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Wheat flour and gum cordia composite system: pasting, rheology and texture studies

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Abstract

Native and acetylated freeze-dried gum cordia (GC) was replaced at 0, 3, 5 and 10% (w/w) of wheat flour, and their pasting and rheological properties were studied. The pasting data indicated a significant ($p \leq 0.05$) increase in peak and final viscosities of blends: especially at higher GC concentrations. The shearing profiles signified an increase in shear stress as a function of shear rate confirming a pseudoplastic behavior of the blends ($n<1$). The consistency coefficient (K) and flow behavior index (n) were estimated using a power law model where higher 'K' values strengthened the pasting data. The activation energies (Ea) calculated by Arrhenius equation were observed between 5.7-7.5 and 5.9-8.4 kJ/mol for native and acetylated gels, respectively. The highest hardness was observed for 10% acetylated GC gel while the same concentration of native GC depicted opposite trend.

Keywords: gum cordia; gel texture; paste viscosity; wheat flour.

Practical Application: A novel gum is tested for quality improvement of wheat-based food products by manipulating rheology.

1 Introduction

Starch is a major component of wheat flour (70-80%) which plays a pivotal role in modifying the texture of flour-based food products. Starch functionality is contingent on its gelatinization, pasting, and retrogradation properties that are considered the basic processes in the preparation of starch-based formulations. Starch gelatinization is an irreversible process signified by granule swelling upon heating in water, leaching of amylose, granules disruption and rise in viscosity (Biliaderis, 2009). In contrast, retrogradation is regarded as a time-dependent recrystallization of amylose and amylopectin that ultimately leads to staling or firmness of starchy foods. Use of non-starch polysaccharides in starchy foods has become a subject of immense importance. These non-starch polysaccharides (hydrocolloids) play a significant role in manipulating starch based food properties: rheology and textural properties. They interfere with starch pasting properties by modifying gelatinization and retrogradation parameters, improving moisture retention and stabilizing end product quality. In addition, variously modified hydrocolloids – physically or chemically – even behave differently in controlling the functional properties of the starch. In a study, guar gum was observed to increase the final viscosity of the starch paste by promoting hydrogen bonding (Brennan et al., 2008). The viscosity of the pastes made from wheat flour was increased by the addition of fenugreek gum (Brennan et al., 2006). Lower retrogradation and syneresis of starch gels were observed in the presence of xanthan gum (Sae-Kang & Suphantharika, 2006).

Cordia myxa (L.) is a deciduous fruit-bearing tree; the fruit contains viscous transparent anionic polysaccharide gum that turns brown on air exposure. It is a high molecular weight (1.8 MDa) polymer with galactose, rhamnose, mannose, xylose, glucose, arabinose as main monosaccharides with their corresponding proportions of 27, 21, 17, 11, 10 and 9.5%, respectively (Benhura & Chidewe, 2002, 2011). Gum cordia (GC) solution possesses a unique pseudoplastic adhesive nature with a higher viscosity that makes it a strong stabilizer, thickener and emulsifier in food and pharmaceutical applications (Rafe & Masood, 2014). Similar to many other gums, GC is also a non-starch polysaccharide but its potential as hydrocolloid has not been divulged. Occasionally, GC has been used as a coating agent to prevent the oxidation of pine nuts and coating of few fruits (Haq et al., 2013). In this context, the current study was attempted to contrast the effect of native and acetylated GC on the pasting, rheological and textural properties of wheat flour.

2 Materials and methods

2.1 Collection of raw materials

Wheat flour (Grain Silos and Flour Mills Org., Saudi Arabia) was purchased from a local supermarket, Riyadh, Saudi Arabia. The flour composition provided by the retailer was as: protein 12.5%, fat 0.8%, fiber 0.25% and total carbohydrates 73.75%. Cordia fruit from *Cordia myxa* tree was collected from Al-Rajhi Farms, South Riyadh, Saudi Arabia. Analytical grade reagents were obtained from AvonChem (10 Waterloo St. W, Macclesfield, England).

2.2 Gum Cordia (GC) extraction and modification

Mature cordia fruits were collected, de-stoned and blended in Waring Blender (New Hartford, Conn., USA) for 60s. The blended pericarps and seeds were suspended separately in 2 volumes of distilled water at 50 °C for 2-3 h and filtered twice through the

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muslin cloth. The supernatants were collected, neutralized by 0.05 N NaOH and finally freeze dried (Virtis 6000, SP Scientific, Warminster, PA, 18974, USA).

For acetylation, freeze-dried GC powder was used to prepare 10% w/v solution at 40 °C and maintained the pH between 8.0-8.5 using 0.5 M NaOH. Acetic anhydride (6% of the solids) was added dropwise while keeping the pH consistently above 8.0. At the end of the reaction, the pH of the solution was adjusted to 6.5 and freeze dried. Degree of acetylation were determined by titration following Wurzburg (1978) method.

2.3 Wheat flour and Gum Cordia (GC) blends preparation

Wheat flour-GC composites were prepared by replacing the wheat flour with freeze-dried 60 mesh powder of native and acetylated GC at 3, 5 and 10% w/w basis. The wheat flour without GC (0%) was considered as control in all the analyses.

2.4 Pasting properties of wheat flour and gum cordia dispersions

The prepared wheat flour-GC blends were studied for their pasting behavior using Rapid Visco-Analyser (Newport Scientific, Sydney, Australia). The control and blends (2.5 g at 14% moisture basis) were weighed directly into RVA aluminium pans, and distilled water was added to get a total weight of 28 g. The suspension was equilibrated by stirring at 960 RPM for 10 s and then speed was reduced to 160 RPM for the remaining test time. The slurry obtained was equilibrated at 50 °C for 50 s, then heated to 95 °C in 3.42 min (13.15 °C/min) and held at 95 °C for 3.30 min. The suspension was then cooled to 50 °C in 3.48 min (12.93 °C/min) and held at 50 °C for 2 min. The viscosity data was processed using Thermocline® for Windows (Newport Scientific, Sydney, Australia). The parameters measured were; peak viscosity (PV), peak time (Pt), breakdown (BD), setback (SB), final viscosity (FV) and peak temperature (PT).

2.5 Steady shear analysis of composite gels

The rheological measurements were made according to the method adopted by Alamri et al. (2013). All the wheat flour-GC gels obtained after RVA measurement were directly utilized to determine the apparent viscosity and steady shear by Brookfield Viscometer (Model DV-III, Brookfield Engineering Laboratories, Inc., USA) using LV3 spindle. Because LV3 spindle was not standardized, hence spindle multiplier constant (SMC) and shear rate constant (SRC) were calculated, and were 128 and 0.33, respectively. The internal diameter of the gel containing cylinder was 2.3 cm. The apparent viscosity of the gel was recorded at different speeds with increment from 20 to 200 RPM, and then downward from 200 to 20 RPM. The corresponding shear rates (SR) for 20 and 200 RPM were 6.6 and 66.6 s^{-1}, respectively. The apparent viscosity values were used to get the shear stress (SS) data. Shear rate (SR) and shear stress (SS) data were fitted to the power law model (Equation 1) to determine the flow behavior of the gels.

$$T = K_{\gamma}^{n} \qquad (1)$$

T = shear stress (Pa.s); γ = shear rate (s^{-1}); K= consistency coefficient (Pa.s); n = flow behavior index (dimensionless). The rheological studies of composite gels were made using a range of temperatures (30, 40, 50 °C), whereas shear stress (SS) and shear rate (SR) data was used in activation energy (*Ea*) calculation through Arrhenius Model (Equation 2).

$$\text{In}(\mu) = \text{In}(\mu_o) + (\text{Ea} / \text{RT}) \qquad (2)$$

where: μ = apparent viscosity; μ_o = frequency factor; R = gas constant; Ea = energy of activation; and T = absolute temperature (in Kelvin).

2.6 Gel texture analysis

The gel obtained from RVA was poured into a 25 mL glass beaker (30 mm internal diameter) and stored for 24 h at room temperature. The gel texture was determined using Brookfield Texture Analyser (Model CT3, Brookfield Engineering Laboratories, Inc., Middleboro, USA); a cylindrical probe of 12.7 mm width and 35 mm height was used. Texture profile analysis (TPA) was exercised with two penetration cycles, having probe speed of 0.5 mm/s for a distance of 10 mm. Gel hardness, cohesiveness, springiness, adhesiveness and gumminess data was recorded in triplicate.

2.7 Statistical analysis

To elucidate the responses of various GC levels, one-way analysis of variance (ANOVA) was adopted. For pair-wise comparison of means at $p \leq 0.05$ Duncan's Multiple Range test (DMR) was adopted using SPSS® (version 15.0).

3 Results and discussion

3.1 Degree of Substitution (DS) and pasting properties

DS is the average number of sites in each glucose unit that contain acetyl group substitutions. DS of the native and modified GC was found 0.12 and 0.76, respectively. The pasting performance of starch and hydrocolloids composites does not depend only the starch but equally affected by the hydrocolloid role which could influence swelling of starch and leaching of amylose. Moreover, the consistency of the hydrocolloid, and the interactions of the hydrocolloids with the starch or its components also have impact as well (Byars et al., 2017). The temperature at which gelatinization starts to occur and viscosity begins to rise is termed as pasting temperature (PT). For all the blends with native or modified GC, a significant ($p \leq 0.05$) but non-linear drop on the pasting temperatures (PT) was observed relative to the control (Table 1). Ragaee & Abdel-Aal (2006) reported that wheat flour PT varied from 80-95 °C depending upon the flour type and mixture used. For native GC pastes, 3% GC replacement caused 3°C drop in PT; while with 5% GC, the drop was much bigger (20 °C). However, the least PT values were observed for 5% native and 10% acetylated GC blends. Similar results of drop on the PT have been documented for wheat flour-crude malva nut gum blends (Phimolsiripol et al., 2011). Lower PT is an indicator of earlier starch gelatinization that is favourable for higher amylolytic enzyme activities during bread

Table 1. Effect of native and acetylated gum cordia (GC) on the pasting properties of wheat flour.

Gum cordia (%)*	0%	3%	5%	10%
Native GC				
Peak viscosity (cP)**	649.0 ± 9.0^{d}	849.6 ± 5.6^{c}	1083.0 ± 4.3^{b}	1227.0 ± 5.5^{a}
Breakdown (cP)	295.0 ± 3.4^{d}	415.0 ± 6.2^{c}	603.3 ± 6.8^{b}	716.3 ± 5.5^{a}
Final viscosity (cP)	855.0 ± 5.5^{d}	883.3 ± 9.7^{c}	945.0 ± 8.7^{b}	961.0 ± 9.0^{a}
Setback (cP)	488.3 ± 4.0^{a}	453.6 ± 5.5^{b}	476.3 ± 8.6^{a}	448.0 ± 7.9^{b}
Peak time (min)	5.4 ± 0.1^{a}	5.1 ± 0.1^{b}	4.9 ± 0.0^{c}	4.9 ± 0.1^{c}
Pasting temp. (°C)	89.5 ± 0.4^{a}	86.6 ± 0.6^{b}	66.0 ± 0.8^{c}	66.3 ± 0.5^{c}
Acetylated GC				
Peak viscosity (cP)	649.0 ± 9.0^{d}	842.6 ± 8.1^{c}	1005.0 ± 12.7^{b}	1301.6 ± 11.3^{a}
Breakdown (cP)	295.0 ± 3.5^{c}	268.3 ± 0.5^{d}	392.0 ± 5.5^{b}	612.0 ± 7.5^{a}
Final viscosity (cP)	855.0 ± 5.5^{d}	1166.0 ± 8.1^{c}	1207.6 ± 10.0^{b}	1298.6 ± 8.5^{a}
Setback (cP)	488.3 ± 4.0^{c}	594.3 ± 7.5^{b}	591.0 ± 5.5^{b}	607.3 ± 6.5^{a}
Peak time (min)	5.4 ± 0.1^{a}	5.3 ± 0.1^{a}	5.1 ± 0.1^{b}	5.0 ± 0.1^{b}
Pasting temp. (°C)	89.5 ± 0.4^{a}	87.5 ± 0.5^{b}	86.4 ± 0.3^{c}	67.4 ± 0.4^{d}

*Mean carrying same letter in rows are statistically non-significant; **cP= centipoise.

baking. Lowering of the PT is favourable as it will minimize the gelatinization time and will aid the fermentation process and will reduce the energy consumption (Lutfi et al., 2017).

Peak viscosity (PV) sets on at the equilibrium point between starch maximum swelling and leaching out of amylose. The PV value is an indication of the maximum swelling and water-binding capacity of the starch. The PV of 10% native GC paste was twice than control (0% GC). The rise in PV can be explained by considering wheat flour-GC-water mixture as a biphasic system, where the GC was located in continuous phase and its concentration increased as starch granules started swelling by taking up water during heating (Alloncle et al., 1989). Nawab et al. (2016) also reported the addition of xanthan and guar gum improved the PV of mango kernel starch. Previously, Brennan et al. (2006) also reported higher PV with increasing amount of fenugreek gum. It was suggested that blends with higher PV might be used for bread and other baked products for better texture along with health benefits (Inglett et al., 2013).

After obtaining the PV (maximum swelling of the starch granules), the continuous shearing at high temperature (95 °C) disintegrates starch molecules and results in reduced paste viscosity. The minimum viscosity during holding is termed as trough, and viscosity difference between PV and trough is referred as breakdown viscosity (BD). The BD has a direct relation with the starch molecule stability under high heat and shear (Ragaee & Abdel-Aal, 2006). Wheat flour with lower BD viscosity displays superior resistance to shear thinning of pastes (Mudgil et al., 2016). In comparison to control, all the blends, both of native and acetylated GC, presented higher BD except 3% acetylated GC that demonstrated lower BD. Acetylated GC pastes exhibited lower BD value compared to their corresponding native GC pastes as presented in Table 1, alluding the stabilization effect of the gum on starch molecules. After holding the paste at 95 °C, cooling was followed up until 50 °C where reduced energy of the system allowed re-association of the starch fractions. Improved BD was also noticed in water cheshnut starch by addition of xanthan gum (Lutfi et al., 2017).

The viscosity at end of the holding period at 50 °C is termed as final viscosity (FV) at which starch gel is formed. Compared to the control, a significant ($p \leq 0.05$) improvement in FV was observed for the entire native and acetylated GC gels; although, the trend was non-linear. The final viscosities driven by native GC were lower than their corresponding acetylated GC levels. The maximum FV (1298 centipoise (cP)) was observed for 10% acetylated GC gel, indicating the highest gelling ability. Higher FV by acetylated GC might be attributed to higher starch retrogradation. Similarly, guar gum addition in Navy bean starch gel resulted in increased the FV during pasting (Byars et al., 2017).

Setback (SB) is the difference between FV and trough viscosity. All the pastes with native GC exhibited lower SB viscosities compared with the control suggesting lesser starch retrogradation and softer gels. Nawab et al. (2016) observed decline in SB when mango kernel starch was added with xanthan and guar gum. Conversely, all acetylated GC pastes depicted increasing trend in SB. The highest SB viscosity (607 cP) was observed for 10% acetylated GC paste, and was 159 cP higher than its corresponding native paste. The overall increasing SB by acetylated GC might be due to the higher amylose-to-amylose interactions (retrogradation). A rise in SB was also noticed when the guar gum was added in the mung bean, corn and potato starch (Kaur et al., 2015). The time corresponding to PV is referred to as peak time (Pt). At each replacement level of native and acetylated GC, lower Pt was observed compared to the control (Table 1).

3.2 Steady shear properties of composite gels

The gels obtained after RVA were tested for steady shear rheological properties using Brookfield Viscometer equipped with LV3 spindle. The percent torque value for a selected RPM (100) and viscosity (cP) of mineral oil as a standard (1190) was used in the calculation of SMC and SRC. The calculated full-scale viscosity range (RI) and SMC were found 12,796cp and 127.95, respectively. The flow profiles for SS versus SR of the entire native and acetylated GC gels (50 °C) are presented in Figure 1. Both types of the gels exhibited higher slopes as a function of GC. Acetylated GC gels presented steeper profiles suggesting significant structural changes in the gels due to continuous shearing.

To obtain consistency coefficient (*K*) and flow behavior index (*n*), the two components of power law, natural log of SS versus SR curve were taken and linear regression model was applied. Higher regression coefficient (R^2) values confirmed the suitability of the power law in the studied range of shear. For all the native and acetylated gels, the flow behavior index (*n*) was less than 1, signifying deviation from Newtonian flow (n=1). Similar behavior was reported for various cereal starches-hydrocolloids gels by Alamri et al. (2012, 2013). At 50 °C, all native GC replacement levels presented lesser pseudoplasticity compared with the control gel. However, the highest '*n*' was demonstrated by 5% GC blend referring it the least pseudoplastic gel. At a given GC concentration, the '*n*' was found to be affected by the change in temperature: the lower the temperature the higher was the pseudoplasticity (Table 2). Charged polysaccharides are widely believed to increase the flow behavior index of many starch-based systems (Abdo Qasem et al., 2017). Gel pseudoplasticity may be due to the disentanglement of the macromolecular chains that ultimately reduces flow resistance under shear. However, water immobilization by GC might have rendered the system less pseudoplastic.

Consistency coefficient (*K*) is considered as a direct indicator of gel viscosity. At a given temperature, with increasing GC concentration the whole native and acetylated GC gels presented higher '*K*' values (Table 2). Abdo Qasem et al. (2017) observed similar rise in the consistency index (*K*) with addition of okra mucilage in starch. However, the acetylated gels represented relatively higher '*K*' values compared to their corresponding native GC gels, indicating more viscous nature with less shear thinning behavior. The data with higher '*K*' values supported the RVA results in terms of higher viscosities for higher GC levels. At a certain GC level, with increasing shearing temperature, decreasing '*K*' signified the relation between thixotropy and temperature. Similar results were reported by Abdo Qasem et al. (2017), who found decrease in '*K*' when okra mucilage was used in starch gel. Increased '*K*' was also observed when xanthan gum was added to waxy maize starch (Wang et al., 2009). Improved viscous properties of gels could be correlated with the restricted molecular movements due to the intermolecular chain entanglements.

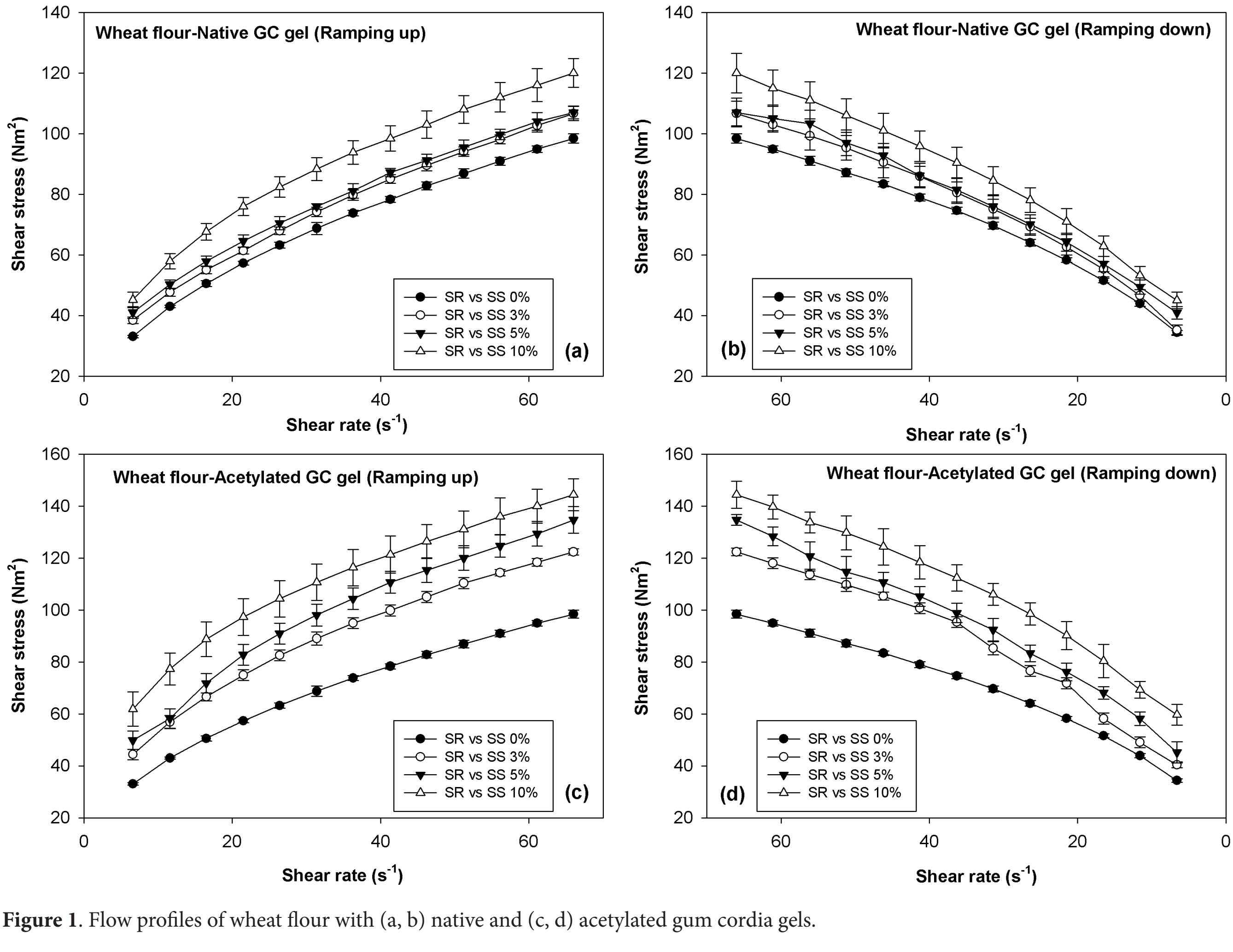

Figure 1. Flow profiles of wheat flour with (a, b) native and (c, d) acetylated gum cordia gels.

The frequency factor (μ_o) and activation energy (Ea) values of the composite gels are presented in Table 3. The values obtained for the determination coefficient (R^2) were found in the range of 0.91-1.0, which authenticated the appropriateness of the Arrhenius model for the current experiment. Ea is the indication of the barrier of energy that must overcome before the elementary flow process can happen (Abdo Qasem et al., 2017). With increasing GC replacement level a decreasing trend in activation energy (Ea) was observed. The highest '*Ea*' was observed for the gel containing 3% native GC with a value of 7534 J/mol. Relative to control, gels containing higher GC concentration (native or acetylated) demonstrated lower '*Ea*' indicating less temperature dependency (Nurul et al., 1999). These observations suggested that higher GC levels reduced the thermal stability of the gels. The decreasing '*Ea*' value with increasing concentration has also reported for rice starch gels with various gum mixtures (Kim & Yoo, 2006; Yoo et al., 2005; Abdo Qasem et al., 2017).

In contrast to the native GC, acetylated GC gel of 10% demonstrated relatively lower '*Ea*' (6209 J/mol) and lesser heat stability. On the whole, the acetylated GC blends showed relatively higher '*Ea*' than the blends with native GC; although, the difference was small (Table 3). Therefore, it could be concluded that the viscosity of the acetylated GC gels (with relatively higher '*Ea*') was less responsive to the temperature variations compared to the native GC gels and vice versa.

3.3 Texture analysis of gels

The hardness (g) of the gel is the force required until deformation. A significant softening of the gel was observed for 3% GC replacement, but subsequent increase in gum did not result in any further decrease in the hardness (Table 4). This data is in agreement with the RVA results where the presence of the native GC lowered SB viscosities indicating softer gels. Softer gels were also reported after the addition of crude malva nut gum

Table 2. Consistency index (K) and flow behavior index (n) of wheat flour with native and acetylated gum cordia (GC).

Temp. (°C)	0%			3%			5%			10%		
	Native GC											
	K*	n**	R^2	K*	n**	R^2	K*	n**	R^2	K*	n**	R^2
Ramping Up												
30	3.20	0.39	0.98	3.25	0.40	0.99	3.32	0.40	0.97	3.36	0.41	0.99
40	3.08	0.39	0.99	3.11	0.41	0.98	3.14	0.41	0.99	3.17	0.40	0.98
50	2.59	0.42	0.97	2.58	0.47	0.99	2.71	0.49	0.99	2.81	0.45	0.99
Ramping Down												
30	3.06	0.43	0.99	3.09	0.44	0.97	3.12	0.45	0.98	3.17	0.44	0.99
40	2.89	0.44	0.98	2.91	0.45	0.99	2.95	0.49	0.99	2.97	0.44	0.98
50	2.65	0.44	0.99	2.67	0.46	0.99	2.71	0.48	0.99	2.78	0.43	0.99
	Acetylated GC											
Ramping Up												
30	3.20	0.39	0.98	3.44	0.44	0.98	3.67	0.49	0.98	3.73	0.34	0.99
40	3.08	0.39	0.99	3.13	0.56	0.98	3.22	0.56	0.96	3.46	0.36	0.99
50	2.59	0.42	0.97	2.61	0.69	0.97	2.74	0.69	0.97	2.96	0.41	0.99
Ramping Down												
30	3.06	0.43	0.99	3.17	0.51	0.99	3.24	0.59	0.99	3.43	0.41	0.99
40	2.89	0.44	0.98	3.07	0.61	0.98	3.12	0.62	0.98	3.21	0.42	0.99
50	2.65	0.44	0.99	2.79	0.67	0.97	2.86	0.67	0.96	3.01	0.43	0.99

*K = consistency index (Pa.s); **n = flow behavior index (dimensionless); R^2= Regression coefficient.

Table 3. Activation energy (Ea) values for wheat flour and gum cordia (native and acetylated GC) composite gels.

GC (%)	Ramping Up			Ramping Down		
	μ_o (Pa.s)*	Ea**(J/mol)	R^2	μ_o (Pas)*	Ea**(J/mol)	R^2
			Native GC			
0	8.54×10^{-2}	6199.74	0.94	7.62×10^{-2}	5947.28	0.99
3	3.44×10^{-2}	7534.63	0.91	3.19×10^{-2}	7234.79	0.98
5	5.09×10^{-2}	6636.74	0.93	4.84×10^{-2}	6102.63	0.99
10	8.13×10^{-2}	5985.82	0.94	7.40×10^{-2}	5761.26	0.99
			Acetylated GC			
0	8.54×10^{-2}	6199.74	0.94	7.32×10^{-2}	5947.28	0.99
3	2.98×10^{-2}	8426.95	0.99	3.01×10^{-2}	8139.16	1.00
5	4.21×10^{-2}	7641.02	1.00	4.65×10^{-2}	7256.77	0.98
10	7.28×10^{-2}	6209.22	0.94	6.79×10^{-2}	6123.24	0.96

*μ_o(Pa.s) = frequency factor at a reference temperature; **Ea = activation energy (J/mol) measured at temperature range of 30-50 °C; R^2 = Regression coefficient.

Table 4. Texture analysis of wheat flour-native and acetylated gum cordia (GC) gels.

		Native GC		
Parameters*	**0%**	**3%**	**5%**	**10%**
Hardness (g)	28.1 ± 1.7^{a}	25.0 ± 2.0^{b}	25.3 ± 1.1^{b}	25.0 ± 0.0^{b}
Cohesiveness	0.51 ± 0.01^{b}	0.57 ± 0.03^{a}	0.54 ± 0.03^{ab}	0.54 ± 0.02^{ab}
Springiness	9.8 ± 0.2^{a}	9.8 ± 0.1^{a}	9.9 ± 0.1^{a}	9.9 ± 0.1^{a}
Adhesiveness (mJ)	0.40 ± 0.10^{ab}	0.30 ± 0.10^{b}	0.40 ± 0.10^{ab}	0.53 ± 0.12^{a}
Gumminess	16.9 ± 0.7^{a}	14.2 ± 1.0^{b}	13.7 ± 1.1^{b}	13.4 ± 0.5^{b}
		Acetylated GC		
Hardness (g)	28.1 ± 1.7^{ab}	24.3 ± 1.5^{b}	28.6 ± 1.5^{ab}	32.3 ± 4.5^{a}
Cohesiveness	0.51 ± 0.01^{ab}	0.45 ± 0.03^{b}	0.55 ± 0.04^{a}	0.53 ± 0.04^{a}
Springiness	9.8 ± 0.1^{a}	9.0 ± 0.1^{b}	8.4 ± 0.3^{c}	10.1 ± 0.1^{a}
Adhesiveness (mJ)	0.40 ± 0.10^{a}	0.20 ± 0.10^{b}	0.33 ± 0.05^{ab}	0.50 ± 0.10^{a}
Gumminess	16.9 ± 0.7^{a}	11.1 ± 0.2^{b}	15.9 ± 1.9^{a}	17.1 ± 1.2^{a}

*Mean carrying same letter in rows are statistically non-significant at $p \leq 0.05$.

in starch (Phimolsiripol et al., 2011). In the case of acetylated GC gels, 3% replacement depicted the hardness lower than the control. However, increased hardness was observed for 5 and 10% acetylated GC gels. Nawab et al. (2016) reported a rise in the gel hardness of mango kernel starch when xanthan and guar gums were added. Higher hardness could be related to the formation of clusters of hydrocolloids chains with amylopectin. Besides, more ordered structures by adjacent clusters could further rise the gel hardness. It is suggested that when softer and viscous gel is desired, higher native but lower acetylated GC concentrations could be used.

The cohesiveness relates to bond strength that makes up gel body. It also indicates the extent of damage in the gel structure during hardness measurement (Byars et al., 2017). For all the native GC gels, statistically higher cohesiveness was seen compared to the control, with the highest value (0.57) for 3% GC. Li et al. (2015) reported rise in gel cohesiveness of pea starch when guar and xanthan gums were added. Springiness is the degree at which a compressed sample retains its original geometry (un-deformed) after removing force of deformation, and it dictates the elasticity of the gel. Gels with higher springiness scatter into larger pieces compared to less elastic ones. The gels with 3% and 5% acetylated GC demonstrated a significant ($p \leq 0.05$) decrease in the springiness relative to the control. However, apparently the highest springiness was exhibited by the 10% acetylated GC gel specifying it a brittle gel, as springy gel breaks into a few large pieces under TPA compression (Marshall & Vaisey, 1972).

Gel adhesiveness is the resultant of the combined effect of adhesive and cohesive forces (Alamri et al., 2013). In comparison to the control, 10% gel of both the native and acetylated GC presented a significant ($p \leq 0.05$) improvement in the adhesiveness. The higher adhesiveness could be attributed to the abundant hydroxyl groups of the GC. Contrarily, lower adhesiveness was observed for starch pudding when okra mucilage was added (Abdo Qasem et al., 2017). Gumminess is the product of gel hardness and cohesiveness. A decrease of 15% and 34% in the gumminess was observed by replacing 3% native and acetylated GC, respectively. Phimolsiripol et al. (2011) reported lower gumminess at higher concentrations of the crude malva nut gum. A similar lowering was also observed for starch pudding when added with okra mucilage (Abdo Qasem et al., 2017).

4 Conclusion

The addition of water soluble native and acetylated GC resulted in improved viscometric and gelling properties of wheat flour pastes. At higher GC concentrations all the gels presented pseudoplastic nature ($n<1$) and higher consistency index (K) values. Shear rate (SR) and shear stress (SS) data of all the gels obeyed the power law model. The temperature dependency of the gels was well established using Arrhenius equation. The higher '*Ea*' observed for all the acetylated gels depicted an obvious influence on gel thermal stability even at lower concentration. Similarly, at higher percentage of acetylated GC, firmer gels were obtained compared to the corresponding native GC gels. Consequently, a significant variation was noticed by the acetylation of GC which altered the viscous and thermal responses of the wheat flour-GC composite system. Specifically, GC and wheat flour blends could improve efficiency of dough fermentation process and lower the baking temperature and overall energy consumption. Besides, the final high fiber bread could better retain textural properties and quality by controlling retrogradation. Thus, this novel gum could be a cheap alternative of commercially available hydrocolloids used in bread making.

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