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Quality Characteristics of Sponge Cake Supplemented with Soy Protein Concentrate

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Abstract The quality parameters of sponge cake supplemented with soy protein concentrate (SPC) were evaluated. The addition of SPC to wheat flour increased the protein content and alkaline water retention value, but decreased the sedimentation value. Protein content had a positive correlation with the alkaline water retention value, and a negative correlation with the sedimentation value. The higher the concentration of SPC, the higher the RVA pasting temperature and the lower the viscosity. Increasing the level of SPC in flour led to a decrease in mixogram peak time, whereas peak height, width at peak, and width at 8 min progressively increased. As the amount of SPC increased in the formulation, the pH and specific gravity of cake batter increased, whereas the volume and specific volume of sponge cake decreased. The total isoflavones content in SPC increased after heat treatment. The hardness, gumminess, and chewiness increased progressively in accordance with increasing level of SPC.

Keywords: sponge cake, soy protein concentrate, wheat flour, rapid visco analyser, mixogram

Introduction

Soybeans are a rich source of phytochemicals. Many of these compounds have important beneficial effects on human health. They include compounds that are found in soybeans at much higher concentrations than in other common foods (e.g., isoflavonoids) (1). The soy isoflavones are polyphenols, a large class of compounds synthesized by plants. Isoflavonoids have structures similar to both physiological and synthetic estrogens (2). Soybeans also contain a variety of phytochemicals such as acid phenolics, isoflavones, phytates, phytosterols, protease inhibitors, and saponis (3). Soy protein products come in a variety of forms: flour, concentrate, isolate, and their modified products. However, the uses of soybean proteins have been limited because of their strong beany, grassy, and bitter flavors (4).

Soy protein concentrate (SPC) has considerable potential for use as a protein supplement in a variety of foods. Since 1972, soy-fortified wheat flour breads have been used by the USDA for overseas food donation programs (5). Soy flour is an excellent source of protein to supplement wheat flour because it has a high protein content and a good balance of essential amino acids. Soy protein concentrate is used in most edible applications for its functional properties. Bahnassey and Khan (6) showed that soybean protein concentrate and soybean flour are good additives to spaghetti as judged by color, cooking loss, weight, and firmness. Soy flour is utilized in cakes for its functional properties rather than for its nutritional quality (7).

Cake products are difficult to define precisely because of their wide variety and the broad range of their formulations. Essentially, they are products that are leavened mainly by baking powder, and occasionally by air incorporation, as in the case of foam-type cakes, and by yeast (8). Sponge cakes, often referred to as foam cakes, rely mainly on air cells produced by mixing or leavening agents for volume and texture (9). Similar to angel cakes, they depend on the air being whipped into the batter as a major leavening agent (10).

Few studies have been reported concerning the use of soy protein concentrate in sponge cakes. In this study, the effects of SPC fortification on various quality parameters of sponge cake such as the physicochemical and rheological properties and the overall quality of sponge cake were evaluated.

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Materials and Methods

Materials The flour used in this study was commercially milled from soft wheat (Daehan Milling Co., Siheung, Korea). Soy protein concentrate (SPC) was obtained from Fuji Oil Co., Japan. Fine granulated sugar and fresh whole eggs were purchased from local markets.

Analytical methods Moisture, protein, fat, ash, non-fibrous carbohydrate, and fiber contents were determined by AACC approved methods 44-19, 46-13, 30-10, 76-11, and 32-10, respectively (11).

The methods of Collins and Post (12) were used to measure water retention capacity. The alkaline water retention capacity of flours was measured by AACC method 56-10 (11). Sedimentation values were determined according to AACC method 56-61A (11).

Extraction and analysis of isoflavones One g of ground sample was extracted with 20 mL of 80% ethanol at 50°C for 1 hr, using an ultrasonicator. Prior to HPLC analysis, the extract was centrifuged at 12,000×g for 15 min, then the supernatant was filtered through a syringe filter (0.22 μm, Waters Co., Milford, MA, USA). Isoflavone analysis was performed by HPLC (Waters) equipped with a Waters 486 Absorbance UV Detector set at 254 nm, using an XTerra™ RP_{18} column (5 μm, 4.6×250 mm, Waters). The HPLC eluent consisted of 0.1%(v/v) acetic acid in water (solvent A), and 0.1%(v/v) acetic acid in acetonitrile (solvent B). The solvent gradient was as follows: the proportion of solvent B increased from 15 to 23% for 0-40 min, increased to 27% within the next 30 min, and then increased to 35% within the next 15 min. It finally reached 40% within the last 5 min at a flow rate of 1 mL/min. Standard curves were obtained by injecting the standards of daidzein, daidzin, genistein, genistin, glycitein, and glycintin based on the corresponding peak area on the HPLC chromatograms. Isoflavone content was determined using standard curves. The average amount of each isoflavone was calculated based on triplicate analysis (13).

Rheological properties Flour gelatinization and pasting properties were assessed by a Rapid Visco Analyser (RVA, Newport Scientific, NSW, Australia). The primary starch pasting viscosity parameters derived from the RVA curve (and their units of measure, RVU) included the onset of gelatinization, peak paste viscosity, minimum viscosity, and final viscosity (11).

A 10-g Mixograph (National Mfg. Co., Lincoln, NE, USA) was used to evaluate the rheological properties of the flours. Mixograph characteristics were determined according to AACC method 54-40 (11).

Sponge cake-baking test Sponge cakes were prepared by the formula and procedure described by Nagao *et al.* (14) and Finney *et al.* (15). Cake batter was mixed using a KitchenAid mixer (model K5SS; KitchenAid Inc., Detroit, MI, USA) with a wire whip attachment. Each batter contained 100 g of flour (shift flour base), 100 g of baker's special-fine sifted sugar, 100 g of fresh whole eggs, and 40 g of water. Sugar and whole eggs were blended for 30 sec on the stir (lowest) speed, then mixed at high speed for 8 min as the first water portion was slowly added. The sides of the bowl were scraped and mixed for 2 min at high speed. The second water portion was slowly added and the creamed mixture (egg-sugar batter) was mixed for 2 min on speed 8. Hand mixing of the flour into the creamed mixture was replaced with mechanical mixing by gently immersing the flour in the creamed mixture with a flat beater for 16 sec at low speed, then for 4 sec at high speed. Batter samples (330 g) were measured into a cake pan (inside dimension, 14.8 cm; depth, 6.9 cm; inside volume, 1,260 mL) and baked in a preheated 180°C oven for 30 min, removed from the pans, cooled another 30 min, and stored in an air-tight container (LDPE Zipper bag).

Batter viscosity was measured by a simple method developed by Ebeler *et al.* (16). Batter pH was read directly from an approximately 10 g sample using a pH meter. Loaf volume was determined by rape seed displacement, and cake volume, symmetry, and uniformity index were determined using the AACC template method 10-91 (11).

Color and texture Crust and crumb color were evaluated using a chromameter (310; Minolta Co., Osaka, Japan) with a 50-mm (diameter) measuring tube. *L*, *a*, and *b* values denoted lightness (white-black), red-green, and yellow-blue, respectively (14). A texture analyzer (TA-XT2, Stable Micro System Co., Haslemere, England) was used to evaluate firmness of the cake crumb. A 2.5-cm compression probe was used, and the midsection of each cake was compressed to 1.0 cm (18). Extended time-firmness studies were also performed on the cake.

Statistical analysis Data were analyzed using the analysis of variance technique, and Duncan's multiple range test and the correlation coefficient was used for the comparison of treatment means (17).

Results and Discussion

Physicochemical properties The results of chemical analyses of SPC are shown in Table 1. Compared with wheat flour, SPC contained a higher protein and ash content, but a lower moisture, fat, and fiber content. Wheat flour consisted primarily of starch, whereas protein was the predominant component of SPC.

As shown in Table 2, the incorporation of SPC into wheat flour increased the protein content in proportion to the level of replacement, but decreased sedimentation values. The alkaline water retention capacity (AWRC) test is actually a standardized method of measuring the water retention ability of flour against centrifugal force. It is generally recognized that the lower the percent of water retained, the better the pastry quality (18). However, in this study, supplementing wheat flour with SPC caused an increase in water absorption.

Simple linear correlation coefficients among protein content, sedimentation value, and AWRC showed that the protein content had significant positive and negative correlations with AWRC ($r = 0.991^{**}$) and the sedimentation value ($r = -0.872^{**}$), respectively. The sedimentation value had a significant negative correlation with AWRC ($r = -0.879^{**}$). A higher protein content resulted in a higher AWRC. The increase in water absorption was probably a result of the higher protein content of the blends which caused greater hydration capacity. These results are in agreement with those found by Peter and Johnson (19), and Sathe *et al.* (20).

Table 1. Chemical compositions of wheat flour and soy protein concentrate (SPC)

Flours	Moisture (%)	Protein (%)	Ash (%)	Fat (%)	Carbohydrate (%)	
					Non-fibrous	Fiber
Wheat flour	12.6	8.5	0.2	0.9	77.4	0.4
SPC	6.7	74.6	3.9	0.5	14.0	0.3

Table 2. Protein content, sedimentation value, and alkaline water retention value (AWRC) of wheat and soy protein concentrate (SPC) flour blends and correlation coefficients between them

SPC in blend (%)	Protein content (%)	Sedimentation value (mL)	AWRC (g)
0	8.7[a1)]	12.6[c]	7.6[a]
3	10.9[b]	15.3[d]	8.0[b]
6	13.1[c]	12.4[c]	8.4[c]
9	15.3[d]	10.7[a]	8.7[d]
12	17.5[e]	8.8[a]	8.9[e]
15	19.7[f]	9.0[a]	9.3[f]
18	21.9[g]	8.5[a]	9.4[f]
21	24.1[h]	8.0[a]	9.7[g]
24	26.3[i]	8.2[a]	9.9[h]
Correlation coeffecient	Protein	Sedimentation value	
Sedimentation value	-0.872**	-	
AWRC	0.991**	-0.879**	

[1)]Means in a column sharing a common superscript letter(s) are not significantly different (p<0.05).
**: Significant at a 1% levels of probability.

The initial pasting temperature value obtained from 72.4 to 84.0°C in the RVA curves for the wheat flour and wheat-SPC mixtures studied are given in Table 3. Both the pasting temperature and viscosity of the SPC pastes were concentration-dependent. Apparently, the higher the SPC concentration, the higher the pasting temperature and the lower the viscosity. Since the initial pasting temperature increased with increasing SPC content, it appears that SPC depresses the gelatinization temperature of wheat starch. This increase was found to be statistically significant (p< 0.05). On the other hand, the RVA peak, minimum and final viscosity values for those mixtures containing SPC flour decreased proportionally to the amount of SPC in the mixture. This phenomenon could be attributed to the much lower starch content of the SPC flour when compared to that of wheat flour (21).

When simple linear correlation coefficients between the RVA characteristics and the quality parameters of flour were calculated, they showed that protein content, sedimentation value, and AWRC increased as the SPC increased. Therefore, the protein content of flour had a significant positive correlation with RVA initial pasting temperature (r = 0981**), and a negative correlation with peak viscosity (r = -0.912**), minimum viscosity (r = -0.973**), and final viscosity (r = -0.940**).

Physical dough test SPC is used in most edible applications for its functional properties. The mixograph characteristics that reflect the dough properties of the control flour and the SPC-wheat flour blends are shown in Table 4. Increasing the proportion of SPC in flour led to a decrease in mixogram peak time (mixing time). However, mixogram peak height, width at peak, and width at 8 min progressively increased in accordance with the increase in SPC concentration.

Table 3. Rapid Visco Analyser (RVA) pasting characteristics of wheat and soy protein concentrate (SPC) flour blends and correlation coefficients between them

SPC in blend (%)	RVA characteristics			
	Initial pasting temp. (°C)	Peak viscosity (RVU)	Minimum viscosity (RVU)	Final viscosity (RVU)
0	72.4[a1)]	237.7[g]	166.8[g]	292.6[g]
3	74.5[b]	221.1[f]	149.9[f]	271.1[f]
6	75.3[b]	215.3[f]	141.0[e]	271.2[f]
9	78.2[c]	193.1[e]	140.4[e]	260.0[ef]
12	80.1[cd]	193.1[e]	134.5[e]	256.3[ef]
15	81.4[de]	178.5[d]	122.7[d]	256.3[e]
18	81.4[de]	145.9[c]	107.1[c]	206.8[c]
21	82.8[ef]	108.1[b]	95.3[b]	182.3[b]
24	84.0[f]	91.4[a]	84.0[a]	162.1[a]
Correlation coefficient	Initial pasting temp.	Peak viscosity	Minimum viscosity	Final viscosity
Protein	0.981**	-0.912**	-0.973**	-0.940**
Sedimentation	-0.893**	0.730*	0.762*	0.699*
AWRC[2)]	0.991**	-0.903**	-0.955**	-0.906**

[1)]Means in a column sharing a common superscript letter(s) are not significantly different (p<0.05).
[2)]Alkaline water retention capacity.
*,**: Significant at 5 and 1% levels of probability, respectively.

Table 4. Mixograph characteristics of wheat and soy protein concentrate (SPC) flour blends

SPC in blend (%)	Mixograph characteristics			
	Peak time (min)	Peak height (mm)	Peak width (mm)	Width at 8 min (mm)
0	4.7b[c1)]	44.7[ab]	11.6[a]	8.2[a]
3	5.3[c]	43.3[a]	13.7[ab]	10.6[ab]
6	4.0[abc]	44.3[ab]	16.3[ab]	12.2[abc]
9	3.3[a]	45.6[ab]	20.3[ab]	14.6[bc]
12	3.4[ab]	46.4[bc]	26.3[bc]	15.2[bc]
15	3.1[a]	47.9[cd]	33.5[cd]	17.6[c]
18	2.7[a]	49.5[de]	45.7[de]	17.0[c]
21	2.5[a]	51.0[e]	46.4[e]	24.8[d]

[1)]Means in a column sharing a common superscript letter(s) are not significantly different (p<0.05).

Misra *et al.* (22) found that the mixing time increased as the content of defatted soybean flour increased in soy-wheat blends. The present results, however, showed that the addition of SPC to flour decreased mixing time. In general, mixing time correlates well with dough strength and, hence final loaf volume (23). When soybean flours were added to bread mixes, mixing time was lower for the flours containing defatted soybean than the untreated wheat flours (24).

The simple linear correlation coefficients between mixogram characteristics and flour quality parameters are summarized in Table 5. Mixogram characteristics were significantly correlated with some of the physical and chemical characteristics of flour measured here. Mixogram peak time had a correlation coefficient of r = -0.825** with protein content, of r = -0.760** with sedimentation value, and of r = -0.752* with AWRC. In addition, the peak time had significant positive or negative correlations with RVA characteristics. The peak height, width at peak and width at 8 min of mixogram were observed to have a significant correlation with flour quality parameters. In general, as the protein content of wheat flour increased, mixogram peak time increased.

Baking studies The cake baking test is also an important test in the evaluation of soft wheat flour. The data obtained from comparative baking studies on wheat flour supplemented with SPC are shown in Table 6. The volume and specific volume of sponge cake decreased with increasing levels of SPC supplementation. In general, soybean flour additives are associated with reduced loaf volume (26). It was reported that the substitution of wheat flour with defatted soy flour at 72% was associated with loaf volume (22), unless native or synthetic glycolipids were also added, in which case, soy flour could be substituted at 16% (27). Similarly, Tsen and Hoover (28) reported that the baking quality of defatted soy flours was inferior to that of full fat flours because the naturally occuring emulsifiers, lecithin and glycolipid, were removed during the extraction process. As the amount of SPC increased in the formulation, the pH and specific gravity of cake batter increased. Batter pH had a correlation coefficient of r = -0.931** with specific gravity. Cake volume is affected by the incorporation of air into the batter and the ability of the batter to entrap leavening gases released from the baking powder system (25).

The volume index of cakes containing up to a 24% replacement of wheat flour with SPC is also shown in Table 6. The volume index decreased slightly when the SPC content increased, which showed that, during baking, a high concentration of SPC made cakes shrink (cake height) in the oven and while cooling. Replacement of more than 9% of the wheat flour in the formulation with SPC caused a significant reduction in the height of the center peak. There were no significant changes in the uniformity index, which means no side-shrinkage was observed as a function of SPC content in the formulation.

Soybeans have been shown to be a major source of functional isoflavones such as genistein, genistin, daidzein, and daizin. The total isoflavone contents of SPC was determined and is presented in Table 7. The total initial isoflavone content of SPC was 1,213.80 μg/g. It was observed that the total amount of isoflavones increased after heat treatment. The amount of individual types of isoflavones, such as daidzein, daizin, genistein, genistin, glycitein, and glycitin, also increased after heat treatment. This data indicates that isoflavones are not only produced from biosynthetic pathways, but are also produced from the conversion of glycosides to aglycone during soaking or heat treatment due to β-glucosidase in soybean (29, 30). That is, the acetyl and malonyl groups in isoflavone

Table 5. Correlation coefficients between mixograph characteristics and quality parameters of wheat and soy protein concentrate flour blends

Quality parameters	Mixograph characteristics			
	Peak time	Peak height	Peak width	Width at 8 min
Protein	-0.825**	0.860**	0.952**	0.950**
Sedimentation	-0.760**	-0.385	-0.530	-0.647*
AWRC[1)]	-0.752**	0.682*	0.767**	0.906**
RVA[2)] characteristics				
Initial pasting temp.	-0.863**	0.725*	0.853**	0.874**
Peak viscosity	0.901**	-0.875**	-0.947**	-0.918**
Min. viscosity	0.862**	-0.870**	-0.955**	-0.921**
Final viscosity	0.854**	-0.910**	-0.976**	-0.916**

[1)]Alkaline water retention capacity.
[2)]Rapid Visco Analyser.
*,**: Significant at 5 and 1% levels of probability, respectively.

Table 6. Properties of sponge cake prepared from wheat and soy protein concentrate (SPC) flour blends

SPC in blend (%)	Batter		Cake					
	Sp. gravity	pH	Volume (cc)	Weight (g)	Sp. volume (cc/g)	Volume index	Symmetry index	Uniformity index
0	0.57[a1)]	7.52[d]	1,010[f]	283[a]	3.57[f]	17.25[e]	-0.15[a]	-0.15[a]
3	0.57[a]	7.44[d]	1,000[ef]	286[b]	3.50[ef]	16.15[de]	0.05[a]	-0.25[a]
6	0.68[b]	7.29[c]	930[de]	286[b]	3.25[de]	15.70[de]	0.05[a]	-0.05[a]
9	0.74[bc]	7.26[bc]	905[de]	287[bc]	3.15[d]	14.70[cd]	-0.15[a]	0.05[a]
12	0.81[c]	7.27[bc]	805[c]	287[bc]	2.81[c]	13.55[bc]	0.55[ab]	0.05[a]
15	0.80[c]	7.21[abc]	755[bc]	286[b]	2.64[bc]	12.60[ab]	0.60[ab]	-0.10[a]
18	0.84[cd]	7.18[ab]	710[ab]	287[bc]	2.47[ab]	12.70[ab]	1.10[b]	-0.10[a]
21	0.92[d]	7.18[ab]	675[a]	287[bc]	2.35[a]	12.00[ab]	1.20[b]	-0.10[a]
24	0.94[d]	7.13[a]	670[a]	289[c]	2.32[a]	11.15[b]	0.40[ab]	0.05[a]

[1)]Means in a column sharing a common superscript letter(s) are not significantly different (p<0.05).

Table 7. Effect of heat treatment on isoflavone content of soy protein concentrate

Isoflavone (μg/g)	Before heat treatment	After heat treatment
Daidzein	149.60	148.64
Daidzin	201.74	278.80
Genistein	304.44	308.00
Genistin	450.42	581.96
Glycitein	63.12	71.56
Glycitin	44.48	55.62
Total	1213.80	1444.58

Table 8. Correlation coefficients between specific loaf volume of sponge cake and quality parameters of wheat and soy protein concentrate flour blends

Quality parameter	Specific loaf volume
Protein	-0.979**
Sedimentation	0.924**
AWRC[1)]	-0.971**
RVA[2)] characteristics	
Initial pasting temp.	-0.965**
Peak viscosity	0.871**
Min. viscosity	0.922**
Final viscosity	0.886**
Batter pH	0.887**
Specify gravity	-0.970**
Mixograph characteristics	
Peak time	0.843**
Peak hight	-0.948**
Width at peak	-0.886**
Width at 8 min	-0.950**

[1)]Alkaline water retention capacity
[2)]Rapid Visco Analyser.
*,**: Significant at 5 and 1% levels of probability, respectively.

isomers might be converted to glucoside forms such as daidzin or genistin by heat treatment.

Table 9. Crust and crumb color of sponge cakes prepared from wheat and soy protein concentrate (SPC) flour blends

SPC in blend (%)	Crust color			Crumb color		
	L	a	b	L	a	b
0	60.4[b1)]	14.9[bc]	36.3[a]	82.5[d]	-3.6[a]	28.2[bc]
3	58.7[a]	15.8[cd]	35.8[a]	81.6b[cd]	-3.2[ab]	28.8[bc]
6	62.1[c]	14.8[bc]	36.0[a]	81.5b[cd]	-3.1[ab]	28.6[bc]
9	58.7[a]	16.7[d]	35.0[a]	81.8[cd]	-2.6[ab]	30.0[d]
12	67.4[d]	13.7[ab]	35.8[a]	80.4[b]	-2.4[b]	28.5[bc]
15	67.7[d]	12.4[a]	34.9[a]	80.7[bc]	-2.3[b]	26.6[a]
18	67.7[d]	12.6[a]	35.1[a]	80.8[bc]	-2.3[b]	28.0[b]
21	67.1[d]	12.4[a]	36.5[a]	80.7[bc]	-2.8[ab]	28.7[bc]
24	67.8[d]	12.5[a]	36.1[a]	78.5[a]	-2.1[b]	29.3[cd]

[1)]Means in a column sharing a common superscript letter(s) are not significantly different ($p<0.05$).

The correlation coefficients between specific loaf volume of sponge cake and quality parameters are summarized in Table 8. The specific loaf volume had a significant positive correlation with the sedimentation value (r = 0.924**) and a negative correlations with protein content (r = -0.979**) and AWRC (r = -0.971**). In general, as the amount of protein content increased in the formulation, the cake volume decreased. AWRC may be influenced by protein content and sedimentation value. Traditionally, AWRC has been used as a predictor of cookie baking quality (31, 32). The RVA and mixogram characteristics were highly correlated with cake volume.

The crust and crumb color of sponge cakes prepared from wheat and SPC flour blends are given in Table 9. The lightness (*L*) of sponge cake crust increased with increasing levels of SPC added to wheat flour. However, the crumb lightness decreased with increasing SPC. The *a* value of crust decreased slightly when the SPC content increased. The presence of SPC seemed to have little effect on the color of the cakes. One noticeable difference was the light colored crust of cake that did not contain water-solubles, probably reflecting the absence of reducing sugars necessary for the browning reaction. The *L* value of

Table 10. Texture properties of sponge cake prepared from wheat and soy protein concentrate (SPC) flour blends

SPC in blends (%)	Hardness (g)	Springiness	Gumminess	Cohesiveness	Chewiness
0	210.1[a1)]	0.82[ab]	135.9[a]	0.65[a]	113.0[a]
3	228.8[a]	0.84[ab]	147.1[ab]	0.64[a]	124.8[a]
6	253.5[ab]	0.82[ab]	162.5[ab]	0.64[a]	133.6[a]
9	299.3[b]	0.80[a]	194.6[bc]	0.65[a]	156.0[ab]
12	393.0[c]	0.84[ab]	250.0[d]	0.63[a]	210.7[bc]
15	394.2[c]	0.83[ab]	242.6[cd]	0.61[a]	203.2[bc]
18	465.2[d]	0.86[ab]	292.3[d]	0.62[a]	251.5[c]
21	553.5[e]	0.87[b]	358.7[e]	0.64[a]	312.0[d]
24	607.8[e]	0.85[ab]	375.6[e]	0.61[a]	323.0[d]

[1)]Means in a column sharing a common superscript letter(s) are not significantly different ($p<0.05$).

sponge crumb cakes decreased with increased level of SPC supplementation in all cases. However, the *a* and *b* values of crumb did not vary between the control and wheat flour supplemented with SPC flour.

The hardness, gumminess and chewiness of sponge cake increased progressively with each increasing level of SPC substitution, although the increase was small for cakes that had 6% of the flour replaced with SPC (Table 10). SPC flour produced cakes that were ranked to be significantly harder in texture. However, little or no significant differences were observed regarding the springiness and cohesiveness of the cakes. The results of this study have indicated that wheat flour could be diluted with SPC flour to a level of 6% without significantly changing rheological batter properties and cake quality.

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