GHOST STRUCTURES, PASTING, RHEOLOGICAL AND TEXTURAL PROPERTIES BETWEEN *MESONA BLUMES* GUM AND VARIOUS STARCHES

TAO FENG1,2,5, QIANG SU1, HAINING ZHUANG2, RAN YE3, ZHENG BIAO GU4 and ZHENG YU JIN4

1School of Perfume and Aroma Technology, Shanghai Institute of Technology, 100 Haiquan Road, Fengxian, Shanghai 201418, China
2Whistler Center for Carbohydrate Research, Purdue University, 745 Agriculture Mall Drive, West Lafayette, IN 47907-2009
3Department of Biosystems Engineering and Soil Science, University of Tennessee, Knoxville, TN
4School of Food Science and Technology, Jiangnan University, Wuxi, Jiangsu, China

5Corresponding author.
TEL: +86-21-60873669;
FAX: +86-21-60873669;
EMAIL: fengtao@sit.edu.cn

Received for Publication May 12, 2013
Accepted for Publication December 31, 2013

10.1111/jfq.12076

ABSTRACT

In this study, the ghost structures of potato starch granule gelatinization in the presence and absence of *Mesona Blumes* gum (MBG) at different temperatures and time points were studied. Our results indicated that ghost structures could form merely after the amylose was completely leached from granules. In addition, MBG could prevent amylose from leaching outside the granules, and thus extend ghost structure existence in aqueous solution. Furthermore, the interactions among eight kinds of starches and MBG were assessed by Brabender parameters. It was concluded that rice, wheat, pea and corn starches could be significantly influenced by MBG (*P* < 0.05), then followed by mung bean and sweet potato starch, whereas the effects of tapioca and potato starch could be insignificant (*P* > 0.05). Textural measurement illustrated that MBG/rice starch gel was the hardest among all samples in this study. Rheological properties of rice starch and various hydrocolloids were evaluated at 25°C by frequency sweep from 1 to 10 Hz with a constant strain 1%. It was shown that rice starch and MBG could also form the strongest gel.

PRACTICAL APPLICATIONS

To understand the interaction between MBG and different starches from various sources, ghost structures, Brabender curves, and textural and rheological properties were investigated in this paper. Ghost structure indicated that gels between MBG and starch might be constituted by collapsed starch granule, MBG and swollen amylose. Brabender curves showed that MBG could affect rice starch gelatinization significantly (*P* < 0.05). Moreover, the results of textural studies also demonstrated that MBG/rice starch gels formed the hardest gel. In addition, the results obtained from rheological properties between various hydrocolloids and rice starch suggested that the strongest MBG/rice starch gel occurred. Therefore, gels formed by MBG and rice starch might be potentially used as a novel filler or thickener in food industry.

INTRODUCTION

Starch and hydrocolloids are commonly used in food system jointly in order to provide desirable texture, proper moisture content and water molecules mobility, improve the high quality and stability of the whole product, and reduce costs and enhance processing procedure. Therefore, it is vital to learn interactions between different starches and hydrocolloids for giving food special function.

Starch ghosts referred to the fragmentary structure after the outmost layer surface of the granule which entrapped the inner amylose and amylopectin was broken (Han and
Hamaker 2002). In general, starch ghosts were visually detected on the confocal laser scanning microscopy (CLSM) images (van de Velde et al. 2002). However, starch ghosts were barely observed in the presence of anionic polysaccharides (Han and Hamaker 2002). The presence of anionic polysaccharides attenuated the formation of gluttonous layer structures around the surface of the granules. In addition, the distribution pattern of polysaccharide outside the starch granules is different (Hongsprabhas et al. 2007). Sae-kang and Suphantharika (2006) demonstrated that the granular ghost structure of tapioca starch (TS) still presented after and Suphantharika (2006) demonstrated that the granular ghost structure of tapioca starch (TS) still presented after gelatinization in an appropriate amount of heated water. Hongsprabhas et al. (2007) used light microscopy and CLSM to investigate structural changes in gelatinized starch granules. Their results indicated that alginate and carrageenan could maintain the granular structure of amyllose-rich swollen granules or induce the aggregation of the swollen ones due to the interference of soluble starch and the incompatibility of swollen granules. Debet and Gidley (2007) found that the formation of starch ghost granules was highly associated with the cross-linking of polysaccharide chains within swollen granules. More specifically, double helices formed in polymer chains appear to shift toward the swelling of heat-induced granules. It was proposed that the size and consistency of granule ghosts depended on the swelling rate and cross-linking of polysaccharide chains within swollen granules.

Pasting properties were generally used as one of the methods to understand interactions between starch and hydrocolloids. Christianson et al. (1981) reported that the presence of different hydrocolloids, such as xanthan, carboxymethyl cellulose sodium and guar gum in starch, respectively, can evidently decrease the pasting temperature of wheat starch (WS) but increase the paste viscosity. Further studies indicated that the mixture solution exhibited a stable and synergistic viscosity after insoluble starch granules were carefully removed. Interactions between gum molecules and soluble amylase and amylopectin might cause the paste viscosity increment.

There are two hypotheses on the synergistic effects between starch and hydrocolloids. One is regarding phase separation. More specifically, amylase and hydrocolloids are located in a continuous phase, and starch granule residues are maintained in a dispersed phase. Because of the high water absorbing capacity of hydrocolloid in continuous phase, amyllose concentration and apparent viscosity of the system had been substantially increased (Closs et al. 1999). The other is pertaining to intermolecular interaction. The hydrogen interaction between amyllose and hydrocolloids formed junction zones that enabled increasing the hydration radius of amyllose and enlargement of the apparent viscosity of the system (Biliaderis et al. 1997).

In our laboratory, we successfully isolated and characterized an acidic polysaccharide of Mesona Blumes gum (MBG) from Mesona Blumes, a common annual herbal plant grown in Asia. The gelling interactions of MBG and rice starch (RS), sensory evaluation of the mixed gels used as fat replacement in sausage, as well as its volatile compounds were investigated (Tao et al. 2008; Feng et al. 2011, 2012, 2013). However, the interactions between MBG and various starches or between various hydrocolloids and RS were still not assayed.

With the goal of understanding interactions mentioned above, we studied: (1) ghost structures of potato starch (PTS) granule gelatinized in MBG solution; (2) pasting properties of mixtures of various starch and MBG; (3) gel strength of MBG and various starches; and (4) viscoelastic properties of mixtures of various hydrocolloid and RS.

MATERIALS AND METHODS

Materials

RS was provided by Baobao Group Co. Ltd. of Jiangsu (China). WS, corn starch (CS), mung bean starch (MBS), pea starch (PS), PTS, TS and sweet potato starch (SPS) were donated by Gaofeng Starch Co. Ltd. of Suzhou (China). Xanthan, λ-carrageenan, gelatin, carboxyl methyl cellulose, Arabic gum and konjac gum were donated by Roquette Co., Ltd. of Shanghai (China). MBG was prepared according to the method of Feng et al. (2007). The crude MBG was extracted from Mesona Blumes leaves, its yield was 29.4% (w/w, dry matter). All chemical reagents were analytically pure and bought from Shanghai Pharmaceutical Group Co., Ltd. (China).

Chemical Component Analysis of Various Starch and MBG

Official methods (AOAC 2006) were used in analysis of ash (method 942.05), moisture content (direct drying method 934.01), the concentration of protein by micro Kjeldahl method (984.13A), fats by Soxhlet extraction (996.01) and crude fiber by acidic washing fiber method (978.10). Blue value of starch was measured by colorimetric method with concentrated iodine solution KI/I_2 (25% KI/10% I_2) and used as an index of binding ability of amyllose and iodine or amyllose content, and was used to represent amyllose content (Jarvis and Walker 1993). Each of chemical component analyses was replicated three times.

Observation of Pasting Procedure of PTS or PTS–MBG Solution

PTS (500 mg) was added into 250 mL distilled water, and then gelatinized at Brabender Micro-Visco-Amylo-Graph
(Brabender Co. Ltd, Duisburg, Germany). The temperature procedure was from 30°C as the initial temperature, increasing up to 95°C at the rate of 5°C/min, then holding for 10 min, decreasing up to 50°C at the rate of 5°C/min, finally holding for 10 min (Jing et al. 2012). Additionally, 500 mg PTS with about 50 mg MBG was added into 250 mL distilled water, then gelatinized as the following temperature procedure: 30°C as the initial temperature, increasing up to 80°C at the rate of 5°C/min, then holding for 15 min, increasing up to 95°C at the rate of 5°C/min, then holding for 15 min, decreasing up to 50°C at the rate of 5°C/min, finally holding for 10 min. PTS granules with and without MBG were observed under a light microscope (Olympus BX 50-34-DIC, Tokyo, Japan) when concentrated KI/I2 solution was added to the starch granules. Microphotographs of the PTS ghosts were taken as described by Seguchi et al. (2003).

Gelatinization Analysis of Starch and MBG Mixed System

Mixtures containing 6% (dry basis [d.b.]) of various starches and 0.1, 0.35 or 0.5% (d.b.) MBG were prepared and their pasting curves were measured by Brabender Micro-Visco-Amylo-Graph. The temperature procedure was the same as above mentioned. The viscosities had been measured continuously, rotation speed was set up as 250 rpm, and viscosity unit was represented as BU (Brabender unit; 1 BU = 700 g·cm). The parameters of the curve are given with the following symbols: A – onset temperature of rapid viscosity increase, B – peak viscosity, B-C – breakdown viscosity, C – trough viscosity, D – final viscosity, D-C – setback viscosity.

Texture Profile Analysis (TPA) of Gel Formed by Starch and MBG

The gels formed by 6% various starches and 0.5% MBG were put into molds (2.5 cm × 2.5 cm) and cooled down to ambient temperature (25°C). TPA of gel was conducted by TA-XT2i (Stable Micro Systems, Surrey, U.K.). In all experiments, samples were compressed under a cylindrical probe (P/0.5). Parameters of TA-XT2i were set up as option: TPA, pretest speed: 1.0 mm/s, test speed: 1.0 mm/s, posttest speed: 1.0 mm/s, distance: 50% strain, trigger type: auto 5 g, time: 10 s, data acquisition rate: 200 pps. Gel hardiness was compared. Determination was repeated three times, average was taken as the results (Huang et al. 2007).

Rheological Properties of RS and Various Hydrocolloids

Mixtures containing 6% (d.b.) RS and 0.5% (d.b.) of various hydrocolloids in solution were mixed, then frequency sweep was done on AR 1000 rheometer (TA Instruments, New Castle, DE) by parallel plate system (4 cm diameter) at a gap of 1,000 μm. For rheological measurements, the sample was loaded onto the plate and the exposed sample edge was covered with a thin layer of light paraffin oil to prevent evaporation during measurements. The detailed conditions of frequency sweep were temperature 25°C, frequency range 1–10 Hz and sweep strain 1%. The 1% strain was in the linear viscoelastic region. TA rheometer Data Analysis software (version VI.1.76) was used to obtain the experimental data and to calculate G', G″ and tan δ. All rheological measurements in oscillatory tests were performed in triplicate (Yoo et al. 2005).

Statistical Analysis

Two-way analysis of variance was used to determine the statistical significance of the data obtained at the different MBG level and significance level was set at 0.05 (P < 0.05). Multiple-paired comparisons were used to determine which mean values differed from one another. All experiments were conducted in triple trials, and the data were analyzed using SPSS 11.0 (SPSS Inc., Chicago, IL) and expressed as means ± standard error.

RESULTS AND DISCUSSION

Chemical Composition of Various Starches and MBG

The chemical composition of various starches and MBG is listed in Table 1. The results suggested that all of the starches with high blue values contained the high concentration of amylase. Huang et al. (2008) determined the amylase content and blue value of six high-amylose wheat cultivars. It was concluded that the Ws containing generally higher amylase contents displayed the higher blue values. The amylase contents of the six wheat cultivars ranged from 28.0 to 36.9%, corresponding to blue values between 0.38 and 0.42. Yamamori and Yamamoto (2011) analyzed the amylase content and blue value of four common wheat species harvested in September 2009 and they found that the amylase content of Wx-A1i, Wx-A1j, Wx-A1a and Wx-A1b (waxy variety) was 7.7, 20.7, 20.6 and 2.2%, respectively, while the corresponding blue value (abs) was 0.141, 0.277, 0.297 and 0.083, respectively.

Gelation Properties of PTS and PTS–MBG Solution

Gelation properties of single potato granules in aqueous solution during different temperatures are shown in Fig. 1A. At 50°C (a), a few amylase molecules were leaching
out (black blue substances in aqueous solution). At 60°C (b), these granules became bright brown and black blue zone around granules increased; at 70°C (c), starch granules reached the biggest swelling volume; at 80°C (d), the ghost structure of starch granules began to break; and at 95°C (e) it broke vigorously. After cooling to 50°C (f), both amylose molecules and starch granules’ ghost structure existed in aqueous solution and entangled with each other, revealing

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture (%)</th>
<th>Crude protein (%)</th>
<th>Crude fat (%)</th>
<th>Total ash (%)</th>
<th>Crude fiber (%)</th>
<th>Blue value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS</td>
<td>11.95*</td>
<td>0.68</td>
<td>0.26</td>
<td>0.3</td>
<td>0.43</td>
<td>0.44</td>
</tr>
<tr>
<td>RS</td>
<td>13.5</td>
<td>0.89</td>
<td>0.3</td>
<td>0.29</td>
<td>0.33</td>
<td>0.57</td>
</tr>
<tr>
<td>CS</td>
<td>14.08</td>
<td>0.48</td>
<td>0.12</td>
<td>0.14</td>
<td>0.21</td>
<td>0.58</td>
</tr>
<tr>
<td>MBS</td>
<td>13.08</td>
<td>0.24</td>
<td>0.05</td>
<td>0.25</td>
<td>0.18</td>
<td>0.68</td>
</tr>
<tr>
<td>PS</td>
<td>13.14</td>
<td>0.33</td>
<td>0.10</td>
<td>0.15</td>
<td>0.20</td>
<td>0.62</td>
</tr>
<tr>
<td>TS</td>
<td>10.6</td>
<td>0.20</td>
<td>0.10</td>
<td>0.10</td>
<td>0.12</td>
<td>0.48</td>
</tr>
<tr>
<td>SPS</td>
<td>12.87</td>
<td>0.24</td>
<td>0.10</td>
<td>0.33</td>
<td>0.33</td>
<td>0.47</td>
</tr>
<tr>
<td>PTS</td>
<td>16.71</td>
<td>0.25</td>
<td>0.10</td>
<td>0.18</td>
<td>0.18</td>
<td>0.44</td>
</tr>
<tr>
<td>MBG</td>
<td>5.12</td>
<td>9.74</td>
<td>3.03</td>
<td>30.9</td>
<td>2.98</td>
<td>–</td>
</tr>
</tbody>
</table>

* All the results were the average of three times determination.

CS, corn starch; MBS, mung bean starch; PS, pea starch; PTS, potato starch; RS, rice starch; SPS, sweet potato starch; TS, tapioca starch; WS, wheat starch.
the formation of the starch gel. Hayashi et al. (2005) reported the skeleton structure of the starch granules. It was indicated that amylose was generally concentrated in the central area of starch granules. When starch was gelatinized, a large amount of amylose was leached out from starch granules, thereby causing the collapse of the granules and appearance of the ghost structure. It was shown from Fig. 1A that ghost structural changes in PTS granules during gelatinization were consistent with the findings of Hayashi et al. (2005).

Gelation properties of PTS granules in 0.5%, w/v MBG solution at different temperatures and time points are shown in Fig. 1B. At 50°C (a), dark blue zones were not leached out. At 60°C (b), there were black blue zones like a volcanic eruption from the granules surface. Compared with the PTS solution without MBG, the leaching amount decreased obviously. At 70°C (c), granules basically presented light brown, transparent "ghost structure," which indicated that amylose granules gelatinized much completely. Seguchi et al. (2003) have shown 39 kinds of RSs that were waxy, low amylose and nonwaxy, respectively. The samples exhibited a complete light brown color of their ghost structure in the absence of amylose. At 80°C/0 min (d), granules were somewhat swelled, but ghost structure of granules was still complete. The ghost structure of those granules without MBG began to rupture at this temperature, which indicated that MBG might inhibit the rupturing of starch granules’ ghost structure. At 80°C/10 min (e), granules’ ghost structures were substantially swelled, and amylose had been leached out more completely. At 95°C/0 min (f), ghost structure of granules began to rupture and there were significantly separated states of black blue amylose and red “ghost” fragments. At 95°C/10 min (g) and 95°C/15 min (h), ghost fragments extensively ruptured into much smaller pieces. After cooling down to 50°C (i), amylose assembled into a cluster due to retrogradation, and “ghost” pieces were entrapped in the amylose cluster, which entangled with each other, and thus formed the gel. Funami et al. (2005b) observed that guar gum was capable of reducing the leaching of amylose from CS. In particular, guar gums with higher molecular weight fractions were more effective for this phenomenon. Liu et al. (2003) indicated that a hydrocolloid decreased amylose leaching within swollen granules. These findings were in agreement with the results from Funami et al. (2005a, 2008), Nakauma et al. (2008) and Nagano et al. (2008).

**Pastening Properties of Various Starches and Their Mixtures with MBG**

Pastening curves of rice, wheat, pea and CSs in the presence and absence of MBG are depicted in Fig. 2A–D. It was illustrated that the pastening curve of each starch was affected more synergistically by MBG. The changes in parameters are summarized in Table 2. The onset temperatures of the rapid increases in viscosities of these four starches decreased with the addition of MBG from 0 to 0.5%; however, the peak viscosities and the final viscosities increased. Although setback viscosities showed no significant trends of consistent changing, they slightly increased with the addition of MBG. RS had the lower onset temperature (65.2°C) and the higher final viscosity (194 BU) with 0.5% of MBG. The initial temperature of the rapid increase in viscosity recorded with a Brabender Viscograph is called the onset temperature of gelatinization. Liu and Eskin (1998) reported that there was no significant change in the gelatinization temperature although the onset of rapid viscosity increase was shifted to a lower temperature, which was consistent with the result of Shi and BeMiller (2002).

Pastening curves of MBS, PTS, SPS and TS in the presence and absence of MBG are displayed in Fig. 2E–H. It was demonstrated that the pastening curves of MBS and SPS were influenced synergistically insignificant by MBG (P > 0.05). However, the effects of tapioca (H) and potato (F) starch with MBG were antagonistic. It was noted that the onset temperature of all starch samples had no significant changes regardless of the type of starch and the concentration of MBG used in this study, except for MBS. Peak viscosity of MBS slightly increased with the increase in the concentration of MBG, but peak viscosity of PTS, SPS and TS initially decreased and subsequently increased with the increase in the concentration of MBG. Except MBS and TS, the setback viscosities of the other two starches increased with the increase in the concentration of MBG, while the final viscosities of all these four starches originally decreased and finally increased with the concentration of MBG. Shi and BeMiller (2002) suggested that negatively charged gums (negatively charged due to monostarch phosphate ester groups) greatly inhibited the granule swelling, gelatinization and pasting processes of PTS, and fundamentally reduced peak viscosity.

Setback value distributions of eight kinds of starch after the addition of MBG on pasting curves are shown in Fig. 3. It was observed that the setback value gradually increased with the addition of MBG in the pasting curve of RS and MBG mixed system, and reached the highest value (134 BU) at the concentration of 0.5% MBG, which indicated that there was a synergistic effect of interaction between RS and MBG. Although setback values of pasting curves of both PTS and TS were higher, they decreased with the addition of MBG, suggesting that there was an antagonistic effect of interactions between two tuberous starches and MBG. In addition, WS, RS, PS and CS, respectively, interacted with MBG in a synergistic state, while mung bean and sweet potato, respectively, interacted with MBG in a relatively weak synergistic state. Of note, the interaction between RS
FIG. 2. PASTING CURVES OF MBG AND (A) RICE, (B) WHEAT, (C) PEA, (D) CORN, (E) MUNG BEAN, (F) POTATO, (G) SWEET POTATO, (H) TAPOCA STARCH

PHYSICAL PROPERTIES BETWEEN MBG AND VARIOUS STARCHES
T. FENG ET AL. 

and MBG showed the strongest synergy. Shi and BeMiller (2002) also stated that PTS and TS behaved differently from cereal starches in gum solutions. A significant increase in viscosity before pasting occurred merely with certain starch-gum mixtures, such as corn and xanthan, rice and guar, potato and xanthan, and tapioca and xanthan, which revealed that interactions between specific gums and specific starches were responsible for the early-stage viscosity increases.

Brabender pasting curve of all starches is shown in Fig. 4 in the presence of 0.5% of MBG. It was indicated that tuberous starch with MBG owned the lower onset temperature (approximately 60.1–75.3°C) of the rapid viscosity increase, and viscosity began to weaken after reaching the highest peak viscosity (approximately 177–410 BU) rapidly, demonstrating the poor heating stability of the system. However, final viscosities of both PTS/MBG (around 254–281 BU) and SPS/MBG (around 208–233 BU) mixed system were correspondingly higher than those of TS/MBG system (171–258 BU). Likewise, peak viscosities were significantly higher than those of both grain starch (rice, wheat, corn)/MBG (about 8- to 10-fold) \((P < 0.05)\) and bean starch (pea, mung bean)/MBG (about five- to sevenfold) \((P < 0.05)\). Although there were no significant differences of pasting

### TABLE 2. PASTING PROPERTIES OF DIFFERENT STARCHES AND THEIR MIXTURES WITH VARIOUS CONTENTS OF MBG

<table>
<thead>
<tr>
<th>Starch</th>
<th>MBG%</th>
<th>A/C</th>
<th>B/BU</th>
<th>C/BU</th>
<th>D/BU</th>
<th>B-C/BU</th>
<th>D-C/BU</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS</td>
<td>0</td>
<td>91.5*</td>
<td>35</td>
<td>32</td>
<td>75</td>
<td>3</td>
<td>43</td>
</tr>
<tr>
<td>0.1</td>
<td>90.8</td>
<td>37</td>
<td>29</td>
<td>80</td>
<td>8</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>86.2</td>
<td>53</td>
<td>46</td>
<td>99</td>
<td>7</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>84.3</td>
<td>61</td>
<td>53</td>
<td>138</td>
<td>8</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>RS</td>
<td>0</td>
<td>88.4</td>
<td>50</td>
<td>35</td>
<td>99</td>
<td>15</td>
<td>64</td>
</tr>
<tr>
<td>0.1</td>
<td>85.7</td>
<td>55</td>
<td>41</td>
<td>117</td>
<td>14</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>65.0</td>
<td>74</td>
<td>54</td>
<td>150</td>
<td>20</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>65.2</td>
<td>87</td>
<td>60</td>
<td>194</td>
<td>17</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td>PS</td>
<td>0</td>
<td>76.8</td>
<td>44</td>
<td>44</td>
<td>71</td>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>0.1</td>
<td>75.2</td>
<td>45</td>
<td>43</td>
<td>78</td>
<td>2</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>74.8</td>
<td>52</td>
<td>50</td>
<td>82</td>
<td>2</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>68.7</td>
<td>55</td>
<td>52</td>
<td>106</td>
<td>3</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>0</td>
<td>84.7</td>
<td>82</td>
<td>58</td>
<td>128</td>
<td>24</td>
<td>70</td>
</tr>
<tr>
<td>0.1</td>
<td>77.9</td>
<td>80</td>
<td>50</td>
<td>113</td>
<td>30</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>74.5</td>
<td>90</td>
<td>52</td>
<td>127</td>
<td>38</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>73.8</td>
<td>96</td>
<td>60</td>
<td>175</td>
<td>36</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>MBS</td>
<td>0</td>
<td>74.8</td>
<td>89</td>
<td>60</td>
<td>118</td>
<td>29</td>
<td>58</td>
</tr>
<tr>
<td>0.1</td>
<td>74.4</td>
<td>82</td>
<td>55</td>
<td>101</td>
<td>27</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>73.5</td>
<td>89</td>
<td>57</td>
<td>99</td>
<td>32</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>70.2</td>
<td>90</td>
<td>59</td>
<td>145</td>
<td>31</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>PTS</td>
<td>0</td>
<td>60.7</td>
<td>410</td>
<td>119</td>
<td>281</td>
<td>291</td>
<td>162</td>
</tr>
<tr>
<td>0.1</td>
<td>60.9</td>
<td>252</td>
<td>104</td>
<td>230</td>
<td>148</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>60.6</td>
<td>205</td>
<td>112</td>
<td>228</td>
<td>93</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>60.3</td>
<td>310</td>
<td>131</td>
<td>254</td>
<td>179</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>SPS</td>
<td>0</td>
<td>74.8</td>
<td>201</td>
<td>114</td>
<td>208</td>
<td>87</td>
<td>94</td>
</tr>
<tr>
<td>0.1</td>
<td>75.1</td>
<td>177</td>
<td>120</td>
<td>206</td>
<td>57</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>73.9</td>
<td>179</td>
<td>132</td>
<td>211</td>
<td>47</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>74.3</td>
<td>194</td>
<td>136</td>
<td>233</td>
<td>58</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>0</td>
<td>65.8</td>
<td>236</td>
<td>90</td>
<td>258</td>
<td>146</td>
<td>168</td>
</tr>
<tr>
<td>0.1</td>
<td>66.3</td>
<td>219</td>
<td>69</td>
<td>171</td>
<td>150</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>66.8</td>
<td>225</td>
<td>79</td>
<td>185</td>
<td>146</td>
<td>106</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>67.1</td>
<td>237</td>
<td>83</td>
<td>199</td>
<td>154</td>
<td>116</td>
<td></td>
</tr>
</tbody>
</table>

* All the results were the average of three times determination. A – onset temperature of rapid viscosity increase, B – peak viscosity, B-C – breakdown viscosity, C – trough viscosity, D – final viscosity, D-C – setback viscosity.

CS, corn starch; MBG, Mesona Blumes gum; MBS, mung bean starch; PS, pea starch; PTS, potato starch; RS, rice starch; SPS, sweet potato starch; TS, tapioca starch; WS, wheat starch.
curves between bean starch and grain starch ($P > 0.05$), PS and WS displayed the weak peak viscosity. For rice and MBS, they firstly had a small peak viscosity, and then had an enhanced peak viscosity (55–87 and 82–90, respectively). During the holding period at high temperature 95°C, the viscosities of starches decreased slightly except for the viscosity of PS still being a slight increment (the breakdown viscosity of PS is the smallest around 0–3 BU among the eight kinds of starches). During the cooling phase, viscosities of all starches increased significantly. The maximum of the setback viscosity of the gel (194 BU) was obtained when 6% RS and 0.5% MBG were introduced into the system. It might be attributed to the unique pasting characteristic of RS/MBG system.

**Texture Profiles of Gels Achieved from Mixtures of Various Starches with 0.5% MBG**

From the results of TPA (as shown in Table 3), the descending order of hardness of gels formed by 0.5% MBG and 6% of various starches was listed as follows: rice > potato > tapioca > corn > sweet potato > mung bean > wheat and pea. This order was consistent with the order of setback viscosity value obtained on Brabender Micro-Visco-Amylo-Graph. Except for PS and PTS, the hardness of each mixed gel and the blue value of corresponding starch basically were proportional to the amylose content in the system. However, Lai et al. (2003) reported the order of the effectiveness of starches in forming gels with hsian-tsao leaf gum (wheat > corn > tapioca). The difference between the conclusion of Lai and the finding in this study might be due to the different molecular weights and structures of hsian-tsao gum (also called MBG). Huang et al. (2007) found that the texture profiles of the RS polysaccharides mixed gel were dependent on the variety of rice and polysaccharides, along with the concentration of the polysaccharide. The low concentration (<0.2%, w/w) of carrageenan and the high concentration of gellan (>0.3%, w/w) could improve the hardness and adhesiveness significantly. In contrast, the presence of the konjac failed to promote the adhesiveness, chewiness and hardness significantly for any kind of RSs.

**Frequency Sweeping between RS and Different Hydrocolloids**

In Fig. 5A, it was concluded that the elastic modulus of the gel formed by RS and MBG reached the maximal value (247–310 Pa). Of particular, $G'$ changed slightly with the frequency in the range of sweeping frequency, suggesting that the gel formed by RS and MBG belonged to a strong gel. The value of viscous modulus of the gel formed by RS and MBG was relatively high (78–99 Pa), and $G''$ also
changed slightly with frequency in the range of sweeping frequency, representing that the gel also had a little stronger viscous property (Fig. 5B). Tan δ in Fig. 5C illustrated that solid properties of gel formed by RS and MBG (around 0.1519–0.157) were higher than that of gel formed by RS alone (around 0.1054–0.1429) in the range of low frequency (1 < ω < 6 Hz), but they are roughly equivalent (approximately 0.1562–0.1571 and 0.1467–0.1592, respectively) in the range of high frequency (10 > ω > 6 Hz). Although both G’ and G” of gels formed by RS and MBG were relatively larger, tan δ of the sample was smaller than those of RS and other gums, indicating that elasticity and viscosity of gel formed by RS and MBG were larger than those of RS and other gums. Thus, this gel might be very close to the strong gel according to the classification on rheology. These findings are consistent with those reported by Lai et al. (2003). They concluded that the interaction of starches with hsiantsaow leaf gum resulted in the formation of gels with both increased G’ and G” (G’ > G”), as well as a decreased tan δ, indicating the occurrence of a strong elastic gel.

CONCLUSIONS

In conclusion, we investigated the ghost structures, pasting, and rheological and textural properties between MBG and starches from different sources. The granule morphology changes during the gel formation of PTS pasting in MBG solution showed that PTS/MBG mixed gel might be formed through the interactions among amylose, ghost residue and MBG. The presence of MBG has a significant impact on the pasting properties of grain starches, PS, MBS, CS and WS. However, the pasting properties of PS, TS and SPS were significantly influenced by MBG. The results of rheological and textural properties suggested that both elasticity and viscosity of gels formed by RS and MBG were the largest among all of the samples, while tan δ of gel formed by RS and MBG was nearly equal to that of gel formed by RS alone, indicating the formation of a strong gel according to the rheological tests.

ACKNOWLEDGMENT

This study is financially supported by the National Science Foundation Committee of China (No. 31371736).

REFERENCES


FIG. 5. MECHANIC SPECTRA OF RICE STARCH AND DIFFERENT GUMS
(A) Elastic moduli G’ versus sweeping frequency. (B) Viscous moduli G” versus sweeping frequency. (C) Tan δ versus sweeping frequency (□ xanthan, △ no gum, ■ MBG, ◆ carrageenan, ▲ gelatin, ○ carboxyl methyl cellulose, ◇ Arabic gum, ○ konjac).


