NOTE

Texture and In Vitro Digestibility of White Rice Cooked with Hydrocolloids

Hyun-Jung Chung,[1] Qiang Liu,[1] and Seung-Taik Lim[2,3]

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Glycemic index (GI) is commonly used to classify food carbohydrates according to acute blood glucose responses (Jenkins et al 1981), and to control the diets for diabetics and other patients with metabolic disorders (Food and Agriculture Organization 1998). Low-GI diets have been reported to effectively control the blood glucose level (Wolever 2004), improve lipid profiles, and reduce risk of cardiovascular disease (Brand Miller 1994, 2002; Morris and Zemel 1999; Roberts 2000; Lang 2004). These diets are favorable for dietary management of metabolic disorders because nutrient receptors in the gastrointestinal tract are stimulated for a longer period of time, resulting in prolonged satiety (Brand Miller 2002; Wolever and Mchling 2002).

Rice is one of the major cereal crops consumed as a staple food in the world. Cooked rice is rapidly digested and absorbed, and thus the GI of cooked rice is known to be relatively high among various starchy foods. However, its glycemic response may vary in a wide range according to cultivar (Panlasigui et al 1991; Brand Miller et al 1992), cooking procedures (Brand Miller et al 1992; Foster-Powell and Brand Miller 1995), matrix structure (Jarvi et al 1995), and amylose-amylopectin ratio (Behall et al 1989; Panlasigui et al 1991; Frei et al 2003). Jenkins et al (1984) reported glycemic indices (GI) of cooked and brown rices to be 96 and 83, respectively. Brand Miller et al (1992) claimed that most rice cultivars, including white, brown, and parboiled rices, should be classified as high GI foods, whereas high-amylose rice was a potential low-GI food. Frei et al (2003) also reported that the GI of cooked rices from six different indigenous cultivars ranged from 68 to 109.

The digestion of a carbohydrate changes with the presence of other food components (Björck 1996; Hoover and Zhou 2003). Various additives have been tested to improve the textural and sensory properties of cooked rice. Addition of surfactants (0.5% based on rice wt) decreased the roughness, hardness, stickiness, and moistness of the cooked nonwaxy and waxy rices (Kim et al 1997a). The hardess of a cooked normal rice was significantly decreased by adding cellulose (0.2% based on rice wt) (Kim and Ahn 1996). The rice cooked with sucrose fatty acid ester (0.25 or 0.5% based on rice wt) and isomaltooligosaccharide (0.5 or 1.0% based on rice wt) also resulted in decreased hardness (Kim et al 1997b). However, no study has been reported on their effects on the digestive behavior of cooked rice.

Hydrocolloids are widely used as food additives to improve the stability and texture of host foods (Hoefler 2004), and they may also retard the retrogradation of many cereal products such as bread (Guarda et al 2004), rice cakes (Song and Park 2003), and tortillas (Friend et al 1993). Most hydrocolloids are readily soluble in water but rarely digested in human upper intestines (Edwards and Parrett 1996; Hoefler 2004), thus providing the same physiological effects as dietary fibers. In the present study, various hydrocolloids were added while rice was cooked, and their effects on the digestion and texture of the cooked rice were investigated. The glycemic response (GI value) based on the in vitro starch digestion profile was also determined.

MATERIALS AND METHODS

Materials

Milled rice (70% milling ratio, Japonica type) was purchased from a local grocery (Cheol-won, Korea). The hydrocolloids purchased from different companies were xanthan, gellan gum, and sodium alginate (NaAlg) from Nutrasweet Kelco (Chicago, IL); locust bean gum (LBG) from Cesalpinia Food (Bergamo, Italy); guar gum from Lotus Gum and Chemicals (Rajasthan, India); and arabic gum from Gum Arabic (Khartoum, Sudan).

Rice Cooking

The rice (30 g, dry basis) was cooked in a dilute hydrocolloid solution (0.3 or 0.7%, dry solid basis of rice, 42 mL) for 30 min using an electric rice cooker (RJ-0666E, LG Electronics, Korea). Prior to analyses, the cooked rice was allowed to remain in the cooker for 10–20 min.

Textural Evaluation of Cooked Rice

Two kernels of the cooked rice, carefully taken from the inside of the rice cooked in the cooker, were placed on the sample plate of a texture analyzer (TA-XT2, Stable Micro Systems, Surrey, UK). After cooling on the plate for 2 min, the rice was analyzed using a texture profile analysis (TPA) mode. A cylinder-type plunger (20 mm diameter) compressed the rice kernels at a crosshead speed of 0.5 mm/sec at a strain of 50%. Four replicates from three different sets of cooked rice kernels were tested, and mean values were obtained.

In Vitro Digestion and Glycemic Index

The in vitro digestion profile of starch in the cooked rice was evaluated according to the method of Englyst et al (1992). On the basis of the digestion rate, the different fractions of starch were quantified (Englyst et al 1992): rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS).

The digestion kinetics and glycemic indices of the cooked rice were calculated in accordance with the procedure established by Goni et al (1997). A nonlinear model following the equation [$C = C_\infty(1 - e^{-kt})$] was applied to describe the kinetics of starch hydrolysis, where C, C_∞, and k were, respectively, the concentration at time (t), equilibrium concentration, and kinetic constant. The hydrolysis index (HI) was obtained by dividing the area under the hydrolysis curve by the area for white bread (reference). The glycemic index was calculated using the equation proposed by Goni et al (1997): GI = 39.71 + 0.549 HI.

Statistics

Statistical analyses were conducted with Duncan's multiple tests to determine significance of the differences among the data.

[1] Agriculture and Agri-Food Canada, 93 Stone Road West, Guelph N1G5C9, Ontario, Canada.
[2] School of Life Sciences and Biotechnology, Korea University, 5-1 Anam-dong, Sungbuk-ku, Seoul 136-701, Korea.
[3] Corresponding author. Phone: 82-2-3290-3435. Fax: 82-2-927-5201. E-mail: limst@korea.ac.kr

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RESULTS AND DISCUSSION

Textural Properties

The effects of added hydrocolloids on the texture of cooked rice are shown in Table I. The minor addition (0.3%) of the hydrocolloids, except guar gum (0.3%), made the cooked rice harder, and hardness was increased with higher concentrations of hydrocolloids (0.7%). However, mixed data were obtained for springiness. Increased springiness values for cooked rice were obtained by adding hydrocolloids (0.3%). But an increase in gum concentration to 0.7% resulted in a decrease in springiness, with the exception of LBG, sometimes to values less than that of the control. The increase in springiness (0.3%) was most significant when sodium alginate (NaAlg) or arabic gum were added. Adding hydrocolloids affected the adhesiveness of cooked rice in a similar manner to the springiness. When the gum content was 0.3%, the adhesiveness was increased by the added hydrocolloids, with the exception of gellan gum. But adhesiveness decreased as the concentration increased (0.7%), in every case, to values less than that of the control. The rice cooked with gellan gum (0.3%) exhibited decreased adhesiveness, and the adhesiveness was exceptionally low with 0.7% gellan gum (Table I). The data for springiness and adhesiveness revealed that the surface of the cooked rice became stickier and more elastic (higher springiness) when a minor amount of hydrocolloids (0.3%) was added. However, excess hydrocolloids (0.7%) made the cooked rice less sticky and less elastic.

During cooking, rice kernels rapidly absorb water and swell. The starch granules in the kernels expand simultaneously allowing the amylose and small amylopectin chains to leach out. This change affects final textural properties of cooked rice (Ong and Blanshard 1995; Leelayuthsoontorn and Thipayarat 2006). It was reported that the leached starch chains contributed to an increase in the surface stickiness (adhesiveness) of cooked rice (Leelayuthsoontorn and Thipayarat 2006). Kasai et al (2005) reported that water penetrated the rice kernels through cracks before boiling and then diffused inside the whole kernels when the temperature reached the boiling point. The changes in surface characteristics by the gum additions suggest that the hydrocolloids may affect the leaching of starch during cooking. They might coat the surface or fill the cracks inherent in the kernels and thus retard the leaching of starch chains during cooking. It was also possible that the hydrocolloids in the cracks could limit the water penetration, so the cooked rice kernels showed increased hardness. Hydrocolloids may interact with the starch chains.

The increased hardness of cooked rice with the added hydrocolloids might be caused by the interactions between the hydrocolloids and starch, either leached or residing on the surface of the cooked rice. With a minor addition of hydrocolloids (0.3%), the interactions between the hydrocolloids and starch chains on the kernel surface might increase stickiness. When the gum concentration was 0.7%, however, the leaching of amylose might be inhibited as a consequence of the surface coating, which led to a decrease in adhesiveness (Table I). Unlike most hydrocolloids, gellan gum is dissolved by heating to >90°C but it may form an elastic and brittle gel when the gum solution is cooled (Hoefler 2004). This unique characteristic may induce the unusually low adhesiveness of cooked rice.

TABLE I
Textural Properties of Rice Cooked with Different Hydrocolloids[a]

Hydrocolloids	Dosage (%)	Springiness	Adhesiveness (g • mm)	Hardness (g)
Control	–	0.699c–e	67.2a–d	510.0b
Xanthan	0.3	0.727a–d	76.6ab	533.8b
	0.7	0.707d–e	64.1b–e	606.1a
Gellan	0.3	0.733a–c	47.9ef	520.6b
	0.7	0.679e	7.4g	638.1a
NaAlg	0.3	0.765a	83.3a	520.9b
	0.7	0.724b–d	57.4d–f	612.2a
LBG	0.3	0.701c–e	74.2a–c	517.6b
	0.7	0.703c–e	59.7c–f	621.7a
Guar	0.3	0.743ab	81.0a	494.3b
	0.7	0.671e	50.7ef	628.9a
Arabic	0.3	0.767a	76.5ab	527.2b
	0.7	0.686de	43.7f	596.7a

[a] Different letters in the same row indicate significant differences ($P \leq 0.05$).

Enzymatic Digestibility and Glycemic Index

The enzymatic digestion pattern of the cooked rice was changed by the addition of gum (Table II). Some hydrocolloids such as xanthan (0.3%), LBG (0.7%), and guar (0.7%) gum appeared to raise the RDS content. However, no clear trend was observed for the effect on the RDS content. The SDS content was clearly increased by the addition of hydrocolloids. The greatest increase in SDS (29.3%) was obtained by the addition of 0.7% gellan gum. Slowly digested carbohydrates are favorable for dietary management of metabolic disorders such as diabetes and hyperlipidemia (Wolever and Mchling 2002; Hu et al 2004). The RS content depends on the type of hydrocolloid added and its concentration (0.3 or 0.7%). At the low concentration (0.3%), LBG, guar, and arabic gums raised the RS content by 3–4%, whereas the other hydrocolloids produced opposite results. However, it was noteworthy that the RS content was reduced by increasing the amount of all hydrocolloids tested from 0.3 to 0.7%.

Overall, the data revealed that the increasing addition of hydrocolloids from 0.3 to 0.7% raised the SDS content but reduced the RS content.

TABLE II
Enzyme Hydrolysis Parameters of Rice Cooked with Different Hydrocolloids[a,b]

Hydrocolloids	Dosage (%)	RDS (%)	SDS (%)	RS (%)	C_∞ (%)	*k*	HI	GI
Control	–	46.6cd	11.8f	23.2b	69.8hg	0.120b	70.8de	78.6de
Xanthan	0.3	50.9a	9.8g	21.8c	70.7hg	0.152a	72.5cd	79.5cd
	0.7	44.4e	16.7cd	20.5de	74.3c–e	0.076d	73.3cd	79.9cd
Gellan	0.3	44.1e	18.1bc	19.4e	75.4cd	0.071d	73.9cd	80.3cd
	0.7	35.6g	29.3a	16.7f	82.0a	0.040f	75.1ab	80.9ab
NaAlg	0.3	45.6c–e	15.0de	21.3cd	73.5d–f	0.077d	72.5cd	79.5cd
	0.7	41.0f	19.8b	20.5de	75.9bc	0.057e	72.8b–d	79.7b–d
LBG	0.3	44.4e	10.0fg	26.5a	64.2j	0.139a	65.6g	75.7g
	0.7	49.1b	10.4fg	22.0c	71.8fg	0.105c	72.3cd	79.4cd
Guar	0.3	47.2c	7.6h	26.7a	73.2ef	0.101c	73.6bc	80.1bc
	0.7	49.1b	14.3e	17.8f	77.5b	0.084d	77.0a	82.0a
Arabic	0.3	44.7e	11.0fg	25.6a	66.7i	0.119b	67.6f	76.9f
	0.7	48.2de	12.1f	24.2b	69.3h	0.099c	69.6ef	77.9f

[a] Different letters in the same row indicate significant differences ($P \leq 0.05$).
[b] RDS, rapidly digestible starch; SDS, slowly digestible starch; RS, resistant starch; C_∞, equilibrium concentration; *k*, kinetic constant; HI, hydrolysis index; GI, glycemic index.

The maximum hydrolysis (C_∞) value determined from in vitro analysis of digestion was increased by the addition of the hydrocolloids, except LBG (0.3%) and arabic gum (0.3%). Among the hydrocolloids tested, gellan gum exhibited the greatest increase (82.0% at 0.7%). When the amount of the hydrocolloids increased, the kinetic constant (the hydrolysis rate at the early stage) was decreased, indicating that the hydrocolloids effectively reduced the hydrolysis rate. The decrease in the kinetic constant was significant with the addition of gellan gum (0.071 at 0.3% and 0.040 at 0.7%), which agreed with the increase in the SDS content.

As found in Table I, gellan gum at 0.7% significantly lowered the adhesiveness but raised the hardness of cooked rice. In digestion results, gellan gum significantly retarded the hydrolysis rate (low k values) but increased the SDS content. The gelling tendency of gellan gum might effectively coat the surface of the cooked rice, thus retarding enzymatic digestion. During digestion, the surface of the cooked rice gradually eroded and the kernal size continually decreased. After 60 min of digestion, only small fragments of the rice kernels remained (Fig. 1). The retarding of the erosion by enzymatic digestion was in agreement with the increased SDS content. After 180 min of digestion, however, the maximum hydrolysis value (C_∞) was higher than that of the control, resulting in a reduced amount of RS (Table II). The amylose leached during cooking retrogrades rapidly when the cooked rice is cooled. Some of the retrograded amylose might reside on the surface of the rice kernels, hindering the enzymatic attack, the effect of which was similar to that of the surface coating by the hydrocolloids. However, it has been reported that the hydrocolloids could retard the amylose retrogradation (Ferrero et al 1994; Lee et al 2002). Therefore, it could be hypothesized that the gellan gum could retard the enzyme attack by coating the surface of cooked rice in the early stage of digestion. However, in the late stage, the degree of enzymatic hydrolysis was increased because the tendency of the leached amylose to retrograde became retarded due to the interaction between starch and hydrocolloid. This process raised the SDS content of the cooked rice. Additional experiments should be done to confirm this phenomenon.

The glycemic index (GI) of the rice cooked with hydrocolloids ranged from 75.7 (LBG at 0.3%) to 82.0 (guar gum at 0.7%). Among the tested samples, only LBG at 0.3% and arabic gum at both concentrations resulted in decreased GI compared with that of the control. The other hydrocolloids showed increases in GI values, presumably due to the increased extent of maximum hydrolysis. Consequently, the addition of hydrocolloids during cooking of rice could reduce the digestion rate but increase the GI, although some differences among the gums tested still exist. The slower digestion of cooked rice by the minor addition of hydrocolloids could be potentially beneficial for dietary management to control diabetes, obesity, and hyperlipidemia.

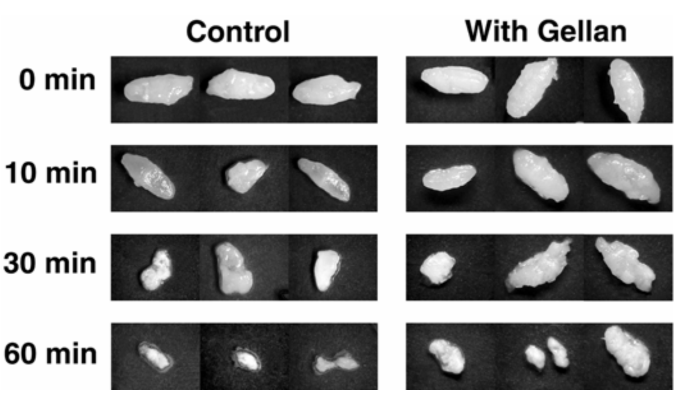

Fig. 1. Cooked rice without and with gellan gum (0.7%) at different digestion times.

CONCLUSIONS

The cooked rice became harder but digested more slowly when a minor amount (0.3 or 0.7%) of commercial hydrocolloids was added. The hydrocolloids at 0.7% addition effectively raised the SDS content. The glycemic index, however, was either reduced or increased depending on the hydrocolloid type. LBG and arabic gum reduced the GI by 2–3%, whereas gellan gum raised it by ≈2%. Among the hydrocolloids tested, gellan gum exhibited the most significant effects on the texture and digestion behavior. It decreased the adhesiveness of the cooked rice and increased the SDS content. Therefore, minor addition of hydrocolloids is a simple way to change the digestion behavior of cooked rice.

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LITERATURE CITED

Behall, K. M., Scholfield, D. J., Yuhaniak, I., and Canary, J. 1989. Diets containing high amylose vs. amylopectin starch: Effects on metabolic variables in human subjects. Am. J. Clin. Nutr. 49:337-344.

Björck, I. 1996. Starch: Nutritional aspects. Pages 505-553 in: Carbohydrates in Food. A.-C. Eliasson, eds. Marcel Dekker: New York.

Brand Miller, J. C., Holt, S. H. A., Pawlak, D. B., and McMillan, J. 2002. Glycemic index and obesity. Am. J. Clin. Nutr. 76(suppl.):S281-285.

Brand Miller, J. C. 1994. Importance of glycemic index in diabetes. Am. J. Clin. Nutr. 59(suppl):S747-752.

Brand Miller, J. C., Pang, E., and Bramall, L. 1992. Rice: A high or low glycemic index food? Am. J. Clin. Nutr. 56:1034-1036.

Edwards, C. A., and Parrett, A. M. 1996. Starch: Physicochemical and functional aspects. Pages 319-345 in: Carbohydrates in Food. A.-C. Eliasson, eds. Marcel Dekker: New York.

Englyst, H. N., Kingman, S. M., and Cummings, J. H. 1992. Classification and measurement of nutritionally important starch fractions. Eur. J. Clin. Nutr. 46:S33-S50.

Ferrero, C., Martino, M. N., and Zaritzky, N. E. 1994. Corn starch-xanthan gum interaction and its effect on the stability during storage of frozen gelatinized suspensions. Starch 46:300-308.

Food and Agriculture Organization. 1998. Carbohydrates in Human Nutrition. Report of an FAO/WHO Expert Consultation on Carbohydrates, April 14-18, 1997. FAO: Rome.

Foster-Powell, K., and Brand Miller, J. 1995. International tables of glycemic index. Am. J. Clin. Nutr. 62:S871-893.

Frei, M., Siddhuraju, P., and Becker, K. 2003. Studies on the in vitro starch digestibility and the glycemic index of six different indigenous rice cultivars from the Philippines. Food Chem. 83:395-402.

Friend, C. P., Waniska, R. D., and Rooney, L. W. 1993. Effects of hydrocolloids on processing and qualities of wheat tortillas. Cereal Chem. 70:252-256.

Goni, I., Garcia-Alonso, A., and Saura-Calixto, F. 1997. A starch hydrolysis procedure to estimate glycemic index. Nutr. Res. 17:427-437.

Guarda, A., Rosell, C. M., Benedito, C., and Galotto, M. J. 2004. Different hydrocolloids as bread improvers and antistaling agents. Food Hydrocoll. 18:241-247.

Hoefler, A. C. 2004. Hydrocolloids. Eagan Press: Minnesota.

Hoover, R., and Zhou, Y. 2003. In vitro and in vivo hydrolysis of legume starch α-amylase and resistant starch formation in legumes—A review. Carbohydr. Polym. 54:401-417.

Hu, P., Zhao, H., Duan, Z., Linlin, Z., and Wu, D. 2004. Starch digestibility and the estimated glycemic score of different types of rice differing in amylose contents. J. Cereal Sci. 40:231-237.

Jarvi, A., Karlstrom, B., Granfeldt, Y., Björck, I., Vessby, B., and Asp, N. G. 1995. The influence of food structure on postprandial metabolism in patients with non-insulin-dependent diabetes mellitus. Am. J. Clin. Nutr. 61:837-842.

Jenkins, D. J. A., Wolever, T. M. S., Jenkins, A. L., Josse, R. G., and Wong, G. S. 1984. The glycemic response to carbohydrate foods. The Lancet 18:388-391.

Jenkins, D. J. A., Wolever, T. M. S., Taylor, R. H., Barker, H., Hasemein, F., Baldwin, J. M., Bowling, A. C., Newman, H. C., Henkins, A. L.,

and Goff, D. V. 1981. Glycemic index of foods: A physiological basis for carbohydrate exchange. Am. J. Clin. Nutr. 34:362-366.
Kasai, M., Lewis, A., Marica, F., Ayabe, S., Hatae, K., and Fyfe, C. A. 2005. NMR imaging investigation of rice cooking. Food Res. Int. 38:403-410.
Kim, S. K., Lee, S. K., and Shin, M. S. 1997a. Effect of surfactants on the characteristics of cooked rice during storage. Kor. J. Soc. Food Sci. 13:278-285.
Kim, M. H., Kim, B. Y., and Kim, S. K. 1997b. Effect of sucrose fatty ester or oligosaccharide addition on texture of stored cooked rice. Food Eng. Progr. 1:107-112.
Kim, Y. K., and Ahn, S. Y. 1996. The effect of cellulose treatment on the physicochemical properties of rice and the texture of cooked rice. Kor. J. Food Sci. Technol. 28:720-729.
Lang, A. 2004. Development of a range of industrialized cereal-based foodstuffs, high in slowly digestible starch. Page 477-504 in: Starch in Food: Structure, Function and Applications. A.-C. Eliasson, eds. CRC Press: Boca Raton, FL.
Lee, M. H., Baek, M. H., Cha, D. S., Park, H. J., and Lim, S. T. 2002. Freeze-thaw stabilization of sweet potato starch gel by polysaccharide gums. Food Hydrocoll. 16:345-352.
Leelayuthsoontorn, P., and Thipayarat, A. 2006. Textural and morphological changes of Jasmine rice under various elevated cooking conditions. Food Chem. 96:606-613.
Morris, K. L., and Zemel, M. B. 1999. Glycemic index, cardiovascular disease, and obesity. Nutr. Rev. 57:273-276.
Ong, M. H., and Blanshard, J. M. V. 1995. Texture determinants in cooked, parboiled rice. I. Rice starch amylose and the fine structure of amylopectin. J. Cereal Sci. 21:251-260.
Panlasigui, L. N., Thompson, L. U., Juliano, B. O., Perez, C. M., Yiu, S. H., and Greenberg, G. R. 1991. Rice varieties with similar amylose content differ in starch digestibility and glycemic response in humans. Am. J. Clin. Nutr. 54:871-877.
Roberts, S. B. 2000. High-glycemic index foods, hunger, and obesity: Is there a connection? Nutr. Rev. 58:163-169.
Song, J. C., and Park, H. J. 2003. Functions of various hydrocolloids as anticaking agents in Korean rice cakes. J. Kor. Soc. Food Sci. Nutr. 32:1253-1261.
Wolever, T. M. S. 2004. Effect of blood sampling schedule and method of calculating the area under the curve on validity and precision of glycaemic index values. Brit. J. Nutr. 91:295-300.
Wolever, T. M. S., and Mchling, C. 2002. High-carbohydrate-low-glycemic index dietary advice improves glucose disposition index in subjects with impaired glucose tolerance. Brit. J. Nutr. 87:477-487.

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