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Swelling and Pasting Properties of Non-Waxy Rice Flour/Food Gum Systems

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Abstract The effects of gellan gum (from *S. paucimobilis*), EPS-CB (exopolysaccharide from *S. chungbukensis*), and a series of commercial gums (arabic gum, xanthan gum, guar gum, deacyl gellan gum), on the swelling, rheological, and pasting properties of non-waxy rice flour dispersions were investigated. The swelling properties of rice flours in gellan or guar gum dispersion after heating were found to have increased with increasing gum concentrations, but the swelling properties of rice flour/other gum systems decreased with increasing concentrations. The rice flour/gum mixtures showed high shear-thinning flow behavior (n=0.14-0.32), and consistency index (K) was higher in guar gum than other gum dispersions. The initial pasting temperatures and peak times increased along with increasing gum concentration. The peak viscosity of rice flour increased in guar gum and deacyl gellan dispersions, and the breakdown and setback viscosity of the rice flour paste was lowest in the xanthan gum system, but remained higher than those of the control. The apparent viscosities of the rice flour/gellan gum mixture pastes were the highest among the tested combinations.

Keywords: non-waxy rice flour, swelling power, rheological behavior, pasting properties, gum

Introduction

Rice constitutes the primary cereal crop grown in both East and Southeast Asia, a region which includes the Republic of Korea. The majority of domestic rice production is targeted toward the consumption of cooked rice, and only 5% of total rice production is actually used in the manufacture of rice products. In the Republic of Korea, it is clearly necessary to concentrate on the development of rice grains and rice flour products, as rice production and importation continue to increase in Korea, whereas the consumption of these products has shown a trend toward gradual decrease. As rice stocks annually increase, rice consumption must be balanced by the development of new rice products, such as bakery products and noodles, as well as products in which traditionally-used wheat flour is supplanted by rice flour. Gluten is a crucially important protein in the formation of the gluten network in wheat flour dough and in the leavening process, however rice flour dough does not develop a network because it lacks gluten. Therefore, in order to form a network for the confinement of a leavening agent in the manufacture of products such as rice bread or cake, new additives must be tested for their efficacy in this regard.

Food gums have been used fairly extensively in starch-based products, often as additives to improve stability and texture, retard the retrogradation of the starch, increase moisture retention, improve the overall quality of the product, confer a variety of gelatinization and rheological properties, and as gluten-substitutes in the production of gluten-free bread (1-6). Such combinations have been utilized in a variety of food products such as bakery and cereal goods (7, 8). Many studies involving food gums have already been conducted in order to characterize the interactions occurring between the hydroxyl groups in the gum and the starch components of the flours (2, 9). Some gums are used as thickeners, stabilizing agents, and gelling agents. Among the food gums which have been previously tested are guar gum, locust bean gum, and xanthan gum. However, the majority of those studies were targeted toward the clarification of the interactions occurring between gum and starch components (9), and those analyses have been generally performed with high gum concentrations. Our laboratory generated novel exopolysaccharides and purified gellan gum from *Sphingomonas* species. Therefore, we will use these gums in bakery products which use rice flour, without the addition of gluten.

The objective of this study was to characterize the effects of different concentrations of various gums on the swelling power, rheological behavior, and pasting properties of rice flour. Therefore, we assessed the influence on the networking of rice flour products due to the produced gums, and compared them to the effects of commercial gums, including xanthan gum, guar gum, deacyl gellan gum, and arabic gum in rice flour/gum mixtures.

Materials and Methods

Materials Rice flour was prepared by soaked and dry milled non-waxy rice (cultivar, Ilmibyeo) and sifting it through a 100-mesh sieve (<150 μm). The moisture, protein, and ash contents were determined to be 10.62, 6.98, and 0.29%, respectively (10). The gellan gum and EPS-CB (exopolysaccharide from *S. chungbukensis*) were generated by *S. paucimobilis* ATCC 31461 and *S. chungbukensis* DJ77, respectively. These microorganisms were obtained from the genetics lab of Chungbuk National University (Cheongju, Korea). The deacyl gellan (gelrite), xanthan gum, guar gum, and arabic gum were all

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purchased from Sigma Chemical Co. (St. Louis, MO, USA).

Production and purification of exopolysaccharides The gellan gum and EPS-CB used in this study were generated by *S. paucimobilis* ATCC 31461 and *S. chungbukensis* DJ77 by the Nampoothiri *et al.* (11) method. The culture broth was diluted two-fold with distilled water, and then centrifuged for 20 min at 3650×g in order to remove the cells. To remove the proteins, the supernatant was heated in a boiling water bath for 15 min, centrifuged again and the supernatant was collected for purification.. In order to purify the gellan gum and EPS-CB, the recovered precipitates were dissolved in distilled water for at least 1 hr, and then centrifuged for an additional 20 min at 3650× g. The supernatants were then mixed with 3 volumes of cold ethanol, stored for 4 hr at 4°C, and centrifuged under the same conditions. The precipitated materials (2 g) were dialyzed using cellulose ester membranes (Cat No 08-671-33, Spectra/Por membrane MWCO: 10,000 Da; Fisher Sci., Pittsburgh, PA, USA) with deionized-distilled water (50 mL). After dialysis, the residues were dried. The sugar composition and molecular weight of gellan and EPS-CB, which were produced in the lab, were determined using high performance anion exchange chromatography (HPAEC), thin layer chromatography (TLC) and gel filtration chromatography. The gellan contained D-glucose, L-rhamnose, and D-glucuronic acid in the molar ratios 2:1:1, and the molecular weight of gellan gum was 6.8 $\times 10^6$ Da. EPS-CB contained glucose, mannose, and an unknown sugar with a molecular weight of ca. 10^3 Da (unpublished data).

Determination of swelling power and solubility The swelling power of each rice flour/gum system was determined in accordance with Schoch's method (12). The gums (0.05 and 0.1%) were prepared in 50 mL vials with distilled water and stirring with a magnetic bar (ϕ3.2 × 13 mm). The rice flour (0.5 g, db) was then added to 50 mL centrifuge tubes with magnetic bars, and the gum dispersions (20 mL) were added. The tubes were heated with stirring for 30 min in a boiling water bath, cooled in cold water, then centrifuged at 1450×g for 20 min. The supernatants were then discarded, and the residues were weighed. Solubilities were determined by drying the supernatants in weighing dishes and weighing the remaining solids.
The equations used in this procedure were as follows.

Swelling power = weight (g) of residue after centrifuging × 100/sample dry wt (g) × (100 - % solubility)

Solubility (%) = Dry weight of supernatant after centrifuging (g) × 100/sample dry weight (g)

Rheological measurements The rheological properties of rice flour/gum mixtures were measured with a Rheometer (Rheometric Scientific ARES, TA Instruments, New Castle, DE, USA) using a parallel plate system (ϕ 2.5 cm) with a gap of 1 mm. The rice flour (5%, w/v) in 0.1% gum dispersion was stirred for 1 hr and heated in a boiling water bath for 30 min with agitation. After heating, the hot paste was immediately transferred to the rheometer plate for measurements of rheological properties. The excess material was wiped off with a spatula. Steady shear (shear stress and shear rate) data were obtained over the shear rate range of 0.02-1,000 sec^{-1} at 80°C.
The data were fitted to the well-known power law model (Eq. 1)

$$\sigma = K\,\dot{\gamma}^{n} \qquad (1)$$

where σ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (sec^{-1}), K is consistency index (Pa · sec^n), and n is the flow behavior index (dimensionless). Apparent viscosity ($\eta_{a,100}$) at 100 sec^{-1} was calculated from the magnitudes of K and n.

Determination of apparent viscosity and morphology The apparent viscosities of the rice flour hot and cold pastes in the gum dispersions were then determined using a Brookfield viscometer (Brookfield Engineering Lab. Inc., Stoughton, MA, USA). The samples of rice flour (0.5 g, db), 0.1% gum dispersion (10 mL) and a magnetic bar (ϕ3.2 × 13 mm) were all placed into 50 mL centrifuge tubs with screw caps. These tubes were heated with continuous stirring in a boiling water bath for 20 min and shaken in order to mix and remove any air bubbles. Samples were maintained in the tubes for 30 sec, after which the apparent viscosity of hot paste was determined as the point recorded after 5 spindle rotations. After measuring the hot paste, the tube was stored at room temperature for 3 hr, and the apparent viscosities were determined again. The hot and cold pastes were compared to determine the maximum viscosity. The LV No. 2 spindle was used at 12 rpm for the aforementioned experiments.

A small portion of the paste was frozen at -70°C and freeze-dried using a freeze-dryer (FD 5505; Vision, Seoul, Korea). The dried sample was coated with Pt and observed using a scanning electron microscope (JEOL JSM-5400; Tokyo, Japan) at an accelerated voltage of 25 kV, phototimes 85 sec, magnification ×1000.

Pasting behavior determined by the Rapid Visco-Analyzer The pasting behavior of the rice flour mixtures was characterized using a Rapid Visco Analyzer (RVA, Model 3D; Newport Scientific Pty., Ltd., Narranbeen, Australia) in accordance with the AACC standard method (10). The rice flour (3 g, 12% moisture) was then transferred into 0.05, 0.1, and 0.2% gum dispersions (25 g) in distilled water within the canister, and mixed thoroughly. The temperature was maintained for 2 min at a uniform 50°C, after which the temperature was raised to 95°C, at a constant rate of 12°C/min. The samples were maintained for 2.5 min at 95°C, cooled to 50°C at the same scanning rate, and then maintained for another 2 min at 50°C. Agitation speed was fixed at 960 rpm for the first 10 sec in order to ensure the uniformity of the dispersion, and was then decreased to 160 rpm, which was maintained throughout the rest of the measurements. A paste viscosity plot expressed in arbitrary RVA units (RVU) versus time was then utilized in order to determine the initial pasting temperature, peak time, peak viscosity (P), trough viscosity (T), final viscosity (F), breakdown viscosity (P-

T), and setback viscosity (F-P).

Statistical analysis All samples were analyzed at least in duplicate, except where otherwise indicated, and all data was expressed as mean values and standard deviations. All statistical analyses were conducted via Duncan multiple range tests, using the SAS software package (SAS Institute Inc., Cary, NC, USA).

Results and Discussion

Effect of various gums on swelling power and solubility of rice flour paste The wet milled rice flour was used for improving flour physicochemical properties (13). The swelling power and solubility of various rice flour/gum mixtures are listed in Table 1. The swelling power of the rice flour suspension (control) was 2.86 at 25°C, but was 24.9 at 100°C. Most of the swelling power values of the rice flour/gum systems were found to have increased slightly with increasing concentrations (0.05 vs 0.1%) of the gums. Gellan gum, guar gum, and xanthan gum (0.1%) exhibited increases in swelling power relative to the control, but other gums exhibited values slightly lower than those of the control. Increases in swelling power may be attributable to interactions between the hydroxyl groups of the gums and swollen starch granules in the rice flour and the gum mixture. Swelling can also be positively related with the amount of soluble solids which leach outside the granules during heating (14). Some starch types have been shown to exhibit reduced swelling power when a greater quantity of solid leaches out during heating at higher temperatures (15). Other components of rice flour, including proteins, lipids, and ash might also influence the swelling properties of starch. Different gums revealed different swelling power trends in rice flour/gum systems. In general, the addition of gum increases swelling power with increasing gum concentrations within the system, but the degree to which this is manifest varies with the type of gum employed. The gellan gum generated by *S. paucimobilis* showed the highest degree of swelling power enhancement, and also the lowest solubility in the rice flour/gum system. This revealed that gellan gum interacted tightly with starch granule components, amylose and the soluble fraction of amylopectin.

Table 1. Swelling power and solubility of rice flour pastes in different types and concentrations of gum dispersions at 100°C

Gum	Concentration (%)	Swelling power at 100°C	Solubility (%) at 100°C
None		24.93±0.59[d1)]	14.93±1.89[ab]
Gellan gum (lab)	0.05	41.92±0.12[b]	0.00±0.00[h]
	0.1	42.88±0.78[a]	0.00±0.00[h]
Deacyl gellan gum	0.05	21.40±0.04[g]	10.77±0.28[fg]
	0.1	21.96±0.19[fg]	12.60±0.00[cd]
Guar gum	0.05	25.40±0.11[cd]	15.04±0.00[ab]
	0.1	25.40±0.38[cd]	15.96±0.43[a]
Xanthan gum	0.05	23.49±0.35[e]	10.26±0.14[g]
	0.1	25.87±0.27[c]	11.18±0.57[efg]
Arabic gum	0.05	21.71±0.06[fg]	13.82±0.29[bc]
	0.1	21.94±0.04[fg]	14.94±0.14[ab]
EPS-CB[2)]	0.05	22.56±0.64[f]	12.37±0.29[de]
	0.1	23.88±0.30[e]	11.99±0.57[def]

[1)]Each value represents mean±SD. Different letters indicate significant differences at $p<0.05$.
[2)]EPS-CB means exopolysaccharide from *S. chungbukensis*.

The solubility of the rice flour/guar gum system (15.04-15.96%) was slightly higher than that measured in the control (14.93%), but the solubilities of the other systems were slightly lower than that of the control (10.26-14.94%) with the exception of the rice flour without gum dispersion. The viscous gellan gum dispersion (under 0.1%) appeared to facilitate the swelling of starch granules, and also inhibited the leaching of soluble material from the granules. We surmise that this effect can be attributed to the strong interaction between the hydroxyl group of the gellan gum and the starch granule components, resulting in a higher degree of water absorption.

Rheological behavior The shear stress (σ) versus shear rate ($\dot{\gamma}$) data for various rice flour (5%)/gum mixtures (0.1% gum dispersion) at 80°C were fitted well to the simple power low model (Eq.1) with determination coefficients, R^2 = 0.94-0.98, as shown in Table 2. The magnitudes of apparent viscosity ($\eta_{a,\ 100}$) and consistency index (K) were obtained from the power-law model. All samples had shear-thinning behavior with values of flow behavior indexes (n) as low as 0.14-0.32. The n value and K of the rice flour/guar gum mixture was the highest. The relative K for each gum is as follows: guar gum > control > deacyl gellan > gellan gum > arabic gum > xanthan gum > EPS-CB. The shear-thinning character of xanthan gum is more pronounced than those of other polysaccharide gums including guar gum (16).

Paste viscosity and morphology of rice flour/gum mixture pastes The Brookfield viscometer was suitable for revealing the synergistic effects in viscosity between starch and gum at low concentrations (4). The relative viscosity of 2.5% rice flour in 0.1% gum dispersions is as follows: gellan > xanthan > guar > deacyl gellan > arabic,

Table 2. Effect of various gum dispersions (0.1%) on power law parameter and apparent viscosity ($\eta_{a,100}$) of rice flour (0.5 %) in gum mixtures[1)]

Gums	$\eta_{a,100}$ (Pa·sec)	K (Pa sec^n)	n (-)	R^2
None	0.32±0.03	9.89±1.26	0.25±0.05	0.95
Gellan gum	0.24±0.01	9.29±0.87	0.20±0.01	0.96
Deacyl gellan	0.34±0.01	9.72±1.44	0.27±0.04	0.94
Guar gum	0.47±0.07	10.64±1.20	0.32±0.01	0.98
Xanthan gum	0.33±0.01	8.88±0.84	0.28±0.03	0.96
Gum arabic	0.17±0.01	9.12±0.05	0.14±0.02	0.95
EPS-CB	0.25±0.01	7.74±0.58	0.26±0.01	0.98

K, consistency index; n, flow behavior index; R^2, determination coefficient.
[1)]Mean ± standard deviation.

EPS-CB. It is known that the negatively charged gums have high viscous properties in water-based systems, but arabic gum does not provide any viscosity (17). The hot paste viscosity might be affected by swollen granules, solubilized materials including amylose and gum, and their interaction. Therefore hot paste viscosity was measured immediately after heating rice flour/gum mixtures.

A comparison of the apparent viscosities of rice flour hot and cold pastes was measured by a Brookfield viscometer as shown in Fig. 1.

In the rice flour/gum mixture, the hot pastes exhibited apparent viscosities ranging from 0.91-1.65 times as high as that (1.43) measured in distilled water. It has been suggested that interactions between gum molecules, solubilized amylose and low molecular weight amylopectin molecules are a possible cause of the increase in paste viscosity. The amylose-gum interaction was mainly responsible for viscosity increase when starch/gum dispersions were heated above the gelatinization temperature (4). However, the viscosity of the rice flour paste in the EPS-CB dispersion (1.30) was lower than that measured for the control preparation. Most of the viscous gum dispersions became thinner when heated and viscosity increased when cooled, but the viscous xanthan dispersion did not change (17). The cold pastes of rice flour/gum dispersions had a high consistency but they did not form a gel like texture.

The apparent viscosities of most rice flour hot and cold pastes in the different gum dispersions were similar to those of the control (0.94-1.44 times), but those of the rice flour/gellan gum dispersion (2.01 times) exhibited a different trend. It is believed that gellan molecules take double helical conformations in dispersions at lower temperatures, and above a critical concentration, they form aggregates which act as junction zones resulting in a three dimensional network (18). Gellan molecules might interact with amylose molecules in rice flour/gum mixtures and form a thickened semi-gel type paste by double helical conformation. These effects of gellan would make it a good additive in breadmaking with rice flour products, facilitating the construction of a network and the formation of a matrix. Because the rice flour contained other components besides starch, its behavior might be different from starch/gum mixture systems. The roles of other components in the flour/gum system will be the subject of future studies.

The morphology of the rice flour pastes in the gum dispersions showed little difference for all types of gum employed (Fig. 2). Rice flour paste in distilled water (control, A) manifested a discontinuous surface, with some swollen starch granules, and a similar pattern was observed in the more soluble gum dispersions, like EPS-CB (G) and arabic gum (F) dispersions. Rice flour paste in the gellan gum (B) and xanthan gum (E) dispersions were observed to manifest a smooth and swollen surface, due to a viscous linear polymer based network between the molecules. The swelling power and rheological properties of the rice flour/gum mixture pastes differed according to the types and concentrations of the gums employed. Gellan gum appears to function effectively as a thickener in the rice flour/gum system, and it appears to facilitate the formation of networks in rice products.

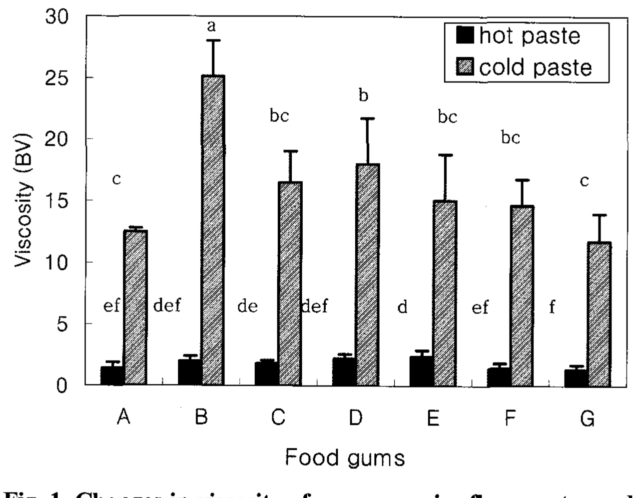

Fig. 1. Changes in viscosity of non-waxy rice flour pastes and gels in different food gum dispersions (0.1%) by Brookfield viscometer. A, distilled water; B, gellan gum from *S. paucimobilis*; C, deacyl gellan gum; D, guar gum; E, xanthan gum; F, arabic gum; G, EPS-CB from *S. chungbukensis*. Each bar represents means±SD of three measurements. Different letters indicate significant differences at $p<0.05$.

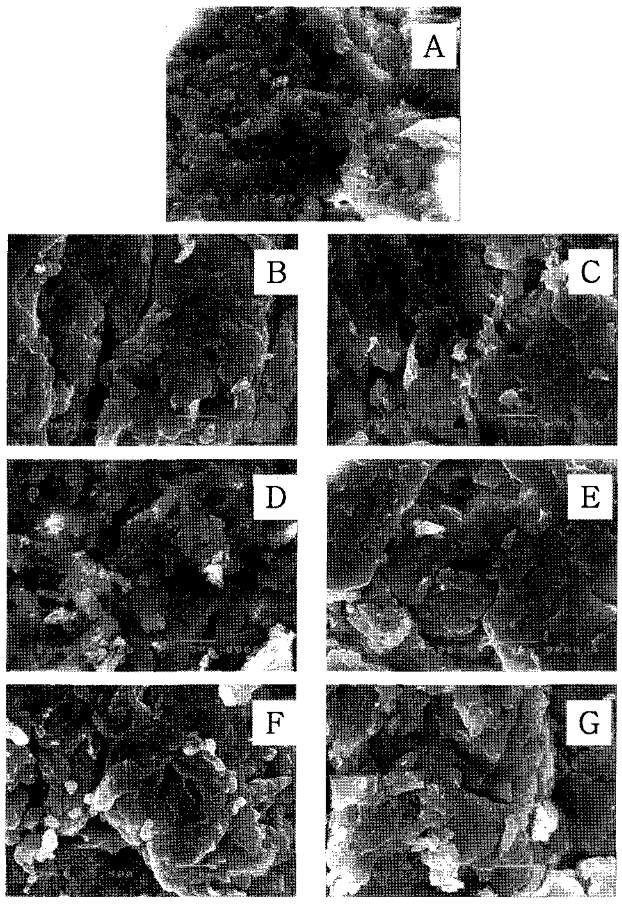

Fig. 2. Scanning electron photomicrographs of rice flour paste in various gum dispersions (magnification × 3000). A, distilled water; B, gellan gum; C, deacyl gellan gum; D, guar gum; E, xanthan gum; F, arabic gum; G, EPS-CB.

Pasting properties of rice flour/gum systems using the Rapid Visco-Analyzer Rice flour exhibited a modification of the pasting properties due to gum addition at three levels. All of the samples exhibited typical results on viscograms without bump area as seen in the wheat flour/gum system (3). The typical pattern of RVA viscogram of the rice flour/gellan gum mixture with different concentrations is shown in Fig. 3. The initial pasting temperature, peak time, and the peak, trough, and final viscosities of all of the rice flour samples in the gum dispersions are listed in Table 3. The changes of pasting temperature, peak time, peak viscosity, and setback viscosity with different gum concentrations are shown in Fig. 4. The initial pasting temperature was observed to increase slightly along with increasing gum concentrations. When mixtures of starch and gum are heated in water, the general effects seen were the lowering of peak temperature, a higher peak viscosity, and a decreased rate of setback but the magnitudes were dependent on the nature of the starch and gum, and their ratio (4, 19, 20). Kim and Setser (21), and Rojas *et al.* (3) reported an increase in the onset gelatinization temperature of wheat starch, which was heated in seven different gum dispersions. Yoshimura *et al.* (22) reported an identical trend for normal maize starch and xyloglucan. Lee *et al.* (23) also reported that some gums when added to sweet potato starch raised the pasting temperature. Yoo *et al.* (24) reported that the apparent viscosity values of acorn flour in a guar gum dispersion increased with increasing guar gum concentrations, but decreased with increasing temperatures in the range of 25-70°C.

In the case of rice flour/gellan and xanthan dispersions, the pasting temperature in a 0.2% dispersion was 4.1 and 2.6°C higher than that of the control, respectively. This was due to the fact that the gellan and xanthan dispersions had a higher viscosity than other dispersions, and the slope of viscosity at initial pasting being lower. Christianson *et al.* (20) attributed the early onset of initial viscosity to the first stage of granule swelling which was affected by media viscosity. The time to reach peak viscosity was shown to increase in the majority of gum additions, but decreased with increasing EPS-CB concentrations. The EPS-CB was very soluble in water and did not have a viscosity similar to arabic gum.

The RVA curve of rice flour/gum systems, such as deacyl gellan gum, arabic gum, and EPS-CB exhibited almost identical patterns and viscosity values. The peak viscosity of rice flour with guar gum increased, but that of rice flour with gellan gum, xanthan gum, arabic gum, and EPS-CB decreased with increasing gum concentrations. Xanthan gum was not only adsorbed on the starch granule, but was also found inside the granules, causing the starch granule to change into a folded or puckered form. This folding of granules reduced the viscosity in the xanthan gum dispersion (25). Arabic gum exhibits a relatively low viscosity in water and does not form a gel (1). It was suggested that gellan inhibited the leaching of soluble amylose at boiling temperatures (Table 1), and that the peak viscosity could be reduced with increasing gum concentrations, but some opposite results were also reported (26). However, peak viscosity was found to increase with the addition of increasing amounts of guar gum to a higher degree than was observed with deacyl gellan gum.

Lee *et al.* (23) reported that xanthan gum significantly reduced the paste viscosity of sweet potato starch, possibly via its profound facilitation of starch network formation, whereas guar gum and alginate were shown to increase viscosity. Peak viscosity reflected the ability of the starch granules to freely swell before undergoing physical breakdown. Starch with high swelling power also exhibited a fairly high maximum viscosity (25). In this experiment, the gellan gum system exhibited the highest swelling power, but the peak viscosity of the gellan gum system was determined to be lower than the peak viscosities of the guar gum and xanthan gum systems. The peak viscosity patterns of the rice flour/guar gum and xanthan gum

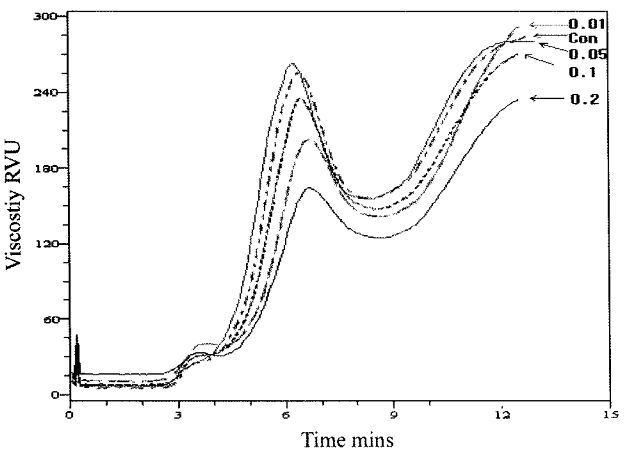

Fig. 3. RVA viscograms of rice flour/gllan gum mixture dispersion with different gum concentrations (0.01, 0.05, 0.1, and 0.2% were used).

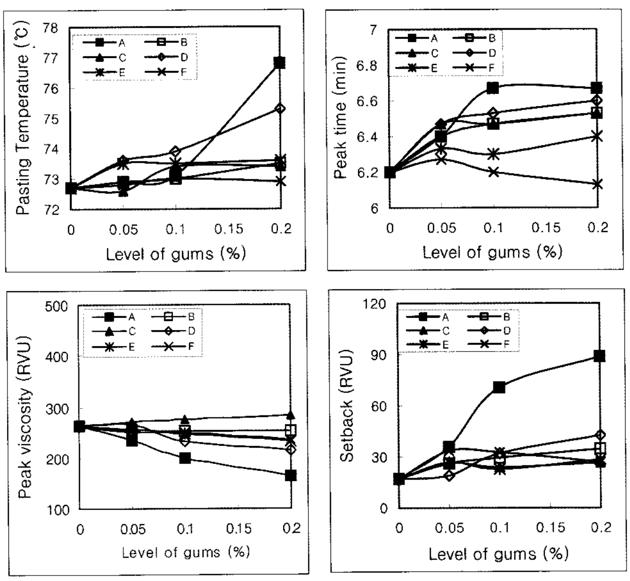

Fig. 4. Changes of pasting temperature, peak time, peak viscosity, and setback viscosity of various rice flour/gum dispersions with different gum concentrations. A, gellan gum; B, deacyl gellan gum; C, guar gum; D, xanthan gum; E, arabic gum; F, EPS-CB.

Table 3. RVA characteristics of rice flour/gum systems with different concentrations of gum

Gum	Conc. (%)	Pasting temp (°C)	Peak time (min)	Viscosity (RVU)				
				Peak (P)	Trough (T)	Final (F)	Breakdown (P-T)	Setback (F-P)
None	-	72.7	6.20	262.8	155.4	279.8	107.4	17.0
Gellan	0.05	72.9	6.40	235.3	147.7	271.3	87.6	36.0
	0.1	73.1	6.67	198.2	136.7	268.8	61.5	70.6
	0.2	76.8	6.67	164.2	124.3	252.9	39.8	88.8
Deacyl gellan	0.05	72.9	6.40	249.3	153.3	275.4	96.0	26.1
	0.1	73.0	6.47	253.5	163.9	283.0	89.6	29.5
	0.2	73.5	6.53	254.1	164.7	288.8	89.4	34.7
Guar gum	0.05	72.6	6.47	270.4	177.3	296.8	93.1	26.4
	0.1	73.4	6.47	276.3	182.0	300.2	94.3	23.9
	0.2	73.4	6.53	282.3	193.8	308.8	88.5	26.5
Xanthan	0.05	73.6	6.47	266.8	168.7	285.8	98.1	19.0
	0.1	73.9	6.53	232.3	163.3	264.3	79.0	32.0
	0.2	75.3	6.60	214.8	161.4	257.5	53.4	42.7
Gum arabic	0.05	73.5	6.33	252.9	160.3	279.7	92.6	26.8
	0.1	73.5	6.30	247.0	153.4	269.8	93.6	22.8
	0.2	73.6	6.40	232.5	149.3	260.9	83.2	28.4
EPS-CB[1)]	0.05	72.8	6.27	256.0	151.3	289.5	104.7	33.5
	0.1	73.0	6.2	250.4	149.8	283.1	100.6	32.7
	0.2	72.9	6.13	234.5	132.8	261.4	101.7	26.9

[1)]EPS-CB means exopolysaccharide from *S. chungbukensis*.

systems differed between the two gums, and the viscosity of guar gum and xanthan gum systems was determined to be higher than that of the control. Christianson *et al.* (20) reported that the addition of guar gum increased maximum viscosity, and also explained the effects of these gums on maximum viscosity. The trough and final viscosity of the rice flour/gum system showed a pattern similar to that of peak viscosity. With the addition of gums to rice flour, setback viscosity increased with increasing gum concentrations, but decreased with increasing concentrations of EPS-CB. The breakdown viscosity was highest in the controls, but the setback viscosity of the control was the lowest among the samples. The lower setback viscosity indicates a retardation of starch retrogradation. Although Bahnassey and Breene (27) reported synergistic interactions occurring between starch and hydrocolloids, the rice flour and gum dispersions used in this experiment showed a lesser degree of interaction between rice starch and gum (unpublished data). Therefore, other components of rice flour may also interact with gum dispersion, and so the degree of interaction may be influenced, to some degree, by the gum structure.

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