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Effect of corn starch–hydrocolloid interactions on the rheological properties of coating batters

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Abstract

In this study, the effect of CMC, xanthan gum, and guar gum addition on corn starch solutions and batters formulated with corn starch was determined. Steady and dynamic rheological tests were evaluated. Herschel–Bulkley model provided a good fit for the flow behavior of the solutions and batters. Flow curves showed that all batters and solutions were to be shear-thinning characteristic. A clear difference between G′ and G″ values of samples were observed. It is observed that adding hydrocolloids in batters that contain corn starch makes them more gelled or become solid regarding the increment of G′ was always greater than G″. Hydrocolloid addition showed significant changes in the apparent viscosity of solutions and batters at 25°C. Comparing the hydrocolloids, CMC had the highest apparent viscosity, followed by xanthan and guar. After 55°C, all batters showed thermo-gelling ability. At the temperature range of 70–80°C corn starch and CMC mixed batter showed the highest complex viscosity values.

Novelty impact statement: We conducted a study considering to create optimum coating dough formulations used in fried products. Rheological tests were evaluated to explore similarities/hidden patterns and there was a clear difference between G′ and G″ values of both solution and batter samples. Thermo-gelation properties of batters were influenced by the addition of hydrocolloids, especially CMC.

1 | INTRODUCTION

A batter might be described as a liquid dough that contains flour, salt, starch, gums, water, and other ingredients such as gluten, egg, seasonings, etc. (Achayuthakan & Suphantharika, 2008). It is frequently used in French fries, chicken nuggets, fried fish, and vegetables for better sensory qualities, texture, and appearance (Achayuthakan et al., 2006). Moreover, batters have a critical role in reducing fat uptake as a result of the displacement of water by oil. The main functions of the batter in fried foods are to decrease water loss throughout frying which causes fat uptake and to help browning and providing a crisp texture.

Depending on ingredients, many physical and chemical changes, especially evaporation, protein denaturation, and starch gelatinization, occur during deep-fat frying (Ahamed et al., 1997). Protein addition in batter formulation provides structure, high coating pick-up, and final yield in fried products. Higher levels of protein produce a darker color and improved crispness of the fried product which in turn increases the consumer acceptability. Higher amylose-containing starches are generally selected for batter because of their good film-forming properties (Fiszman & Salvador, 2003). Altunakaret et al. (2004) studied the influence of different starch types (corn, pregelatinized tapioca, amylomaize, waxy maize) on quality attributes of deep-fat fried chicken nuggets. They found that the addition of starch into the batters improved the crispness of the products. Soya flour and different types of starch-blends used in deep-fat fried products by (Altunakar et al., 2004). Also, these researchers observed that increasing starch content decreased the oil content of the fried product.

Modifying their microstructural and functional properties, batters can be more effective on the oil uptake of fried foods. The influence of enzymatic modification on starch as an efficient oil delivery system

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for bake-only chicken nuggets was investigated (Ferrero et al., 1994). They proposed that enzyme-modified starches may deliver a sufficient amount of oil to create sensory qualities. In another work of these authors, they studied the utilization of oxidized starch in bake-only chicken nuggets (Fiszman & Salvador, 2003). Gelatinization temperature of starches was not affected by oxidation but the pasting viscosity of corn and rice starches increased, while both tapioca and potato starch decreased. Funami et al. (2005) treated frying batters with two different enzymes, which were viscozyme (cell wall degrading) and transglutaminase (cross-linking). The effect of the enzyme on rheological characteristics of batters and oil uptake of batter-coated fried foods were determined. Apparent viscosity and elastic properties of batters increased with transglutaminase treatment. In addition, reduction of oil uptake, greater batter pickup, and moisture retention of the fried samples were observed. Cross-linking of wheat starches with different degrees and its effects on the crust properties of deep-fried battered food and starch gelatinization in the batter were determined by (Gamonpilas et al., 2013). The batter picks up and viscosity was affected by the degree of starch cross-linking. By modifying matrix properties, cross-linked wheat starch improved crust crispness of deep-fried battered food. Achayuthakan et al. (2006) investigated the performance of cross-linked tapioca starches in wheat-based batter and with different breading formulations. The substitution of 20% (wt/wt) cross-linked starches for wheat flour in the batter formulation remarkably decreased the water-holding capacity (WRC) and consistency index of the batters. Additionally, cross-linked starch represents remarkably lower oil content with at least 17% relative oil reduction in deep-fried breaded chicken strips.

Recently, numerous studies focused on the characteristics of starch gels modified with hydrocolloids. Compared with starch or hydrocolloid alone sample, starch-hydrocolloid interactions have indicated a synergistic effect that resulting in a viscosity increase. The influences of xanthan and guar gums on rheological and pasting characteristics of waxy corn starch were studied by (Heyman et al., 2014). Viscosity and pasting temperature of the waxy corn starch dispersion throughout pasting increased as xanthan or guar gums concentration increased. Jeon et al. (2013) studied the effects of the microwave-assisted dry heating on pasting, morphological, and structural characteristics of waxy and normal corn starch impregnated with xanthan gum. Pasting viscosity, morphological properties, gelatinization, crystalline structure, and syneresis of starches were significantly affected by microwave-assisted dry heating treatment. Rheological, textural, and sensory properties of corn, oat, and potato starches blended with xanthan gum as a thickener in dessert strawberry sauces were investigated by (Long et al., 2012). They reported that the xanthan gum–starch combinations were appropriate thickeners for dessert strawberry sauces. Pasting behavior of xanthan gum, guar gum, and waxy maize starch blends in mild temperature were determined by (Primo-Martín, 2012). Gums did not create important differences in granule swelling but xanthan gum reduced the shear-induced breakdown of the granules, while no difference was observed for guar gum. Long particle size distributions were determined between xanthan and guar gum systems, large differences in pasting profiles were observed. The aim of this study is to create optimum coating dough formulations used in fried products. In the literature, the studies about the coating dough are mostly on raw material diversifications. Studies mostly focus on the effects of different flour, starch or hydrocolloid usage on the sensory, textural, and rheological properties of coated products. There are very limited studies on the interactions of the raw materials in coating formulations. With this study, it is planned to fill these gaps in the literature.

TABLE 1 Batter formulations with different hydrocolloids

Ingredients	Weight (g)
Wheat flour	20
Corn starch	2
Hydrocolloids	
CMC	
Guar	0.5
Xanthan	
Leavening	0.1
Salt	1.5

2 | MATERIALS AND METHODS

Batter formulations consisted of wheat flour, corn starch, hydrocolloids, leavening, and salt as shown in Table 1.

Wheat flour and leavening were purchased from a local market (Ülker, Turkey). Hydrocolloids (CMC, guar, and xanthan) were supplied by Sigma Aldrich (Taufkirchen, Germany), corn starch was purchased from Ay Starch (Mardin, Turkey). According to manufacturer, ash, moisture, and protein contents of corn starch were 0.3% (wt/wt), 11%–13% (wt/wt), 0.4% (wt/wt), respectively. Batters were prepared by mixing pre-blended powders and cold water. The dry mix/water ratio was 1/1.5 during the analysis and mixture was stirred with ULTRA-TURRAX (IKA-T25, IKA-Werke GmbH & Co. KG, Staufen, Germany) at 5,000 rpm for 1 min to ensure uniform mixing. Batter samples were then placed at 25 ± 1°C for 60 min before further analysis.

The blends of corn starch (4% wt/vol)–hydrocolloid (0.2% wt/vol) solution was prepared. Weighted samples were dissolved in cold water and the temperature of the solution was increased to 90°C, rapidly. The solution was kept at 90°C at a safety control hot plate (IKA-RCT basic IKAMAG, IKA-Werke GmbH & Co. KG, Staufen, Germany) for 5 min and cooled to 25°C. After waiting 24 hr for complete hydration, rheological measurements were conducted. Rheological analyses of the samples were performed with a strain/stress-controlled rheometer (Thermo-Haake MARS III, Karlsruhe, Germany) which had a Peltier heating system. A plate-plate configuration (cone diameter 35 mm) was used for the shearing of samples. The apparent viscosity of solutions was recorded in the range of 1–100 s^{-1} shear rate at room temperature. A total of 24 data points was obtained at 10 s intervals (Cengiz et al., 2016). Each measurement was replicated with two repetitions.

Due to the highest regression value (Purcell et al., 2014) Herschel–Bulkley model was used for the calculations as following:

TABLE 2 Rheological parameters of corn starch-hydrocolloid solutions and batters including corn starch–hydrocolloid combinations using Herschel–Bulkley model

	Solution			Batter		
	Consistency Index K (Pa s^n)	Flow Behavior Index n	Regression Coefficient R^2	Consistency Index K (Pa s^n)	Flow Behavior Index n	Regression Coefficient R^2
CS	3.55[c]	0.3775[a]	0.995	4.47[c]	0.6095[a]	0.999
CS + CMC	6.29[c]	0.4228[a]	0.998	34.40[c]	0.6196[a]	0.999
CS + G	11.90[b]	0.2258[b]	0.999	167.83[a]	0.2441[b]	0.999
CS + X	24.5[a]	0.1257[b]	0.986	122.07[b]	0.2975[b]	0.996

**CS: Corn Starch; CS + CMC: Corn Starch + CMC; CS + G: Corn Starch + Guar; CS + X: Corn Starch + Xanthan.
[+]Small letters show the statically differences in the same column ($p < .05$).

$$\tau = \tau_0 + K\gamma^{-n} \quad (1)$$

where τ is the shear stress (Pa); τ_0 is the yield stress (Pa); K is the consistency index (Pa s^n) and n is the flow index ($n < 1$ for a shear-thinning fluid and $n = 1$ for a Newtonian fluid).

A strain/stress-controlled rheometer (Thermo-HAAKE, Rheostress 1, Germany) with a temperature-control unit (Thermo-HAAKE, Karlsruhe K15 Germany) was used for the determination of the dynamic shear rheological characteristics of the sample solutions. The measurements were conducted with a plate-plate configuration which had a gap of 0.500 mm and a plate diameter of 35 mm at a constant temperature of 25 ± 1°C. The sample solutions were placed between the two plates and the measurement was initiated immediately.

Prior to initiate the frequency sweep tests, the stress sweep test was conducted to determine the linear viscoelastic region (LVR) of prepared gelatin solution (5%). Thereafter, the frequency sweep test was carried out for all gelatin solutions with a dynamic oscillatory shear rheometer. The frequency range of 0.1–10 Hz at a constant shear stress (0.2 Pa) was used for dynamic shear measurements in the LVR and constant temperature (25°C). Dynamic shear values determined at the frequency values ranging between 0.1 and 10 Hz in order to interpret the dynamic mechanical spectra of the solutions.

The following equations used for the calculation of the dynamic mechanical spectra parameters of G′ (storage or elastic modulus) and G″ (loss or viscous modulus):

$$G' = G \times \cos\delta \quad (2)$$

$$G'' = G \times \sin\delta \quad (3)$$

Loss tangent (tan δ), which is a dimensionless number that is a clear indication of whether the material behavior is liquid or solid, is calculated with the following equation (Sikora et al., 2007).

$$\tan\delta = G''/G' \quad (4)$$

Temperature sweep tests included heating at 1°C/min from 15°C to 80°C at a constant frequency of 1 Hz. After placing the samples at the rheometer plates, samples were covered with silicone oil to inhibit the water loss.

Statistical analysis was conducted with the Statistical Analysis System (SAS) Software. One-way analysis of variance (ANOVA) was performed using the general linear model procedure. Duncan multiple range test was utilized to observe the differences among mean values with the significance level of 0.05.

3 | RESULT AND DISCUSSION

Rheological parameters of corn starch–hydrocolloid solutions and batters are shown in Table 2. The obtained data were well fitted to the Herschel–Bulkley model with high determination coefficients (R^2 = 0.986–0.999). As the flow behavior index values of samples were lower than 1, all hydrocolloid–corn starch solutions and batters into which they were added had shear thinning behavior. Except the CS + CMC solutions, the addition of hydrocolloids in corn starch solutions decreases all samples (solution and batters) flow behavior index, which means mixtures become more pseudoplastic. This result proved the viscosity increase of the solution continuing the addition of hydrocolloids with a high determination coefficient. The consistency coefficient (K) values obtained from Herschel–Bulkley model increased with hydrocolloid adding to the solutions and batters. Shear stress and apparent viscosity changes in solutions are shown in Figure 1 as a function of shear rate (1/s). At a constant temperature (25°C), all samples showed shear thinning behavior, decreasing apparent viscosity with increasing shear rate. Compared to the apparent viscosity value of CS solutions at 50 s^{-1} (0.2495 Pa s), CMC, guar, and xanthan addition dramatically changed the apparent viscosities of corn starch solutions ($p < .05$). With a 44.54 Pa s, CS + CMC solution had the highest apparent viscosity value which was followed by CS + X (37.84 Pa s) and CS + G (27.94 Pa s) solutions. Ferrero et al. (1994) studied the xanthan gum–corn starch interaction and its influence on the rheological behavior and the storage stability of the frozen gelatinized suspension. In their study, it stated that the xanthan gum addition affected rheological properties, amylose retrogradation, and syneresis. These results might be attributed to the hydrocolloid's role as a suspension stabilizer and its ability to prevent phase separation. Similar results related to guar and xanthan gums

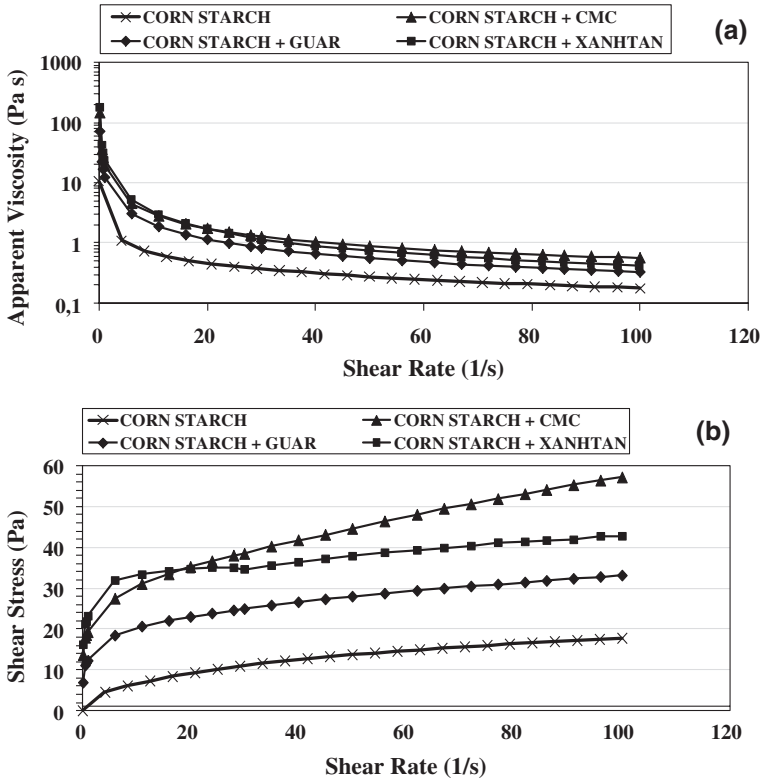

FIGURE 1 Flow curves of corn starch–hydrocolloid mixed solutions

(0.35%–1.0% wt/wt) on rheological and pasting characteristics of waxy corn starch (6.0% wt/wt) were reported by Heyman et al. (2014). They found that xanthan gum–waxy corn starch blend pastes showed slightly better viscoelastic properties to the guar gum–corn starch pastes. Similarly, the addition of xanthan gum to waxy corn starch solution increased intrinsic viscosity and decreased overlap concentration by the research of Wang et al. (2001). The gums can affect the adhesive properties of starches in a number of ways. Some of these phenomena may be directly caused by the increased viscosity of the continuous phase, for example by slowing the heat transfer or changing the turbulence within the cell during adhesion. Sikora et al. (2007) studied the xanthan gum–starch (corn, oat, and potato) combinations and their effect on textural, rheological, and sensory characteristics of strawberry sauces. Similar to the results of our study, flow curves of strawberry sauces were fitted to the Herschel–Bulkley model and all sauces showed pseudoplastic, shear-thinning characteristic. Also Achayuthakan et al. (2006) reported that xanthan gum had a synergistic impact on the yield stress of waxy maize and cold water swelling (CWS) starch dispersions. The increase in xanthan concentration resulted in an increase in the yield stress of waxy maize starch dispersions. Controlling the rheological behavior of corn starch through the addition of guar gum with a different molecular weight was studied by Funami et al. (2005). As a texture modifier for starch-based food products, guar gum increased the viscosity of starch–guar gum mixed solutions with interacting amylopectin which becomes stronger as the molecular weight of guar increases. They reported that interactions between guar and amylose could be responsible for the onset of viscosity increase during heating, whereas the interactions between guar and amylopectin for an increase in the peak viscosity. Furthermore, the addition of gum to the formulations had an increasing effect on the consistency coefficient values of both batters and the solutions. This result may stem from the interactions between starch exudates (amylose) and gums that is explained by the physical properties of the gum starch granules, physical properties such as size, shape, and granule integrity, as well as the amount of exudate from starch granules (Cengiz et al., 2016). Effect of temperature on apparent viscosity, storage modules, and loss modules of hydrocolloid added corn starch solutions is shown in Figure 2. CS solution's complex viscosity was the lowest value (with 0.7363 Pa s at 18°C) when compared with CMC, guar, and xanthan adding solutions. The complex viscosity of solutions that contained CMC, guar, and xanthan were estimated 1.1055 Pa s, 2.6808 Pa s, and 9.8815 Pa s, at 18°C, respectively. As shown in Figure 2, all samples' complex viscosities increased after temperatures of approximately 45°C. When compared with CS and CS + G solution, CS + CMC, and CS + X solutions showed more thermo-gelling ability due to higher viscosities after 60°C. At the highest measured temperature, 80°C, xanthan gum showed highest apparent viscosity with 21,970 Pa s whereas the CS solution was 1,191 Pa s. The patterns of behavior upon heating were found very similar for all solutions. For all samples, G′ and G″ showed a remarkable increase after the temperature of 45–50°C. At the end of the temperature sweep (T = 80°C), similar G′ values were found at CS + CMC and CS + X solutions. Rosell et al. (2011) studied pasting, viscoelastic and swelling properties of three different hydrocolloids (hydroxypropyl methylcellulose, xanthan gum, and guar gum)–rice starch blends. Effects of cooling–heating cycles on viscoelasticity, swelling, and pasting were also determined. They reported that during the heating–cooling cycle, xanthan and guar gums encouraged an

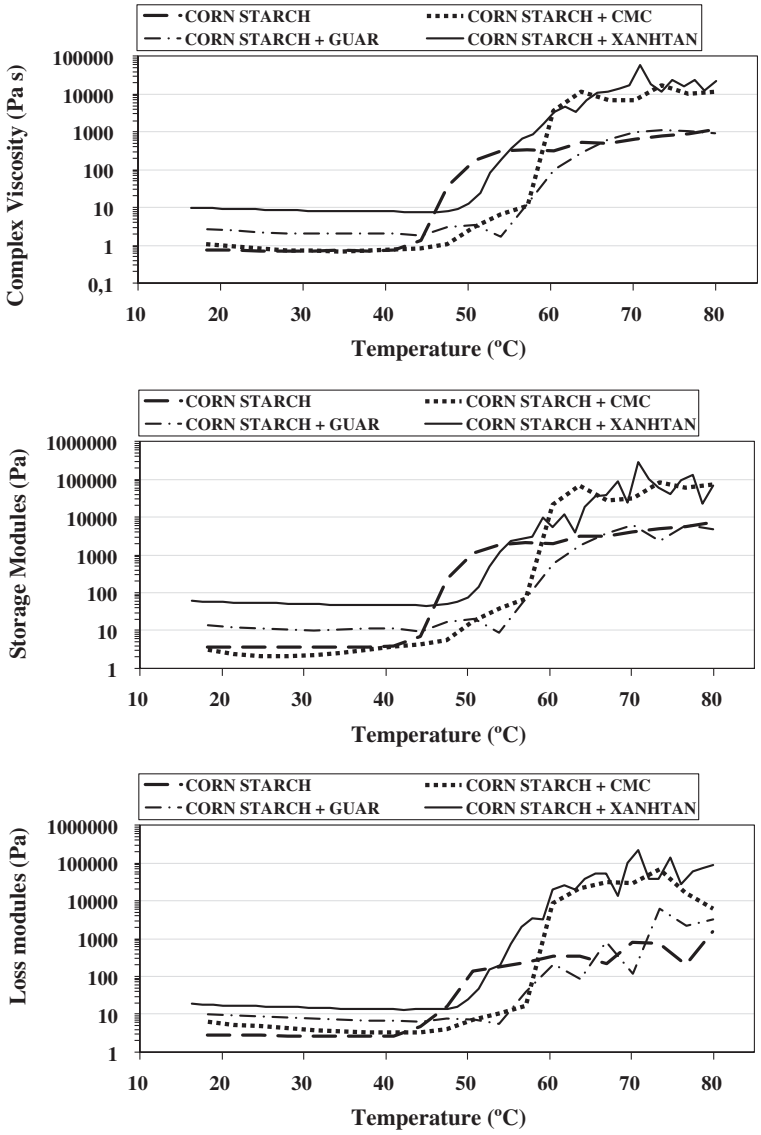

FIGURE 2 Effect of temperature on complex viscosity, storage modules, and loss modulus of hydrocolloid added corn starch solutions

		G′	G″	η^*	G*	tan (δ)
Solution	CS	4.517^{b}	2.411^{c}	0.815^{b}	5.126^{b}	0.544^{a}
	CS + CMC	53.363^{a}	12.575^{a}	8.726^{a}	54.828^{a}	0.236^{b}
	CS + G	65.780^{a}	13.805^{a}	10.713 ^{a}	67.300^{a}	0.234 ^{b}
	CS + X	58.908^{a}	9.768^{b}	9.504 ^{a}	59.710^{a}	0.167 ^{b}
Batter	CS	128.595^{d}	49.592 ^{c}	21.942^{d}	137.875^{d}	0.381 ^{c}
	CS + CMC	379.733^{c}	193.600^{b}	67.863^{c}	426.433^{c}	0.523^{b}
	CS + G	581.100^{b}	354.350^{a}	109.155^{b}	685.875^{b}	0.605^{a}
	CS + X	1,162.670^{a}	323.567^{a}	192.067^{a}	1,206.670^{a}	0.278^{d}

TABLE 3 Dynamic mechanical spectra values of corn starch–hydrocolloid solutions and batters including corn starch–hydrocolloid combinations

**CS: Corn Starch; CS + CMC: Corn Starch + CMC; CS + G: Corn Starch + Guar; CS + X: Corn Starch + Xanthan, G′: Storage Modulus, G″: Loss Modulus, η*: Complex Viscosity, G*: Complex Modulus tan (δ): Phase Angle.

$^{+}$Small letters show the statically differences in the same column ($p < .05$).

increase of the rice starch viscosity which changed depending on hydrocolloid concentrations. In addition, when compared with starch alone solution, viscosity increase began much earlier than guar or xanthan–rice starch mixture. In the previous study, it was stated that the interaction between hydrocolloids and amylose leaking out of the granules below the gelatinization temperature increases the viscosity

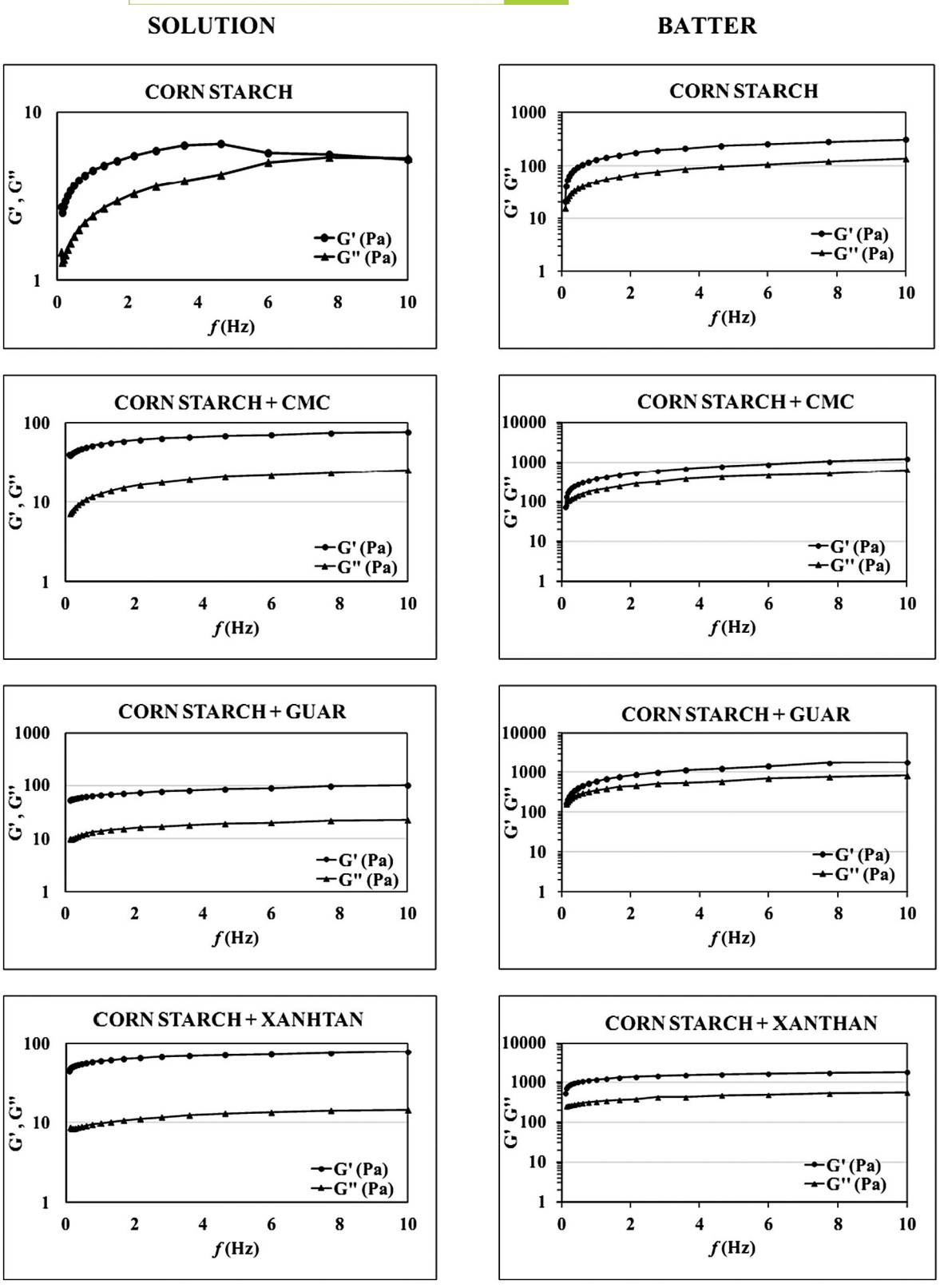

FIGURE 3 Dynamic rheological properties of corn starch–hydrocolloid mixed solutions and corn starch–hydrocolloid added batters

with the susceptibility to hydrocolloid to the surface or periphery of the granule (Shi & BeMiller, 2002). Because of its anionic character, xanthan gum modifies the starch gelatinization by retarding amylose leaching and stabilizing the integrity of starch granule (Shi & BeMiller, 2002). In another work, cassia gum–starch interactions were performed by measuring pasting and dynamic rheological properties and evaluating structural characteristics by microscopy (Kaur et al., 2008). They reported that starch type, concentrations of

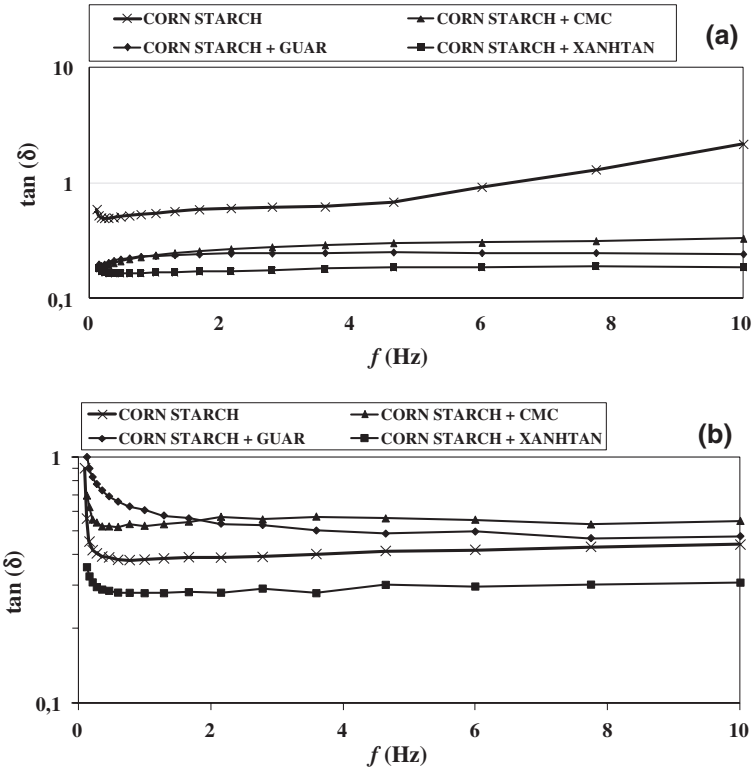

FIGURE 4 Plot of loss tangents (tan δ) of hydrocolloid and corn starch added solutions (a) and batters (b)

amylose, and granule size are the significant factors, affecting cassia gum–starch interactions and its functional behavior. When different starches (high amylose; waxy; normal; potato starch; waxy corn starch; cross-linked)-cassia gum mixtures with a different concentration compared, normal and high amylose corn starch showed the highest final viscosity increment. The influence of the addition of guar gum and xanthan gum on pasting characteristics of cationic tapioca starch was investigated by (Chaisawang & Suphantharika, 2005). Xanthan gum addition resulted in prominent increases in pasting temperatures and setback viscosity of cationic tapioca starch; however, guar gum addition showed no effect. Xanthan addition effect on the pasting and gelatinization behavior of tapioca starch were studied by conventional rheometers and Rapid Visco Analyzer (RVA) with the heating–cooling cycle (Chantaro et al., 2013). After 62–63°C, the tapioca starch–xanthan dispersions viscosity increased due to the gelatinization of tapioca starch. In conclusion, they claimed that the addition of xanthan to tapioca starch solution increased the gelatinization temperature, breakdown, peak, and final viscosity; however, decreased setback values. Dynamic mechanical spectra values (G′, G″, G*, tan (δ), and η*) of corn starch–hydrocolloid solutions and batters including corn starch–hydrocolloid combinations (in 1 Hz) are shown in Table 3. As can easily be seen in Table 3, the addition of hydrocolloids (CMC, guar, and xanthan) always increased storage modules (G′). With a 65.780 Pa, G′ of guar + corn starch solution is the highest value whereas the lowest value is corn starch solution with 4.517 Pa, G′. Storage modules of the other hydrocolloids, xanthan and CMC were found 58.905 Pa and 53.363 Pa, respectively. According to previous investigations, guar gum addition should accelerate the gelation of starch, more specifically the amylose fraction (Miles et al., 1985; Orford et al., 1987). During gelatinization, guar and amylose interactions could occur and contribute to the increase in G′ (Christianson et al., 1981; Funami et al., 2005; Shi & BeMiller, 2002). As can be seen in Table 3, the addition of hydrocolloids in the corn starch solutions and batters which contain corn starch causes important changes in G′ and G″ besides the type of hydrocolloid is not important for solutions storage modulus. A clear difference between G′ and G″ is seen in Figure 3 and it can be simply verified as tan (δ) < 1 (the increase in G′ value was greater than that of G′′) which means liquid sample either gelled or became solid. A significant decrement in tan (δ) was observed in hydrocolloid added solutions when compared with the control corn starch solution (Figure 4a). Type of hydrocolloid was not important both for phase angle and storage modulus, statistically (Table 3). The lowest tan (δ) value was recorded in corn starch + xanthan gum blend for solutions and in corn starch alone samples for the batters. From the rheological point of view, the decrease in tan (δ) corresponded to a stronger three-dimensional network that was constructed by the amylose and gum–amylose system (Hsu et al., 2000). This corresponded to a sol-gel transition, for instance, 3-dimensional gel network was formed from amylose reinforced by strong interaction between swollen starch particles.

Figure 5 illustrates steady shear rheological properties of corn starch–hydrocolloid added batters. As shown in the figure, adding hydrocolloid in batter formulations, even in very low concentrations, effects batter apparent viscosity remarkably ($p < .05$). It is evident that the presence of hydrocolloids resulted in a significant increase in apparent viscosity and shear stress of batters and as shear rate increased through the range 1–100 s^{-1}, apparent viscosity of all batters decreased. So, all batter that well fitted the Herschel–Bulkley

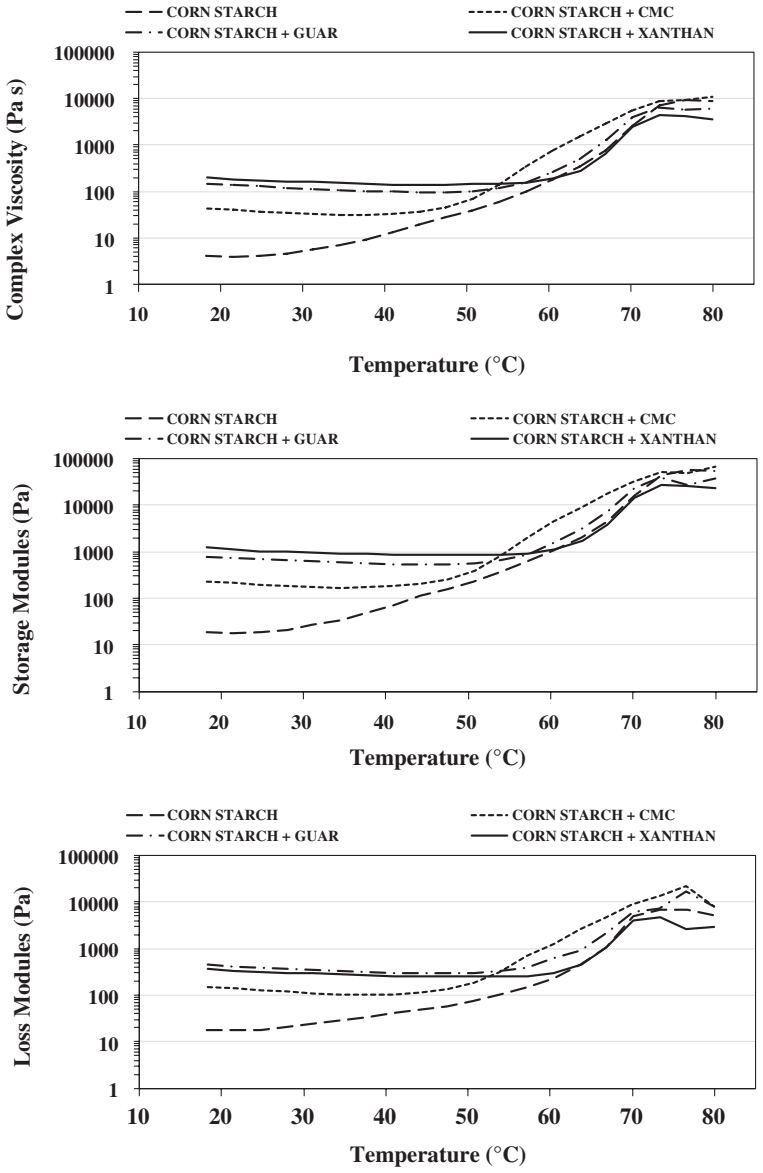

FIGURE 6 Effect of temperature on complex viscosity, storage modules, and loss modulus of hydrocolloid and corn starch added batters

model (R^2 > 0.996) had shear thinning behavior. It can also be assumed from the flow behavior index (*n*) values of batters all of which were less than 1.0. Consistency index of corn starch added batters was determined to be 4.47 Pa s^n, it reached 34.40, 167.83, and 122.07 Pa s^n for CMC, guar, and xanthan, respectively. The study of the effect of a number of commercial-grade constituents (methylcellulose, corn starch, wheat starch, dried egg, gluten, etc.) on the viscous and dynamic viscoelastic behavior of a batter was investigated by Sanz et al. (2005). They also reported that all batters showed shear thinning behavior and both dried egg and gluten were more noticeable among the ingredients. As shown in Figure 3 (right column), storage moduli of all batter samples were higher than loss moduli. Tan (δ) values of batters were determined below 1 (tan (δ) < 1) which means more solid-like behavior was predominant in the coating batter systems. Highest complex viscosity determined 192.067 Pa s in corn starch + xanthan including batter sample. This was followed by CS + G and CS + CMC, 109.155 Pa s and 67.563 Pa s, respectively. However, it was interesting to note that type of hydrocolloid was unimportant on complex viscosities of solutions, even though there were substantially statistical differences on complex viscosities of batter systems. It can be explained by batter ingredients and their complicated interactions. Watanabe et al. (2002) found that dough with a higher starch content had less resistance to strain and dough with a lower starch content had a rubber-like structure. Similarly Chen et al. (2008) reported that the solidification of batter with protein enrichment and addition of hydrocolloid (HPMC) resulted in consistency increases and flowability abatement. Figure 6 illustrates the influence of temperature on complex viscosity, storage modules, and loss modules of batter systems. It is clearly observed that after 55°C, all batters showed thermo-gelling ability which is very critical about oil absorption during deep-fat frying (Varela & Fiszman, 2011). Control batter in which only corn starch added showed the lowest complex viscosity, storage modules, and loss modules at lower temperatures (approximately 15–55°C). Although CS + CMC added

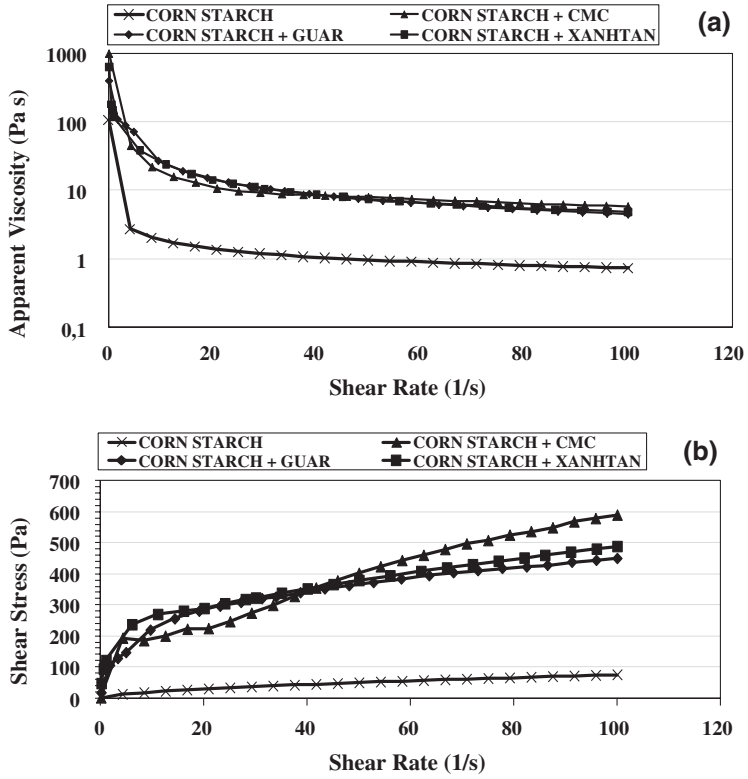

FIGURE 5 Flow curves of corn starch–hydrocolloid added batter solutions. Apparent viscosity as a function of shear rate (a); Shear stress as a function of shear rate (b)

batter showed lowest storage and loss modules among hydrocolloid added batters, interestingly, it showed the highest after 55°C. The presence of wheat protein and starch and their interactions with hydrocolloids, especially CMC, affected, indeed, batter viscosities and thermal characteristics (Chen et al., 2009). The mechanisms of starch gelatinization (Gamonpilas et al., 2013), protein denaturation (Jeon et al., 2013), presence of salt (Salvador et al., 2003) and hydrocolloid–starch interaction (C Primo-Martín et al., 2010; Sanz et al., 2005) could be responsible for thermal-gelation characteristics of batter formulations. At the temperature range of 70–80°C, CS + CMC mixed batter showed the highest complex viscosity which was 10,985 Pa s, at 80°C. When compared with the others, although the starting complex viscosity is very high, CS + X contained batter did not maintain this performance against the temperature rise.

4 | CONCLUSION

The rheological influence of CMC, xanthan, and guar gum addition on corn starch solutions and batters formulated with corn starch were evaluated. Steady and dynamic shear rheological parameters exhibited that adding hydrocolloids affected the viscosities of solutions and batters significantly. Corn starch + guar solution was found to provide the highest complex viscosity among the solutions, while corn starch + xanthan blend is the highest in batter systems. A clear difference between G′ and G″ values of both solution and batter samples was observed. The increment of G′ was always higher than G′′ and liquid samples either gelled or became solid. Also, thermo-gelation properties of batters were influenced by the addition of hydrocolloids, especially CMC. On the whole, with the usage of corn starch–hydrocolloid interactions, more rheological characteristics can be brought in batters and functional properties of batters can be improved.

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CONFLICTS OF INTEREST

The authors have declared no conflicts of interest for this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, Mahmut Doğan, upon reasonable request.

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REFERENCES

Achayuthakan, P., & Suphantharika, M. (2008). Pasting and rheological properties of waxy corn starch as affected by guar gum and xanthan gum. *Carbohydrate Polymers*, *71*(1), 9–17. https://doi.org/10.1016/j.carbpol.2007.05.006

Achayuthakan, P., Suphantharika, M., & Rao, M. A. (2006). Yield stress components of waxy corn starch–xanthan mixtures: Effect of xanthan concentration and different starches. *Carbohydrate Polymers*, *65*(4), 469–478. https://doi.org/10.1016/j.carbpol.2006.02.007

Ahamed, N. T., Singhal, R. S., Kulkarni, P. R., & Pal, M. (1997). Deep fat-fried snacks from blends of soya flour and corn, amaranth and chenopodium starches. *Food Chemistry*, *58*(4), 313–317. https://doi.org/10.1016/S0308-8146(96)00160-4

Altunakar, B., Sahin, S., & Sumnu, G. (2004). Functionality of batters containing different starch types for deep-fat frying of chicken nuggets. *European Food Research and Technology*, *218*(4), 318–322. https://doi.org/10.1007/s00217-003-0854-5

Cengiz, E., Karaman, S., & Dogan, M. (2016). Rheological characterization of binary combination of gleditsia triacanthos gum and tapioca starch. *International Journal of Food Properties*, *19*(6), 1391–1400. https://doi.org/10.1080/10942912.2015.1063067

Chaisawang, M., & Suphantharika, M. (2005). Effects of guar gum and xanthan gum additions on physical and rheological properties of cationic tapioca starch. *Carbohydrate Polymers*, *61*(3), 288–295. https://doi.org/10.1016/j.carbpol.2005.04.002

Chantaro, P., Pongsawatmanit, R., & Nishinari, K. (2013). Effect of heating–cooling on rheological properties of tapioca starch paste with and without xanthan gum. *Food Hydrocolloids*, *31*(2), 183–194. https://doi.org/10.1016/j.foodhyd.2012.10.026

Chen, H.-H., Kang, H.-Y., & Chen, S.-D. (2008). The effects of ingredients and water content on the rheological properties of batters and physical properties of crusts in fried foods. *Journal of Food Engineering*, *88*(1), 45–54. https://doi.org/10.1016/j.jfoodeng.2008.01.017

Chen, S.-D., Chen, H.-H., Chao, Y.-C., & Lin, R.-S. (2009). Effect of batter formula on qualities of deep-fat and microwave fried fish nuggets. *Journal of Food Engineering*, *95*(2), 359–364. https://doi.org/10.1016/j.jfoodeng.2009.05.016

Christianson, D., Hodge, J., Osborne, D., & Detroy, R. (1981). Gelatinization of wheat starch as modified by xanthan gum, guar gum, and cellulose gum. *Cereal Chemistry*, *58*, 513.

Ferrero, C., Martino, M. N., & Zaritzky, N. E. (1994). Corn starch-xanthan gum interaction and its effect on the stability during storage of frozen gelatinized suspension. *Starch - Stärke*, *46*(8), 300–308. https://doi.org/10.1002/star.19940460805

Fiszman, S. M., & Salvador, A. (2003). Recent developments in coating batters. *Trends in Food Science & Technology*, *14*(10), 399–407. https://doi.org/10.1016/S0924-2244(03)00153-5

Funami, T., Kataoka, Y., Omoto, T., Goto, Y., Asai, I., & Nishinari, K. (2005). Food hydrocolloids control the gelatinization and retrogradation behavior of starch. 2a. Functions of guar gums with different molecular weights on the gelatinization behavior of corn starch. *Food Hydrocolloids*, *19*(1), 15–24. https://doi.org/10.1016/j.foodhyd.2004.04.008

Gamonpilas, C., Pongjaruvat, W., Methacanon, P., Seetapan, N., Fuongfuchat, A., & Klaikherd, A. (2013). Effects of cross-linked tapioca starches on batter viscosity and oil absorption in deep-fried breaded chicken strips. *Journal of Food Engineering*, *114*(2), 262–268. https://doi.org/10.1016/j.jfoodeng.2012.08.008

Heyman, B., De Vos, W. H., Depypere, F., Van der Meeren, P., & Dewettinck, K. (2014). Guar and xanthan gum differentially affect shear induced breakdown of native waxy maize starch. *Food Hydrocolloids*, *35*, 546–556. https://doi.org/10.1016/j.foodhyd.2013.07.011

Hsu, S., Lu, S., & Huang, C. (2000). Viscoelastic changes of rice starch suspensions during gelatinization. *Journal of Food Science*, *65*(2), 215–220. https://doi.org/10.1111/j.1365-2621.2000.tb15982.x

Jeon, S., Lim, J., Inglett, G. E., & Lee, S. (2013). Effect of enzymatic treatments on the rheological and oil-resisting properties of wheat flour-based frying batters. *Journal of Food Engineering*, *115*(2), 215–219. https://doi.org/10.1016/j.jfoodeng.2012.10.015

Kaur, L., Singh, J., Singh, H., & McCarthy, O. J. (2008). Starch–cassia gum interactions: A microstructure – Rheology study. *Food Chemistry*, *111*(1), 1–10. https://doi.org/10.1016/j.foodchem.2008.03.027

Long, Z., Zhao, M., Zhao, Q., Yang, B., & Liu, L. (2012). Effect of homogenisation and storage time on surface and rheology properties of whipping cream. *Food Chemistry*, *131*(3), 748–753. https://doi.org/10.1016/j.foodchem.2011.09.028

Miles, M. J., Morris, V. J., & Ring, S. G. (1985). Gelation of amylose. *Carbohydrate Research*, *135*(2), 257–269. https://doi.org/10.1016/S0008-6215(00)90777-8

Orford, P. D., Ring, S. G., Carroll, V., Miles, M. J., & Morris, V. J. (1987). The effect of concentration and botanical source on the gelation and retrogradation of starch. *Journal of the Science of Food and Agriculture*, *39*(2), 169–177. https://doi.org/10.1002/jsfa.2740390210

Primo-Martín, C. (2012). Cross-linking of wheat starch improves the crispness of deep-fried battered food. *Food Hydrocolloids*, *28*(1), 53–58. https://doi.org/10.1016/j.foodhyd.2011.12.002

Primo-Martín, C., Sanz, T., Steringa, D., Salvador, A., Fiszman, S., & Van Vliet, T. (2010). Performance of cellulose derivatives in deep-fried battered snacks: Oil barrier and crispy properties. *Food Hydrocolloids*, *24*(8), 702–708. https://doi.org/10.1016/j.foodhyd.2010.04.013

Purcell, S., Wang, Y.-J., & Seo, H.-S. (2014). Application of oxidized starch in bake-only chicken nuggets. *Journal of Food Science*, *79*(5), C810–C815. https://doi.org/10.1111/1750-3841.12466

Rosell, C. M., Yokoyama, W., & Shoemaker, C. (2011). Rheology of different hydrocolloids–rice starch blends. Effect of successive heating–cooling cycles. *Carbohydrate Polymers*, *84*(1), 373–382. https://doi.org/10.1016/j.carbpol.2010.11.047

Salvador, A., Sanz, T., & Fiszman, S. (2003). Rheological properties of batters for coating products-effect of addition of corn flour and salt. *Food Science and Technology International*, *9*(1), 23–27. https://doi.org/10.1177/1082013203009001004

Sanz, T., Salvador, A., Vélez, G., Munoz, J., & Fiszman, S. (2005). Influence of ingredients on the thermo-rheological behaviour of batters containing methylcellulose. *Food Hydrocolloids*, *19*(5), 869–877. https://doi.org/10.1016/j.foodhyd.2004.11.003

Shi, X., & BeMiller, J. N. (2002). Effects of food gums on viscosities of starch suspensions during pasting. *Carbohydrate Polymers*, *50*(1), 7–18. https://doi.org/10.1016/S0144-8617(01)00369-1

Sikora, M., Kowalski, S., Tomasik, P., & Sady, M. (2007). Rheological and sensory properties of dessert sauces thickened by starch–xanthan gum combinations. *Journal of Food Engineering*, *79*(4), 1144–1151. https://doi.org/10.1016/j.jfoodeng.2006.04.003

Varela, P., & Fiszman, S. M. (2011). Hydrocolloids in fried foods. *A Review. Food Hydrocolloids*, *25*(8), 1801–1812. https://doi.org/10.1016/j.foodhyd.2011.01.016

Wang, F., Sun, Z., & Wang, Y. J. (2001). Study of xanthan gum/waxy corn starch interaction in solution by viscometry. *Food Hydrocolloids*, *15*(4–6), 575–581. https://doi.org/10.1016/S0268-005X(01)00065-0

Watanabe, A., Larsson, H., & Eliasson, A.-C. (2002). Effect of physical state of nonpolar lipids on rheology and microstructure of gluten-starch and wheat flour doughs. *Cereal Chemistry Journal*, *79*(2), 203–209. https://doi.org/10.1094/CCHEM.2002.79.2.203

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