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Rheological Properties of Wheat Flour-based Batter Containing Tapioca Starch

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ABSTRACT

Batter properties are important in the development of fried battered products. In this study, the effects of tapioca starch (TS) and temperature on the viscosity of wheat flour-based batters were investigated. Flour blended (91.4%) from commercial all-purpose wheat flour (WF) and TS at three different mixing ratios (WF:TS = 100:0, 75:25 and 50:50), leavening powder (3.1%) and salt (5.5%) were mixed to obtain dry-mix. Batter was prepared by adding water (15°C) to the dry-mixes in the proportion of 1:1.3 (w/w) and kept for 1 h at 10°C before rheological property evaluation using a rotational viscometer at 10, 15, 20 and 25°C. The rheograms of all batters with different mixing ratios of flour exhibited shear-thinning behavior at all studied temperatures. The apparent viscosity of WF-based batter systems decreased with an increase in the substitution of TS and with temperature. The power law equation was a suitable representation of all batter formulations with different mixing ratios of WF and TS (r^2 = 0.989-1.000). Replacement of TS in batters decreased the consistency coefficient (K) but increased the flow behavior index (n). The activation energy values from the Arrhenius equation of the batters with and without TS were about 23-26 kJ/mol and not significantly different (p>0.05) suggesting that adding TS did not alter the thermal stability of the WF-based batters.

Key words: apparent viscosity, batter, Arrhenius equation, temperature, consistency coefficient, flow behavior index

INTRODUCTION

Batter application prior to deep-frying with fat is a widely used method for food preparation. Batter forms a continuous and uniform layer over the food surface and enhances the desired texture, flavor and appearance of foods. Usually, the batter is a liquid mixture comprised of water, flour, starch and seasonings. The consistency of the batter plays an important role in determining its performance in relation to the processes of pickup and frying, which influences the final quality of the fried product (Hsia *et al*., 1992; Shih and Daigle, 1999; Dogan *et al*., 2005).

Application of batter containing different flours provides unique flavors and textures in fried products. The batter uniformity and thickness for coating on the food surface depend on the viscosity and temperature of the batter, which, in turn, determines the quality and acceptability of the fried product (Moreira *et al*., 1999). Therefore, the viscosity of the batter applied to products deep-fried in fat is a critical coating characteristic that may affect the quantity and quality of batter

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pickup, appearance, texture, and the handling property of the coated products. Rheological property measurements are used to determine and monitor changes in the properties during batter coating and frying (Chang *et al*., 1996). The factors that affect the rheological properties of batters are the composition and proportion of the ingredients, the solids-water relationship and temperature (Fiszman and Salvador, 2003).

Wheat flour (WF) is the most common flour used in batter systems (Loewe, 1993). However, other types of flour also have been studied in batter systems, such as rice flour (Shih and Daigle, 1999) and wheat-corn and corn-rice (Xue and Ngadi, 2007), to reduce the oil absorption after frying. Tapioca starch (TS) produced from cassava roots, is a favored thickener used in food industries due to its high viscosity, clear appearance and low production cost, compared to other starches, especially in Thailand (Pongsawatmanit *et al*., 2006). Therefore, the objective of this study was to determine the effect of TS substitution on the viscosity of WF-based batters at different temperatures to gain more understanding of the rheological properties for further application in fried battered products.

MATERIALS AND METHODS

Materials

Commercial all-purpose wheat flour (WF), tapioca starch (TS) (Chorchaiwat Industry Co., Ltd, Thailand), leavening agent ($Na_2H_2P_2O_7$/$NaHCO_3$) and commercial refined salt were used for batter preparation. Moisture contents of the WF and TS were determined as 12.65 and 11.52%, respectively, according to the methods of AOAC (1995). The protein content of WF, according to the manufacturer was 10.35%, whereas that of tapioca starch was 0.14% (AOAC, 1995).

Batter preparation

WF and TS were premixed at three different mixing ratios (WF:TS = 100:0, 75:25 and 50:50). The dry-mix was prepared from flour blend (91.4%), leavening powder (3.1%) and salt (5.5%) as shown in Table 1. Using a mixer, water (15°C) was added to the dry-mix, with the proportion of dry-mix to water being 1:1.3 (w/w) to obtain a homogeneous batter, which was kept at 10°C for at least 1 h before the measurement of rheological properties.

Rheological property measurement

The apparent viscosity of the prepared batters was measured as a function of shear rate and ranged from 2.5 to 62.5 s^{-1} at 10, 15, 20 and 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. Sample temperatures were kept constant for at least 5 min before starting measurement. The flow characteristics of the batters were evaluated using a power law model. The effect of temperature on the rheological properties was determined using the Arrhenius equation.

Table 1 Dry-mix formulations for batter preparation with different mixing ratios of WF and TS.

Ingredient	Ingredients for each mixing ratio of WF and TS (%)		
	100:0	75:25	50:50
Wheat flour (WF)	91.4	68.55	45.7
Tapioca starch (TS)	0.0	22.85	45.7
Leavening powder	3.1	3.1	3.1
Salt	5.5	5.5	5.5

Statistical analysis

All measurements were performed at least in triplicate and mean values were reported with the standard deviation. Analysis of variance (ANOVA) was used to determine any significant differences among the treatment parameters associated with the rheological properties. Duncan's multiple range test was also applied to determine any differences of means ($p \leq 0.05$) from the ANOVA.

RESULTS AND DISCUSSION

Steady shear measurement

From the steady shear measurement, batters prepared from flour blends of WF and TS (mixing ratios of 100:0, 75:25 and 50:50) mixed with water (dry-mix:water ratio = 1:1.3) were determined at 10, 15, 20 and 25°C after preparation for 1 h to ensure the complete swelling of starch granules. The rheograms of the batters with different mixing ratios of flour blends were plotted for shear stress and shear rate (2.5-62.5 s^{-1}) at 10, 15, 20 and 25°C as shown in Figure 1. All batters exhibited pseudoplastic behavior. At the same temperature, TS substitution in WF-based batters (WF:TS = 75:25 and 50:50) decreased the shear stress at the same shear rate. When the shear stress values of batters were measured at higher temperatures, shear stress values of the batters from each mixing ratio of flour blends were lower with increasing temperature.

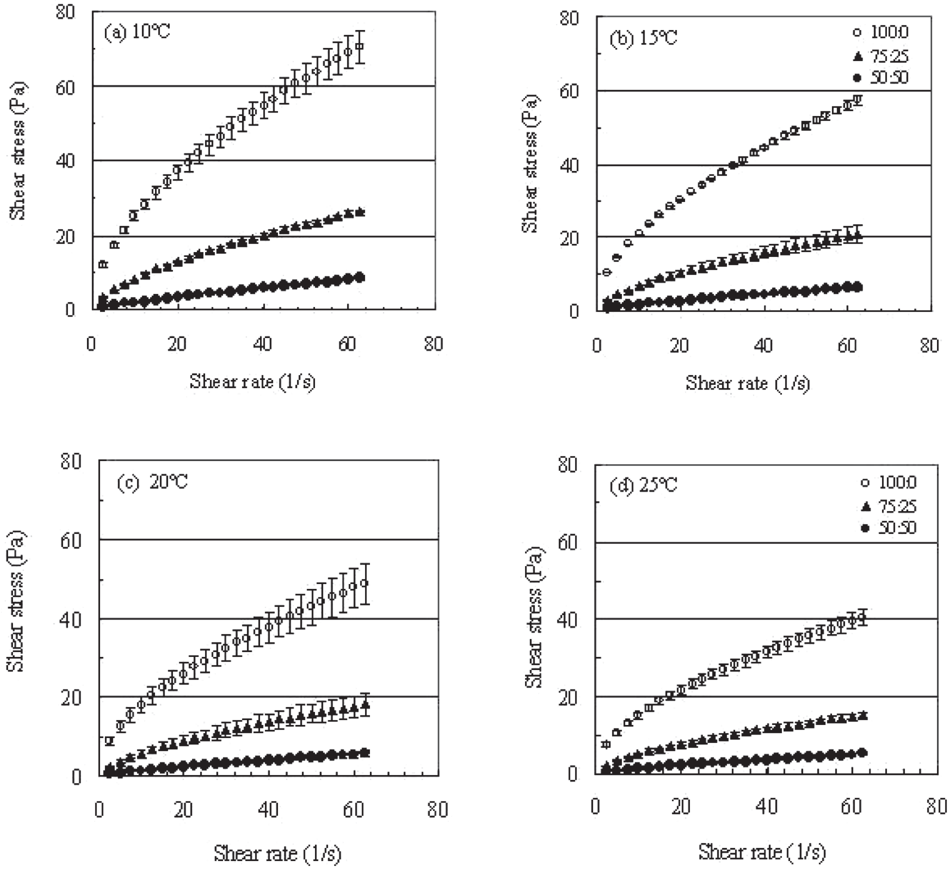

Figure 1 Rheograms of batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) determined at: (a) 10°C; (b) 15°C; (c) 20°C; and (d) 25°C.

The apparent viscosity of batters containing different mixing ratios of WF and TS (100:0, 75:25, 50:50) were investigated at temperatures ranging from 10 to 25°C. The apparent viscosity values of all batters decreased with increasing shear rate, TS substitution and temperature (Figure 2). The shear-thinning behavior (Figure 2) was exhibited in the middle region where the apparent viscosity was changing (decreasing for shear thinning) with shear rate. Thus, the power law equation (Equation 1) was suitable to describe the flow behavior of these batter systems.

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

where τ = shear stress (Pa), $\dot{\gamma}$ = shear rate (s^{-1}), K = consistency coefficient ($Pa.s^n$), and n = flow behavior index (Steffe, 1996).

The power law equation was found to model all batter formulations with different mixing ratios of WF and TS (r^2 = 0.989 – 1.000). The consistency coefficient values of WF-based batters without TS were higher than those containing TS (Table 2). The addition of TS in the batters altered the flow behavior index of the batter from 0.5 to 0.6-0.8 (Table 2). The results suggested that the batters containing TS exhibited more pronounced Newtonian behavior due to the flow behavior index more closely approaching a value of n = 1.

Influence of temperature on flow properties

During manufacturing of fried battered food, especially at the batter-coating stage, the viscosity of batters plays an important role in the quality of the fried products. The apparent

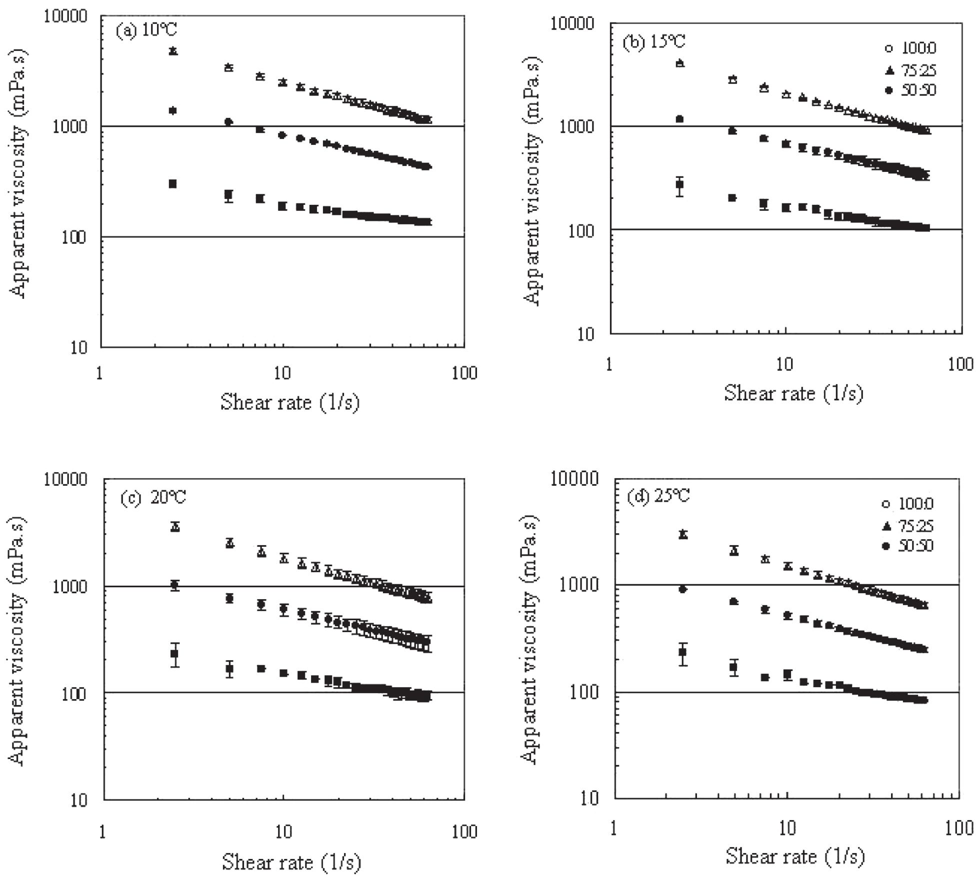

Figure 2 Apparent viscosity of batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) determined at: (a) 10°C; (b) 15°C; (c) 20°C; and (d) 25°C.

viscosity plotted against the temperature of the batters revealed that the viscosity was lowered with increasing temperature for all flour mixing ratios (Figure 3). The apparent viscosity values of the WF-based batter (mixing ratio = 100:0) decreased from 1,240 to 710 mPa.s as temperature was increased from 10 to 25°C, respectively. However, the apparent viscosity of WF-based batter containing TS with mixing ratios of 75:25 and 50:50, decreased from 460 to 260 and from 140 to 85 mPa.s, respectively.

The influence of temperature on the apparent viscosity at a specified shear rate of liquid or semi-solid foods can be calculated using the Arrhenius equation (Pongsawatmanit *et al.*, 2006) in Equations (2) and (3):

$$\eta_a = \eta_\infty \exp(\frac{E_a}{RT}) \quad (2)$$

$$\ln \eta_a = \ln \eta_\infty + (\frac{E_a}{RT}) \quad (3)$$

where η_a is the apparent viscosity at a specific shear rate, η_∞ is the frequency factor, E_a is the activation energy (J/mol), R is the gas constant (J/mol K), and T is the absolute temperature (K).

When ln η_a at a shear rate of 50 s^{-1} was plotted as a function of 1/T (Figure 4), the change in apparent viscosity for all batters containing

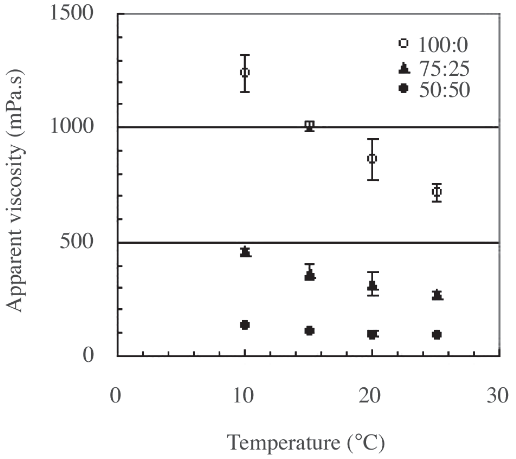

Figure 3 Temperature dependence of apparent viscosity for batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) at shear rate of 50 s^{-1}.

Table 2 Power law parameters (K = consistency coefficient, n = flow behaviour index) of the batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) determined from the shear rate ranged from 2.5 to 62.5 s^{-1} at 10, 15, 20 and 25°C.

WF:TS	Temperature (°C)	K (Pa.s^n)	n (-)	r^2
100:0	10	7.03 ± 0.19a	0.556 ± 0.009	1.000 ± 0.0003
	15	6.16 ± 0.14b	0.536 ± 0.010	0.999 ± 0.0002
	20	5.40 ± 0.58c	0.529 ± 0.009	0.999 ± 0.0003
	25	4.57 ± 0.28d	0.524 ± 0.009	0.999 ± 0.0004
75:25	10	1.94 ± 0.06e	0.633 ± 0.006	1.000 ± 0.0001
	15	1.64 ± 0.04ef	0.615 ± 0.023	1.000 ± 0.0000
	20	1.44 ± 0.11f	0.613 ± 0.022	1.000 ± 0.0001
	25	1.30 ± 0.05f	0.594 ± 0.006	0.999 ± 0.0003
50:50	10	0.347 ± 0.02g	0.761 ± 0.006	0.997 ± 0.0014
	15	0.325 ± 0.05g	0.720 ± 0.051	0.995 ± 0.0032
	20	0.281 ± 0.05g	0.729 ± 0.063	0.993 ± 0.0024
	25	0.269 ± 0.04g	0.704 ± 0.044	0.989 ± 0.0109

Mean ± standard deviation values of consistency coefficients within the same column followed by different lower case letters are significantly different ($p < 0.05$) by Duncan's multiple range test.

different mixing ratios of WF and TS followed the Arrhenius model and the linear regression coefficients (r^2) were higher than 0.95 (Table 3). The slopes of the plots were used to determine E_a from the Arrhenius equation (Equation 3), reflecting the sensitivity of the viscosity to temperature. The E_a values of the batters, with and without TS, were about 23-26 kJ/mol and were not significantly different (p>0.05, Table 3), indicating the addition of TS did not alter the thermal stability of the batter systems.

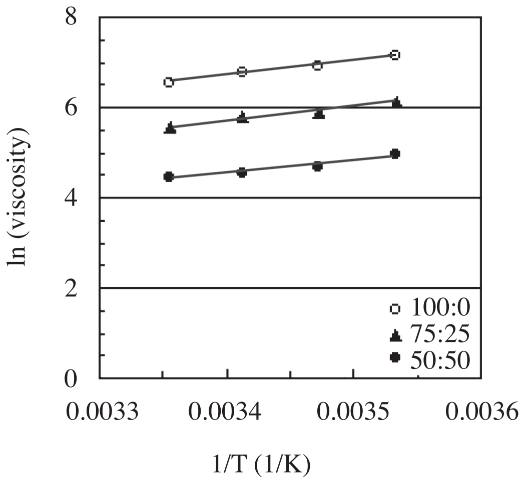

Figure 4 Arrhenius plot of apparent viscosity for batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) evaluated from selected shear rate at 50 s^{-1}.

CONCLUSION

Flow curves of all batters prepared from dry-mixes containing flour blends of WF and TS at different mixing ratios (100:0, 75:25 and 50:50) showed shear thinning behavior. The viscosity values of the batters decreased with increasing TS content as shown by steady shear measurements. The influence of temperature on the apparent viscosity of batters, with and without TS, could be described by the Arrhenius equation and the activation energy (E_a) was not significantly different. The results from these studies have provided information related to batter pickup on the surface of fried battered products that could be further applied in the food industry.

ACKNOWLEDGEMENTS

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Table 3 Activation energy of batters prepared from flour blends at different mixing ratios of WF and TS (100:0, 75:25 and 50:50) derived from the Arrhenius relationship and evaluated at shear rate of 50 s^{-1}.

Dispersions of WF: TS	Flour concentration (%)		E_a (kJ/mol)	r^2
	Wheat flour	Tapioca starch		
100:0	91.4	0.0	25.7 ± 6.05a	0.998
75:25	68.55	22.85	25.1 ± 2.50a	0.992
50:50	45.7	45.7	22.7 ± 1.01a	0.951

Mean ± standard deviation values of activation energy values within the same column followed by different lower case letters are significantly different ($p < 0.05$) by Duncan's multiple range test.

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