemic effects (Anderson et al 1990, Gordon 1989). Their viscous nature in solution may alter the absorption of nutrients, bile salts, or lipids from the intestinal tract. Oatmeal and oat bran are rich in the water soluble (1→3)(1→4)-β-D-glucans, which have significant hypocholesterolemic effects (Anderson et al 1984, Storch et al 1984). Oat products can selectively decrease serum low-density lipoprotein (LDL) cholesterol, while preserving or actually increasing serum high-density lipoprotein (HDL) cholesterol (Anderson et al 1990, Dreher 1987, Pilch 1987). Until now, no one has investigated the hypocholesterolemic potential of the fiber-rich wheat water solubles (WWS) from a gluten-washing stream.

The cost of each ingredient in a given food must be evaluated carefully by the food processor with respect to current economic conditions. Opportunities are limited for adjusting formulations,

[1]Contribution 93-285-J of the Kansas Agricultural Experiment Station.

[2]Department of Grain Science and Industry, Kansas State University, Manhattan.

yet bakers and food processors are being forced to consider alternatives for such functional, but costly, ingredients as eggs (Miller and Setser 1983). Eggs are not only basic ingredients in cakes, they quite frequently represent the single most expensive component of the batter (Pyler 1988). Their importance to cake quality derives from their multiple effects on structure, volume, tenderness, and eating properties of the final cake product. The functionality of WWS in white layer cake and meat products was tested by Oomah and Mathieu (1987), but the literature contains little, if any, information on the functionality of WWS as an egg white replacement in angel food cake or as a soluble fiber food supplement.

The objectives of this study were to evaluate the use of WWS in partial replacement of egg whites in angel food cake and to determine their effect on total serum, HDL, and liver cholesterol levels in rats.

MATERIALS AND METHODS

Water solubles from hard red winter wheat were recovered from a by-product stream of a gluten-starch washing plant (Midwest Grain Products, Atchison, KS). The waste water was cooled immediately after collection and held at 0°C to retard microbial activity until it could be freeze-dried and analyzed for proximate contents (Table I) using standard methods (AACC 1983). The solids concentration of the stream ranged from 12 to 20 g/L; the pH of the freeze-dried material was 5.07.

Use of WWS in Angel Food Cake

A commercial soft wheat patent cake flour containing 8.3% protein (N × 5.7), 0.48% ash, and 0.70% fat (Softasilk, General Mills, Minneapolis, MN) was used in making the angel food cakes. Other ingredients were: sugar (Domino Superfine, Amster Sugar, New York); dried egg white (Dried Angel Type Egg Whites, Universal Foods, Milwaukee, WI.); acid salt (monocalcium phosphate, monohydrate; Stauffer Chemical Co., Westport, CN); and food-grade sodium chloride. The formula is shown in Table II.

Standard methods (AACC 1983) were used for testing baking quality of angel food cake flour. WWS were sifted with the first portion of sugar, acid salt, and sodium chloride before being added to the egg whites. The egg whites were whipped for 3 min at the second speed of a mixer (Hobart model N50) to dissolve the ingredients.

Foam specific gravity was standardized by whipping egg whites with WWS to a desired specific gravity of 0.14. The sifted flour-sugar mixture was added at low (first) speed over a period of 20 sec, and finished by folding with a Rubbermaid spatula (30 folds). The bowl was turned at a 45° angle every five folds. The batter was poured into an ungreased moistened tube pan and baked in a Reed gas-fired reel oven with transite hearth at 375°F for 40 min. Cakes were allowed to cool for 40 min. They were then depanned and measured for height. After 4 hrs of cooling, cake height was measured again to determine shrinkage index. The cakes were loosely covered with plastic and stored overnight at room temperature before being evaluated.

A slurry containing 10 g of foam and 50 ml of distilled water was used to determine foam pH. The foam specific gravity was determined by standard method 10-15 (AACC 1983). Cake batter viscosity was determined by using the Rapid Visco-Analyzer (RVA-3D) interfaced to a computer. A 15-g sample of batter was placed in an aluminum RVA sample can (70 mm high, 38 mm diameter), and a plastic paddle was inserted in the can. The can, sample, and paddle were placed in the RVA. The temperature was set at 24°C, and data were collected at 4 and 14 min. RVA units (stirring numbers) were converted to centipoise (cP) units using the manufacturer equivalence of 1 stirring number = 10 cP. The difference in viscosities at 14 and 4 min was calculated to determine viscosity breakdown.

Cake Measurements

Cake volume, height, and shrinkage index were measured by standard method 10-15 (AACC 1983). For cake volume, the outside and inside diameters were measured. A cross section of the cake was scored visually for internal characteristics (grain, crumb color, and crust color) (method 10-90, AACC 1983). The cakes were scored by two panelists on a 1–10 scale with 1 = poor and 10 = good.

Cake firmness was measured using a Voland-Stevens texture analyzer (Voland Corp., Hawthorne, NY) (Kim and Walker 1992). A crosshead speed of 1.0 mm/sec and a chart speed of 20 cm/min were used to compress the cake samples by 40% of their original heights. A 2-cm diameter cylindrical indenter was used. A 1 in. (2.54 cm) thick piece was removed 2 cm from each side of the center of the cake; three measurements were performed per cake. Compression was done horizontally.

Nutritional Evaluation (Rat Feeding Study)

For eight weeks, three groups of 10 male Wistar rats (Charles River Breeding Laboratory, Wilmington, MA), each with average weights of 116 ± 2 g, were fed: 1) casein and straight-grade flour

TABLE I
Composition of Oat Bran, Wheat Water Solubles (WWS), and Wheat Flour

Constituent, %	Oat Bran	WWS	Wheat Flour
Protein	17.6[a]	15.5[b]	11.6[b]
Fat	8.25	0.04	0.94
Ash	2.38	5.80	0.45
Moisture	10.5	11.6	12.6
Insoluble dietary fiber	11.0	0.00	1.31
Soluble dietary fiber	6.46	9.70	2.01
Total dietary fiber	17.5	9.70	3.32

[a] N × 6.25.
[b] N × 5.27.

TABLE II
Control Angel Food Cake Formula[a]

Ingredient	Weight, g	% Flour Basis
Flour	110.0	100.0
Sugar	314.0	285.0
Dried egg white	40.0	36.4
Acid salt (MCP)[b]	1.5	1.4
Sodium chloride	3.0	2.7
Water	295.0	268.0

[a] As is basis.
[b] Monocalcium phosphate, monohydrate.

TABLE III
Percent Composition of Rat Diets

Ingredient, %	Diet[a] Control	Water Solubles	Oat Bran
Casein[b]	15.8	15.2	15.4
White straight-grade flour[c]	65.5	55.9	56.4
Sucrose	6.3	12.2	12.3
Soybean oil	4.7	4.5	4.2
Cellulose[d]	1.0	0.5	...
Water-solubles	...	5.1	...
Oat bran	...	...	5.1
Protein	22.8	21.3	21.7
Fat	6.30	6.11	6.24
Ash	3.54	3.66	3.60
Insoluble fiber	1.86	1.23	1.30
Soluble fiber	1.32	1.63	1.46
Total dietary fiber	3.18	2.86	2.76
Viscosity (cps)	60	50	80

[a] All diets contained 4% AIN mineral mix 76, 1% AIN vitamin mix 76 (ICN Nutritional Biochemicals, Cleveland, OH), 0.2% choline chloride, 0.3% *dl*-methionine, 1% cholesterol (Sigma Chemical Co., St. Louis, MO).
[b] Vitamin-free casein from Sigma.
[c] Department of Grain Science and Industry, Kansas State University, Manhattan, KS.
[d] Alphacel cellulose from ICN.

diet (control), 2) casein and flour diet with 5% freeze-dried WWS, or 3) casein and flour diet with 5% oat bran (ConAgra Milling Co., Omaha, NE) (Table III). Diets were formulated to be isonitrogenous and isocaloric (375 kcal/100 g) and all contained 1% cholesterol. Standard methods were used to measure moisture (44-15A), protein (46-16), crude fat (30-25), and ash (08-01) contents of the diets (AACC 1983). Dietary fiber was measured using AACC method 32-07. Diet viscosity (Table III) was measured with an RVA-3C interfaced to a computer (Newport Scientific Pty. Ltd., Sydney, Australia). The procedure for sample preparation, as described by Deffenbaugh and Walker (1989), was used to determine viscosity of diet slurries (25% solids) at 37°C.

Animals were housed individually in stainless steel cages in an environmentally controlled room with a 12-hr light-dark cycle. Diets and water were provided *ad libitum*. Animals were weighed weekly, feed consumption records were kept, and feed efficiencies were calculated.

Total Serum Cholesterol

Blood samples were drawn by cardiac puncture from ether-anesthetized animals after the eighth week. Blood was allowed to clot at room temperature, then centrifuged at 12,000 × *g* for 15 min. Serum samples were analyzed in duplicate for total and HDL cholesterol using reagents from Sigma Chemical Company (St. Louis, MO, Procedure 352 and 352-3).

Liver Cholesterol

After eight weeks of feeding, the animals were sacrificed by placing them in an ether atmosphere. Their livers were removed, rinsed under cold tap water, blotted dry, weighed, and frozen. Lipids were extracted with chloroform-methanol (Klopfenstein and Clegg 1980). An aliquot of the extract was evaporated to dryness under nitrogen. The lipid residue, redissolved in absolute ethanol, was used for determination of total liver cholesterol (Rosenthal et al 1957).

Statistical Procedures

For the baking study, a 3 × 4 randomized factorial design was used, with three treatments (reduction of egg whites, addition of WWS, or substitution of WWS for egg whites) at four levels (0, 10, 20, and 30%). The 0% level was the control. Data for three replicates of the treatments (10, 20, or 30%) plus control were evaluated with the Statistical Analysis System (SAS 1989), using the analysis of variance procedure with Fisher's Protected Least Significant Difference (LSD) test for significant differences among means (Ott 1988).

Data from the animal feeding study were also analyzed using one-way analysis of variance with the LSD test (Ott 1988). A complete randomized experimental design was used.

RESULTS AND DISCUSSION

Effect of WWS on Egg White Whipping Time, Foam pH, and Relative Specific Gravity

Up to 30% reduction of egg whites in an angel food cake formula did not significantly alter whipping time of egg whites, but partial substitution of WWS for egg whites or the addition of WWS at the 10, 20, or 30% levels resulted in significantly increased whipping times (Table IV).

Partial replacement with WWS or reduction of egg whites did not affect foam pH (Table IV). The pH of the freeze-dried WWS was acidic (5.07).

The reduction of egg whites or their partial replacement with WWS resulted in foam specific gravities significantly different than that of the control. Data indicated that more air was incorporated into foams with 20 and 30% egg white reduction, 10 and 20% WWS addition, and 10% WWS substitution than was incorporated into the control foam (0% levels). Less air was whipped into foams with 30% WWS addition and 20 and 30% WWS substitution (Table IV).

Matz (1987) stated that when aeration is insufficient, the air cell walls are not extended to their full capacity during baking, resulting in suboptimal volume and texture. On the other hand, excessive whipping of the egg whites causes coagulation of some of the proteins, so that the bubble walls lose extensibility and break during baking, leading to a reduction in cake volume and a coarser crumb. Foams with similar specific gravities would be expected to result in cakes of similar volume and texture.

Batter Viscosity

Any reduction of egg whites resulted in batters of higher viscosity than that of the control batter (Table V). That was also true for 10 and 20% addition of WWS to the control formula. WWS addition (30%) and substitution (all levels) resulted in batter viscosity significantly lower than that of the control. Addition of WWS to the batter caused greater viscosity decreases than did reduction of egg whites.

According to Bath et al (1992), if the viscosity of the cake batter system is low, the bubbles may coalesce into large bubbles that rise to the surface of the batter and eventually leave the system, producing a dense final product. Hoseney (1994) stated that a good cake batter must retain sufficient viscosity during heating to keep the starch suspended. If the starch settles, a tough rubbery layer will form at the bottom of the cake. For cakes containing high levels of sugar and water, a higher batter viscosity is important in obtaining a noncollapsing, porous, cake structure (Kim and Walker 1992).

Cake Volume and Shrinkage Index

As egg whites in the cake formula were reduced, cake volume decreased (Table VI). Egg white reductions of 10% resulted in

TABLE IV
Effect of Wheat Water Solubles (WWS) on Whipping Time, pH, and Specific Gravity of Foam[a]

Variable	Level, %	Egg White Reduction	Addition of WWS	Substitution of WWS for Egg Whites
Whipping time, min	0	2.5 d	2.5 d	2.5 d
	10	2.5 d	3.0 c	3.0 c
	20	2.5 d	5.0 b	5.0 b
	30	2.0 d	5.0 b	7.0 a
Foam relative specific gravity, g/cm^3	0	0.145 d	0.145 d	0.145 d
	10	0.145 d	0.142 e	0.141 e
	20	0.142 e	0.143 e	0.157 c
	30	0.142 e	0.153 b	0.162 a
Foam pH	0	5.2 a	5.2 a	5.6 a
	10	5.3 a	5.4 a	5.8 a
	20	5.3 a	5.6 a	5.7 a
	30	5.6 a	5.7 a	5.2 a

[a]Means (three replicates) for the same variable not followed by the same letter are significantly different ($P < 0.05$).

TABLE V
Effect of Wheat Water Solubles (WWS) on Batter Viscosity (cP)[a]

Viscosity	Level, %	Egg White Reduction	Addition of WWS	Substitution of WWS for Egg Whites
4 min	0	1,070 e	1,070 e	1,070 e
	10	1,120 c	1,160 b	950 g
	20	1,100 d	1,130 c	990 f
	30	1,320 a	870 h	950 g
14 min	0	950 e	950 e	950 e
	10	1,010 b	1,010 b	850 g
	20	980 c	960 d	870 f
	30	1,120 a	720 i	830 h
Drop[b]	0	120 d	120 d	120 d
	10	110 de	150 bc	100 e
	20	120 d	170 b	120 d
	30	200 a	150 bc	120 d

[a]Means (three replicates) for the same variable not followed by the same letter are significantly different ($P < 0.05$).
[b]Viscosity drop = viscosity at 4 min − viscosity at 14 min.

cake volumes similar to that of the control, but 20 and 30% reductions resulted in significantly lower volumes. Addition of WWS to the control formula tended to lower cake volume. However, these differences were not significant. Substitution of WWS for 10% of the egg whites resulted in cake volume similar to that of the control, but substitution at the 20 or 30% level resulted in significantly lower cake volumes (Table VI).

Decreases in specific volume with egg white reduction, addition of WWS, or substitution of WWS for egg whites generally paralleled those noted for volume (Table VI). No significant differences in shrinkage index were observed among any of the treatments (Table VI).

No significant relationship was observed between cake volume and batter viscosity. Our results suggest that foam specific gravity, which is an index of the amount of air incorporated, and whipping time seem to contribute more to cake volume than batter viscosity does ($r = -0.4617$, $P = 0.0102$ and $r = -0.3924$, $P = 0.0320$).

Cake Characteristics

Up to 20% reduction of egg whites showed no significant effect on angel food cake grain, crumb color, or crust color (Table VII). However, a 30% reduction negatively affected all the variables measured. Addition of >10% WWS to the control formula reduced scores for cake grain and crumb and crust color and increased firmness. WWS could be substituted for egg whites at the 10% level without significant adverse effects on the cake grain, crumb and crust color, or firmness. At higher levels of substitution, cakes had coarse grain with thick cell walls.

In general, cakes prepared with WWS were firmer than cakes containing no WWS. An inverse relationship was observed between cake firmness and cake volume ($r = -0.5024$, $P = 0.0047$). Cake firmness was also positively related to foam specific gravity ($r = 0.7024$, $P = 0.0001$).

From our data, WWS at 10% addition or substitution for egg whites had no significant effect on whipping time. These results suggest that WWS at the 10% level have the same whipping potential as egg whites. At higher levels of addition or substitution, whipping time significantly increased. Also, at 10% addition, no effects were observed on cake volume, grain, crumb color, crust color, and firmness characteristics.

TABLE VI
Effects of Wheat Water Solubles (WWS) on Cake Volume, Specific Volume, and Shrinkage Index[a]

Variable	Level, %	Egg White Reduction	Addition of WWS	Substitution of WWS for Egg Whites
Volume, cm^3	0	2,320 a	2,320 a	2,320 a
	10	2,210 ab	2,310 a	2,150 ab
	20	2,030 b	2,200 ab	1,790 c
	30	1,460 d	2,150 ab	1,220 e
Specific volume, cm^3/g	0	4.3 a	4.3 a	4.3 a
	10	4.1 ab	4.2 a	3.9 ab
	20	3.7 b	4.1 ab	3.3 c
	39	2.7 d	4.0 ab	2.3 e
Shrinkage index	0	6.0 a	6.0 a	6.0 a
	10	6.6 a	5.0 a	6.5 a
	20	7.6 a	6.3 a	6.6 a
	30	7.9 a	5.5 a	8.2 a

[a]Means (three replicates) for the same variable not followed by the same letter are significantly different ($P < 0.05$).

TABLE VII
Effects of Wheat Water Solubles (WWS) on Characteristics of Angel Food Cake[a]

Variable	Level, %	Reduction of Egg Whites	Addition of WWS	Substitution of WWS for Egg Whites
Grain[b]	0	8.3 a	8.3 a	8.3 a
	10	8.0 ab	8.2 ab	7.8 ab
	20	7.9 ab	7.5 b	6.9 cd
	30	6.4 de	7.4 bc	5.9 e
Crumb color[b]	0	8.3 a	8.3 a	8.3 a
	10	8.1 a	8.2 a	8.1 a
	20	8.1 a	7.1 b	6.9 bc
	30	6.9 bc	6.4 cd	6.0 d
Crust color[b]	0	8.3 a	8.3 a	8.3 a
	10	7.8 ab	8.1 a	7.8 ab
	20	7.7 ab	7.3 bc	6.9 cd
	30	6.6 de	6.1 ef	5.8 f
Firmness, g/cm^2	0	42.5 f	42.5 f	42.5 f
	10	35.4 h	42.1 f	38.8 g
	20	37.2 gh	49.9 d	45.1 e
	30	53.2 c	66.2 a	62.8 b

[a]Means (three replicates) for the same variable not followed by the same letter are significantly different ($P < 0.05$).
[b]Numbers closer to 10 indicate more desirable characteristics.

Effect of WWS on Rat Weight Gains, Feed Efficiencies, and Feed Intakes

Although Antoniou et al (1981) and Fengler and Marguardt (1988) reported that soluble pentosans from rye exhibited antinutritional activity in chicks, WWS or oat bran at 5% dietary levels in this experiment did not affect overall rat weight gains, feed efficiencies, or feed intakes (Table VIII). Antoniou et al (1981) attributed the negative effects of soluble rye pentosans to their ability to form highly viscous solutions, which reduced the rate of digestion or absorption of nutrients. Viscosity of the WWS diet used in the present experiment was lower than that of the control diet (Table III). Although care was taken to cool the WWS immediately after collection and store them at 0°C until analysis, it is possible that the WWS suffered bacterial degradation before freeze-drying, which could have reduced their impact on viscosity.

Effects on Cholesterol

Although all animals ingested similar amounts of cholesterol, serum cholesterol levels after eight weeks were significantly higher in animals fed the diet containing WWS than they were in those animals fed the control or oat bran diets (Table VIII). Animals fed oat bran had lower serum and liver cholesterol and higher percent HDL cholesterol than did the control animals. Liver cholesterol and percent HDL cholesterol were not different in animals fed WWS or the control diet. A significant inverse relationship occurred between total serum and liver cholesterol and diet viscosity ($r = -0.7922$, $P = 0.0001$ and $r = -0.5765$, $P = 0.0050$, respectively). A positive relationship occurred between diet viscosity and percent of HDL cholesterol ($r = 0.7461$, $P = 0.0001$).

CONCLUSIONS

Baking studies showed that WWS at the 10% level can be added or substituted for egg whites in angel food cake with no adverse effects.

Neither WWS nor oat bran added to wheat flour diets had a significant effect on rat weight gains or feed efficiencies. Although animals fed the WWS diet had higher serum cholesterol levels than those fed control or oat bran diets, they were not as high (179 mg/dl) as those reported in animals fed synthetic

TABLE VIII
Effect of Wheat Water Solubles (WWS) and Oat Bran in Rat Diets[a]

Variable	Diet: Control	+ 5% WWS	+ 5% Oat Bran
Weight gain, g	313 a	313 a	329 a
Feed efficiency[b]	0,246 a	0.256 a	0.257 a
Feed intake, g	1,272 a	1,221 a	1,279 a
Serum cholesterol, mg/dL	94.1 b	120.1 a	63.1 c
% HDL cholesterol	39.7 b	29.1 b	59.6 a
Liver cholesterol, mg/g	30.6 a	32.6 a	24.4 b

[a]Means in the same row not followed by the same letter are significantly different ($P < 0.05$).
[b]Grams gained/grams of feed consumed.

diets containing casein, cornstarch, and sugar (Klopfenstein 1990). Animals fed oat bran had lower serum cholesterol than did the control animals. Liver cholesterol levels in rats fed WWS were not significantly higher than those in control animals, but they were higher than in animals fed oat bran. Diet slurry viscosity was inversely related to total serum and liver cholesterol concentrations and directly correlated with percent of HDL.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 08-01, approved April 1961, revised October 1981; Method 10-15 approved October 1976, October 1982; Method 10-90 approved October 1976, revised October 1982; Method 30-25, approved April 1961, revised October 1976, October 1981, October 1991; Method 32-07, approved October 1991; Method 44-15A, approved October 1975, revised October 1981; Method 46-16, approved October 1988. The Association: St. Paul, MN.

ANDERSON, J. W., DEAKINS, D. A., and BRIDGES, S. R. 1990. Soluble fiber: Hypocholesterolemic effects and proposed mechanisms. In: Dietary Fiber: Chemistry, Physiology, and Health Effects. D. Kritchevsky, C. Bonfield, and W. J. Anderson, eds. Plenum Press: New York.

ANDERSON, J. W., STORY, L., SIELING, B., and CHEN, W. L. 1984. Hypocholesterolemic effects of high-fiber diets rich in water-soluble fibers. J. Can. Diet. Assoc. 45:140.

ANTONIOU, T., MARGUARDT, R. R., and CANSFIELD, P. E. 1981. Isolation, partial characterization, and antinutritional action of a factor (pentosans) in rye grain. J. Agric. Food Chem. 29:1240.

BATH, D. E., SHELKE, K., and HOSENEY, R. C. 1992. Fat replacers in high-ratio layer cakes. Cereal Foods World 37:495.

CUMMINGS, J. H. 1986. The effect of dietary fiber on fecal weight and composition. In: Handbook of Dietary Fiber in Human Nutrition. CRC Press: Boca Raton, FL.

DEFFENBAUGH, L. B., and WALKER, C. E. 1989. Laboratory experiments with the Rapid Visco-Analyzer. Foss Food Technology Corp.: Eden Prairie, MN.

DREHER, M. L. 1987. Handbook of Dietary Fiber: An Applied Approach. Marcel Dekker: New York.

FENGLER, A. I., and MARGUARDT, R. R. 1988. Water-soluble pentosans from rye: II. Effects on rate of dialysis and on the retention of nutrients by the chick. Cereal Chem. 65:298.

FINLEY, J. W. 1981. Utilization of cereal processing by-products. Page 545 in: Cereals: A Renewable Resource. Theory, and Practice. Y. Pomeranz and L. Munck, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.

GORDON, D. T. 1989. Functional properties vs physiological action of total dietary fiber. Cereal Foods World 34:517.

HOSENEY, R. C. 1994. Principles of Cereal Science and Technology, 2nd ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

KIM, C. S., and WALKER, C. E. 1992. Interactions between starches, sugars, and emulsifiers in high-ratio cake model systems. Cereal Chem. 69:206.

KLOPFENSTEIN, C. F. 1990. Nutritional properties of coarse and fine sugar beet fiber and hard red wheat bran. I. Effects on rat serum and liver cholesterol and triglycerides and fecal characteristics of coarse and fine sugar beet fiber and hard red wheat bran. Cereal Chem. 67:538.

KLOPFENSTEIN, C. F., and CLEGG, R. E. 1980. Effects of ascorbic acid, vitamin E, and fatty acids on lipid composition in cockrels. Poult. Sci. 59:2267.

MATZ, S. A. 1987. Ingredients for Bakers. Pan-Tech International: McAllen, TX.

MILLER, L. L., and SETSER, C. 1983. Xanthan gum in a reduced-egg-white angel food cake. Cereal Chem. 60:62.

OOMAH, B. D., and MATHIEU, J. J. 1987. Functional properties of commercially produced wheat flour solubles. Can. Inst. Food Sci. Technol. J. 20:81.

OTT, L. 1988. An Introduction to Statistical Methods and Data Analysis. 3rd ed. PWS-Kent: Boston, MA.

PILCH, S. M. 1987. Physiological Effects and Health Consequences of Dietary Fiber. Federation of American Societies for Experimental Biology: Bethesda, MD.

PYLER, E. J. 1988. Baking Science and Technology, Vol. 2, 3rd ed. Sosland: Merriam, KS.

ROSENTHAL, H. L., PFLUKE, M. L., and BUSCAGLIA, S. 1957. A stable iron reagent for determination of cholesterol. J. Lab. Clin. Med. 50:318.

SAS. 1989. SAS User's Guide to Statistical Analyses. SAS Institute: Cary, NC.

STORCH, K., ANDERSON, J. W., and YOUNG, V. R. 1984. Oatbran muffins lower serum cholesterol of healthy young people. Clin. Res. 34:740A.

[Received June 10, 1993. Accepted February 23, 1994.]