Baking Formula Innovation to Eliminate Chlorine Treatment of Cake Flour

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ABSTRACT

Chlorine treatment of soft wheat flour improves cake volume and produces a stiffer, more resilient crumb. Four pairs of chlorine-treated and untreated flours were obtained. A selected portion of the area under the Rapid Visco Analyser hot pasting flour viscosity curve was used to determine how much starch could be used with a nonchlorine-treated flour so that the area is equivalent to that produced by a chlorine-treated cake flour with no added starch. Replacement of nonchlorine-treated flour with up to 43% starch produced areas under the pasting curve that were equivalent to those produced by chlorine-treated flours. Increased concentration of dried egg albumen plus added soya lecithin and xanthan gum were included in the formulation containing starch and nonchlorine treated flour to produce a new basic ingredient set. The basic ingredient set was evaluated for its influence on cake geometry, crumb structure, and crumb texture response to compression (hardness and spring-back rate). High-ratio white layer cakes using the new basic ingredient set produced similar or better cake quality characteristics than those produced using control chlorine-treated flours. The same new basic ingredient set was used to produce pound cakes, cupcakes, and sheet cakes using nonchlorinated flours. The geometry and objective texture of those cakes also were equivalent to respective cakes produced with chlorine-treated flour. The basic ingredient set does not require any special flour treatment.

Chlorine treatment of cake flour is functionally beneficial to the production of high-ratio (more sugar than flour, weight basis) cakes. The production of baked products using untreated wheat flour assumes increased importance as the cereals industry becomes more international, and the safety aspects of chemically treated foodstuffs are subjected to increased scrutiny. Daniels et al (1963) observed no adverse reaction when rats were fed cake made with chlorine-treated flour at ingestion levels equivalent to the consumption of cake in the human diet. However, at higher ingestion levels, they observed effects on lactation in female rats and on the coat texture in male rats. Cunningham et al (1977) observed reduced growth rate and increased liver weight when they fed rats chlorine-treated flour as a highly concentrated component of their diet. Ginocchio et al (1983) observed dose-related increases in heart and kidney weights and reduction in ovary weight among female mice fed high levels of chlorine-treated four.

The treatment of pastry flour with chlorine gas has at least two distinct functional advantages that have proven difficult to overcome by replacing the chlorine treatment. Chlorination changes the hexane-extractable flour lipids to increase batter expansion in the oven (Clements and Donelson 1982a,b). Chlorination also alters flour starch such that it accelerates the thickening of the viscosity of the batter, which allows improved setting of the batter at the final stage of baking (Gaines and Donelson 1982a). The stronger setting retains the larger volume of the cake created by the chlorine-treated flour lipids.

The objective measurement of the stickiness of cake crumb has been associated with the amount of chlorine gas used to achieve the desired lower pH value (Gaines 1982, Gaines and Donelson 1982a,b). Chlorine-treated flour produces cake crumb with a drier, less sticky mouthfeel (Kissell and Yamazaki 1979) that coalesces and compacts less in the mouth, producing a lighter, drier, and looser sensation in the mouth than cakes produced with nonchlorinated flour, which are often referred to as gummy. That phenomenon is observable by compressing cubed aliquots of the crumb. Within ≈5–10 sec, cubes of cakes produced with chlorine-treated flour quickly return (expand) almost all of their original height after moderate compression, unlike cakes produced with nonchlorine-treated flour, which after moderate compression slowly expand to only about half of their original height.

White layer cakes baked with nonchlorinated flour are unsatisfactory in volume, contour, crumb grain, and texture. Thus, various schemes have been devised to produce cakes with characteristics that are similar to those produced using chlorine-treated flour. Johnson and Hoseney (1979) reported improved cake volume and contour using nonchlorinated flour and starch blends. Egg albumin contributes strength to cake crumb and improves cake volume (Pyler 1973). In a heated flour system using nonchlorinated flour, Russo and Doe (1970) replaced some whole egg solids with dried egg albumin to reduce crumb friability. Acceptable cake volume can be achieved by heating but the dryer, stiffer crumb that springs back upon compression is not produced by heated flours. Hanamoto and Bean (1979) improved the cake baking properties of nonchlorinated cake flours and isolated starch by controlled heat treatments. A few added ingredients have been used to improve cake quality produced using nonchlorine-treated flour. Thomasson et al (1995) used xanthan gum L-cysteine, and hydrogen peroxide plus peroxidase to heat-treated flour and obtained volumes equivalent to cakes produced using chlorine-treated flour.

The objectives of this study were to evaluate four pairs of chlorine-treated and untreated flours and observe any common hot pasting viscosity characteristics of treated and untreated flours. Those viscosity characteristics were used to formulate a novel basic ingredient set that would replace traditional chlorine-treated cake flour with nonchlorine-treated flour and starch. There was no heat treatment applied to the flours. Critical cake quality characteristics using the new formula were compared with those of cakes produced from chlorine-treated flour. Quality characteristics were geometric aspects of cake size, crumb structure, and apparent texture. The next objective was to use the new chlorine-free formula to produce different types of cakes (pound cake, low-ratio cupcake, and Texas sheet cake) and evaluate them for the same critical quality characteristics.

MATERIALS AND METHODS

Flours, Starch, and Ingredients

Four pairs of chlorine-treated and untreated cake fours were provided by ConAgra Inc., Columbus, OH; DCA Food Industries Inc., Hillsdale, MI; Mennel Milling Co., Fostoria, OH; and Siemer Milling Co., Teutopolis, IL. The chlorine-treated flours were the same as the untreated flours except for the chlorine-treatment. The protein content, pH level, ash content, and alkaline water retention

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capacity (AWRC) for the four sets of flours are shown in Table I. Soya lecithin (Centrolex F) was provided by Central Soya, Fort Wayne, IN. Xanthan gum (Keltrol F) was provided by Kelco, Chicago, IL. Dried egg albumin (type P-20) were obtained from Henningsen Foods, Inc., White Plains, NY. Unmodified and nonchlorinated hard wheat starch (Midsol 50) was provided by Midwest Grain Products, Atchison, KS. A laboratory sample of starch was prepared by the aqueous fractionation (Yamazaki et al 1977) of nonchlorinated Compton soft wheat cultivar flour.

Pasting and Viscosity Analysis

The pasting viscosity and temperature-time analysis of flour, starch, and flour and starch combinations were accomplished using a Rapid Visco Analyzer, Model RVA-4 (Foss North America, Inc., Eden Prairie, MN). The "standard 1" heating profile of that instrument's software (Thermocline for Windows, version 2.0, Newport Scientific Pty. Ltd., Warriewood, NSW, Australia) was employed to produce pasting curves based on 4 g (14% mb) of flour, starch, or flour and starch combinations. After exporting the data to spreadsheet form, the area under the pasting curve (pasting viscosity and temperature-time profile) was analyzed by the PC software program Origin (Microcal Software Inc., Northhampton, MA). The portion of the pasting curve used was from the point of inflection to the point of minimum viscosity after the pasting peak, which occurred after cooling started. The software made a best-fitted Lorentzian curve along the data points and then determined the area under the selected portion of the pasting viscosity and temperature curve.

TABLE I
Protein Content, pH Level, Ash Content, and Alkakine Water Retention Capacity (AWRC) of Four Flours Treated and Not Treated with Chlorine Gas

Four and Treatment	Protein (%)	pH Level	Ash (%)	AWRC (%)
ConAgra				
None	8.0	6.0	0.36	55.7
Cl_2	8.0	4.6	0.36	59.7
Mennell				
None	7.8	6.0	0.33	55.8
Cl_2	7.8	4.4	0.33	60.5
DCA				
None	8.8	6.0	0.33	55.5
Cl_2	8.8	4.7	0.33	60.5
Siemer				
None	8.0	5.9	0.38	58.1
Cl_2	8.0	4.9	0.38	60.9

Baking Procedures

High-ratio white layer cakes were baked according to Approved Method 10-90 (AACC 1995). It was modified for a single 20.3 cm (8 in.) layer cake (Kissell et al 1979). Baking times were 23 min, except for cakes produced using the new basic ingredient set, which were baked for 27 min. Cake volumes were determined by rapeseed displacement. Pound cakes (page 71 in: *Betty Crocker's Cookbook, 1991.* Prentice Hall: New York, NY.) were produced using the DCA flours, Texas sheet cakes (page 163 in: *Country Cuisine From Maxine, 1989.* Cookbook Publishers, Inc.: Olathe, KS.) were produced using the Siemer flours, and cupcakes (page 121 in: *Women's Centennial Cookbook, 1986.* Oak Chapel United Methodist Church, Wooster, OH.) were produced using the Mennel flour. The commercial starch was used to prepare the basic ingredient set for the pound cakes, Texas sheets, and cupcakes.

Cake Crumb Texture Response

Cake interior crumb was cut into seven crustless 2-cm cubes from a center section of cake. Cubes were individually weighed. Each cube was compressed (80%) to 4 mm thickness using a 2.6 cm diameter round plunger attached to an Instron universal testing

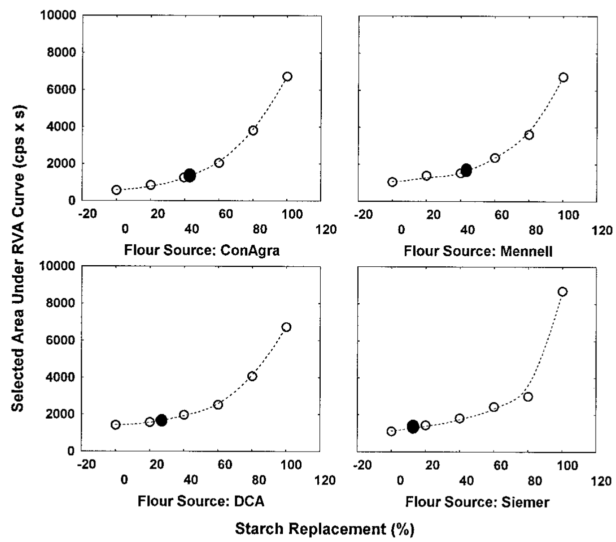

Fig. 1. Selected portion of area under the Rapid Visco Analyzer (RVA) hot pasting curve vs. degree of starch replacement for nonchlorine treated flour from four sources. ● = Companion chlorine-treated flour.

TABLE II
Mean Cake Volume, Crumb and Contour Scores, and Crumb Texture Values for Formula Selection Treatments[a]

Treatment (%)	Volume (cm^3)	Crumb Score	Cake Contour Score	Compression Resistance (kg/g)	Compression Return Height (cm)	Compression Return Time (sec)
Unchlorinated	1,095a	52b	90b	0.81b	1.2b	120a
Chlorinated control	1,014b	87a	100a	1.17a	2.0a	3b
Commercial starch	1,178a	76a	83a	1.13a	1.81a	24a
Laboratory starch	1,155a	76a	83a	1.09a	1.81a	18a
20% Starch	1,160b	77a	100a	1.12a	1.80a	33a
40% Starch	1,197a	77a	100a	1.07a	1.82a	18ab
60% Starch	1,141b	76a	50b	1.04a	1.83a	11b
12% Egg albumin	1,141a	76a	83a	0.99b	1.71a	42a
15% Egg albumin	1,174a	75a	83a	1.06b	1.83a	11b
18% Egg albumin	1,183a	78a	83a	1.29a	1.90a	9b
0.0% Xanthan gum	1,153b	77a	85a	1.16a	1.82a	31a
0.1% Xanthan gum	1,162a	76a	77a	1.08a	1.80a	11b
0.2% Xanthan gum	1,189a	77a	90a	1.09a	1.83a	20b
0.0% Soya lecithin	1,137b	76b	67b	1.18a	1.82a	22a
0.1% Soya lecithin	1,194a	77a	100a	1.05b	1.80a	20a
Selected formula[b]	1,218	78	100	1.23	1.90	5

[a] Mean values are means across all other treatments using the Siemer flour.
[b] 40% starch and 60% flour, 18% egg albumin, 0.15% xanthan gum, and 0.1% soya lecithin.

machine, model 1000 fitted with a 5-kg transducer. Crosshead speed was 100 mm/min. After compression, the plunger was immediately reversed at fast speed, and the time required for the cube to return to 1.5 cm height was measured. Compressed cubes were stored overnight and evaluated the next day for return height.

Statistical Analysis

All data were duplicated and were analyzed by Statistica for Windows statistical PC software (StatSoft, Inc., Tulsa, OK), and Origin technical graphics and data analysis PC software (Microcal Software Inc., Northhampton, MA). Regression analysis was accomplished using a simple least squares model. After analysis of variance, where appropriate, differences among means were tested using least significant difference ($P = 0.05$).

RESULTS AND DISCUSSION

Other than volume, geometry, and crumb appearance, the main subjective difference between cakes baked using chlorine-treated versus untreated flours is the very noticeable difference in mouthfeel that is rarely reported. Those textural differences are observed by compressing the cake crumb. Chlorine-treated flour produces a drier cake crumb that has much greater resistance to compression and after compression will spring back almost to its original height. Cake produced using nonchlorine-treated flour is soft and gummy in the mouth and normally will not spring back to more that about half its original height, if at all. Those differences have not been discussed in most reported schemes to replace chlorine-treatment and suggest that cakes baked using nonchlorine-treated flour are not sufficiently physically durable for commercial production. Cake volume and contour are relatively easy to attain, thus the main features of the present study were textural responses of cake crumb to compression: compression resistance, rate of return of crumb height after compression, and final return height.

TABLE III
White Layer Cake Formula and Treatment Formula

Ingredient	AACC Method 10-90 (%)	Basic Ingredient Set Formula (%)
Chlorinated cake flour	100	. . .
Unchlorinated cake flour	. . .	60
Unchlorinated wheat starch	. . .	40
Egg albumin	9	18
Xanthan gum	. . .	0.15
Soya lecithin	. . .	0.10
Sugar	140	140
Shortening	50	50
Nonfat dry milk	12	12
Salt	3	3
Baking powder	6	6
Water	130	135
Baking time	23 min	27 min

Hot Pasting Equivalent Viscosity

Flours treated with chlorine gas increase in hot pasting viscosity at a faster rate than untreated flours (Kulp 1972). Those differences are pronounced and affect water relationships in cake crumb (Huang et al 1982). It was thought that a new cake ingredient formulation that could control water relationships during heating could also produce cake crumb with critical characteristics similar to those of cakes produced using chlorine-treated flour.

For each of the four flours, commercial starch replaced 0, 20, 40, 60, 80, and 100% of the nonchlorine-treated flour. RVA curves were produced, and the area under the heating portion of the curve (to the trough) was determined. That area versus replacement percentage is plotted for each flour in Fig. 1. The area under the curve for the chlorine-treated counterpart flour was also determined and placed on each plot as a dark circle (area coefficient of variation = 1.5%). Thus the percentage replacements of nonchlorine-treated flour with starch that produced the same areas under the curve as the chlorine-treated flours were determined to be 39.5, 42.9, 26.2, and 11.3% for the flours.

Basic Ingredient Set

Preliminary studies revealed that egg albumin, xanthan gum, and soya lecithin affect important aspect of cake geometry and crumb texture. The effects of three levels of starch, egg albumin, xanthan gum, and two levels of soya lecithin were evaluated using cake volume, crumb score, contour, compression resistance, compression return height (spring back), and the rate of return of compressed crumb height (Table II). Increasing levels of starch and egg albumin improved crumb texture and substantially increased the return height and the speed of return. Cake volumes increased as egg albumin was increased to 18%. Cake volume peaked at 40% starch concentration. Overall, the presence of gum made a better looking (contour) cake and the presence of lecithin gave a smoother batter surface during baking and a slightly softer crumb.

The basic ingredient set for use with nonchlorinated flour was chosen based on the overall textural response to compression (speed of return and final return height), cake contour, cake crumb score, and volume of cakes, as well as the equivalent hot past viscosities observed in Fig. 1. The basic ingredient set and the standardized formula are shown in Table III. The basic ingredient set contained the 60:40 nonchlorinated flour to starch combination, 18% egg albumin, 0.15% xanthan gum, and 0.10% soya lecithin. Baking time was lengthened by 4 min because surface browning was lowered when 40% of the flour was replaced with starch. The additional minutes of baking time had no perceptible difference on crumb texture as measured.

Across the four flours, the new basic ingredient set (using both commercial and laboratory prepared starches) was compared with control cakes produced using chlorine-treated and untreated flours (Table IV). The increased egg albumin caused cake volumes to increase an average of 18%. The additional volume could be reduced to that of the cakes produced using chlorine-treated flours by reducing the batter weight by 13%. The cakes produced using the new basic ingredient set had crumb scores, height after compression

TABLE IV
Mean Critical Cake Quality Characteristics for Cakes Produced from Chlorine-Treated Flour, Nonchlorinated Flour, and New Base Ingredient Sets Containing Commercial and Laboratory Prepared Starch for Four Flours[a]

Formulation and Treatment	Starch	Volume (cm^3)	Crumb Score	Cake Contour	Compression Resistance (kg/g)	Compression Return Height (cm^3)	Compression Return Time (sec)	Pasting Curve Area (cps sec × 106)
Standard								
Chlorinated	. . .	994b	89a	100a	1.13b	1.99a	3.9c	1.47a
Nonchlorinated	. . .	1,020b	59c	68b	0.91c	0.86c	>120.0a	1.04b
Basic Ingred. Set								
Nonchlorinated	Commercial	1,194a	82b	100a	1.22ab	1.81b	11.0b	1.65a
Nonchlorinated	Laboratory	1,155a	82b	100a	1.35a	1.96ab	5.2c	1.62a

[a] Means followed by the same letter are not different at $P = 0.05$.

(commercial starch), and spring-back return rate (commercial starch) almost as good as those from cakes produced using chlorine-treated flour. Cake contour, compression resistance, height after compression (laboratory starch), spring-back return rate (laboratory starch), and area under the pasting curve were either the same or better for cakes produced using the basic ingredient set compared with those produced using chlorine-treated flours. Irrespective of their different classes and sources, the two unmodified starches made essentially the same contributions to cake quality. Cake cubes baked using nonchlorine-treated flour regained only ≈43% of their height after compression. Cake cubes baked using the basic ingredient set quickly regained ≈95% of their original height.

Application of Basic Ingredient Set to Other Cake Formulations

The basic ingredient set was applied to three very different types of cake formulations: pound cakes, Texas sheet cakes, and cupcakes. Formulations for the three cake types are shown in Table V. The pound cake formula included butter. The sheet cake formula used a procedure in which flour and sugar were incorporated into boiling liquid. The cupcake formula was relatively lean. Among these three formulations and the standardized white layer cake, sugar-to-flour ratios ranged from 0.54 to 1.62, shortening-to-sugar ratios ranged from 0.35 to 1.38, and shortening-to-sugar ratios ranged from 0.30 to 2.23. Those ranges likely will include most commercial cake formulations. Table VI shows the mean results for those cakes produced using the respective chlorine-treated and untreated flours and the new basic ingredient set using nonchlorine-treated flours. For each cake type, cakes made using new basic ingredient set and nonchlorinated flour had larger fresh baked product height and had cake cubes that exhibited stronger compression force resistance. Cake heights after compression and recovery times were equivalent to those of cakes made with the control chlorine-treated flour and agree with the results obtained using the standard white layer cake formula.

CONCLUSIONS

A selected portion of the area under the RVA hot pasting curves was used to determine how much starch should be used to replace nonchlorine-treated flour in a white layer cake formula to produce hot paste viscosities similar to those made by chlorine-treated flours. That percentage varied depending on the nonchlorine-treated flour from ≈42% down to 12%. Forty percent was selected for a basic ingredient set that can be used to produce various types of cake without chlorine-treated flour.

Starch acts as a water sink during baking, contributing to the setting of the structure of the cake during baking. However, nonchlorine-treated flour produces a cake crumb with a wet, gummy, dense crumb. The 60:40 blend of nonchlorinated flour and wheat starch produces the same or greater selected portion of the area under the RVA curve as does chlorine-treated flour. Apparently the 60:40 blend produces a degree of hydrophilicity within the baking

TABLE VI
Response of Basic Ingredient Set to Compression and Fresh Product Height of Pound Cakes, Texas Sheet Cakes, and Cupcakes[a]

Flour and Treatment	Compression Force (kg)	Recovery Height (cm)	Recovery Time (sec)	Fresh Product Height (cm)
Pound Cakes				
Nonchlorinated	4.43a	1.18a	>120c	7.58a
Chlorinated	4.35a	1.80b	5.3a	8.41b
Basic Ingred. Set	5.67b	1.72b	18.7b	11.70c
Texas Sheet Cakes				
Nonchlorinated	3.57a	0.75a	>120b	2.00a
Chlorinated	3.74a	1.50b	44.0a	2.25b
Basic Ingred. Set	5.87b	1.56b	58.2a	2.35c
Cupcakes				
Nonchlorinated	0.79a	0.91a	>120b	4.69b
Chlorinated	1.55b	1.68b	3.0a	4.40a
Basic Ingred. Set	1.85b	1.61b	3.0a	5.08c

[a] Means followed by the same letter are not different at $P = 0.05$.

TABLE V
Formulations of Pound Cakes, Texas Sheet Cakes, and Cupcakes

	Pound Cakes		Sheet Cakes		Cupcakes	
	Weight (g)	Flour Basis[a] (%)	Weight (g)	Flour Basis[a] (%)	Weight (g)	Flour Basis[a] (%)
Control ingredients						
Flour (chlorinated or nonchlorinated)	384.00	100.00	254.00	100.00	193.00	100.00
Sugar	579.00	150.78	412.00	162.20	104.00	53.89
Salt	1.53	0.40	3.07	1.21	3.07	1.59
Baking powder	4.43	1.15	4.43	1.74	8.86	4.59
Whole eggs	267.00	69.53	106.80	42.05	53.40	27.67
Butter	794.00	206.77	···	···	···	···
Margarine	···	···	567.00	223.23	57.00	29.53
Vanilla	5.70	1.48	5.70	2.24	5.70	2.95
Milk	244.00	63.54	···	···	122.00	63.21
Buttermilk	···	···	274.32	108.00	···	···
Cocoa	···	···	21.00	8.27	···	···
Treatment ingredients						
Flour (nonchlorinated)	230.40	60.00	152.40	60.00	115.80	60.00
Starch	154.00	40.10	101.60	40.00	77.20	40.00
Dried egg albumin	34.60	9.01	22.90	9.02	17.50	9.07
Soya lecithin	0.38	0.10	0.25	0.10	0.19	0.10
Xanthan gum	0.57	0.15	0.38	0.15	0.29	0.15
Sugar	579.00	150.78	412.00	162.20	104.00	53.89
Salt	1.53	0.40	3.07	1.21	3.07	1.59
Baking powder	4.43	1.15	4.43	1.74	8.86	4.59
Whole eggs	267.00	69.53	106.80	42.05	53.40	27.67
Butter	794.00	206.77	···	···	···	···
Margarine	···	···	567.00	223.23	57.00	29.53
Vanilla	5.70	1.48	5.70	2.24	5.70	2.95
Milk	244.00	63.54	···	···	122.00	63.21
Buttermilk	···	···	274.32	108.00	···	···
Cocoa	···	···	21.00	8.27	···	···

[a] Based on flour = 100 for control ingredients, flour + starch = 100 for treatment ingredients.

crumb that is similar to that produced by chlorine-treated flour. Once that degree of water control is established in the crumb, the crumb has more strength and resiliency, observed as increased resistance to compression, return to original height after compression, and increased rate of return to original height after compression. In fact, those quality characteristics of cake crumb that are produced using chlorine-treated flour define the cake quality characteristics that are essential for a successful replacement for chlorine-treatment of cake flour.

The basic ingredient set consisted of a 60:40 blend of nonchlorinated flour and wheat starch, 18% egg albumin, 0.15% xanthan gum, and 0.1% lecithin (all on % flour basis). Use of the basic ingredient set produced cakes with good size, contour, and visual qualities, and excellent objective textural characteristics that are similar to those of cakes produced using chlorine-treated cake flour. Cake volumes were increased an average of 18%, which could be reduced to that of the cakes produced using chlorine-treated flours by reducing the batter weight by 13%. The basic ingredient set produced good quality white layer cakes, pound cakes, Texas sheet cakes, and cupcakes. Those cake types ranged in flour-to-sugar ratios from 0.54 to 1.62, suggesting a wide application for the chlorine replacing basic ingredient set.

The essential functional features of the basic ingredient set are the use of starch for hydrophillic properties and additional egg albumin (predominately) for crumb strength. The wheat class source of the (unmodified) starch component of the basic ingredient set was not observed to affect cake quality. The basic ingredient set does not require any special flour treatment (such as heat treatment) and does not require a chemical addition to cake formulation other than low concentrations of commonly used soya lecithin and xanthan gum. Additionally, the basic ingredient set appears to be applicable to a wide range of cake types.

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