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PASTING, THERMAL, TEXTURAL AND RHEOLOGICAL PROPERTIES OF RICE STARCH BLENDED WITH 6 DIFFERENT HYDROCOLLOID GUMS

Syed Ali Shahzad, Shahzad Hussain*, Abdellatif A. Mohamed, Mohamed S. Alamri, Akram A. Abdo Qasem, Mohamed A. Ibraheem and Magdi A. Osman

[1]Department of Food Sciences, College of Food and Agricultural Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia.
***Corresponding author's e-mail: shhussain@ksu.edu.sa**

Study was planned to modify the properties of rice starch with the use of different hydrocolloid gums. Pasting, rheological, textural and thermal properties of rice starch blends prepared with 0.5 and 2% replacement with arabic, xanthan, okra, flaxseed, cress seed and fenugreek gums were investigated by rapid visco analyzer measurements (RVA), hybrid rheometer, texture analyzer and differential scanning calorimeter (DSC). Peak viscosity was increased by the addition of all gums except arabic gum which decreased the peak viscosity when compared to control. Data obtained from hybrid rheometer revealed that dynamic mechanical loss tangent (tan δ) was increased by the inclusion of fenugreek and flaxseed gums, that shows an increase in viscous character because of the greater change in loss modulus (G″) than storage modulus (G′). It supports the hypothesis that there was interaction between amylose and these gums in the composite system. Consistency coefficient (*k*) was increased by the addition of xanthan, fenugreek and flaxseed gums at 25°C. The data of flow behavior index (*n*) indicate that rice starch - gum blends exhibited more psuedoplasticity than those of the control except flaxseed and okra gums. Activation energy values revealed that addition of gums regardless of their concentrations had increased the heat dependency of rice starch except xanthan which behaved contrarily. The hardness was significantly decreased with the inclusion of arabic, xanthan, cress seed and okra gums irrespective of their concentrations as compared to the control. The data obtained from DSC clarified that onset temperature (To) and peak temperatures (Tp) were increased as a function of gum type and their concentrations.
Keyword: Rice starch, hydrocolloids, gums, rheology, texture.

INTRODUCTION

Rice (*Oryza sativa* L.) is a cereal, that belongs to family Poaceae and is widely cultivated in Asian countries like China, India, Indonesia, Bangladesh and Pakistan (Wani *et al.*, 2012). Rice grains are rich source of starch as they comprise of 80% of starch (Lin *et al.*, 2011). Rice starch granules are very small in size that ranges between 2-8 microns and having polygonal and angular shape with smooth surface. Rice starch provides a texture feeling similar to that of fat and it is considered to be non-allergic due to the hypoallergenicity of the linked proteins (Champagne, 1996). Amylose content in different rice types vary from high (25-33%), intermediate (20-25%), low (12-20%) to very low (5-12%), whereas waxy rice contains less than 2% (Wani *et al.*, 2012). Numerous studies showed that rice starch could be used in the preparation of rice cakes and bread as an alternative to wheat for the development of gluten free products having good flavor and the high nutrient levels (Sun *et al.*, 2017). Usually, properties of native starches are not ideal for many food applications due to poor gel stability during heating, shear thinning during acidic conditions, retrogradation on cooling and syneresis during storage and transportation (Gałkowska *et al.*, 2013; Chen *et al.*, 2018). The paucities in native starches are therefore corrected by means of physical, chemical, enzymatic modifications (relatively expensive, non-safe or time consuming) or by addiction of non-starch hydrocolloids (gums or mucilage).

Hydrocolloids mainly hetro-polysaccharides comprises of deoxy and hexoses sugars like glucose, xylose, mannose, galactose, arabinose and uronic acids. They belong to the diverse group of high molecular weight biopolymers and hydrophilic in nature that forms viscous dispersions when dissolved in water (Sciarini *et al.*, 2009). These hydrocolloids help in water holding, dietary fiber addition, thickening, stabilizing, dispersing, foaming, gelling, modification of texture, improving moth feel and gas retention when added to different food products (Ferrero, 2017). Their main applications are in the manufacturing of cookies, bread, cakes, jellies mayonnaise, dressings, dessert and ice-cream (Funami, 2011). Furthermore, they are also used in the starch modification. Due to drawbacks in commonly used chemical and enzymatic starch modification techniques, they are preferred because of their low reactivity, low cost and availability (Baveja *et al.*, 1988).

The properties like gelatinization temperature, rheological behavior and pasting behavior of native starches are modified by different hydrocolloids to attain the desired objectives.

Furthermore, they could maintain the stability for prolonged time and give appropriate textural characteristics to the products (Temsiripong *et al.*, 2005). Therefore, blends of starch and gums could be useful in the extensive range of food products. The main purpose of this study was to explore the pasting, rheological, textural and thermal properties of rice starch blended with two different levels of commercial (arabic, xanthan) and non-commercial (flaxseed, fenugreek, okra, cress seed) gums. The outcome of this research could be a help to find some unconventional and relatively cheap source of plant based hydrocolloids having properties comparable with commercial sources.

MATERIALS AND METHODS

Winlab Laboratory Chemicals, Leicestershire, (UK) supplied commercial rice starch while commercial arabic and xanthan gums were obtained from Qualikems Fine Chem Pvt. Ltd. (India). All plant materials like cress seed, fenugreek, flaxseed and okra pods for gums extraction were purchased from local market.

***Extraction of gums*:** Water extraction method was used to extract gums from according to methods followed by Karazhiyan *et al.* (2011) for cress seed, Alamri (2014) for okra pods and Qian *et al.* (2012) for fenugreek and flaxseed seeds. The extracted gums were freeze dried and ground to fine powders (60 mesh) and stored in air tight jars at 5°C till further use.

***Preparation of starch gum blends*:** Rice starch was mixed with different gums (arabic, xanthan, cress seed, fenugreek, flaxseed and okra) @ 0.5% and 2 % (w/w) replacement levels whereas; plain rice starch was kept as control. Blends were prepared by wet mixing method by which slurry was prepared of starch and gums and freeze dried. The freeze dried blends were ground to fine powder (60 mesh) and stored in airtight jars in refrigerator till further use.

***Pasting properties*:** Pasting characteristics of starch blends were determined by Rapid Visco Analyzer (Newport Scientific, Australia) according to the method followed by Hussain (2015). The rotation rate of paddle was maintained at 960 rpm for initial 10 seconds then maintained to 160 rpm throughout the remainder experiment. The sample was prepared by taking 3g of sample at 14% moisture in RVA aluminum canister and distill water was added to attain a total weight of 28g. The suspension was held at 50°C for 30 seconds, heated @ 10.23°C/minute to reach 95°C in 4.40 minutes, and kept at 95°C for 4 min. The cooked sample was cooled to 50°C in 4.40 min @ 10.23°C/minute and retained at 50°C for 2 min. The data processing was done through Thermocline software (Newport Scientific, Australia).

***Dynamic rheology, steady flow behavior and temperature dependency*:** Dynamic rheology of starch blends was carried out by using TA (New Castle, USA), Discovery Hybrid Rheometer (HR-1). The equipment was mounted with a (2°) cone and 40 mm diameter plate geometry. Sample was prepared (5% w/v) in RVA by using same method as discussed above. Cooked samples were shifted to plate and the rheometer was calibrated for 1 minute at 25°C. Extra sample on plate was removed with spatula and 100µm sample to geometry gap was adjusted. Dynamic shear data was collected at frequency sweeps ranging from 0.1-100 rad/s at 25°C with 5 % constant strain. The rheological parameters such as storage moduli (G′), loss moduli (G″) and dynamic mechanical loss tangent (tan δ = G″/G′) were calculated. At various temperatures (25, 45 and 65°C), shear rate versus shear stress data was also determined and Arrhenius Equation model was used to calculate activation energy of samples. The power law model was used to explain the steady flow behavior was also employed to determine the dependence of shear stress versus shear rate.

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

T = shear stress (Pa.s), K= consistency coefficient (Pa.s), γ = shear rate (s^{-1}), and n = flow behavior index (dimensionless).

***Texture profile analysis of starch gum blends gel*:** The starch gels collected from RVA experiments were kept in the aluminum canisters (65 mm in height and 36 mm diameter) and stored at room temperature overnight. Textural parameters such as hardness, cohesiveness, springiness and adhesiveness were determined by using Brookfield Texture Analyzer model CT3 (Brookfield Engineering Laboratories, Inc., Middleboro, USA). The test was performed by cylindrical probe (35mm high and 12.7mm wide) with a speed of 0.5 mm/sec up to 10 mm depth in two penetration cycles. Hardness, springiness, cohesiveness and adhesiveness were recorded directly from the screen while chewiness was calculated from hardness, cohesiveness and springiness.

***Thermal properties*:** Thermal properties of rice starch gum blends were analyzed by using Differential scanning calorimetry, TA, Q2000 according to the method as explained. Samples were prepared by weighing (5-10 mg) in aluminum pans and 60-80% distilled water was added. The pans were hermetically sealed and allowed to equilibrate. The samples were heat scanned at the rate of 10°C/minute from 25-120°C. Empty pan was used as a reference. The data was recorded as onset temperature (To), and peak temperature (Tp) and enthalpy ΔH (J/g).

***Statistical Analysis*:** Data collected from all the experiments in triplicate and one-way ANOVA. Comparison of means was done by applying Duncan's Multiple Range (DMR) test at sig ≤0.05 by using SPSS software (IBM Statistical Analysis Version 21).

RESULTS AND DISCUSSION

***Pasting properties*:** Pasting properties of rice starch gum blends are listed in Table 1. The pasting properties and hydration behavior of starch blends were affected due to the presence of different gums at both levels i.e. 0.5 and 2%. Peak

Table 1. Effect of gums at 0.5% and 2.0% concentration on pasting properties of rice starch.

Parameter	Conc. (%)	Control	Arabic	Xanthan	Cress seed	Fenugreek	Flaxseed	Okra
Peak Viscosity	0.5	1495±45[c]	1485±23[c]	2321±41[a]	1526±18[bc]	1536±77[bc]	1555±80[bc]	1611±19[b]
(cp)*	2.0	1495±45[d]	1454±67[d]	3944±84[a]	1554±38[cd]	1766±30[b]	1605±54[c]	1654±54[c]
Breakdown	0.5	0516±35[bc]	0452±12[c]	0618±57[a]	0470±17[c]	0557±45[ab]	0595±54[a]	0631±28[a]
Viscosity (cP)	2.0	0516±35[cd]	0474±22[de]	1188±75[a]	0424±17[e]	0619±45[b]	0480±39[de]	0588±26[bc]
Final Viscosity	0.5	2087±36[b]	2082±21[b]	2667±62[a]	2076±36[b]	2128±61[b]	2111±58[b]	2099±21[b]
(cP)	2.0	2087±36[c]	1798±63[d]	3559±42[a]	2031±21[c]	2336±13[b]	2268±40[b]	2037±38[c]
Setback (cP)	0.5	1113±24[a]	1047±31[b]	0964±49[c]	1037±12[b]	1145±34[a]	1114±32[a]	1096±45[ab]
	2.0	1113±24[b]	0816±43[e]	0802±27[e]	0903±14[d]	1191±57[a]	1147±32[ab]	0990±35[c]
Pasting Temp.	0.5	70.9±0.2[b]	71.9±0.1[a]	69.4±0.1[c]	71.0±0.1[b]	71.0±0.8[b]	70.3±0.1[c]	71.0±0.1[b]
(°C)	2.0	70.9±0.2[c]	72.2±0.4[a]	66.3±0.4[d]	71.5±0.4[ab]	71.8±0.1[ab]	71.1±0.1[bc]	71.8±0.8[ab]

Means estimated from three replicates with different superscripts within the same rows are statistically significant. *Centipoise

viscosity was increased as a function of gum regardless of their concentration except with arabic gum. However, at lower level of gum inclusion significant increase was observed only with xanthan while at higher level it was increased significantly with xanthan, flaxseed, fenugreek and okra gums. Previously, different authors reported an increase in peak viscosity with okra and xanthan gums (Alamri *et al.*, 2012a; Chen *et al.*, 2016). Increase in peak viscosity was explained by believing gum/starch/water as a biphasic system which consists of continuous and dispersed phase. Continuous phase mostly comprises of low molecular weight amylopectin and leached amylose in water. In contrast, dispersed phase consist of swollen amylopectin granules.

According to Heyman *et al.* (2014) pasting characteristics were mainly influenced by scattered gum which was localized in continuous phase. During gelatinization, swelling of starch granules increased their volume in continuous phase, as a result availability of the gums were decreased, which results in evident raise in the viscosity (Samutsri and Suphantharika, 2012). According to Correa *et al.* (2013), association between low molecular weight amylopectin and leached amylose in water with gum molecules in the continuous phase also increases the peak viscosity of starch. On contrary, peak viscosity was decreased by the addition and increasing concentration of arabic gum but it was statistically same as the control. It could be ascribed to the absence of synergistic relationship between leached amylose and arabic gum in the continuous phase bordering the starch molecules. Gums have capability to cover the surface of starch granules and boost the interactions between them, which cause limited granule swelling and decrease in the peak viscosity (Singh *et al.*, 2017). Similar author reported decrease in the peak viscosity by the addition of arabic gum in tapocia starch.

Final viscosity revealed the ability of starch to form viscous pastes. It was increased with xanthan, fenugreek and flaxseed gums regardless of their concentrations. Plane rice starch exhibited (2087 cP) final viscosity, which was dramatically increase to (2667 and 3559 cP) by the incorporation of 0.5 and 2.0% xanthan gum, respectively. Increase in final viscosity was reported by Hussain (2015) and Yadav *et al.* (2018) during studying the effect of flaxseed gum on rice starch and xanthan or guar gum on colocasia starch, respectively. The latter author reported that it could be due to the thickening effect of the gums which cause evident increase in the final viscosity. Furthermore, special behavior of xanthan could be ascribed to the unique molecular structure and the flexibility of the gum molecular chains (Achayuthakan and Suphantharika, 2008). Significant reduction in final viscosity was observed with the addition of arabic gum at 2 % concentration while at 0.5% it was statistically same as the control along with cress seed and okra gum. This could be ascribed to the substitution of the starch with gum. Earlier decrease in final viscosity of rice starch with various concentrations of okra was also reported (Alamri *et al.*, 2012a).

With decreasing temperature (cooling) leached amylose molecules starts uniting and form junction zones of amylose which were responsible for the setback. A higher setback viscosity indicates a poor resistance against retrogradation. Increasing trend was observed in the setback viscosity by the addition of fenugreek and flaxseed irrespective of their concentrations. Similar results of an increase in setback viscosity was reported by Brennan *et al.* (2006) and Hussain (2015) with fenugreek and flaxseed gums, respectively. The latter author attributed it to the higher water absorption capacity of the gums. They renders the biphasic system in a water deficient state and assists in the retrogradation of amylose, which cause higher setback values as compared to the control. In contrast, significant decrease in the setback values was noticed by the incorporation of arabic, xanthan, cress seed and okra. It could be attributed to the ability of the gum which worked as an obstacle between leached amylose and prevent their lining up together and in development of network (Alamri *et al.*, 2012a). Moreover, substantial decrease in setback viscosity of xanthan blend was attributed to the development of xanthan and amylose intermolecular interactions during cooling which decreases the amylose-amylose associations. As the concentration of xanthan increased to 2 %, amylose-xanthan interactions seemed to emerge with more force that results in further decrease in the setback value (Chen *et al.*, 2016). The results were the agreement of the previous investigations (Chen *et al.*, 2016;

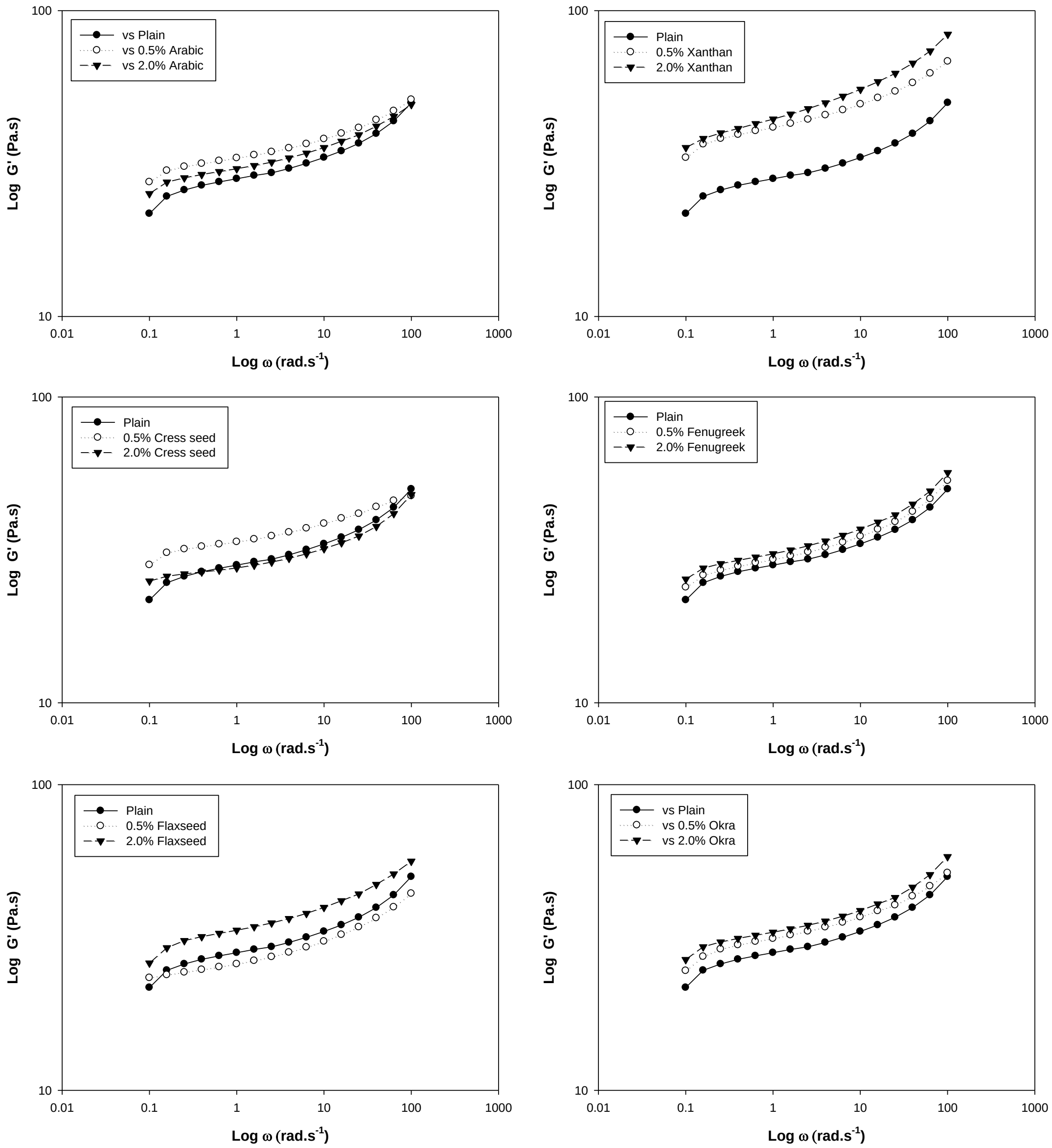

Figure 1. Plots of log G′ versus log ω of rice starch gum blends at different gum concentrations.

Yadav *et al.*, 2018). Pasting temperature is used as an indicator of least energy needed to cook starchy food. It was significantly increased by the addition of arabic gum regardless of their concentration and with higher concentration of cress seed, fenugreek and okra gums. It could be ascribed to the ability of the gum to cover the starch granules and delayed the starch gelatinization. In contrast, it was significantly reduced by the inclusion of xanthan gum. Gałkowska *et al.* (2014) explained that decrease in pasting temperature might be due to the increase in starch granules concentration in the continuous phase, which boosted the interactions between granules of starch.

Dynamic rheology**:** Dynamic rheological properties of rice starch alone and with gums are depicted in Figure 1-3. Storage modulus (G´) represents solid properties while loss modulus (G″) indicates viscous properties. They were increased as a function of angular frequency. G´ was found to be higher than G″ and no crossover were identified between them throughout the studied frequency range. Moreover, all samples in this study were less frequency dependent. Incorporation of gums into rice starch, increases the values of G´ and G″ as compared to the control except higher concentration of cress seed and low concentration of flaxseed. Increase in moduli as a function of gum were in consistent with the findings of Chen *et al.* (2016) and Singh *et al.* (2017). These results revealed that gum addition had a synergistic effect on rice starch, which improves its viscoelastic character. The possible explanation could be the shrinkage of available area of the

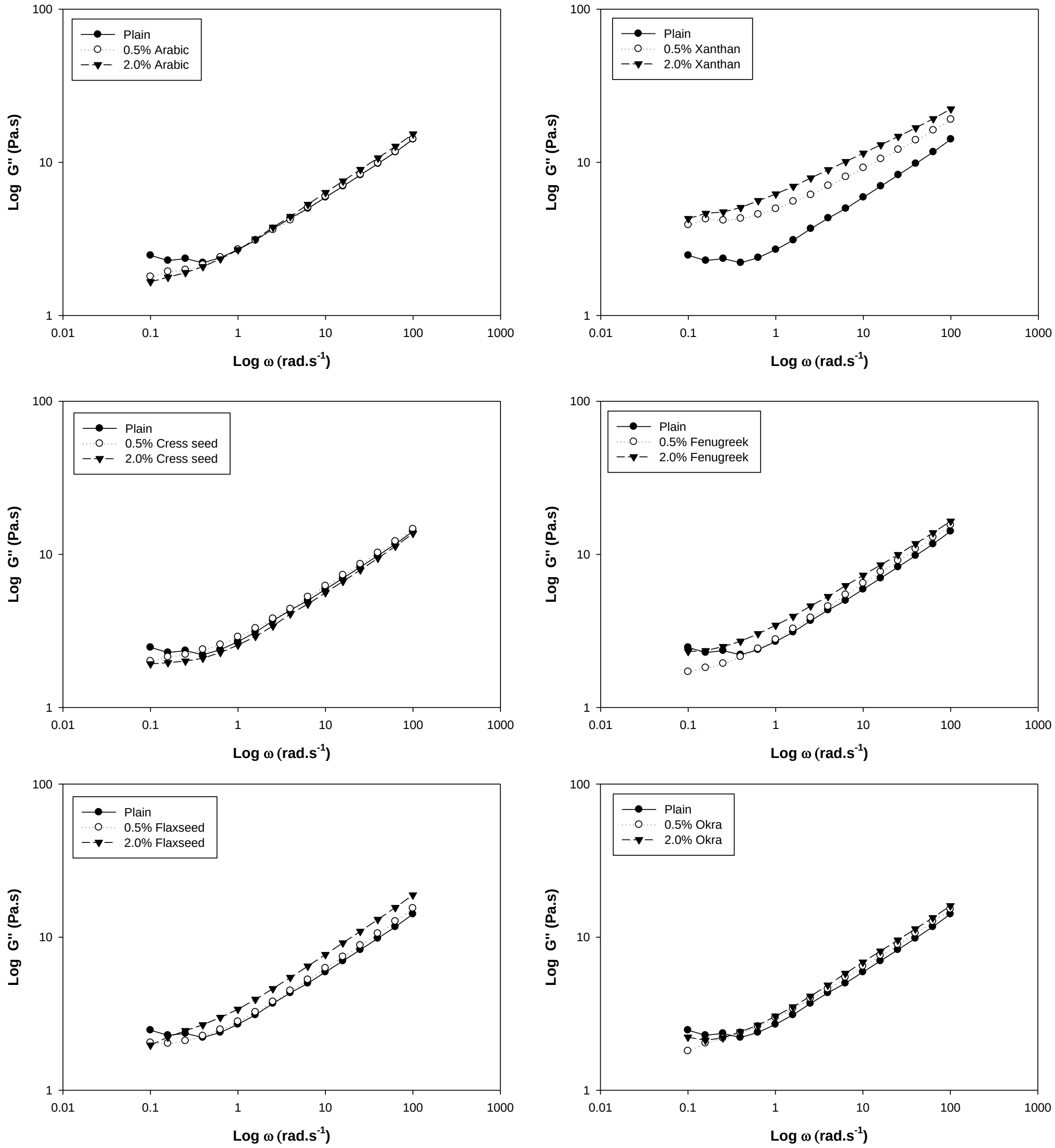

Figure 2. Plots of log G″ versus log ω of rice starch gum blends at different gum concentrations.

phase to the gum which cause gum to be clustered in the continuous phase due to the swelling of starch granules during gelatinization (Alloncle and Doublier, 1991).

Dynamic mechanical loss tangent (tan δ) is the ratio of G′ and G″. For viscoelastic material it illustrates the structural organization (Varela *et al.*, 2016). Its value was increased by the inclusion of fenugreek and flaxseed irrespective of their concentrations. It revealed that inclusion of fenugreek and flaxseed gums caused increase in viscous character because of the greater change in G″ than G′ as compared to the control. The results were consistent with the findings of Yoo *et al.* (2005) and Lee *et al.* (2017) who study the influence of tara gum and galactomannan on rice starch, respectively. The possible explanation might be the interactions between these gums and amylose hinder the aggregation of amylose which results in development of less junction zones (BeMiller, 2011). Another plausible explanation could be the reduction in the amount of leached amylose by the inclusion of these gums which ultimately reduces the amylose aggregation (Yu *et al.*, 2018). In contrast, opposite trend was noticed by the addition of arabic, xanthan cress seed and okra gums. Values of (tan δ) were decreased by the inclusion of these gums as compared to the control. Moreover, the effect of xanthan was pronounced in reducing (tan δ) which showed that network of xanthan and rice starch was much stronger than the rice starch alone and with other gums. Samutsri and Suphantharika (2012) and Chen *et al.* (2016) also compared the effect of xanthan and other hydrocolloids on rice starch and reported

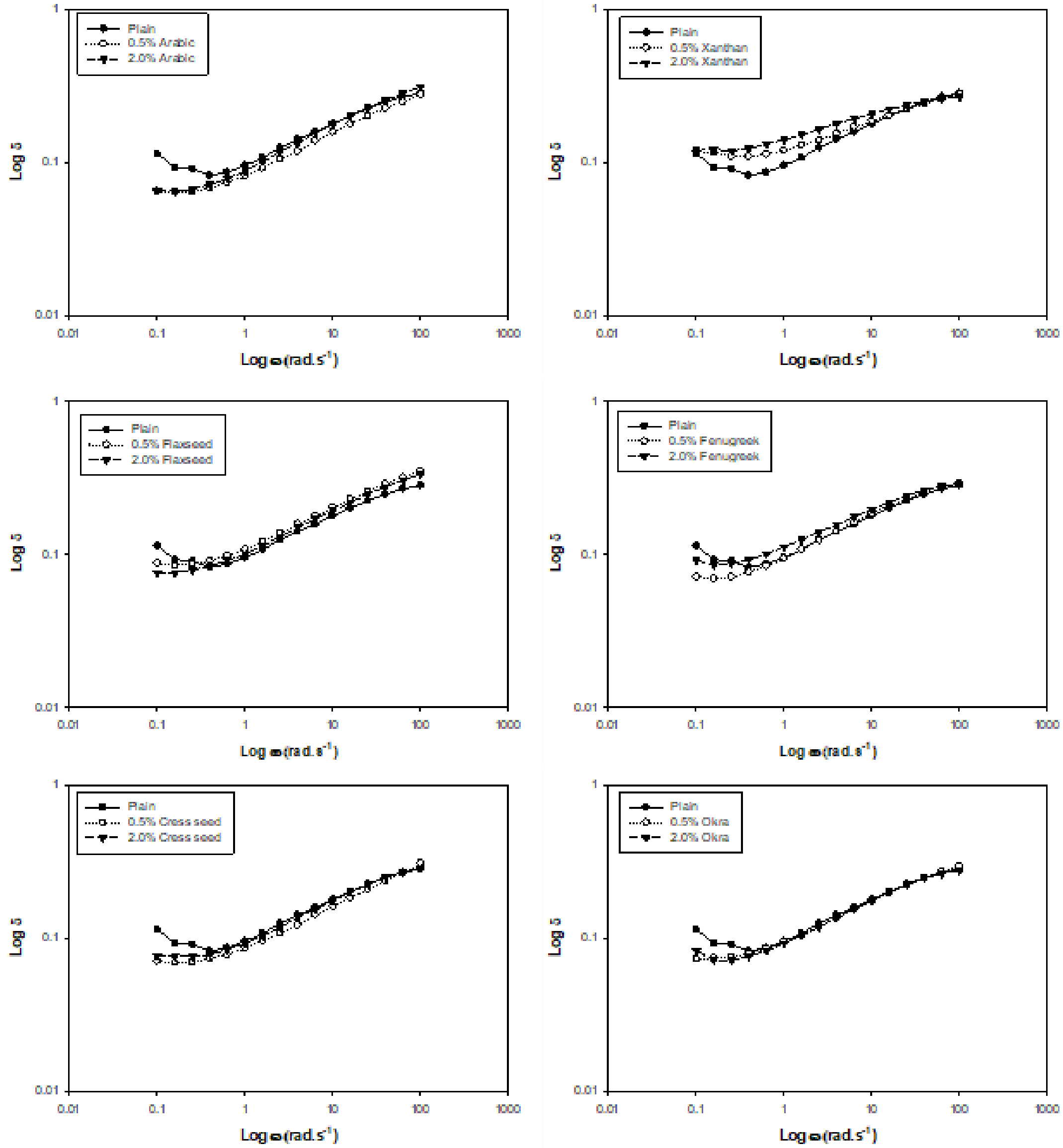

Figure 3. Plots of log δ versus log ω of rice starch gum blends at different gum concentrations.

that inclusion of xanthan gave the least (tan δ) values. It might be ascribed to the synergism effect of xanthan and rice starch in the development of cross-linked hydrogel network (Samutsri and Suphantharika, 2012).

***Steady flow behavior and temperature dependency*:** Starch pastes (5% w/v) with or without gums obtained from RVA were investigated to perceive the rheological behavior of starch/gum dispersions. Flow behavior index (n) and consistency coefficient (K) and values were calculated by plotting shear stress against shear rate and fitting with power law model. The data were well fitted with power law model with high determination coefficient (0.96-0.99) as presented in Table 2. All sample exhibited $n < 1$ regardless of the gum type, level and temperature, which indicates the non-Newtonian (pseudo-plastic) nature of the starch pastes. Plain rice starch exhibited n value (0.27) at 25°C, which was increased by the incorporation of flaxseed and okra gums. Alamri *et al.* (2012b) also reported an increase in n value with the addition of okra gum at various levels. However, contradictory results were reported by Hussain (2015) who evaluated the effect of flaxseed gum on rice starch. The difference might be ascribed to the different testing conditions, nature of gum and quantity used. On contrary, decreasing trend was observed in n value by the addition of arabic, xanthan, cress seed and fenugreek gums. This was in agreement with previous researches that gum inclusion significantly reduced the n value (Song *et al.*, 2006; Singh *et al.*, 2017). It could be attributed to the more structural

Table 2. Effect of gums at 0.5% and 2.0% concentration at different temperatures on consistency coefficient (*K*) and flow behavior index (*n*) of rice starch measured at 25, 35, and 45°C.

Temperature	Parameter	Conc.%	Control	Arabic	Xanthan	Cress seed	Fenugreek	Flaxseed	Okra
25°C	K^*	0.5	8.67	8.61	11.74	8.62	9.40	9.23	8.20
		2.0	8.67	7.70	13.47	7.68	10.67	11.27	7.95
	$n^\dagger$	0.5	0.27	0.25	0.26	0.25	0.26	0.29	0.28
		2.0	0.27	0.26	0.24	0.26	0.26	0.28	0.31
	R^2	0.5	0.99	0.99	0.97	0.96	0.99	0.98	0.97
		2.0	0.99	0.99	0.98	0.96	0.96	0.98	0.96
45°C	K	0.5	3.26	3.15	4.81	3.10	3.78	3.68	3.39
		2.0	3.26	2.52	7.60	2.86	4.43	3.96	3.12
	n	0.5	0.40	0.38	0.38	0.38	0.38	0.42	0.40
		2.0	0.40	0.40	0.36	0.39	0.39	0.41	0.40
	R^2	0.5	0.99	0.99	0.99	0.99	0.99	0.99	0.99
		2.0	0.99	0.99	0.99	0.99	0.99	0.99	0.99
65°C	K	0.5	2.78	2.66	4.60	2.56	3.08	2.95	2.40
		2.0	2.78	2.17	5.80	1.87	3.49	3.36	2.32
	n	0.5	0.37	0.36	0.35	0.39	0.37	0.41	0.38
		2.0	0.37	0.36	0.34	0.41	0.37	0.38	0.38
	R^2	0.5	0.99	0.99	0.99	0.98	0.99	0.99	0.99
		2.0	0.99	0.99	0.99	0.98	0.99	0.99	0.99

*K= (Pa.s) indices are obtained by fitting the data to power law $T = K\gamma^{\cdot n}$ and †n= flow behavior index (dimensionless). This Table was used for Arrhenius equation.

Table 3. Effect of gums at 0.5% and 2.0% concentrations on Arrhenius-type equation parameters of rice starch.

Parameters	$\mu_\circ$ (Pa s^n)*		E_a (J/mol K^{-1})†		R^2	
Conc. (%)	0.5	2.0	0.5	2.0	0.5	2.0
Control	1.99×10^{-8}	1.99×10^{-8}	24163	24163	0.88	0.88
Arabic	9.33×10^{-9}	1.09×10^{-9}	24948	26929	0.88	0.86
Xanthan	1.90×10^{-6}	2.51×10^{-5}	19980	17766	0.81	0.97
Cress seed	4.36×10^{-9}	8.70×10^{-11}	25772	29811	0.88	0.96
Fenugreek	3.98×10^{-8}	5.49×10^{-8}	23659	23668	0.90	0.92
Flaxseed	2.39×10^{-8}	8.51×10^{-9}	24177	25713	0.91	0.87
Okra	3.71×10^{-9}	3.01×10^{-9}	25949	26055	0.95	0.94

*μo (Pa s^n) = is the apparent viscosity at a reference temperature; †Ea = activation energy (J/mol K^{-1}) parameters were obtained by fitting experimental data to Arrhenius equation ($\ln \mu_a = \ln \mu_o + E_a/RT$).

breakdown caused by the presence of hydrocolloids because of shearing. Furthermore, the effect of xanthan was pronounced as compared to all other hydrocolloids, where it drops up to 0.24 at 2% xanthan concentration. Distinct behavior of xanthan gum could be ascribed to its high molecular weight, rod like conformation and rigidity (Kim and Yoo, 2006). Value of *n* was increased with increase in temperature from 25°C to 45°C. However, it was decreased with an increase in temperature from 45°C to 65°C. According to the (Alamri, 2014), it could be attributed to the natural characteristics of biomaterials which caused more pseudo-plasticity at higher temperature.

Consistency index (*K*) could be used as paste viscosity indicator. It was decreased by the addition and increasing concentration of arabic, cress seed and okra gums. It could be attributed to the presence of considerable amount of polysaccharides in the liquid phase of the composite system, which could signify that majority of the gum present in the liquid phase (Alamri, 2014). The results were consistent with the Alamri *et al.* (2012b) and Shrivastava *et al.* (2018) who studied effect of okra on rice and arabic on colocasia starch respectively. On contrary increasing trend was observed by the incorporation of xanthan, fenugreek and flaxseed gums. Similar results of increase in *K* value were reported by Hussain (2015) and Ji *et al.* (2017) who evaluated the effect of flaxseed gum on rice starch and xanthan gum on corn starch. Furthermore, substantial increase with xanthan gum could be attributed to the thickening effect of xanthan (Wang *et al.*, 2009), which was also recorded in RVA measurements as shown in Table 1. Value of *K* was reduced with increasing temperature implied that decrease in the viscosity as a function of temperature.

Meanwhile, these results were fitted with the Arrhenius equation model, which was used to evaluate the effect of temperature. It was critical to assess the effect of temperature of starch containing food products because they are subjected to various temperatures during processing, storage and transportation. The log of (*K*) was plotted against the reciprocal of temperatures in Kelvin and activation energy was calculated as shown in Table 3. The data were well fitted in the model as indicated by higher regression coefficient values, which ranges between (0.81-0.97). Remarkable decrease in the activation energy of xanthan incorporated rice starch blend (19980, 17766 J/mol K^{-1}) was recorded in comparison to the control (24163 J/mol K^{-1}). It revealed that the viscous properties of xanthan containing rice starch was least dependent on temperature followed by fenugreek blend as compared to the control. The results were consistent with the findings of Kim and Yoo (2006), who studied the effect of xanthan on rice starch and reported decrease in activation energy values. In contrast, activation energy was increased by the addition of arabic, cress seed, flaxseed and okra gums irrespective of their concentrations. Highest activation energy was observed with 2% cress seed gum (29811 J/mol K^{-1}), which indicated that it was the most temperature dependent with reference to the control.

***Texture analysis of rice starch gels*:** Textural parameters of rice starch alone and with various gums after overnight storage at room temperature are presented in Table 4. Rice starch gel possessed harness 0.212 N which was significantly increased by addition of fenugreek gum irrespective of their concentration and also with higher concentration of flaxseed gum. However, hardness was statistically same as a control at lower concentrations of flaxseed and okra gums. The plausible explanation might be the formation of hydrogen bonds between gums and starch, which cause significant increase in the hardness of the gels (Gałkowska *et al.*, 2014). Another plausible explanation might be the competition between gum and starch polymers for the water and decrease in amylose-amylose association (Arocas *et al.*, 2009). These results revealed that hardness values were positively correlated with the setback values as tabulated in Table 1.

On contrary, significant reduction in hardness was noticed by the incorporation of arabic, xanthan and cress seed gums regardless of their concentrations and also with higher level of okra gum. It showed that softer gels were produced by these gums as compared to the control. It could be attributed to the hindrance in the network development, which was caused by the associations between gums and leached amylose (Tang *et al.*, 2013). Same results were reported by Alamri *et al.* (2012a) and Matia-Merino *et al.* (2019) who evaluated the effect of okra on rice starch and xanthan on corn starch, respectively. Furthermore, it was noticed that the hardness was further decreased with increasing concentration of arabic, xanthan, cress seed and okra gums as compared to the control. It revealed that starch retrogradation was reduced with increasing concentration of these gums. Some others reasons might include properties of gel and good water holding capacity (Feng *et al.*, 2018). Cohesiveness revealed bonds strength increase with cress seed, fenugreek flaxseed and okra gums at both concentrations. However, significant increase was only observed at higher concentration of cress seed, fenugreek and flaxseed gums, where it increases to (0.75, 0.79 and 0.81) respectively. In contrast, reducing trend was noticed with arabic and xanthan gums. Springiness of the starch gel signifies the recovery from distortion. Higher values indicated that the structure of gel was broken down into big pieces while lower values revealed that the gel structure was damaged into small ones (Phimolsiripol *et al.*, 2011). It was significantly increased with arabic and xanthan gums while with fenugreek and flaxseed gums it was significantly decreased. According to Hussain (2015) it could be ascribed to the slow polymer aggregate formation because of the occurrence of gum, which caused high viscous region with less springiness. Adhesiveness was not changed significantly with the inclusion of gums irrespective of their type and concentration. The results were well supported by the observations reported for sweet potato and rice starch with okra and flaxseed gums respectively (Alamri, 2014; Hussain, 2015).

***Thermal properties*:** Thermal properties of rice starch blends are summarized in Table 5. Gums incorporation significantly affects the thermal attributes i.e. onset temperature, peak temperature and gelatinization enthalpy. However, effect was reliant on the gum type and level of inclusion. Increasing trend was noticed in onset and peak temperatures by the addition of gums irrespective of their type and concentration

Table 4. Effect of gums at 0.5% and 2.0% concentration on the TPA of rice starch.

Parameters	Conc. (%)	Control	Arabic	Xanthan	Cress seed	Fenugreek	Flaxseed	Okra
Hardness (N)	0.5	0.212±0.01^{ab}	0.193±0.01^{de}	0.183±0.01^{e}	0.199±0.01^{cd}	0.219±0.01^{a}	0.216±0.00^{ab}	0.206±0.01^{bc}
	2.0	0.212±0.01^{b}	0.163±0.01^{e}	0.167±0.01^{e}	0.180±0.01^{d}	0.229±0.01^{a}	0.222±0.01^{a}	0.193±0.01^{c}
Cohesiveness	0.5	0.72±0.04^{ab}	0.70±0.03^{b}	0.72±0.01^{ab}	0.74±0.02^{ab}	0.76±0.01^{a}	0.77±0.01^{a}	0.75±0.02^{ab}
	2.0	0.72±0.04^{cd}	0.69±0.02^{d}	0.70±0.02^{d}	0.75±0.01^{bc}	0.79±0.01^{ab}	0.81±0.02^{a}	0.73±0.01^{cd}
Springiness	0.5	9.50±0.10^{bc}	9.83±0.12^{a}	9.86±0.11^{a}	9.33±0.05^{cd}	9.26±0.11^{d}	9.30±0.10^{d}	9.60±0.10^{b}
(mm)	2.0	9.50±0.10^{b}	9.90±0.10^{a}	10.1±0.10^{a}	9.50±0.10^{b}	9.10±0.10^{c}	9.16±0.15^{c}	9.63±0.15^{b}
Adhesiveness	0.5	0.53±0.05	0.56±0.05	0.60±0.00	0.53±0.05	0.63±0.05	0.53±0.05	0.60±0.10
(mJ)	2.0	0.53±0.05	0.60±0.10	0.76±0.23	0.66±0.15	0.56±0.05	0.60±0.10	0.70±0.10
Chewiness	0.5	1.46±0.13^{abc}	1.33±0.04^{cd}	1.31±0.04^{d}	1.38±0.07^{bcd}	1.53±0.06^{a}	1.54±0.02^{a}	1.48±0.07^{ab}
(N.mm)	2.0	1.46±0.13^{b}	1.13±0.03^{d}	1.18±0.03^{cd}	1.29±0.01^{c}	1.65±0.04^{a}	1.64±0.02^{a}	1.43±0.03^{b}

Means estimated from three replicates with different superscripts within the same column are statistically significant.

Table 5. Effect of gums at 0.5% and 2.0% concentration on the DSC profile of rice starch.

Parameters	**Onset temperature (°C)**		**Peak temperature (°C)**		**Enthalpy (J/g)**	
Conc. (%)	**0.5**	**2.0**	**0.5**	**2.0**	**0.5**	**2.0**
Control	58.61±0.40^{a}	58.61±0.40^{c}	68.28±0.25^{c}	68.28±0.25^{c}	11.78±0.25^{a}	11.78±0.25^{c}
Arabic	59.21±0.61^{a}	59.32±0.35^{b}	68.99±0.19^{ab}	69.20±0.17^{b}	12.05±0.17^{a}	12.18±0.05^{ab}
Xanthan	59.16±0.83^{a}	59.40±0.45^{ab}	69.14±0.56^{ab}	69.18±0.13^{b}	12.14±0.14^{a}	12.31±0.07^{ab}
Cress seed	59.01±0.56^{a}	59.98±0.32^{ab}	69.26±0.09^{ab}	69.92±0.44^{a}	11.76±0.38^{a}	12.39±0.27^{a}
Fenugreek	59.07±0.19^{a}	59.37±0.30^{ab}	68.72±0.35^{bc}	69.42±0.34^{b}	11.85±0.45^{a}	11.98±0.12^{bc}
Flaxseed	59.02±0.71^{a}	60.03±0.03^{a}	69.02±0.65^{ab}	69.32±0.10^{b}	11.09±0.28^{b}	10.81±0.22^{e}
Okra	59.38±0.11^{a}	59.70±0.35^{ab}	69.60±0.09^{a}	70.21±0.24^{a}	11.24±0.07^{b}	11.17±0.21^{d}

Means estimated from three replicates with different superscripts within the same column are statistically significant.

but onset temperature at lower gum concentration (0.5%) was not increased significantly. Gelatinization involves the destruction of starch crystalline structure and loss of helical conformation. Increase in onset could be ascribed to less available water to the starch granules as it was immobilized by the gum (Hussain, 2015). Delayed in peak temperature might be due to the gums capability of delaying water diffusion to the starch granules which results in significant increase in the peak temperature (Chen *et al.*, 2016). Earlier, both these authors also reported delay in onset and peak temperatures of rice starch with flaxseed and xanthan gums at various levels.

Gelatinization enthalpy was increased by the addition of arabic, xanthan, cress seed and fenugreek gums and also with increasing concentration of these gums. It could be ascribed to the behavior of gums, which avoids the diffusion of water because of their hydrophilic behavior. It caused rise in the amount of energy required for the gelatinization of starch (Varela *et al.*, 2016). Previously, similar results were reported by the same author and Chen *et al.* (2016) during studying the effect of xanthan on rice starch and arabic on wheat-potato starch. In contrast, despite the delay in onset and peak temperatures, reducing trend was noticed with the inclusion of flaxseed and okra gums regardless of their concentration. Moreover, enthalpy was further dropped by increasing concentration of these gums. The results were consistent with the findings of Hussain (2015) and Alamri *et al.* (2012b) who studied the effect of these gums on rice starch at various concentrations. According to Lee *et al.* (2002), drop in enthalpy could be attributed to the partial mobility of amylopectin chains due to the presence of the gums as they were also competing for the water with starch components i.e. amylose and amylopectin. The second possible explanation might be the development of interactions between starch and gums or the partial starch gelatinization due to less available water (Chaisawang and Suphantharika, 2006).

***Conclusion*:** The presence of different gums strongly affected the functional properties of native rice starch. RVA results indicated that gum incorporation significantly decreased the setback viscosities of rice starch gum blends except fenugreek and flaxseed gums. Dynamic rheology data revealed an increase in moduli (G′ and G″) by the addition of gums as compared to the control except higher concentrations of cress seed and low concentration of flaxseed gums. Steady flow data stated that all samples exhibited $n < 1$ regardless of gum type, level and temperature, which indicated non-Newtonian nature of the starch pastes. Addition of Fenugreek and flaxseed gums increased the hardness and cohesiveness of starch gels. Thermal results suggested that enthalpy of gelatinization was increased by the addition of arabic, xanthan, cress seed and fenugreek gums as well as with the increase in concentration of these gums. The knowledge of pasting, rheological and thermal properties of rice starch/gum blends in the composite system could help in improving the rice starch based products formulations.

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