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Quality of Batter and Sponge Cake Prepared from Wheat-Tapioca Flour Blends

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ABSTRACT

The type of flour used in a sponge cake plays an important role in improving product quality. The possibility of cake preparation using tapioca starch (TS) as partial substitution for wheat flour (WF) for further application in the food industry was investigated. Sponge cake batter formulations containing flour blends of WF (10˘20%) and TS (0˘10%) at three mixing ratios (100:0, 75:25 and 50:50) were studied. Apparent viscosity of batters was determined from steady shear measurement and decreased with increasing TS substitution for WF. The batter density decreased with increasing TS content, indicating a higher amount of air incorporated into the cake batter during mixing. The specific volume of cakes after baking at 175 °C for 20 min increased with increasing TS substitution. The texture profile analysis hardness values of baked cakes containing 50% TS substitution were significantly ($P < 0.05$) lower than those prepared from only WF. Softness and overall liking scores of cakes prepared from WF and TS (mixing ratio = 50:50) were significantly ($P < 0.05$) higher than those prepared from only WF. The results suggest that partial replacement of WF by TS (up to 50%) decreased batter viscosity and density leading to higher specific volume and lower hardness in sponge cakes after baking. Therefore, TS could be used in sponge cake preparation for modifying textures in the baking industry.

Keywords: viscosity, power law model, specific volume, texture, sensory evaluation

INTRODUCTION

The quality of the ingredients and the nature of their interactions influence the quality of a final food product. In the bakery industry, cake is one type of air-leavened product. The quality of cakes depends on many factors such as the ingredients used for batter preparation, aeration of batters and process conditions. There are many reports investigating the quality of cake batter determining the final quality of cake products (Sakiyan *et al.,* 2004; Yang and Foegeding, 2010). Batters are obtained by aerating the liquid mixture via mechanical mixing to form a foam structure in order to obtain cakes as the final product; therefore, these batters are complex emulsion systems whose density and rheological properties play an essential role in determining the characteristics of the resulting cakes. High quality cakes can be characterized as having various attributes, including high volume, uniform crumb structure, softness and a long shelf life with tolerance to staling (Gelinas *et al.,* 1999). The expansion of cake products comes from the volume of air bubbles entrapped in the cake batter and the liquid part in the system. The cake

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expansion increases with increasing temperature of the batter according to the gas laws and with increasing water vapor pressure from the liquid in the mixture (Matz, 1992). As the ingredients play an important functional role in the structure and eating quality of the product (Conforti, 2006), cake batters prepared from whole eggs containing egg yolk lipids exhibit very fine bubbles in the crumb (internal structure) of baked products leading to a silky and tender texture. In addition, a formula based on egg yolks containing added shortening further changed the structural qualities of both the batter and the baked cake (Matz, 1992). Baking powder is also used in sponge cake and has been suggested to be added at the final stage of ingredient mixing (Matz, 1992).

Not only wheat flour but also other flour types have been investigated for developing cakes of lower cost and better quality in terms of consumer acceptance (Turabi *et al.,* 2008). The cakes studied were prepared from various types of flour such as wheat-chickpea flour blends (Gomez *et al.,* 2008), rice flour (Turabi *et al.,* 2008) and flour obtained from wheat, rye, and barley (Gomez *et al.,* 2010). Tapioca starch (TS), produced from cassava roots, is a thickener used in the food industry due to its high viscosity, clear appearance and low production cost compared to other starches, especially in Thailand. However, the effect of partial substitution of wheat flour (WF) with TS on the quality of the batter and the sponge cake has rarely been investigated. Therefore, the objective of the present study was to establish the influence of partial substitution of WF with different levels of TS in the cake formulation on the rheological properties, density and microscopic analysis of cake batters. In addition, the influence of the partial substitution of WF with TS on cake volume, texture and the sensory properties of baked cake was also determined. The results of the present study could be used to design cake emulsions with improved properties needed for further applications in product and process development.

MATERIALS AND METHODS

Materials

Tapioca starch (TS) was purchased from Siam Modified Starch Co., Ltd. (Pathum Thani, Thailand) with 11.1% moisture, 1.0% protein and 0.2% ash contents on a wet basis and was determined using a hot air oven at 105 °C, by the Kjeldahl method, and by dry ashing in a furnace at 550 °C, respectively, according to the methods of AOAC (2000). Wheat flour (WF) for cake preparation containing 11.6% moisture, 7.9% protein and 0.4% ash contents on a wet basis (AOAC, 2000) was used in the study. Fresh whole eggs, whole milk powder, baking powder with double-action, emulsifier (SP®), sugar and butter containing 1.5% salt (Orchid®) were purchased from a supermarket and used without any further purification.

Cake preparation

The experiments used sponge cake batter formulations containing WF (10˘20%) and TS (0˘10%) to obtain flour blends at three mixing ratios (WF:TS = 100:0, 75:25 and 50:50), 28.0% liquid whole eggs, 2.0% whole milk powder, 0.4% baking powder, 1.6% emulsifier, 24.0% sugar, 16.0% butter and 8.0% water (Table 1). In the cake batter preparation (500 g), the liquid whole eggs, water, sugar and emulsifier were mixed in a Kitchen-Aid mixer (5K5SS, St. Joseph, MI, US with machine speeds from 1 to 10) at speed 3 for 1 min and further mixed at speed 6 for 9 min. Then, dry ingredients (the flour blend of WF and TS, whole milk powder and baking powder) were added simultaneously to the mixture at speed 1 for 1 min and further mixed at speed 3 for 2 min. The melted butter was added finally and mixed at speed 1 for 20 s. Each batter formulation (125 g) was placed in an aluminum pan (8.5 × 16 × 5 cm) and baked in an electric oven (Teba™, TFL10-

Table 1 Percentage of ingredients in sponge cake formulations (100 g) containing different mixing ratios of wheat flour (WF) and tapioca starch (TS).

Ingredients	Flour blend (WF:TS) (%)		
	100:0	75:25	50:50
Wheat flour (for cake)	20.0	15.0	10.0
Tapioca starch	0	5.0	10.0
Liquid whole egg	28.0	28.0	28.0
Whole milk powder	2.0	2.0	2.0
Baking powder	0.4	0.4	0.4
Water	8.0	8.0	8.0
Emulsifier (SP®)	1.6	1.6	1.6
Sugar	24.0	24.0	24.0
Butter (1.5% salt)	16.0	16.0	16.0
Total	100.00	100.00	100.00

31) at 175 °C for 20 min. After baking, the cakes were removed from the pans, cooled upside down on a wire rack for 30 min at room temperature and kept in plastic bags to prevent drying before being measured for physical properties and sensory evaluation within 12 h.

Batter quality measurement

Apparent viscosity

The shear stress and apparent viscosity of the prepared batters were recorded as a function of a shear rate range between 2.5 and 62.5 s^{-1} controlled at 25 °C using a rotational viscometer (DV-III, Brookfield-RVT) with the coaxial cylinder geometry of the small sample adapter and the SC4- 29 spindle according to the method of Ketjarut *et al.* (2010). Sample temperatures were kept constant for at least 5 min before starting measurements. The flow behavior of each batter formulation was evaluated using a power law model as shown in Equation 1 by plotting *ln* (shear stress) and *ln* (shear rate) to obtain the consistency coefficient (K) and flow behavior index (n):

$$\tau = K\dot{\gamma}^n \quad (1)$$

where: τ = shear stress (Pa)

$\dot{\gamma}$ = shear rate (s^{-1})

K = consistency coefficient ($Pa.s^n$)

n = flow behavior index.

The coefficient of determination (R^2) was also calculated. All measurements were carried out at a controlled temperature (25 ± 2 °C). At least three replications were completed.

Batter density

The batter was filled into an aluminum cup immediately after removal from the mixer, leveled off using a rubber spatula and weighed. The batter density was calculated as the ratio of the batter weight (W_1) to the distilled water weight (W_2) filled in the same cup (modified from Gomez *et al.,* 2007). The density of the water was 1 g/cm^3.

Microscopic analysis

For each cake batter sample with and without TS substitution, a thin layer of freshly prepared samples was prepared immediately by placing a drop of the batter on a microscope slide and covering with a cover slip. The samples were observed under an optical microscope (Model CH30RF200, Olympus®, Tokyo, Japan) with a 10× magnification. A digital camera was mounted on the microscope for taking photographs.

Cake quality determination

Specific volume

The final cake volume was obtained using the rapeseed displacement method. The cake was cut into 25 × 25 × 25 mm cubes. Then, one piece of cake was weighed (W_o), placed in a container and the rest of the container volume was filled with rapeseed (V_2). The volume of the empty container (V_1) was calculated by filling with rapeseed. Both V_1 and V_2 were later determined by a graduated cylinder and the difference between V_1 and V_2 was defined as the cake volume (V_o). The specific volume was then calculated as the ratio of the volume to weight (V_o/W_o).

Crumb texture

Texture profile analysis (TPA) was performed to evaluate the texture of the cakes using a Texture Analyzer (TA-500, Lloyd Instruments Ltd., UK) equipped with the texture NEXYGEN™ software program (Ametek, Inc., UK). The cake samples were cut into 25 × 25 × 25 mm cubes before TPA measurement. A standard double-cycle program was used to compress the samples at a speed of 50 mm/min with 50% deformation using a 50 mm diameter probe (modified from Pongsawatmanit *et al.,* 2007) without the waiting time before starting the second compression. Hardness (N), cohesiveness (no unit), springiness (mm) chewiness (Nm) and gumminess (N) were calculated by the software program. At least 5 samples were measured to obtain an average value of all texture parameters for each formulation.

Sensory evaluation

An affective test for sensory evaluation of sponge cake containing different TS levels was performed using 30 untrained panelists (the students and staff of the Department of Product Development, Kasetsart University). Each panelist was presented with individual cake samples (about 3 × 3 × 1.5 cm) with and without TS that had been baked within the previous 12 h and were placed on a tray in a plastic bag coded with a three-digit random number and served in a randomized order. During the panel session, water was provided to panelists to minimize any residual effect before testing a new sample. Each panelist was asked to rate the liking of quality attributes according to appearance, color, odor, softness and overall liking of each sample using a 9-point hedonic scale (1 = dislike extremely, 5 = neither dislike nor like, and 9 = like extremely).

Statistic analysis

All measurements were performed using three replications. The results were reported as the mean value with standard deviation. The data were subjected to analysis of variance (ANOVA) using the SPSS V.12 statistical software package (SPSS (Thailand) Co., Ltd.). Duncan s multiple range test (DMRT) was also applied to determine significant differences at the 5% level of significance ($P < 0.05$) between the treatment parameters associated with the properties of the batter and baked cake.

RESULTS AND DISCUSSION

Quality of cake batter with and without tapioca starch

The flow curves of the cake batters containing different mixing ratios of WF and TS (100:0, 75:25, 50:50) were determined from steady shear measurements at 25 °C. All batters with and without TS exhibited a pseudoplastic behavior. The apparent viscosity of the batters decreased with increasing shear rate and TS substitution for WF (Figure 1a). The results obtained were in good agreement with the results obtained from batters containing WF and TS mixtures for fried products (Ketjarut *et al.,* 2010). Therefore, the WF content in the cake batter played a predominant role in increasing the batter viscosity due to the wheat protein being the main cause of batter viscosity development during mixing (Loewe, 1993).

Since the shear-thinning behavior was exhibited in the middle region, the apparent viscosity decreased with increasing shear rate for the shear thinning fluid. Thus, the power law equation (Equation 1) described the flow behaviors of all cake batter formulations with different mixing ratios of WF and TS (R^2 = 0.998˘1.000; Table 2; Figure 1b). The consistency index (*K*) of all batters decreased with increasing TS substitution from 15.4 to 8.0 for batters without TS and with 50% TS substitution for WF (Table 2), respectively. The addition of TS in the batters significantly altered the flow behavior index of the batters from 0.64 to 0.71 for the samples without and with TS, respectively (Table 2) suggesting that the batters containing TS had more pronounced Newtonian behavior due to the value of *n* approaching close to one.

In general, the methods used to characterize cake batters are mainly based on the measurement of the viscosity and the density. Density is a key measurement used in the industry to characterize aeration. It is generally measured by weighing a known volume of batter (Fox *et al.,* 2004). Then, the batter density can be related to the amount of air incorporated in the batter during the mixing process and applied to determine the expected quality of the final baked cake. The present study found that the batter density decreased with increasing TS substitution (Table 2), indicating there was a higher amount of air incorporated into the batter. The lower viscosity was expected to have lower resistance to the applied shear during the mixing process leading to a higher amount of air being incorporated. The batter without TS (100% WF) showed the highest batter density values (0.488 g/cm^3) but was not significantly different to the batter containing 25% TS substitution for WF (0.467 g/cm^3), whereas the

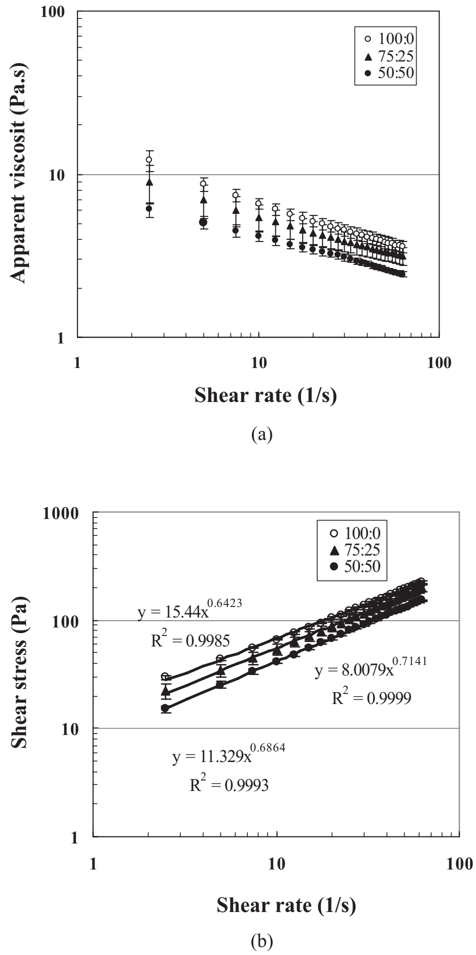


Figure 1 Apparent viscosity shown as mean ± standard deviation bars (a) and rheogram with power law model (b) of cake batters prepared from flour blends with different mixing ratios of WF and TS (100:0, 75:25 and 50:50) determined at 25 °C. The equations in the plot follow Equation 1: $\tau = K\dot{\gamma}^n$.

Table 2 Power law constants and density of batters prepared from flour blends of wheat flour (WF) and tapioca starch (TS) with different mixing ratios.

Flour blend (WF:TS)	*K* (Pa.s^n)	*n*	R^2	Batter density (g/cm^3)
100 : 0	15.4±0.4^a	0.64±0.01^b	0.998	0.488±0.015^a
75 : 25	11.4±2.1^b	0.70±0.02^a	0.999	0.467±0.009^{ab}
50 : 50	8.0±0.9^c	0.71±0.03^a	1.000	0.459±0.037^b

Mean ± standard deviation values (n = 9) followed by a different lower-case letter within the same column are significantly different (P < 0.05) by Duncan s multiple range test.

batter density was significantly different to that containing 50%TS substitution (0.459 g/cm^3) as shown in Table 2. To confirm the explanation of the relationship between the batter density and bubble size and distribution, images of the cake batters are shown in Figures 2a˘2c. The bubble size distribution was dependent on the batter density as well as on the level of TS substitution for WF. The smaller bubble size with more uniform appearance was observed in the batter samples prepared from WF only, due to the higher batter viscosity with higher WF content (Table 2). The bubbles in the batters containing TS with lower batter density (0.467˘0.459 g/cm^3) exhibited a wide variation in bubble size distribution due to the low viscosity of the batter containing TS having lower gluten content which affected the larger number of air cells initially incorporated during mixing (Sahi and Alava, 2003). A higher number of larger air bubbles was observed in the photomicrographs of cake batters containing higher TS contents. The larger air bubble sizes that existed in the batters containing TS with lower viscosity were expected to reveal evidence of coalescence where two or more bubbles had merged to form a larger bubble (Irene *et al.,* 2006) during the aeration stage before baking.

Quality of cakes containing tapioca starch

The specific volume of baked cake indicates the amount of air that can remain in the final product. A higher gas retention and higher expansion of the product (Gomez *et al.,* 2008) leads to a higher specific volume. After baking at 175 °C for 20 min, the specific volumes of cake with and without TS were determined and showed a significantly higher value with increasing TS content indicating a higher amount of air remained in the cake. When the specific volume of baked

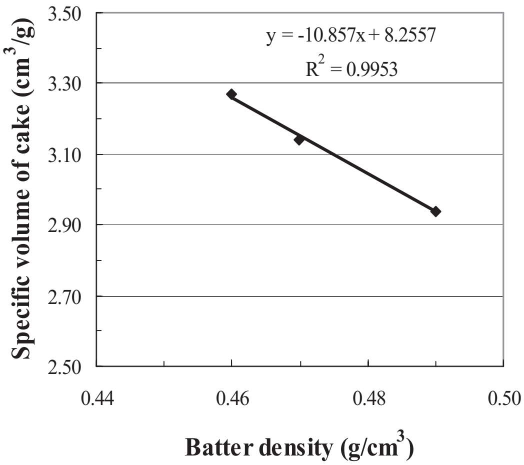
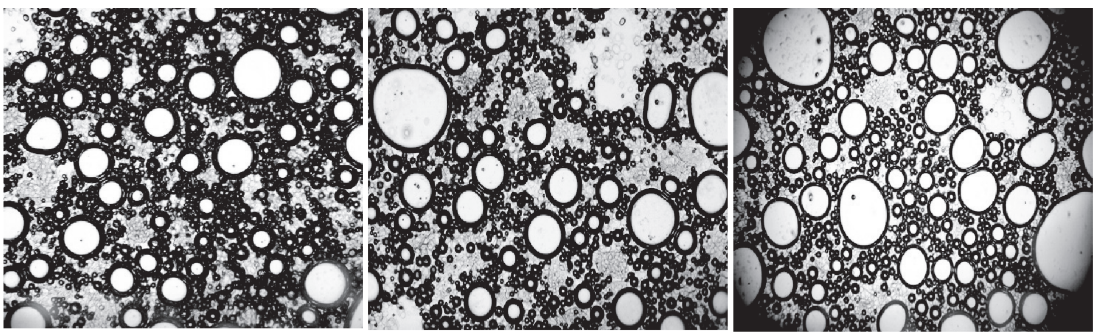


Figure 3 Specific volume of cake as a function of batter density prepared from flour blends with different mixing ratios of WF and TS (100:0, 75:25 and 50:50).



(a) (b) (c)

Figure 2 Images of aerated cake batters (a-c) (10× magnification) prepared from different mixing ratios of WF and TS. (a) 100:0; (b) 75:25; (c) 50:50.

cake as a function of batter density was plotted (Figure 3), a linear relationship was observed. Cake batters containing TS with lower batter density exhibited higher gas retention resulting in a higher specific volume, due to the expansion of gas retained in the batter. The air entrapped in the system that related to final cake volume could be explained by the changes in batter viscosity during baking.

According to a preliminary rapid visco analyzer (RVA) experiment for monitoring the heating profile of the cake batter (data not shown), the viscosity of the batters increased after being subjected to the pasting temperature due to the starch gelatinization and protein denaturation (Wilderjans *et al*., 2008). The cake batter viscosity increased earlier in the samples containing higher TS contents. Peak viscosity increased with increasing TS content along with the earlier increase in viscosity, leading to air bubbles created during whipping being retained in the cake crumb. Thus the changes of batter viscosity during baking with different mixing ratios of WF and TS were expected to modify the cake structure (data not shown). However, the baked cakes prepared from 100% TS had a very low volume with a dense, gummy layer at the bottom. Therefore, the relationship between specific volume and batter density as shown in Figure 3 could explain the batters prepared from the WF and TS within the studied mixing ratios.

Texture profile analysis is a very useful technique for investigating food products. In the present study, the TPA parameters of cake with and without TS substitution were determined from the texture analyzer using double compression tests and are shown in Table 3. Hardness was defined as the maximum force of the first compression of the product at the point of 50% compression (12.5 mm) of the original sample height. The hardness values of baked cakes decreased significantly with increasing TS substitution up to 50% (Table 3) from about 4.5 to 3.4 N in the cakes containing only WF and 50% TS substitution, respectively. However, cohesiveness determined from the area of work during the second compression divided by the area of work during the first compression (Borne, 2002) ranged between about 0.52 and 0.56 with no significant difference between any samples with and without TS. Springiness was defined as the distance to which the sample recovered in height during the time that elapsed between the end of the first compression cycle and the start of the second compression cycle. The springiness of baked cakes with and without TS exhibited no significant difference (Table 3). Gumminess was calculated by the product of (that is by multiplying) hardness and cohesiveness, whereas chewiness, defined as the energy required to masticate solid food to a state of readiness for swallowing (Karaoglu and Kotancilar, 2009) was obtained from the product of hardness, cohesiveness and springiness. Chewiness and gumminess values in cakes with and without TS exhibited a similar trend with the hardness values, as shown in Table 3. Significantly lower chewiness and gumminess were found in the cake samples containing 50%

Table 3 TPA parameters of sponge cakes prepared from different mixing ratios of WF and TS.

Flour blend (WF:TS)	Hardness (N)	Cohesiveness (-)	Springiness (mm)	Gumminess (N)	Chewiness (Nm)
100 : 0	4.49±0.70[a]	0.523±0.053[a]	10.8±1.0[a]	2.366±0.551[a]	0.026±0.008[a]
75 : 25	4.69±0.31[a]	0.559±0.112[a]	10.5±0.8[a]	2.604±0.387[a]	0.027±0.003[a]
50 : 50	3.39±0.37[b]	0.529±0.046[a]	10.9±0.9[a]	1.797±0.273[b]	0.020±0.003[b]

Mean ± standard deviation values (n = 30) followed by a different lower-case letter within the same column are significantly different ($P < 0.05$) by Duncan s multiple range test.

Table 4 Sensory scores of sponge cakes prepared from different ratios of WF and TS*.

Flour blend (WF:TS)	Appearance	Color	Odor	Softness	Overall liking
100 : 0	6.7±1.3[a]	6.7±1.4[a]	6.7±1.4[a]	6.4±1.6[b]	6.3±1.3[b]
75 : 25	6.5±1.2[a]	6.7±1.5[a]	6.6±1.5[a]	6.8±1.6[ab]	6.6±1.3[ab]
50 : 50	6.2±1.5[a]	6.6±1.6[a]	6.5±1.4[a]	7.4±1.2[a]	7.0±1.3[a]

Mean ± standard deviation values (n = 30) followed by a different lower-case letter within the same column are significantly different ($P < 0.05$) by Duncan s multiple range test.

* = Sensory scores are based on a 9-point hedonic scale ranging from 1 = dislike extremely to 9 = like extremely.

TS substitution (Table 3). The results suggest that partial (50%) TS substitution for WF in cakes increased the cake volume and softened the texture (as shown by lower values of hardness, chewiness and gumminess).

The sensory evaluation was carried out by rating the liking of the sensory attributes of cakes with and without TS substitution for appearance, color, odor, softness and overall liking using a 9-point hedonic scale. There was no significant difference among the samples with and without TS substitution for the liking scores of appearance, color and odor exhibited (Table 4). However, the mean scores of cakes evaluated in terms of softness and overall liking were higher with higher TS content in the cake and significantly different (Table 4). The overall liking score of the cake with 50% TS substitution was about 7.0 (like moderately) and was significantly different from the cake prepared from 100% WF (Table 4). It was observed that the higher softness scores with higher TS substitution resulted in an increase in the overall liking values.

CONCLUSION

Substitution of WF by TS decreased batter viscosity with the decrease in batter density indicating more air was incorporated into the cake batter during mixing. The higher specific volume in baked cakes containing TS was expected from the retention of air bubbles during baking leading to lower hardness of the cake after baking. The results suggested that TS substitution up to 50% for WF could be used in cake preparation for modifying textures in the bakery industry. As a result, in the food industry, the quality of cake in terms of softness, leading to higher overall liking, can be improved by partial substitution of WF with TS.

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