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Characters of rice starch gel modified by gellan, carrageenan, and glucomannan: A texture profile analysis study

Min Huang [a], J.F. Kennedy [b,c], B. Li [a,*], Xiao Xu [a], B.J. Xie [a]

[a] *College of Food Science and Technology, Huazhong Agricultural University, Wuhan 430070, China*
[b] *School of Chemical Sciences, University of Birmingham, Birmingham B15 2TT, UK*
[c] *Chembiotech Laboratories, Institute of Research and Development, University of Birmingham, Research Park, Vincent Drive, Edgbaston, Birmingham B15 2SQ, UK*

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Abstract

Mixed gel was prepared with rice starch (indica, japonica, or sticky rice starch), polysaccharides (gellan, carrageenan, or konjac glucomannan), $CaCl_2$, and deionized water. Rice starch, deionized water, and $CaCl_2$ were kept constant; a mixture design was used to study the effects of varieties of rice starch, polysaccharides and its concentration on the quality of the mixed gel by texture profile analysis (TPA) method. The texture profile of the rice starch–polysaccharides mixed gel was dependent not only on the variety of rice and polysaccharides, but also on the concentration of the polysaccharide. The addition of the non-suitable polysaccharide or non-proper concentration would lead to deterioration of the gel. Only the suitable polysaccharide at a proper concentration would endow the gel with the excellent quality. Low concentration (<0.2% (w/w)) of carrageenan and high concentration of gellan (>0.3% (w/w)) could increase the hardness and adhesiveness significantly; the indica rice starch–polysaccharides always owned the largest hardness, adhesiveness, and chewiness. Considering the economic factor, adding 0.2% (w/w) carrageen to the indica rice starch was found to be valuable for improving the texture of rice gel food, when a higher adhesiveness/hardness ratio was needed, 0.3% (w/w) gellan could be added to indica rice starch. The konjac glucomannan could not improve the adhesiveness, chewiness, and hardness significantly for any kinds of rice starches. The three varieties of rice starch, polysaccharides and their concentration had no significant effect on the springiness of the mixed gel.

Keywords: Rice starch; Textural profile analysis; Konjac glucomannan; Carrageenan; Gellan

1. Introduction

Starch is a major storage energy reserved in plants, where it exists as insoluble granules. It is commercially extracted from many botanical sources including rice, potato, maize, and wheat to produce a wide variety of industrial products (Tester & Karkalas, 2002). The granules are mainly composed of two different glucose polymers: amylose and amylopectin molecules (Cura, Jansson, & Krisman, 1995; Hizukuri, 1986). Generally (normal) starch contains around 25% amylose and 75% amylopectin, and waxy genotypes contain considerably higher amounts of amylopectin, while high amylose genotypes are rich in amylose (Hizukuri, 1986; Suzuki, Hizukuri, & Takeda, 1981). As for the rice starch, the non-waxy indica rice starch contains about 17–22% amylose, the non-waxy japonica rice starch contains about 14–18% amylose, and the sticky rice starch contains almost no amylose.

When starches are subjected to high temperature, typically higher than 50 °C in the presence of water, the granules swell and rupture due to disruption of the double helices amylopectin (hydrogen bonds dissociation), while amylose preferentially has been leached out from the swollen granules (Tester, 1989). These events, all known as 'gelatinization', are accompanied by a dramatic increase in the systems viscosity as the granule structure is progressively

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[*] Corresponding author. Tel.: +86 27 6373 0040; fax: +86 27 8728 8636.
E-mail address: libinfood@mail.hzau.edu.cn (B. Li).

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ruptured (Yang & Rao, 1997). When gelatinized starch is stored, particularly at low temperature (Jang & Pyun, 1997), it undergoes 'retrogradation' (or staling in baked foods) caused by re-crystallization of the polymer (dispersed amylose and amylopectin) chains. Starch retrogradation occurs in two stages. Firstly, two days post-processing, the amylose component associates rapidly (Miles, Morris, & Ring, 1985; Miles, Morris, Orford, & Ring, 1985), secondly followed by lower re-crystallization of the amylopectin fraction (Ring et al., 1987), a process that may proceed for several weeks.

The gelatinization parameters and extent of starch retrogradation are influenced by the starch composition and structure (Fredriksson, Silvero, Andersson, Eliasson, & Aman, 1998; Ring et al., 1987; Sasaki, Yasui, & Matsuki, 2000); moisture content during both gelatinization (Donavan, 1979; Eliasson, 1980; Svensson & Eliasson, 1995) and storage (Jang & Pyun, 1997; Liu & Thompson, 1998); storage temperature (Jang & Pyun, 1997; Kim, Kim, & Shin, 1997) and the presence of non-starch polysaccharides (Biliaderis, Arvanitoyannis, Izydorczyk, & Prokopowich, 1997; Ferrero, Martino, & Zaritsky, 1996; Rojas, Rosell, & Benidito de Barber, 1999; Sommerville, 1999). Although these effects are obvious in the industrial and nutritional importance, the interaction of different industrial hydrocolloids with various types of starch has received only little attention. In particular, research concerning interactions between gellan, carrageenan, and konjac glucomannan and starch during processing is sparse.

Carrageenans, sulphated polysaccharides obtained from red seaweeds, are frequently used in combination with starch in gelled desserts (Descamps, Langevin, & Combs, 1986; De Vries, 1992; Mleko, 1997; Rapaille & Vanhemelrijck, 1992; Tye, 1988). Starch imparts body and mouthfeel to the product, and carrageenan provides the appropriate texture: firm and brittle with κ-carrageenan, soft and elastic with τ-carrageenan (Imeson, 2000). The interactions between the different ingredients have been resulted in the structural organization and rheological properties of the desserts. κ-Carrageenan is frequently used as a gelling agent in desserts because it has the negatively charged sulfate groups (Snoeren, Payens, Jeunink, & Both, 1975).

Gellan gum is a gel-forming polysaccharide produced by the microbe *Sphingomonas elodea* (formerly *Pseudomonas elodea*) (Kang, Veeder, Mirrasoul, Kaneko, & Cottrell, 1982) and has been approved for food use by the FDA in 1992 (Pszczola, 1993). Gellan polymer consists of monosaccharides: glucose, glucuronic acid, and rhamnosein in the molar ratios of 2:1:1 (Sanderson, 1990) that linked together to form a linear primary structure. The native polymer is high acyl gellan (H) containing O-5-acetyl and O-2-glyceryl groups on the 1,3-linked glucose residue. When exposed to alkali at high temperatures, both acyl groups are hydrolyzed and deacylated, and a form of low acyl gellan (L) is obtained. Low acyl gellan dissolves in water at temperatures above 90 °C. These solutions form gels in the presence of cations when cooled to gelling temperature (Tang, Tung, & Zeng, 1997). Addition of gellan produces gellan–starch mixtures with different elastic properties, depending on the extent of granular disruption and gellan concentration in the gellan–starch mixture.

Konjac glucomannan has been introduced into Europe (E425) and the USA as a food additive due to its gelling and emulsifying properties. It is an essential linear polysaccharide composed of blocks of β-1,4-linked mannose and glucose residues in the ratio of 1.6:1, with acetylation around every 19-sugar residues (Gidley, McArthur, & Underwood, 1991; Kato & Matsuda, 1969). In China, konjac flour is extracted from the root tuber of the *Amorphophallus konjac* plant and has been used traditionally in Chinese cookery for centuries. The effects of konjac flour on gelatinization and retrogradation of maize starch (Yoshimura, Takaya, & Nishinari, 1996), and its effects on the rheological properties of maize starch gels (Bahnassey & Breene, 1994; Fanta & Christianson, 1996; Shelso, 1990; Yoshimura, Takaya, & Nishinari, 1998) have received the most attention lately.

No study was focused on the effects of carrageenan, gellan, and konjac glucomannan on the gelatinization of rice starches with different ratios of amylose and amylopectin to reflect the real food systems. Hence, the following study will undertake this responsibility using indica rice, japonica rice and sticky rice starch. This study will also be helpful for the improvement of the quality of Chinese traditional rice food – rice noodle, rice cake, and rice paste.

2. Experimental

2.1. Materials

Zhouyou 903 (ZY903, no waxy indica,), Luoyou 8 (LY8, non-waxy japonica,) and Eluo 1 (ET1, sticky) from the first crop of 2005 was obtained from Jingzhou District Agriculture Improvement Station, Hubei, China. All the three varieties of rice starches were prepared as follows: Rice flour (100 g) was soaked in 200 ml of 0.1% NaOH for 18 h (Wang & Wang, 2004), blended in a Waring blender at a high speed for 2 min, passed through a 63 μm screen, and centrifuged at 3500*g* for 10 min. The soft, top layer was carefully removed, and the underlying starch layer reslurried, and washed with 0.1% NaOH and collected by centrifugation. The starch layer was washed with deionized water and centrifuged, the starch was reslurried and neutralized with 1.0 M hydrochloric acid to pH 6.5 and centrifuged. The neutralized starch was washed with deionized water three times, dried at 45 °Cfor 48 h, passed through a 150 μm sieve and stored in a plastic jar at room temperature until being used.

Konjac glucomannan was extracted and purified from the tuber of *Konjac Amorphophallus*. The tubers were sliced off about 8 mm in thickness and then dried under heated air at 65 °C for about 6 h. The dried sheets were pulverized by mill. The crude flour was immersed in 50% (v/v) aqueous methanol for 3 h, and then dried at 50 °C under reduced pressure. Afterwards, the raw konjac flour was extracted with benzene–absolute alcohol (4:1 v/v) and trichloromethane–*n*-butanol (Sevag method) for five times, respectively. The fat- and protein-extracted flour was dissolved with a mixture of distilled water/hydrogen peroxide [$H_2O_2$30%:$H_2O = 5:1$ (v/v)] and heated at 40 °C for 20 min. After environmental cooling to room temperature, the hydrosol was centrifuged at 17,000*g* for 20 min (Himac Centrifuge, Hitachi). And acetone was added to the supernatant and stirred. After being filtered with a 130 μm mesh sieve, the white cotton-like precipitate was squashed, and then dried by vacuum freeze drying (Li & Xie, 2004).

Highacyl gellan (H) KelcogelLT100 was purchased from CP Kelco Co. (Atlanta, GA 30339, United States). And the κ-carrageenan (BR) and calcium chloride (AR) was purchased from Wuhan Tianyuan biomaterial Co. (Wuhan, China). They were used without further purification.

2.2. Preparation of rice starch–polysaccharides mixed gel

The starch gels were prepared using a dry starch-to-water in the ratio of 35:65% of the required amount of starch was added to the required amount of distilled deionized water in the cylindrical plastic cup measuring φ 3 × 4 cm. The slurry was heated to 100 °C, simultaneously added polysaccharide solutions (0, 0.1%, 0.2%, 0.3%, and 0.4%, w/w) and the calcium chloride solution (5.0 mmol/L), and then cooled to 80 °C to form a paste. The remaining amount of starch was added to the slurry. Such a two-step procedure was adopted to prevent from settling of starch during subsequent heating, and achieved complete starch gelatinization. After thorough mixing by manual stirring, paraffin oil was poured into the surface of the slurry to prevent excessive evaporation of water on heating. And then the sample was heated to 100 °C for 0.5 h in an water-bath to ensure a 100% gelatinization. After cooling to room temperature, the paraffin oil was poured away and the surface of the gel was wiped with absorbent tissue, great care was being taken to ensure that the external surface of the gel was excluded. The samples were stored at 4 °C overnight.

2.3. Instrumental texture profile analysis (TPA)

A Texture Analyzer TAXT2i (Stable Micro Systems, Surrey, England) was used to measure the force–time curve. In all experiments, samples were compressed under a cylindrical probe (P/0.5) at a test speed of 1 mm/s and a control force of 5 g, using the Texture Analyzer with accompanying computer software (SAS). The deformation level was 25% of original sample height and the gels were compressed twice.

In TPA experiments, samples were usually subjected to large deformations (75–80%). In these experiments, a smaller deformation level was chosen, which was recommended by Pons and Fiszman (1996), the deformation level between 20% and 50% had been applied on starch gel food systems. Because under large deformation, the samples collapsed and invalid parameters were obtained. A crosshead speed (50 mm/min) was chosen, thus avoiding a total destruction of the gel structure in the first compression. This speed was also recommended to get values highly correlating with the sensory responses (Pons & Fiszman, 1996). Three replicate samples were tested.

All the parameters were measured by the Instron machine software and their validity was controlled by the user. From the first deformation curve, the point where peak force occurred was recorded as the deformation peak force and it was used as an indicator for the samples structure strength. Although the deformation level was low, many samples underwent fractionation but did not broke into several pieces. Their fractionation was dependent on their preparation but mainly on the varieties of starch and polysaccharides.

2.4. Statistical analysis

The statistical analysis of results was conducted by the variance analysis. Duncan's multiple range tests was used to determine significant difference ($P < 0.05$) among samples prepared by varieties of starch and polysaccharide and different gum concentration. Results of statistical analysis were presented as comments in the text. The data were fitted using second-order polynomial equations. The degree of fit was judged by the R^2 coefficient.

3. Results and discussion

3.1. Hardness

The changes of the hardness of starch gels mixed with or without polysaccharides, were recorded in Fig. 1a–c. It showed that with the increasing concentration of polysaccharides, the hardness of the starch mixed gels also increased on the whole. As for the indica rice starch–polysaccharides mixed gel (Fig. 1a), the hardness increased significantly ($P < 0.05$) for carrageenan and gellan, and gellan showed its stronger ability for improving the hardness of the mixed gel when its concentration was more than 0.3% (w/w), the carrageenan represented itself more suitable when its concentration was lower than 0.3% (w/w). However, with the increasing konjac glucomannan concentration, the hardness of the mixed gel did not increase significantly ($P > 0.05$).

As for the japonica rice starch–polysaccharides mixed gel (Fig. 1b), the hardness changed with the variety and their concentration of polysaccharides just as that of indica rice starch–polysaccharides mixed gel. The main difference was the effect of konjac glucomannan on the mixed gel hardness, it showed that with the increasing of the concentration of konjac glucomannan, the hardness decreased evidently when its concentration was more than 0.3% (w/w) instead of increasing by degrees . The hardness of sticky rice starch–glucomannan could not be examined because the samples could not form a gel but only a paste, which meant

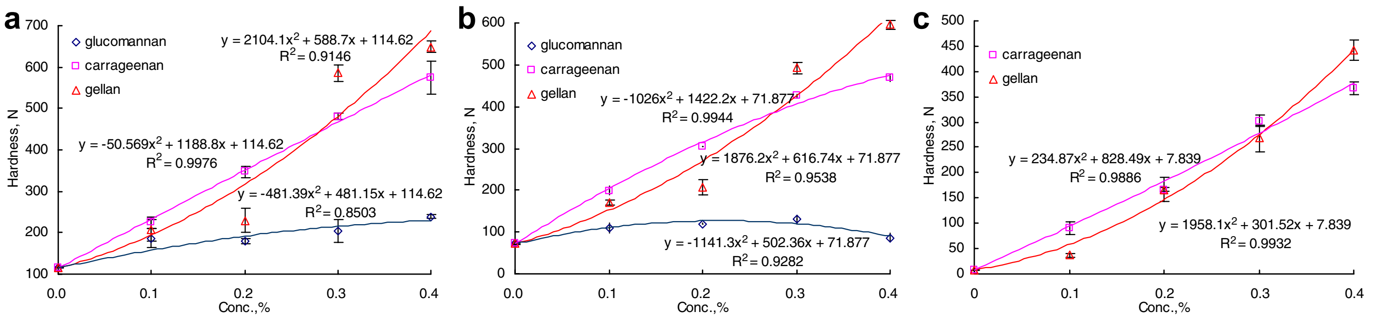

Fig. 1. Effect of different conc. polysaccharides on the hardness of three kinds of rice starch–polysaccharides gel. (a) Indica rice starch, (b) japonica rice starch, and (c) sticky rice starch.

that the addition of konjac glucomannan would act against the hardness of the starch gel, so only two curves were recorded in Fig. 1c, it was also showed that low concentration (<0.3%) of carrageenan and high concentration of gellan (>0.3%) could increase the hardness much notably.

Effect of different concentrations of gellan on the hardness of rice starch–gellan gel was recorded is Fig. 2a, it showed that the addition of gellan to three varieties of rice starch could increase the mixed hardness in exponential equation; however, it increased the hardness of indica rice starch–gellan mixture more sharply than the sticky and japonica rice starch. It indicated that when the high hardness of rice starch gel was needed, the method of addition of gellan would be distinguished especially for indica rice. It could also be concluded that the hardness of the rice starch–gellan mixed gel mainly came from the network structure of gellan rather than the rearrangement of amylose.

The carrageenan also gave the approximately parallel current (Fig. 2b) as that of gellan. However, it showed a linear equation. It proved that the hardness of the rice starch–carrageenan mixed gel mainly came from the network structure of gelatin polysaccharides rather than the retrogradation of amylose.

By contraries, the konjac glucomannan could not improve the hardness of all the three varieties of rice starch gel (Fig. 2c) and it had unconspicuous difference ($P > 0.05$) in the gellan and carrageenan. It was well-known that konjac glucomannan had extremely high viscosity and water holding ability, but it could not increase the hardness of the mixed gel evidently, the main reason might be that the konjac glucomannan was a kind of non-gelatin polysaccharide, and it could not form an undivided network structure, so it only increased the hardness slightly. The gellan and the carrageenan belonged to gelatin polysaccharide, and the gellan had higher viscosity than carrageenan.

3.2. Adhesiveness

Adhesiveness is more of a surface characteristic and depends on a combined effect of adhesive and cohesive forces, and others include viscosity and viscoelastic as well (Adhikari, Howes, Bhandari, & Truong, 2001). The changes of the adhesiveness of starch gels, with and without polysaccharides, were recorded in Fig. 3a–c. As for the indica rice starch–polysaccharide mixed gel (Fig. 3a), the adhesiveness increased markedly for carrageenan and gellan, and gellan improved the adhesiveness of the mixed gel greatly when its concentration was more than 0.2% (w/w), the carrageenan represented itself more suitable when its concentration was lower than 0.2% (w/w). However, with the increasing konjac glucomannan concentration, the adhesiveness of the mixed gel did not change significantly ($P > 0.05$).

The adhesiveness of japonica rice starch–polysaccharides mixed gel, changed with the variety and its concentration of polysaccharides just as that of indica rice starch–polysaccharides mixed gel (Fig. 3b). It also showed that low concentration (<0.2%) of carrageenan and high concentration of gellan (>0.2%) could increase the adhesiveness much notably. The adhesiveness of sticky rice starch–glucomannan could not be examined (Fig. 3c), with the increasing

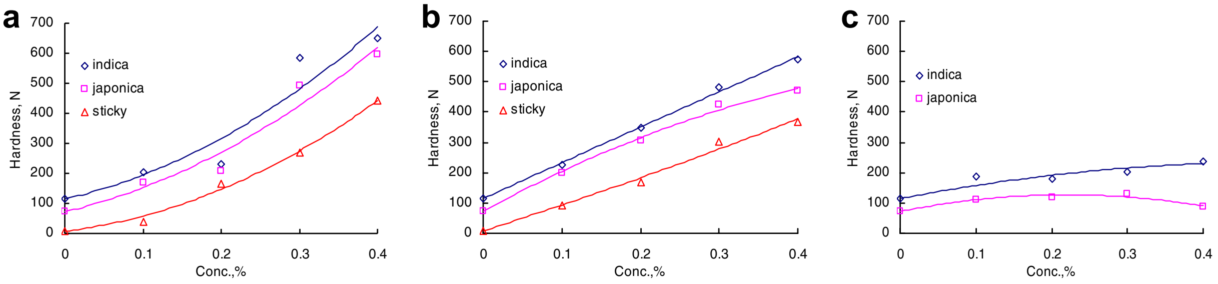

Fig. 2. Effect of different conc. polysaccharide on the hardness of rice starch–polysaccharide gel. (a) Gellan, (b) carrageenan, and (c) konjac glucomannan.

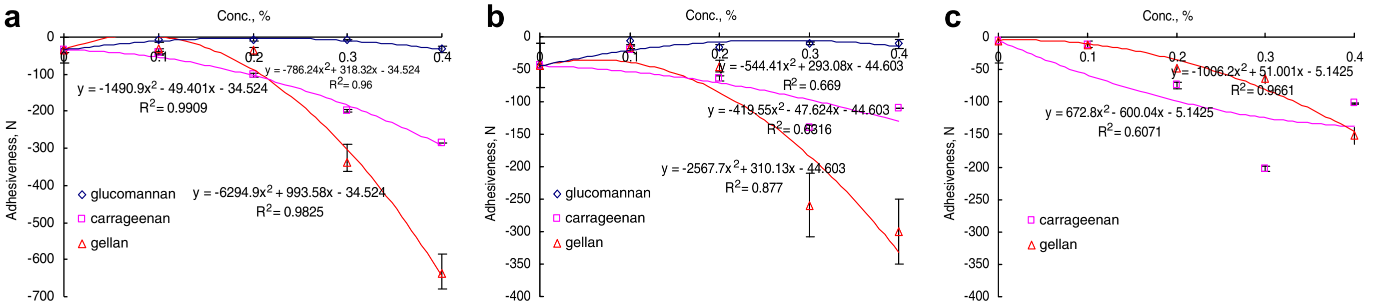

Fig. 3. Effect of different conc. polysaccharides on the adhesiveness of three kinds of rice starch–polysaccharides gel. (a) Indica rice starch, (b) japonica rice starch, and (c) sticky rice starch.

concentration of carrageenan or gellan, since increased although the absolute value was rather lower than the indica and japonica rice starch–polysaccharides mixed gel although the adhesiveness increased.

Effect of different concentrations of gellan on the adhesiveness of rice starch–gellan gel was recorded in Fig. 4a, it showed that the addition of gellan to all the three varieties of rice starch could increase the mixture adhesiveness in exponential equation; however, it increased the adhesiveness of indica rice starch–gellan mixture more sharply than the sticky and japonica rice starch. The carrageenan increased the adhesiveness of rice starch–carrageenan in a linear equation (Fig. 4b); it also increased the adhesiveness to the greatest amount in the three kinds of starch. It was proved that the adhesiveness of the rice starch–gellan and carrageenan mixed gel mainly came from gelatin polysaccharide rather than the rice starch. Due to the low adhesive and viscosity of incida rice starch– polysacharides gel, it could be concluded that the high cohesive forces and viscoelastic created the gel with high adhesiveness. The konjac glucomannan could not change the adhesiveness of all the three kinds of rice starch gel (Fig. 4c). In spite of its high viscosity, the non-gelatin polysaccharide konjac glucomannan could not form the high cohesive and viscoelastic, the adhesiveness of the mixture was still low; the three kinds of starch had no significant difference when added to the konjac glucomannan solution.

The high adhesiveness and low hardness of rice food often had a good tasting (Guo & Ma, 2006). Effect of different concentrations of polysaccharide on the ratio of the adhesiveness to hardness of rice starch–polysaccharides gel was recorded in Fig. 5a–c. It showed that the addition of konjac glucomannan resulted in the decrease of the ratio, at the same time, the absolute value of the adhesiveness to the hardness was also low, so it could be concluded that the addition of konjac glucomannan was not an efficient method for improving the texture of rice starch gel (Fig. 5c). The carrageenan also could not improve the

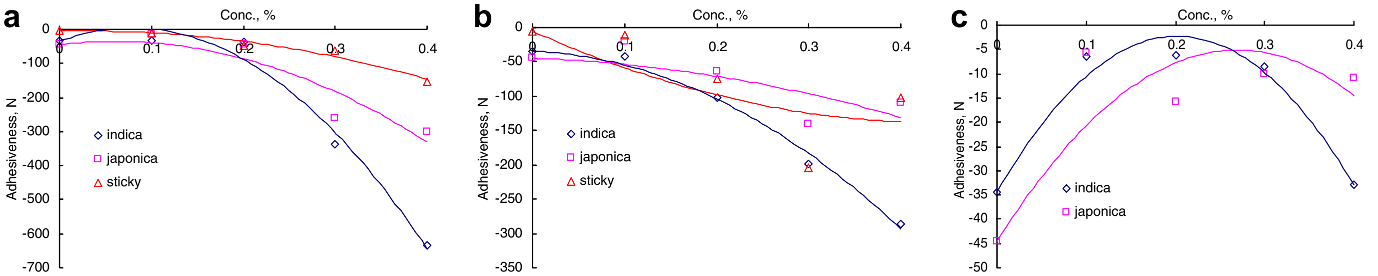

Fig. 4. Effect of different conc. polysaccharide on the hardness of rice starch–polysaccharide gel. (a) Gellan, (b) carrageenan, and (c) konjac glucomannan.

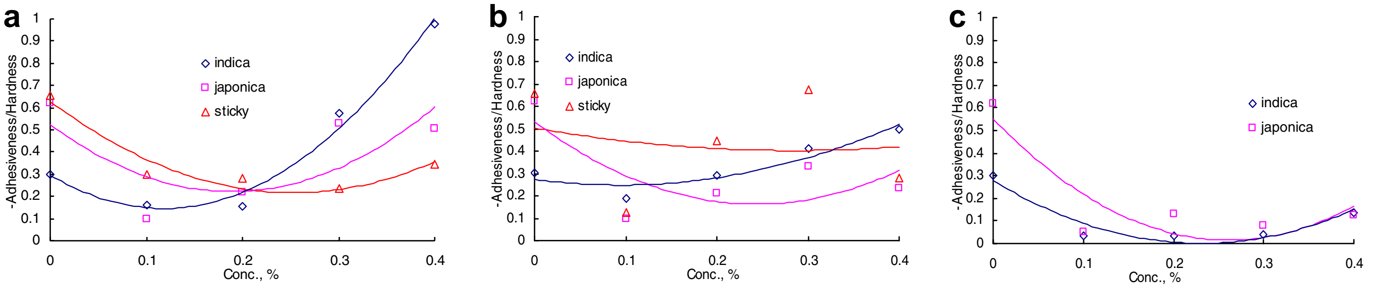

Fig. 5. Effect of different conc. polysaccharide on the adhesiveness/hardness of rice starch–polysaccharide gel. (a) Gellan, (b) carrageenan, and (c) konjac glucomannan.

texture of rice starch gel markedly except the indica rice starch, and indica rice starch–carrageenan mixed gel owned a comparative high ratio of adhesiveness/hardness (Fig. 5b). Considering the economical and operational reason, adding carrageen to the rice starch gel with a low concentration (<0.2%) was valuable. When the better rice starch gel with a good taste and a higher adhesiveness/hardness ratio was needed, the gellan was useful (Fig. 5c), especially for indica rice starch at a high concentration (>0.3%).

In a word, the texture profile of the mixed rice starch–polysaccharides gel had relationship with not only the variety of rice and polysaccharides, but also with the concentration of the polysaccharides. On the contrary, the addition of the non-suitable polysaccharide or non-proper concentration would lead to worsening of the gel. Only the suitable polysaccharide at a proper concentration would endow the gel with an excellent texture profile.

3.3. Springiness

Springiness (sometimes also referred to as "elasticity") is a perception of gel "rubberiness" in the mouth, and is a measure of how much the gel structure is broken down by the initial compression (Sanderson, 1990). High springiness appears when the gel structure is broken into few large pieces during the first TPA compression, whereas low springiness results from the gel breaking into many small pieces. Less springy gels, such as low-methoxy pectin, carrageenan, and agar gels will break down more easily during mastication than a firm and spring gelatin gel (Marshall & Vaisey, 1972). Effect of different concentrations of polysaccharides on the springiness of three kinds of rice starch–polysaccharides gel was recorded in Fig. 6a–c. In general, the springiness of all the three kinds of rice starches and polysaccharides mixed gel of different concentration was rather higher than most of pure hydrocolloid gel.

As for the indica rice starch–polysaccharides mixed gel (Fig. 6a), the springiness did not change significantly ($P > 0.05$) for carrageenan and konjac glucomannan, which meant that the addition of the konjac glucomannan and carrageenan had none or little influence on the gel "rubberiness" in the mouth. Gellan decreased the springiness markedly with low concentration addition, but it increased the springiness in high concentration, and 0.2% (w/w) concentration of gellan showed the mixed gel the lowest springiness. Such a change also occurred in the japonica rice starch–gellan mixed gel (Fig. 6b) and even in the sticky rice starch–gellan gel (Fig. 6c). The reason might be the structural phase separation of rice starch–gellan gel in such a ratio was just as it was in Fig. 5a. The addition of carrageenan could increase the springiness of japonica rice starch gel slightly in low concentration (<0.2%) and then decreased (>0.2), the reason might be that theκ-carrageenan gel was a kind of brittle gel, and the highacyl gellan KelcogelLT100 gel belonged to the elastic gel.

The differences among three kinds of rice starch when added to the same polysaccharide was rather minor, it indicated that the springiness of the mixed gel was mainly depend on the rice starch, taking the similar curve of three kinds of starch into account, it would be drawn that the

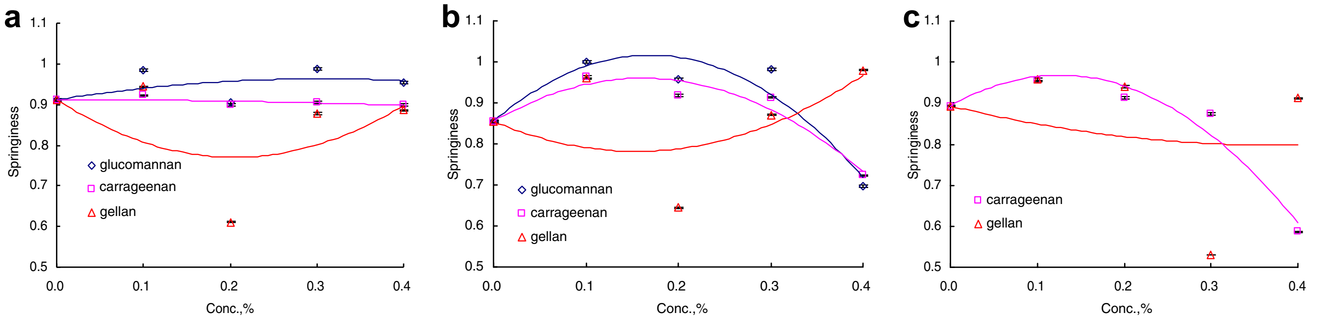

Fig. 6. Effect of different conc. polysaccharides on the springiness of three kinds of rice starch–polysaccharides gel. (a) Indica rice starch, (b) japonica rice starch, and (c) sticky rice starch.

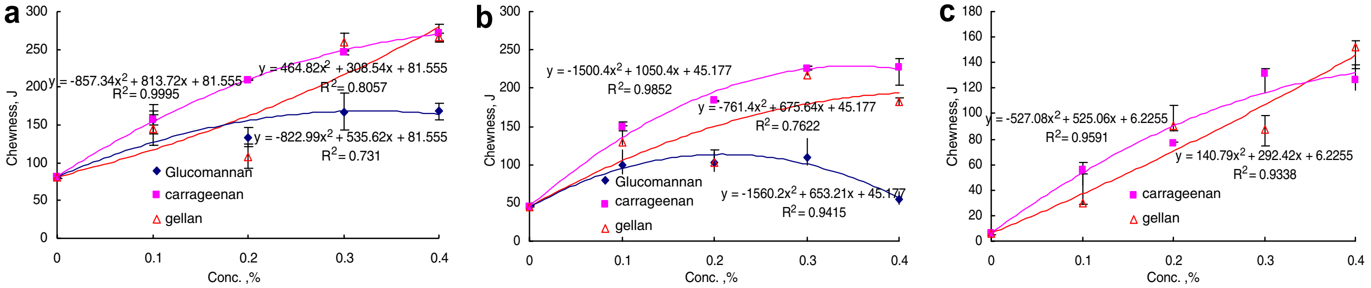

Fig. 7. Effect of different conc. polysaccharides on the chewiness of three kinds of rice starch–polysaccharides gel. (a) Indica rice starch, (b) japonica rice starch, and (c) sticky rice starch.

springiness of the mixed gel had strong relationship with the existence of the amylopectin.

3.4. Chewiness

Chewiness is the quantity to simulate the energy required for masticating a semi-solid sample to a steady state of swallowing. The changes of the chewiness of starch gels mixed with or without polysaccharides, were recorded in Fig. 7a–c. It showed that with the increase of the concentration of polysaccharides, more energy was needed to masticate the gel on the whole. As for the indica rice starch–polysaccharides mixed gel (Fig. 7a), the chewiness increased significantly ($P < 0.05$) for carrageenan and gellan, and the chewiness of indica rice starch–gellan was little lower than that of the carrageenan in the whole range of 0–0.4% (w/w) concentration. However, with the increasing konjac glucomannan concentration, the chewiness of the mixed gel did not increase significantly ($P > 0.05$) and reached its highest value at 0.3% (w/w) just as the japonica rice starch–glucomannan mixed gel (Fig. 7b). As for japonica rice starch the chewiness changed with the variety and its concentration of polysaccharides just as that of indica rice starch–polysaccharides mixed gel, except its absolute value was lower than that of the latter. This meant that the chewiness was dependent greatly not only on the variety and its concentration of polysaccharides but also on the variety of rice starch. The sticky rice starch–polysaccharides gel (Fig. 7c) also showed the same explanation.

4. Conclusions

1. The addition of three kinds of polysaccharides could increase the hardness of rice starch–polysaccharides mixed gel, low concentration (<0.3%) of carrageenan and high concentration of gellan (>0.3%) could increase the hardness more significantly, the konjac glucomannan could not increase the hardness notably. The three varieties of rice starch had different hardness of the mixed gel, the indica rice starch was always the largest and the sticky rice starch had the lowest value. The hardness of the rice starch–gellan mixed gel mainly came from the network structure of gelatin polysaccharides rather than the retrogradation of amylose.
2. The carrageenan and gellan could increase the adhesiveness of the mixed gel significantly, and the carrageenan represented itself more suitable when its concentration was lower than 0.2% (w/w) and the gellan concentration was higher than 0.2% (w/w). The high cohesive forces and viscoelastic of these two kinds of gelatin polysaccharides endowed the high adhesiveness rather than the rice starch. And the konjac glucomannan could not improve the adhesiveness due to its non-gelatin polysaccharide character.
3. The indica rice starch–carrageenan mixed gel owned a comparative high adhesiveness/hardness ratio. Considering the economic factor, adding the carrageen to the rice starch gel with a low concentration (<0.2%) was valuable. When a higher adhesiveness/hardness ratio was needed, the gellan was useful, especially for indica rice starch at a high concentration (>0.3%).
4. The three varieties of rice starch, three kinds of polysaccharides and its concentration had no significant effect on the springiness; the springiness of the mixed gel had strong relationship with the existence of the amylopectin.
5. The chewiness of the mixed gel was dependent greatly not only on the variety and its concentration of polysaccharides but also on the variety of rice starch. The gellan and carrageenan could improve the chewiness in the whole testing range (0.1–0.4%), but the konjac glucomannan could not improve the chewiness efficiently.

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