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Native Rice Starch and Linseed Gum Blends: Effect on Pasting, Thermal and Rheological Properties

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Abstract

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Native rice starch was replaced at 3, 6, 9, and 12% with linseed gum. The objective of replacement was to modify the starch properties as an alternative to chemical and enzymatic modification. In the presence of linseed gum, peak and final viscosities were increased significantly as compared to plain rice starch. Pasting temperature was decreased in the presence of gum. The differential scanning colorimeter (DSC) data of different blends showed that the peak temperature increased with higher levels of gum replacement. Data obtained from the Brookfield rheometer were best fitted to the power law model and demonstrated an increase in shear stress as a function of shear rate. Pseudoplasticity ($n < 1$) of the gels was increased as a function of gum concentrations. The texture profile analysis of gels revealed that increasing the linseed gum level resulted in higher hardness and adhesiveness.

Keywords: rice starch; linseed gum; pasting properties; thermal properties; blends

Starch is a major energy reserve in plants and is considered as a main component in a balanced human diet (Tester & Karkalas 2002). Starches are commercially extracted from sources like rice, potato, maize, and wheat. Starches have different functional properties depending upon the nature, amylose content, grain size and amylopectin chain length (Boudries *et al*. 2009). Starches are used as gelling, thickening, and texturising agents (Slattery *et al*. 2000). The native starches may have natural paucities like limited shear stress resistance during prolonged mixing, synaeresis, thermal decomposition, and higher retrogradation (Temisiripong *et al.* 2005). Repeated freezing and thawing of frozen foods containing starches can also lead to water separation and larger ice crystals may be formed if poorly handled during transportation in supply chain operations (Lee *et al*. 2002). The properties of native starches are therefore modified by physical, chemical, enzymatic or other means to improve their properties (Hussain *et al*. 2013; Alamri *et al*. 2013a,b). Due to market demand for economical, safe, and natural food ingredients, different types of hydrocolloid gums are used to modify the pasting, thermal, and functional properties of different native starches (Rojas *et al*. 1999; Funami *et al*. 2005; Nagano *et al*. 2008; Alamri *et al*. 2012a, 2013a,b). The freeze-thaw stability of starches and textural properties can also be modified by the inclusion of hydrocolloids (Lee *et al.* 2002; Liu *et al*. 1997).

Linseed (*Linum usitatissimum L.*) gum is extracted from grain and is composed of D-xylose, L-galactose, L-arabinose, L-rhamnose, and D-galacturonic acid (Warrand *et al*. 2005). The linseed gum has strong water-holding properties and its rheological properties are similar to the guar gum (Fedenuik & Biliaderis 1994). Linseed gum with maize starch was studied by Wang *et al*. (2008b), who reported that rheological properties were significantly influenced. The objectives of this work were to isolate linseed gum and study the effect on pasting, thermal, rheological, and textural properties of rice starch.

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MATERIAL AND METHODS

Material. Linseed grains were purchased from a local supermarket. Rice starch was supplied by Winlab Laboratory Chemicals, Leicestershire, UK.

Extraction of linseed gum. The extraction of linseed gum was conducted at room temperature using distilled water (Qian *et al*. 2012). Linseed grains (1000 g) were soaked overnight in 10 l of distilled water under gentle stirring. Extracted gum was filtered through muslin cloth to separate the grains. The mucilage gum was collected and centrifuged at 20 000 *g* at room temperature for 20 minutes. The supernatant was precipitated in 100% ethanol. The precipitate was freeze dried to obtain linseed gum powder.

Preparation of linseed gum starch blends. Rice starch was replaced by linseed gum powder at 3, 6, 9, and 12% levels to prepare starch blends while pure native rice starch was kept as the control in all experiments.

Rapid Visco Analyser measurements (RVA). Starch control or starch/linseed gum blends (3 g on 14% moisture basis) were directly weighed into RVA (Newport Scientific, Warriewood, Australia) aluminium canisters and distilled water was added to a total weight of 28 grams. The slurry was held at 50°C for 30 s, heated to 95°C in 4.40 min (at 10.23°C/min) and held at 95°C for 4 minutes. It was then cooled to 50°C in 2 min (at 22.5°C/min) and held at 50°C for 2 minutes. The rotating speed of the paddle was 960 rpm for the first 10 s and then it was reduced and kept at 160 rpm throughout the remainder of the experiment. Data were replicated thrice and Thermocline for Windows Software was used to process the data (Hussain *et al.* 2013).

Differential Scanning Calorimetry (DSC). DSC analysis was conducted to determine the thermal properties of starch blends using Setaram instruments Micro Evo DSC III (Setaram Instruments, Caluire, France). Starch samples (individual or blends, 240 mg) were placed in a standard Hastelloy cell and 400 µl distilled water was added. A suitable amount of distilled water was added in another cell to use it as a reference cell. Samples were sealed, equilibrated for 2 h and scanned at 2°C/min heating rate from 20°C to 110°C. Data was recorded for different parameters like gelatinisation enthalpy (ΔH in J/g), peak temperature (°C) and onset temperature for the major gelatinisation peak and the second peak representing the amylose-lipid complex (Alamri *et al*. 2013a).

Texture profile analysis of starch gels. Gels obtained from RVA experiments were poured in glass beakers (35 mm height, 30 mm internal diameter) and stored at room temperature overnight. Gels were compressed using a Brookfield CT3 Texture Analyser (Brookfield Engineering Laboratories, Inc., Middleboro, USA) in two penetration cycles at a speed of 0.5 mm/s to a distance of 10 mm using 12.7 mm wide and 35 mm high cylindrical probe. Gel hardness, springiness, cohesiveness and adhesiveness were recorded. The chewiness was calculated as a product of gumminess and springiness (Alamri *et al*. 2013b).

Synaeresis studies on starch gels. Starch gels from RVA canisters were poured to centrifuge tubes and frozen at –20°C. Tubes were taken out from the freezer on the 4th day and placed in water bath at 50°C for 30 minutes. Centrifugation was performed on gels at 3000 *g* for 15 minutes. Separation of water from gels was recorded and the gels were restored in a freezer. A similar procedure was performed on the 8th day of storage and the percent synaeresis from gels after three freeze-thaw cycles was reported on the 4th and 8th day of storage (Hussain *et al*. 2013).

Rheological measurements. Gels obtained from the RVA experiment were used to determine the viscosity and steady shear measurements using a rheometer (Brookfield DV-III; Engineering Laboratories, Inc., Middleboro, USA). An LV3 spindle of 0.7 cm in diameter was used. Apparent viscosity was recorded at RPM's starting upward from 20 to 160 RPM with an increment of 20 RPM and then coming downward from 160 to 20 RPM with a decrement of 20 RPM. Data were recorded for apparent viscosity (mPa·s) and shear stress (N·m^2) for each freshly prepared gel at 50°C.

Statistical analysis. All types of experiments were replicated thrice and data were subjected to one-way analysis of variance. Comparison of means was done by Duncan's Multiple Range (DMR) test at $P \leq 0.05$ using the PASW® Statistics v. 18 software (SPSS Inc., Chicago, USA.).

RESULTS AND DISCUSSION

Pasting properties of starch-gum mixtures. The pasting properties of the suspensions of rice starch and linseed gum blends are presented in Table 1 and typical RVA profiles are shown in Figure 1. The peak viscosity is actually an equilibrium point between maximum swelling of granules and leaching of starch molecules, i.e. amylose, and is an indication of the water-binding ability of starch. The rice starch without linseed gum indicated the lowest

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Table 1. Rapid visco analyser parameters of different starch blends

	Linseed gum (%)				
	0	3	6	9	12
Peak viscosity (cP)	1634.5 ± 26.16^{e}	2116.5 ± 126.57^{d}	2153.5 ± 7.78^{c}	2361.5 ± 45.96^{b}	2524.5 ± 108.19^{a}
Final viscosity (cP)	2125 ± 14.14^{d}	2660.5 ± 33.23^{c}	3059 ± 12.73^{b}	3224.5 ± 96.87^{a}	3329 ± 56.57^{a}
Setback (cP)	1121.5 ± 0.71^{c}	1418 ± 118.79^{b}	1723.5 ± 3.54^{a}	1657.5 ± 130.81^{a}	1497.5 ± 136.47^{b}
Peak time (min)	6.93 ± 0.00^{b}	7.00 ± 0.00^{a}	7.00 ± 0.00^{a}	7.00 ± 0.00^{a}	7.00 ± 0.00^{a}
Pasting temperature (°C)	89.525 ± 0.88^{a}	75.35 ± 0.85^{c}	74.025 ± 0.04^{c}	76.3 ± 1.27^{b}	77.5 ± 1.34^{b}

Means carrying same letters in the rows are statistically non significant

peak viscosity (PV) that improved with an increasing gum concentration with the most viscous nature of the blend at the highest replacement level. All the levels of linseed gum resulted in a significant improvement in PV of the blends; however, the maximum shift in PV was observed between 0 and 3% of linseed gum, which was 482 cP. The increasing PV can be explained by presupposing the rice starch/gum/water mixture to be a biphasic system where the linseed gum was located in the continuous phase and its effective concentration increased as the starch granules start swelling by taking up water at a high temperature. This starch granule swelling and rising up of the linseed gum concentration resulted in the improved viscous nature of gels that alluded the thickening ability of gum (Achayuthakan & Suphantharika 2008). Brennan *et al*. (2006) also observed higher PV with increasing concentrations of fenugreek gum. It is suggested that the blends with high PV might be used for bread and other baked products for the better texture (Inglett *et al*. 2013).

In the case of final viscosity (FV) compared to the control rice (0%) starch a significant ($P \leq 0.05$) improvement was observed in all the concentrations of linseed gum gels, although the rising trend was non-linear. Following a similar trend for peak viscosity, the 12% blend was again at the highest FV viscosity

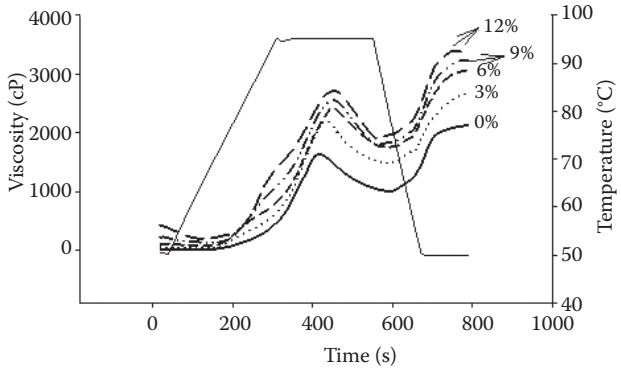

Figure 1. Rapid visco analyser profiles of different starch blends

indicating the maximum gelling ability of the blend. Compared to the control, a 25% increase in viscosity was observed by adding 3% linseed gum, which became about doubled for the 9% blend. However, the highest change (56%) in FV was seen for the blend with 12% linseed gum. So, the overall trend of increasing FV was 0 < 3 < 6 < 9 < 12%. Alamri *et al.* (2012a) reported higher PV and FV for rice starch after adding okra insoluble precipitates.

Setback (SB) viscosity has a direct relation with the texture of starch-based food products and it is an indication of starch retrogradation. With the increasing gum concentration up to 6%, an increasing SB was observed with the highest value of 1723 cP. This increase of SB is a typical behaviour of non-starch hydrocolloids because of their high water absorption that ultimately renders the starch/water system in a water deficit state and facilitates amylose retrogradation resulting in higher SB viscosities. But a further increase of linseed gum concentration up to 9 and 12% indicated an opposite trend of lowering SB. The plausible explanation might be that the linseed gum acted as a spacer between leached amylose fractions, and retarded their lining up together and networking ability, and finally resulted in the lowering of SB (Alamri *et al*. 2012a). So, higher linseed gum concentrations are good to get a softer and thicker gel.

In the RVA profile, the time corresponding to the peak viscosity (PV) is referred to as peak time (Pt). A significant increase in Pt was seen for 3% blend while from 3% to 12% a similar time for pasting was observed. A small increase in pasting time indicated a delay in the swelling of starch when blended with linseed gum.

In the RVA study, pasting temperature (PT) refers to the temperature at which viscosity starts rising and is considered the initiation point of gelatinisation. This temperature is an indication of the minimum heat needed to cook any starch-containing sample, and it

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Table 2. Differential scanning colorimeter parameters of different starch blends

		Linseed gum (%)				
		0	3	6	9	12
ΔH (J/g)		10.71 ± 0.16^a	9.71 ± 0.04^b	9.52 ± 0.12^c	9.11 ± 0.11^d	8.59 ± 0.08^e
PR (°C)		65.53 ± 0.15^e	66.49 ± 0.04^d	67.15 ± 0.03^c	67.69 ± 0.13^b	67.99 ± 0.08^a
OT (°C)		57.27 ± 0.18^e	57.45 ± 0.15^d	57.71 ± 0.25^c	57.93 ± 0.03^b	58.20 ± 0.17^a
Amylose lipid complex	ΔH (J/g)	1.28 ± 0.01^a	1.18 ± 0.12^b	1.11 ± 0.09^c	1.08 ± 0.05^d	0.66 ± 0.16^e
	PT (°C)	100.51 ± 0.06^a	99.76 ± 0.49^a	100.28 ± 0.28^a	100.10 ± 0.64^a	100.31 ± 0.03^a
	OT (°C)	93.40 ± 0.04^a	92.30 ± 0.28^a	91.75 ± 0.66^a	92.36 ± 0.67^a	93.54 ± 0.02^a

Means carrying same letters in the rows are statistically non significant; PT – peak temperature; OT – onset temperature

also provides the energy cost estimation. Control rice starch (0% blend) indicated the maximum pasting temperature (89.5°C); 3% blend resulted in a 14°C reduction in pasting but 6% blend presented a similar PT. With 9% blend there was a significant ($P < 0.05$) rise in temperature, however 12% blend indicated a similar PT again.

Maximum PT might imply the stronger interactions of starch granules with the least swelling as already indicated by the lowest peak viscosity. Lowering in PT could lead to the higher starch-gum interactions (spacer) that resulted in water penetration and earlier pasting. Reduced PT is an excellent indicator of earlier starch gelatinisation that is favourable for high amylolytic enzyme activities during bread baking.

Thermal properties of starch-gum mixtures. The DSC study was conducted for rice: linseed gum blends at various replacement levels of gum 0, 3, 6, 9, and 12% and the data are shown in Table 2. In each of the DSC profile of the studied blends two prominent peaks of endothermic transitions were seen. The first major and earlier transition in curve indicated the rice starch gelatinisation temperature curve while the second delayed and minor transition is an indication of order-disorder interactions of amylose with naturally present starch lipids at higher temperatures mostly observed near 100°C. The amylose–lipid complex formation has been identified in various cereal and non-cereal starches (Liu *et al*. 1997; Alamri *et al*. 2012b).

The temperature at the first peak of gelatinisation is referred to as PT in Table 2. A distinct and significant increase ($P \leq 0.05$) in peak temperature was observed as a function of the linseed gum concentration as presented in Table 2. This behaviour of increasing PT could be attributed to the gum ability to impede water absorption to starch granules for gelatinisation (as discussed earlier in RVA peak viscosity by considering the system as biphasic). Basically, the water molecule acts as a plasticiser in a polymer molecule solution where the least water content results in the highest gelatinisation temperature. Therefore, gelatinisation temperature is a moisture dependent property of starchy foods. Earlier, Alamri *et al.* (2012b) also reported increasing PT for rice starch blends with okra gum extract.

Energy required for the reversible swelling of granules corresponds to onset temperature (OT). The rice/linseed gum blends presented significantly higher OT values (°C) compared to control rice starch, which indicates higher energy requirements to start the starch gelatinisation process. A total higher shift of about 1°C in OT was observed from the control to 12% linseed gum blend. This delayed OT could be attributed to the lower water to starch ratio due to its immobility by gum (Biliaderis *et al*. 1980) and lower rate of heat transfer (Krüger *et al*. 2003). Alamri *et al.* (2012b) also reported a more pronounced delay of starch gelatinisation noticed by higher OT after the addition of okra extract (OE) with rice starch at various replacement levels.

In the DSC profile, enthalpy of gelatinisation (ΔH) is represented by the area under the curve, and it

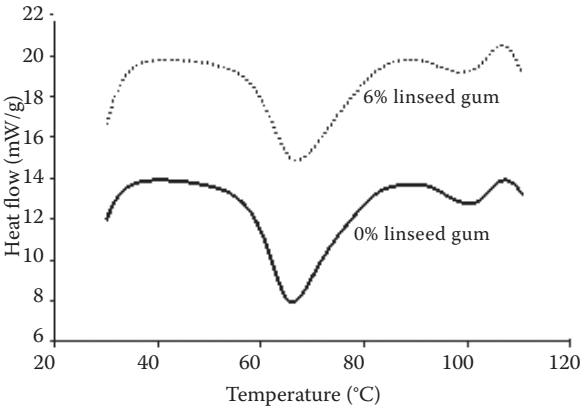

Figure 2. Differential scanning colorimeter thermograms of different starch blends

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Table 4. Syneresis from gels prepared from different starch blends

Linseed gum (%)	Syneresis (%)		
	1st 4 days	2nd 4 days	total
0	4.17 ± 1.52[a]	3.61 ± 0.69[c]	7.78 ± 1.1[c]
3	4.00 ± 0.3[a]	2.50 ± 0.8[c]	6.50 ± 0.41[c]
6	3.25 ± 0.26[b]	7.53 ± 0.9[b]	10.78 ± 0.8[b]
9	2.50 ± 0.15[c]	9.20 ± 1.18[b]	11.70 ± 1.2[b]
12	0.56 ± 0.29[d]	12.30 ± 0.07	12.86 ± 0.7[a]

Means carrying same letters in the columns are statistically non significant

was found significantly ($P \leq 0.05$) reduced with the increasing linseed gum concentration in the rice starch blends. The highest and the lowest value of ΔH was 10.71 and 8.59 observed for 0 and 12% linseed blends, respectively, with a shift of 2.12 (J/g). This drop in the blend enthalpy could be attributed to the reduced water availability resulting from partial gelatinization in starch crystalline regions, and the effect of starch-gum interactions (Chaisawang & Suphantharika 2006). In Indian black gram cultivars, a negative correlation was found between starch gelatinisation enthalpy (ΔH) and setback and final viscosity (Singh *et al*. 2004).

The peak temperature of rice/linseed gum blends PT for the amylose–lipid complex was found in the range of 99.76–100.51°C. Similarly, the onset temperature of blends was found statistically unchanged by increasing the linseed gum concentration with the maximum of 93.54°C for 12% blend. However, the ΔH of the complex was significantly ($P \leq 0.05$) decreased at higher linseed gum concentrations following the pattern presented by the gelatinisation enthalpy. This lowering of enthalpy could be attributed to the lower availability of amylose at higher gum concentrations that might be due to the amylose physical interaction with gum that hindered the amylose–lipid inclusion formation. Alamri *et al.* (2012b) also reported decreased ΔH of the rice starch amylose–lipid complex by higher OE addition.

Gel texture studies. Gels obtained from the RVA experiment were stored in beakers for 24 h at room temperature. The texture profile analysis was performed on different gels and the data for their different parameters like hardness, cohesiveness, springiness, adhesiveness and chewiness is presented in Table 3. Control starch (100% rice) exhibited the lowest hardness (0.25 ± 0.01). The hardness value increased with an increase in the linseed gum concentration. The hardness value of the different gels and the setback value observed from the RVA experiment are linearly correlated with each other. The higher hardness value observed with a higher level of gum can be attributed to the presence of gum that caused a competition for available moisture in the system and decreased the amylose–amylose interaction (Arocas *et al*. 2009). Similar results of higher hardness were obtained with the addition of gums like gellan, carrageenan, and glucomannan in rice starch (Huang *et al*. 2006). A slight reduction in the springiness of different starch samples was observed as a function of the gum level. Since the texture profile analysis comprised two compression cycles, most of the gels fractured after the first compression (Sanderson 1990). The deformation in samples with gums was more evident in comparison with the control. Less springy gels having lower rubberiness are easy to masticate (Marshall & Vaisey 1972). It was reported by Alamri *et al*. (2013b) that the slower polymer aggregate formation due to the presence of gum results in more viscous regions with reduced springiness. A significant increase in the adhesiveness of starch gels was observed with the inclusion of linseed gum. Higher adhesiveness of food containing rice is reported to have good taste (Marshall & Vaisey 1972).

Synaeresis studies. It has been reported that the presence of more setbacks reflects the higher degree of retrogradation and that it can be correlated with

Table 4. Texture profile analysis parameters of different starch blends

	0%	3%	6%	9%	12%
Hardness (N)	0.25 ± 0.01[e]	0.36 ± 0.02[d]	0.50 ± 0.00[c]	0.78 ± 0.10[b]	0.97 ± 0.06[a]
Cohesiveness	0.30 ± 0.01[e]	0.37 ± 0.02[d]	0.49 ± 0.01[c]	0.61 ± 0.00[b]	0.73 ± 0.01[a]
Springiness (mm)	9.48 ± 0.23[a]	9.10 ± 0.31[a]	8.25 ± 0.10[b]	8.01 ± 0.23[b]	7.82 ± 0.15[c]
Adhesiveness (mJ)	0.13 ± 0.00	0.18 ± 0.01	0.28 ± 0.01	0.36 ± 0.02	0.41 ± 0.01
Chewiness (N.mm)	2.37 ± 0.01	3.28 ± 0.03	4.13 ± 0.01	6.25 ± 0.05	7.59 ± 0.04

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a higher degree of synaeresis (Pomgsawatmanit & Sriunthongsiri 2008). The data presented in Table 4 indicate that during the first freeze-thaw cycle (the first four days of storage), the synaeresis was lowest (0.56 ± 0.29%) in the starch blend having 12% of linseed starch, while it was highest (4.17 ± 1.52%) in 100% rice starch gel. The reduction in synaeresis due to the presence of hydrocolloids was also reported by Lee *at al.* (2002) and Arocas *et al.* (2009). This reduction in synaeresis in the presence of hydrocolloids could be due to two possible reasons, either by the interaction of gum with amylose which competes against amylose- amylose interaction or by binding the available water in the system (Lo & Ramsden 2000; Arocas 2009; Alamri 2013a). It is evident from the table that synaeresis from the starch gels with a higher gum level was higher during the 2nd freeze-thaw cycle (the second four days), thus overall synaeresis was also higher. A possible reason for higher synaeresis during the second cycle could be the fact that the same gel used in the 1st cycle was restored and its structure was not intact after the centrifugation performed. The results of the present studies are in agreement with the findings of Alamri *et al.* (2012, 2013a,b) when okra gum was mixed with different starches.

Rheological measurements. Starch gels obtained from the RVA canisters were poured into 25 ml cylinders to study the flow properties. Data on apparent viscosity during ramping up and down for different rpm (20–160 rpm) with an increment of 20 rpm was recorded at 50°C. Shear stress data (ramping up and down) obtained at different shear rates were fitted into the power law model (Eq. 1).

$$T = K\gamma^n \quad (1)$$

where: T – shear stress (Pas); K – consistency coefficient ($Pas^{-1/n}$); γ – shear rate (s^{-1}); n – flow behaviour index (dimensionless)

The natural log of shear stress plotted against shear rate was used to obtain the values of K and n. The slope of the line obtained as a result of linear regression was used as n and the intercept as K value. Steady shear flow properties (K and n values) of the gels with or without linseed gums are presented in Table 5 while Figure 3 represents the plot of shear stress versus shear rate. It is evident from the data presented in Table 5 that all the blends were non-Newtonian (n value is lower than 1) and pseudoplastic irrespective of the gum concentration. The data document that as the level of linseed gum in blends increased, the blends became more pseudoplastic. The blend with 12% of gum was highly pseudoplastic (n = 0.16) as compared with control rice starch (n = 0.30) during ramping up of the shear rate studies. Higher coefficient of determination (R^2 = 0.99) confirms the best fitting of the power law model to correlate the flow properties of linseed-rice starch blends within the studied viscosity range. The increase in pseudoplasticity with the increasing gum concentration was also reported by many researchers (Wang *et al.* 2008a; Alamri *et al.* 2012b, 2013a). As observed in our studies, linseed

Table 5. n and K values of starch gels

	Rice starch and linseed gum (%)				
	0	3	6	9	12
Ramping up					
n	0.30	0.25	0.21	0.17	0.16
K	4.06	4.50	4.86	5.16	5.12
R^2	0.99	0.99	0.99	0.99	0.99
Ramping down					
n	0.35	0.36	0.36	0.36	0.39
K	3.82	4.07	4.26	4.36	4.48
R^2	0.99	0.99	0.99	0.99	0.99

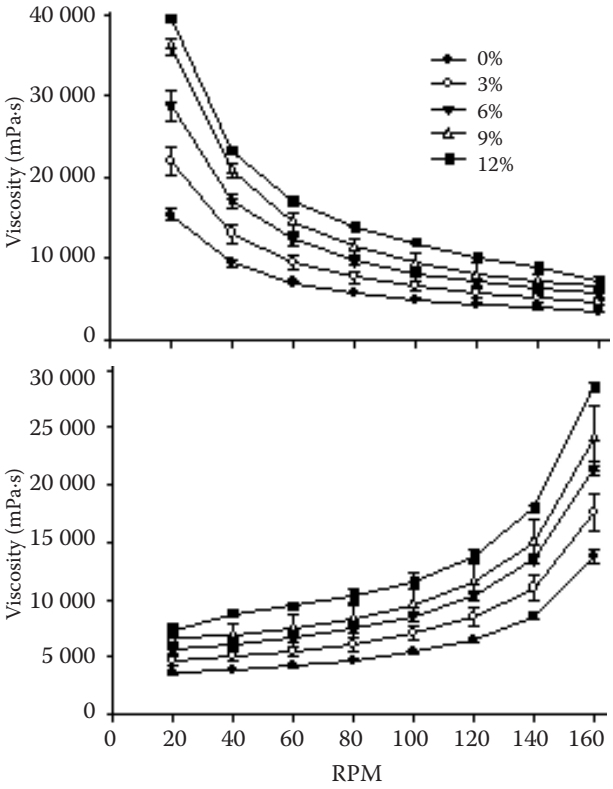

Figure 3. Steady shear properties of starch gels – rice starch/linseed gum ramping up (A) and ramping down (B)

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gum did not affect the overall flow behaviour but only changed the pseudoplasticity of the system. It is believed that pseudoplasticity depends on the number of molecules, their chain length and conformation (Szezesniak 1977). According to Nurul *et al*. (1999), disentanglement of long chain molecules causes a reduction in intermolecular resistance to flow under high shear conditions. It was reported by Wang *et al.* (2008b) that inclusions of flaxseed gum in maize starch decreased the *n* value which is indicative of higher plasticity. In our case, the effect of gum on starch paste was studied at 50°C, but the pseudoplasticity of rice starch-xanthan gum mixture increased at a higher temperature (Kim & Yoo 2006). The value of *K* (consistency coefficient, which has a direct relation with the viscosity of the system) was increased with the increasing concentration of linseed gum. The value of *K* for rice without linseed gum during ramping up was 4.06 and it was increased to 5.12 with the addition of 12% of linseed gum. A similar trend was also observed for ramping down studies. The increase in *K* value is directly related to the thickness of the sample and it is also clearly evident from the final viscosity of the sample observed in the RVA experiment (Table 1). The presence of gum in the starch samples affects the consistency due to a higher molecular weight and it is dependent on its concentration (Urlacher & Noble 1997). The shear thinning at a lower gum concentration is more evident as compared to a higher gum concentration, as observed during ramping up and down studies. Results obtained during current studies are in agreement with those reported by Kim and Yoo (2006) in which higher consistency coefficients were observed in rice starch with higher xanthan gum concentration.

CONCLUSION

The results of pasting properties of starch revealed that final, peak, and setback viscosities were increased in the presence of linseed gum. A significant influence on the thermal properties of rice starch was observed. There was a decrease in synaeresis from starch gels during the first freeze-thaw cycle, while an increase during the second freeze-thaw cycle was noticed in the presence of higher levels of linseed gum. Hardness of starch gels was higher in the presence of linseed gum. Overall, pseudoplasticity of the system was improved in the presence of linseed gum. This gum can be used as a suitable choice in those products where higher viscosity is required. Improvement in flowing properties of rice starch can also help to increase its application versatility in different products like soups, frozen desserts and gravies.

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