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Starch–galactomannan interactions: functionality and rheological aspects

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Incorporation of hydrocolloids into starch pastes modifies the rheological properties and also causes a synergistic increase in viscosity. These have been utilized in stabilizing products such as industrial dairy desserts and puddings. In the present work, an attempt has been made to study the interaction of corn starch and the less-explored waxy *Amaranthus paniculatas* starch at 5% w/v with the widely used galactomannans, namely guar gum and locust bean gum, in the concentration range 0–0.2% w/v, with respect to changes in paste viscosity and the gelatinization temperature, when heated in a Brabender amylograph. Some functional properties (e.g. freeze–thaw stability and stability under canning conditions) were also studied.

INTRODUCTION

Modification of the gelatinization as well as retrogradation characteristics of hydrocolloids make starch–hydrocolloid combinations useful in a wide variety of foods. Improvement in the texture, mouthfeel and processing properties are further advantages (Descamps *et al.*, 1986; Tye, 1988; Alloncle & Doublier, 1991).

Galactomannans are water-soluble polysaccharides found in seed endosperms of a variety of legumes. They essentially consist of 1–4-linked β-D-mannopyranosyl backbone partially substituted at 0–6 with D-galactopyranosyl side groups. Guar gum, obtained from *Cyamopsis tetragonolobus* seeds and locust bean gum, isolated from *Ceratonia siliqua* seeds, are the widely used industrial galactomannans. Guar gum and locust bean gum basically differ in their mannose:galactose ratio, which is around 2:1 for guar gum and 4:1 for locust bean gum (Sprenger, 1990).

The functional properties of these water-soluble polysaccharides are widely used in the food industry. These galactomannans confer desired properties such as texture and stability by controlling the rheological properties of the aqueous phase. They also confer gel properties in aqueous systems (Dea *et al.*, 1977) and they are known to participate in synergistic interactions with other polysaccharides such as xanthan, carrageenan and agar (Dea *et al.*, 1972; McCleary, 1979).

No reports are as yet available on the interaction of galactomannans with the widely-used versatile polymer, starch. Hence this present work was aimed at studying the behaviour of corn starch and waxy small-sized (1–2 μm) *Amaranthus paniculatas* (Singhal & Kulkarni, 1988) starch with guar gum and locust bean gum with respect to the pasting characteristics, gelatinization temperature, freeze–thaw stability, stability under canning conditions and the rheological profiles.

MATERIALS AND METHODS

Materials

Corn starch, food grade guar gum and locust bean gum were obtained from M/S Laxmi Starch Pvt. Ltd, Bombay, Indian Gum Industries, Bombay and Sigma Chemicals, USA, respectively. *Amaranth* starch was isolated from the grains by the alkali steeping method (Yanez & Walker, 1986)

Methods

Paste viscosity and gelatinization temperature

In a total volume of 450 ml water, 5% corn starch (having a moisture content of approximately 10%) was mixed individually with 0–0.2 w/v of guar gum (having a moisture content of 8%) and locust bean gum (having a moisture content of 8%) and heated in a Brabender amylograph (Model PT 100) from 35 to 95°C at a rate of 1.5°C/min at 75 rpm, held at 95°C for 10 min and then cooled back to 40°C at the same rate. Similar experiments were carried out with *Amaranth* starch. The

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results were interpreted with respect to gelatinization temperature and cold paste viscosity.

Freeze–thaw stability

Ten grammes each of the pastes of starch alone, and starch–gum combinations prepared as above, were taken in several test tubes and the freeze–thaw stability was studied by alternate freezing and thawing (18 and 6 h at −18°C and room temperature of 30°C) followed by centrifugation at 4000 rpm for 10 min (Kite *et al.*, 1963). Freeze–thaw stability was expressed as the percentage of water separated after each freeze–thaw cycle.

Stability under canning conditions

Five per cent starch and 0–0.2% gums were weighed separately and transferred to beakers containing 150 ml water. These combinations were then stirred well and steamed at 100°C for 30 min. The resulting pastes were then cooled, homogenized for about 30 s and the viscosity measured using a Brookfield viscometer (RVT Model) using an appropriate spindle at 100 rpm. The same pastes were then autoclaved for 30 min at 15 psig to simulate canning conditions and the viscosity again measured (Kite *et al.*, 1963).

Rheological study of starch–galactomannan combinations

Five grammes of starch (corn as well as amaranth) were mixed individually with 0.05, 0.10 and 0.25 g of guar gum in 100 ml water. Each of the above mixtures were stirred well and heated to 95°C for 10 min and then cooled to room temperature (30 ± 1°C). Rheological behaviour of the pastes as prepared above were studied using an Haake viscometer (Model RV3) in the shear rate range of 100–1200 s^{-1}. The flow behaviour index and the consistency index were calculated using a log–log plot of shear rate vs shear stress (Holdsworth, 1971). The experiments were also performed with locust bean gum.

RESULTS AND DISCUSSION

The cold paste viscosity and the gelatinization temperature of 5% corn starch and its combinations with 0–0.2% locust bean gum and guar gum are shown in Table 1. It is observed that, as the concentration of the gum increases, the gelatinization temperature decreases and the cold paste viscosity increases. For instance, peak viscosity increases from 130 BU for corn starch alone to 250 BU for its combination with 0.2% w/v guar, and to 170 BU for its combination with 0.2% w/v locust bean gum. The corresponding values for cold paste viscosity for corn starch alone, its combination with guar gum and locust bean gum are 240, 480 and 420 BU, respectively. These data suggest a higher synergism with guar gum, which could be because of its greater hydration capacity as compared to locust bean gum (Glicksman, 1969). This is partially supported from the evidence obtained from rheological properties of cereal starch–galactomannan mixtures (Alloncle *et al.*, 1989). According to this report, starch pastes are described as suspensions of swollen particles dispersed in a macromolecular medium. It is suggested that galactomannans are located within the continuous phase, and thus the volume of the phase accessible to the galactomannan is reduced, which causes a dramatic increase in its concentration in the continuous medium, thereby resulting in a very high viscosity. The swollen particles are mainly composed of amylopectin, while the continuous medium consists of amylose. It is probably the amylose–galactomannan interaction which is dominating in the system. This is clearly seen in Table 2 which shows pasting characteristics of guar gum and locust bean gum with amaranth starch, which is devoid of amylose. Although the incorporation of guar gum and locust bean gum did increase the peak viscosity as well as the cold paste viscosity of amaranth starch, in contrast to corn starch, no sharp differences among starch–guar gum and starch–locust bean gum combinations were noticed. For instance, peak viscosity

Table 1. Comparative effect of addition of guar gum and locust bean gum on the viscosity and the gelatinization temperature of corn starch

Ingredients	Gelatinization temperature (°C)		Peak viscosity (BU)		Viscosity at 95°C (BU)		Viscosity after 10 min at 95°C (BU)		Cold paste viscosity at 40°C (BU)	
	GG	LBG	GG	LBG	GG	LBG	GG	LBG	GG	LBG
5% CS	86.6	86.6	130	130	120	120	100	100	240	240
5% CS+X1	84	86	140	130	130	130	130	100	280	260
5% CS+X2	82.5	85	160	150	140	150	130	130	340	300
5% CS+X3	80.3	84	250	170	220	170	210	160	480	420

CS: 5% w/v corn starch.
X1: 0.05% w/v hydrocolloid.
X2: 0.10% w/v hydrocolloid.
X3: 0.25% w/v hydrocolloid.
GG: guar gum.
LBG: locust bean gum.

Table 2. Comparative effect of addition of guar gum and locust bean gum on the viscosity and the gelatinization temperature of amaranth starch

Ingredients	Gelatinization temperature (°C)		Peak viscosity (BU)		Viscosity at 95°C (BU)		Viscosity after 10 min at 95°C (BU)		Cold paste viscosity at 40°C (BU)	
	GG	LBG	GG	LBG	GG	LBG	GG	LBG	GG	LBG
5% AS	68.5	68.5	220	220	190	190	180	180	280	280
5% AS + X1	68	69	270	250	250	240	240	220	350	320
5% AS + X2	68.2	68.5	310	280	290	260	300	240	390	360
5% AS + X3	68.5	69	370	350	340	310	320	300	460	450

AS: 5% w/v amaranth starch.
X1: 0.05% w/v hydrocolloid.
X2: 0.10% w/v hydrocolloid.
X3: 0.25% w/v hydrocolloid.
GG: guar gum.
LBG: locust bean gum.

increases from 220 BU for amaranth starch alone to 370 BU for its combination with 0.2% w/v guar, and to 350 BU for its combination with 0.2% w/v locust bean gum. The corresponding values for cold paste viscosity for amaranth starch alone, and its combination with guar gum and locust bean gum are 280, 460 and 450 BU, respectively. Amaranth starch itself has a high swelling power owing to its waxy nature and it is possible that the two hydrocolloids increase the swelling power of amaranth starch to similar extents, as is evident from the peak viscosity values.

It can be seen from Tables 1 and 2 that the gelatinization temperatures of starch–hydrocolloid combinations are affected differently by corn and amaranth starch. While there was no significant change in the gelatinization temperature of amaranth starch on the addition of either guar gum or locust bean gum, a decrease was observed with corn starch. However, the comparative decrease in gelatinization temperature was greater for guar gum. For instance, the gelatinization temperature of 86.6°C of corn starch decreased to 80.3°C and 84.0°C on addition of 0.2% guar gum or locust bean gum, respectively. These results also suggest a stronger influence of guar gum (from locust bean gum) on pasting properties of corn starch. While the reasons for the decrease in gelatinization temperature are difficult to comprehend, a similar effect has been reported by Christianson *et al.* (1981).

Figures 1 and 2 give the freeze–thaw stability of corn starch and the effect of incorporation of guar gum and locust bean gum, respectively. Figures 3 and 4 give similar data for amaranth starch. It is evident that amaranth starch shows better freeze–thaw stability, a fact that can be attributed to its low retrogradation tendency which in turn is due to its waxy nature (Singhal & Kulkarni, 1990; Sudhakar *et al.*, 1992). This is further improved on incorporation of both the galactomannans. In the case of corn starch, which itself has a poor freeze–thaw stability, incorporation of guar gum and locust bean gum improves the stability quite significantly. For instance, at the end of the sixth cycle, the percentage water separation for corn starch alone and its combinations with 0.2% w/v guar or locust bean gum were 60.3, 37.6 and 35.3%, respectively. Guar gum was better than locust bean gum in this respect. The improvements in freeze–thaw stability could be owing to interaction of these hydrocolloids with amylose, thereby slowing down the retrogradation. This is in accordance with an earlier report where guar gum and locust bean gum were used in frozen pie fillings (Carlin *et al.*, 1954), which prevented dehydration and also gave better product stability.

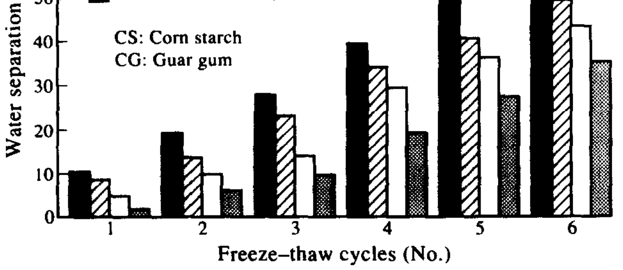

Fig. 1. Freeze–thaw stability of corn starch–guar gum combinations.

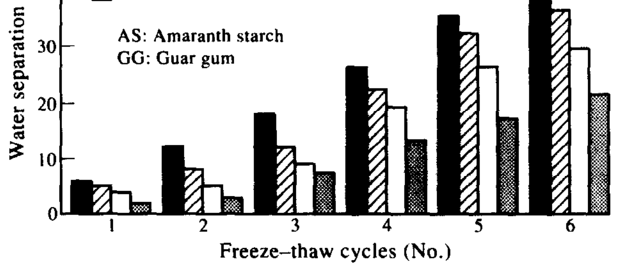

Fig. 2. Freeze–thaw stability of amaranth starch–guar gum combinations.

Table 3. Effect of galactomannans on the canning stability of starch pastes[a]

Ingredients	Viscosity before canning (cPs)		Viscosity after canning (cPs)	
	GG	LBG	GG	LBG
5% CS	575	575	570	570
5% CS+X1	700	675	710	665
5% CS+X2	810	740	805	750
5% CS+X3	1450	1180	1460	1170
5% AS	495	495	505	505
5% AS+X1	560	540	555	545
5% AS+X2	700	680	720	690
5% AS+X3	980	900	970	890

[a]Values are average of two determinations.
CS: 5% w/v corn starch.
AS: 5% w/v amaranth starch.
X1: 0.05% w/v hydrocolloid.
X2: 0.10% w/v hydrocolloid.
X3: 0.25% w/v hydrocolloid.
GG: guar gum.
LBG: locust bean gum.

Table 4. Rheological profile of corn and amaranth starch and its combinations with guar gum (GG) and locust bean gum (LBG)

Ingredients	Flow behaviour index (n)		Consistency index (K)(Pa.s^n)	
	GG	LBG	GG	LBG
CS	0.75	0.75	0.089	0.089
CS+X1	0.70	0.68	0.386	0.335
CS+X2	0.46	0.49	1.61	1.45
CS+X3	0.45	0.45	1.925	2.35
AS	0.35	0.35	7.03	7.03
AS+X1	0.39	0.39	7.65	7.67
AS+X2	0.39	0.40	8.14	8.27
AS+X3	0.40	0.40	8.87	10.05

CS: 5% w/v corn starch.
AS: 5% w/v amaranth starch.
X1: 0.05% w/v hydrocolloid.
X2: 0.10% w/v hydrocolloid.
X3: 0.25% w/v hydrocolloid.

Stability of corn starch–galactomannan and amaranth starch–galactomannan combinations are as presented in Table 3. It can be seen that all the combinations had a good resistance to viscosity breakdown at sterilization temperatures. Guar gum (Glicksman, 1969) as well as locust bean gum (Mckiernan, 1957) are known to possess heat shock resistance and this feature is retained even when used in combination with starch. Good stabilities of corn starch–CMC and amaranth starch–CMC combinations have already been reported from our laboratories (Sudhakar *et al.*, 1992).

Results in Table 4 depict the flow behaviour index (n) and the consistency index (K) of corn starch–galactomannan and amaranth starch–galactomannan combinations. While the flow behaviour index of corn starch decreased on incorporation of hydrocolloids, a similar trend was not seen with amaranth starch. A lower value of flow behaviour index indicates a pseudoplastic nature, and hence it can be concluded that corn starch–galactomannan combinations are more pseudoplastic than starch alone. Wheat starch–guar is reported to have a higher pseudoplasticity than wheat starch–locust bean gum combination (Sajjan & Rao, 1987). However, in the range of gum concentrations studied, no significant differences in the flow behaviour index were found between guar gum and locust bean gum. With amaranth starch, such an effect was not seen. *Amaranth* starch itself has a higher degree of pseudoplasticity, which again is attributed to its waxy nature. Guar gum is a non-ionic hydrocolloid in which the alternate galactose branches inhibit the formation of intramolecular hydrogen bondings. This keeps the molecule in an extended form, which can readily interact with amylose molecules through non-covalent hydrogen bonding. This results in an extended conformation, which in turn increases the degree of pseudoplasticity. A similar explanation may hold true for the effect of locust bean gum on the flow behaviour index. The consistency index increases on incorporation of both the galactomannans, a fact attributed to synergism (Descamps *et al.*, 1986; Allonce *et al.*, 1989)

In order to compare the results obtained using the

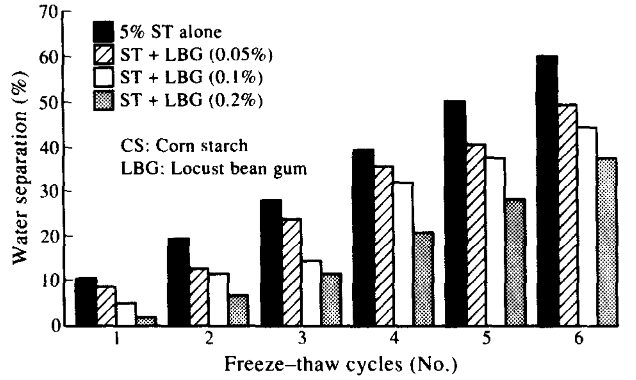

Fig. 3. Freeze–thaw stability of corn starch–locust bean gum combinations.

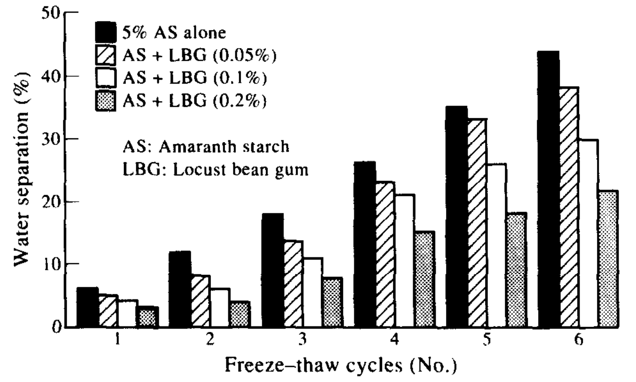

Fig. 4. Freeze–thaw stability of amaranth starch–locust bean gum combinations.

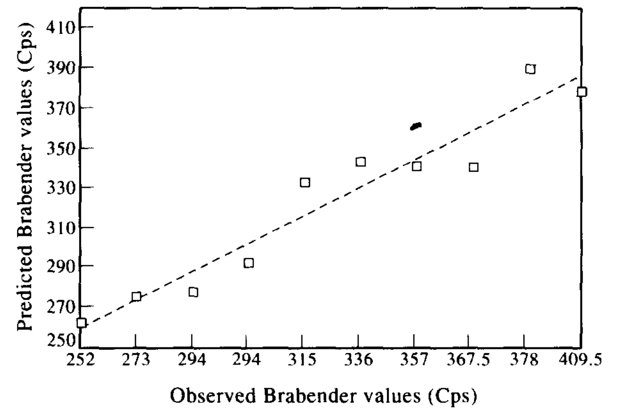

Fig. 5. Predicted vs observed Brabender cold paste viscosity of all the model systems.

Brabender amylograph which has a fixed configuration and shear rate (approximately 40 s^{-1}), plots of Brabender cold paste viscosity vs consistency index of corn starch–galactomannan combinations and amaranth starch–galactomannan combinations were individually obtained to give a regression output using Lotus software. The consistency index was converted to cPs by the formula 1 $Pa.s^n = 100$ cPs. Similarly, Brabender cold paste viscosity values were also converted into cPs using the relationship 1 BU = 1.05 cPs under the experimental conditions of a bowl speed of 75 rpm, heating rate 1.5°C/min and a 350 cmg cartridge used (Wood & Goff, 1973). Correlation coefficients of 0.86 for corn starch–galactomannan combinations and 0.81 for amaranth starch galactomannan combinations were obtained. Using the regression equation, predicted Brabender cold paste viscosity was calculated in both cases. Figure 5 shows a plot of predicted vs observed Brabender cold paste viscosity of all the model systems ($R^2 = 0.89$). The close proximity of the observed Brabender values to the predicted values validates the starch–galactomannan interactions as obtained only from a single point measurement using the Brabender amylograph.

These results are of value in designing new thickeners for starch-based canned products, sauces, soups, salad dressings and frozen desserts at economical costs with better product quality. Rheological data suggest ease in pumping and filling operations in food processing lines resulting from the high pseudoplastic nature of these combinations.

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