Food Sci. Biotechnol. Vol. 17, No. 1, pp. 180 ~ 183 (2008)

RESEARCH NOTE

Food Science and Biotechnology

In Vitro Digestibility of Rice and Barley in Forms of Raw Flour and Cooked Kernels

Jung-Ah Han, Su-Hae Jang[1], and Seung-Taik Lim[1]*

Division of Human Environmental Sciences, Sangmyung University, Seoul 110-743, Korea

[1]School of Life Sciences and Biotechnology, Korea University, Seoul 136-701, Korea

Abstract Digestion properties of 3 types of cereals, white rice, brown rice, and barley, were measured after cooking or grinding. Regardless of the processing methods, white rice showed the highest rate and the greatest extent of digestion, whereas barley showed the lowest values. During the early digestion period, cooked white rice kernels had a larger k (kinetic constant) value than uncooked white rice flour, indicating that cooking induced faster digestion than grinding. In the case of brown rice and barley, the cell wall in cooked kernels remained intact and resulted in a lower k values than those of uncooked flour. However, after 3 hr of digestion, the total digestion extent was greater for the cooked brown rice and barley than that for uncooked flours. The high content of slowly digestible starch (SDS) in cooked brown rice and barley might be due to the starch fraction which was protected by the cell wall. The resistant starch (RS) content, however, was greater for the uncooked flours than that for cooked kernels. The cooked kernels of 3 cereal samples tested showed higher glycemic index (GI) values than the uncooked flours.

Keywords: rice, barley, cooking, digestion, glycemic index (GI)

Introduction

Starch can be classified into 3 groups based on the digestion behavior; rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) (1). Among these, SDS has been focused in nutritional aspects because it may prolong satiety and can be effectively incorporated in processed foods for weight loss. Therefore, raising the SDS content thereby results in a diet with low glycemic index (GI) and thus is considered to contribute to public health (2). Rice is one of the most important cereals worldwide and is the primary source of calories. Barley is another major cereal consumed in Asian countries as a staple food. Rice and barley are consumed mostly in the form of steam-cooked kernels. However, they can be used as components in processed food products (3). Recently, uncooked cereals are consumed in ground flour forms as a common meal because those are considered promoting health.

Cooking considerably increases the susceptibility to digestion because it ruptures the granular structure of starch (4). According to Englyst *et al.* (5), raw cereals are partially inaccessible to digestion because the pericarp and seed coat may impede the efficiency of amylase digestion of starch in cereal grains. Grinding, as another processing method, is reported to affect digestion by increasing the surface area for the enzyme to contact (6). In this study, 2 processing methods: cooking (kernel) and grinding (uncooked flour) were compared in digestion behaviors for 3 types of cereals, white rice, brown rice, and barley. The starch fractions different in digestion behavior (RDS, SDS, and RS), and GI for the cereal samples were measured from an *in vitro* digestion analysis.

*Corresponding author: Tel: +82-2-3290-3435; Fax: +82-2-921-0557
E-mail: limst@korea.ac.kr
Received April 24, 2007; accepted August 7, 2007

Materials and Methods

Materials White rice, brown rice, and barley (6-rowed type) were purchased from a local grocery in Seoul, Korea. The rices are japonica types harvested in 2005, Korea. Barley was a milled product like white rice.

Sample preparation For uncooked flour, white rice, brown rice, and barley grains were milled using a Cyclotec sample miller (Tecator, Höganäs, Sweden) and sieved (by 50 mesh). For cooked intact samples, washed cereal grains (30 g) were cooked with water (40 mL) using an electric rice cooker (RJ-0666E; LG Electronics, Seoul, Korea) for 30 min. The cooked grains were then allowed to settle in the cooker for 10 min, and then 1 g was taken from center to measure the digestibility.

***In vitro* digestibility** Digestibility was determined using the method described by Englyst *et al.* (5) with minor modifications (7). The different fractions of starch were then categorized based on digestion rate (5); rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS).

Glycemic index (GI) The glycemic indices of the samples were estimated using Goñi *et al.*'s (8) method with white bread as reference. The hydrolysis curve of each noodle product followed the first order equation, $[C=C_\infty(1-e^{-kt})]$. The k value, representing the digestion rate at time t, was obtained using the equation, where C and C_∞ were the concentrations at time t and at equilibrium, respectively. The glycemic indices of the samples were estimated according to the equation proposed (8): GI= 39.71+0.549 HI, in which HI was hydrolysis index calculated as the percentage of total glucose released from the samples based on that from white bread.

Optical microscopy To observe the cross section, cooked grains were frozen by storing at −70°C for 24 hr, and then cut to a thin slice (80 μm thickness) using microtome (CM 3050 S; Leica, Nussoloch, Germany). Each sample slice was dyed with an iodine solution and then observed using an optical microscope (Olympus CX 40; Olympus Corp., Tokyo, Japan).

Statistics Statistical analyses were carried out using Duncan's multiple tests to determine the significance of differences among the data.

Results and Discussion

Digestion behavior of each sample throughout 3 hr of incubation is shown in Fig. 1. In both of the uncooked flour and cooked intact samples, white rice showed the fastest digestion among the samples, whereas barley showed the slowest. For uncooked flour samples, there was not much difference in the digestion rate at the beginning stage between the 2 rice samples (white rice and brown rice), but the difference increased as hydrolysis time increased. Cooked and intact kernels showed significant difference among the samples in the early digestion. However, they appeared to be hydrolyzed to a similar extent after 3 hr

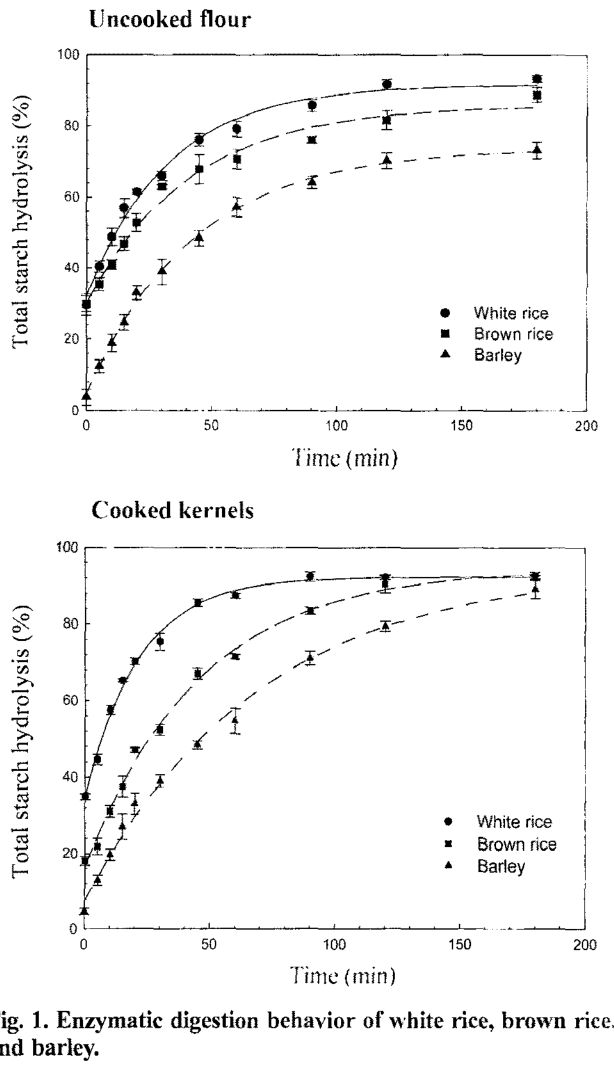

Fig. 1. Enzymatic digestion behavior of white rice, brown rice, and barley.

(Fig. 1). Both flour and kernel samples exhibited same order of digestion level: white rice > brown rice > barley, although the profile was not same between flour and cooked kernels. Barley showed the lower degree of digestion than rice, consistent with other researchers' reports (9,10). Digestion level of the 3 flour samples reached their plateaus after 2 hr of incubation. For cooked samples, however, the maximum levels of digestion were different among the samples. The cooked white rice reached its maximum level of hydrolysis at about 90 min, but cooked brown rice and barley showed continuous increases in the degree of digestion until 180 min. The maximum digestion level was 90% for both uncooked flour and cooked white rice, and those for barley were 70% (flour) and 85% (cooked kernels).

Digestion kinetics can be more precisely compared using the k value (Table 1). For white rice, cooked kernels showed a higher k value (0.0462) than flour sample (0.0342), indicating that cooking increased digestion rate more effectively than grinding. The fast digestion allowed the cooked sample to reach the maximum level of digestion at approximately 90 min, whereas the maximum level of the flour sample was obtained at approximately 120 min. In the case of brown rice and barley, however, the k values of uncooked flour (0.0244 and 0.0244, respectively) were greater than those of cooked kernels (0.0218 and 0.0145, respectively), indicating that grinding induced faster digestion than cooking. Because smaller particles have more surface area so that the digestive enzyme accesses more readily. The continuous increase of digestion for the cooked kernels of brown rice and barley until 180 min supported low k values. The brown rice contains aleuronic layers, which may behave as protective coating against the enzymatic attack. Barley kernels contain almost no aleuronic layers, but non-digestive fiber components, and these non-digestible coatings and fibers might remain intact in the kernels even after cooking. However, grinding to flours disrupts the fibrous coating or cell walls in the kernels, so that starch granules become readily exposed to the enzyme.

GI values are also shown in Table 1. The GI followed the same order as the k values: white rice > brown rice > barley. For all samples, cooked kernels showed higher GI values than uncooked flours, indicating that cooking increased GI to a greater extent than grinding.

Each digestive fraction of starch in the samples is shown in Fig. 2. For the uncooked flours of white and brown

Table 1. Kinetic constants for digestion and glycemic indices for rice and barley in the forms of uncooked flour and cooked kernels[1)]

	Materials	k	GI	TS (%)
Uncooked flour	White rice	0.0342^{b}	86.4±0.6	90.2
	Brown rice	0.0244^{c}	82.1±1.2	76.8
	Barley	0.0244^{c}	72.8±0.8	74.8
Cooked kernels	White rice	0.0462^{a}	89.1±0.2	87.2
	Brown rice	0.0218^{d}	82.6±0.9	86.0
	Barley	0.0145^{e}	76.9±0.5	75.2

[1)]Each value represents the mean of triplicates. Data with different alphabets were different with statistical significance ($p<0.05$). k, Kinetic constant; GI, calculated from the equations proposed by Goñi *et al.* (1997); TS, amount of total starch.

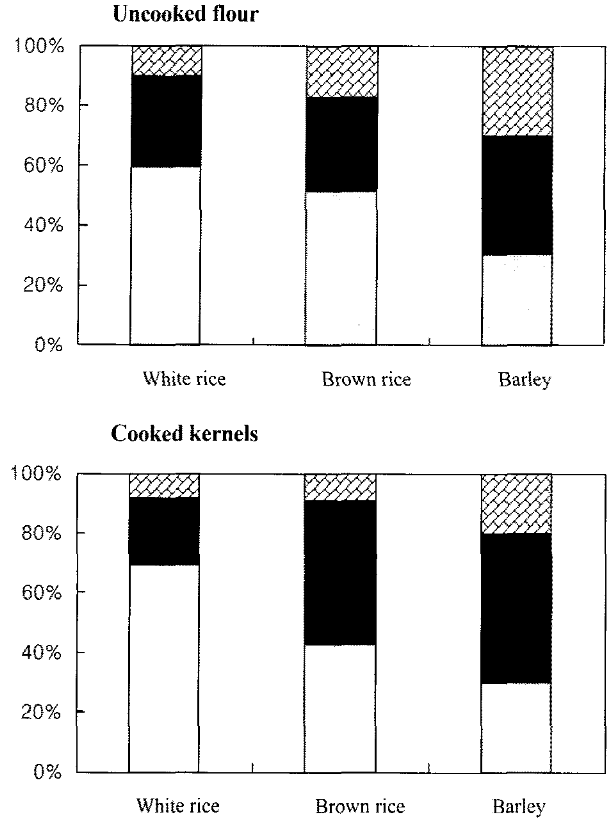

Fig. 2. Starch fractions different in digestibility (RDS ▒, SDS ■, and RS ▨) for rice and barley in the forms of uncooked flour and cooked kernels.

rices, the amount of starch fractions was in the order: RDS >SDS>RS. In barley, SDS portion was the highest. For cooked kernels, white and brown rice were different in the starch fraction. The amount of starch fractions in white rice was RDS>SDS>RS, whereas that in brown rice was SDS>RDS>RS. Barley showed the same order as brown rice. This trend supports the kinetic data in which the cooked brown rice was slower in digestion than the uncooked flour of brown rice. Barley showed the lowest value for RDS, regardless of its physical state.

Light microscopy Starch granules in cereals exist inside the endosperm cell wall. Therefore the presence of cell wall may physically inhibit the hydrolysis of starch by digestive enzymes. The cell wall of rice endosperms is composed of cellulose, arabinoxylan, hemicellulose, and pectin (11), whereas that of barley is composed of mainly β-glucan (>70%) and arabinoxylan (20-25%). The β-glucan, which is a primary cell wall material, doesn't exist in rice. Figure 3 shows the endosperm of cooked kernels observed by an optical microscopy. The cell wall of white rice kernels was mostly disrupted by the cooking (30 min), whereas that of barley remained intact under the same cooking condition. Brown rice showed more preserved structure than white rice, but less intact than barley. The differences in the endosperm structure, more precisely, the intactness of cell wall clearly demonstrated the reason for barley to be exceptionally resistant to the digestive enzymatic action.

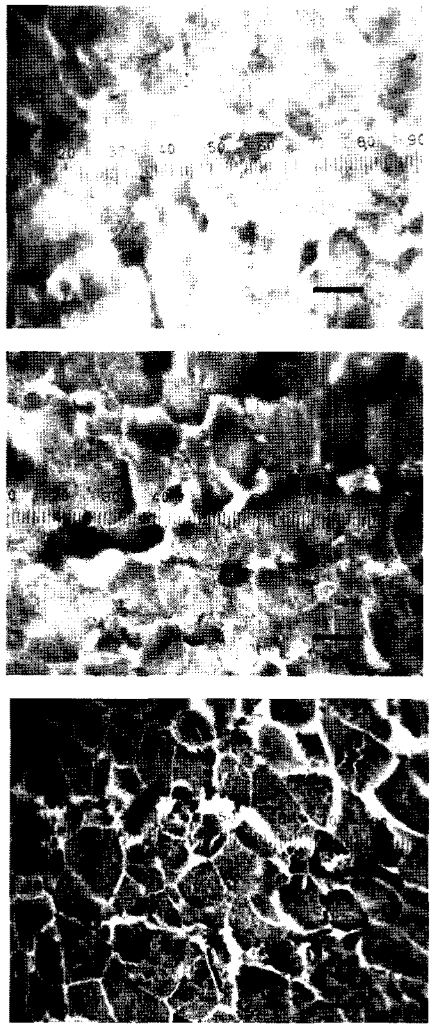

Fig. 3. Microscopic pictures of endosperm section of cooked cereals (bar = 100 μm).

Cooking the rice or barley kernels increased GI at higher degree than did grinding to flours without cooking. However, the digestion rate could be raised more effectively by grinding. Especially, for the cereals containing protective outer layers or non-digestible cell walls in endosperms, such as brown rice and barley, the mechanical grinding disrupted their protective effect, and thus the starches could be exposed to the digestive enzyme. On the other hands, the cooked kernels, although starch inside was mostly gelatinized, contained the cell wall less disrupted than grinding, resulting in higher resistance to the digestion. In terms of digestive starch fractions, cooked brown rice and barley kernels revealed containing the SDS fraction more than RDS fraction, whereas cooked white rice kernels contained SDS less than half of that in brown rice or barley. Barley was highly resistant to digestion because the stability of cell wall structure upon the cooking process. The rigidity of cell wall may be related to the constituent materials such as β-glucan for barley (12).

References

1. Englyst HN, Hudson GJ. The classification and measurement of dietary carbohydrates. Food Chem. 57: 15-21 (1996)

2. Han J-A, BeMiller JN. Preparation and physical characteristics of slowly digesting modified food starches. Carbohyd. Polym. 67: 366-374 (2007)
3. Chun S-Y, Kim H-I, Yoo B. Effect of gum addition on the rheological properties of rice flour dispersions. Food Sci. Biotechnol. 15: 589-594 (2006)
4. Holm J, Björck I, Asp N-T, Sjöberg L-B, Lundquist I. Starch availability *in vitro* and *in vivo* after flaking, steam-cooking, and popping of wheat. J. Cereal Sci. 3: 193-206 (1985)
5. Englyst HN, Kingman SM, Cummings HJ. Classification and measurement of nutritionally important starch fractions. Eur. J. Clin. Nutr. 46: S33-S50 (1992)
6. Granfeldt Y, Lijeberg H, Drews A, Newman R, Björck I. Glucose and insulin responses to barley products: Influence of food structure and amylose-amylopectin ratio. Am. J. Clin. Nutr. 59: 1075-1082 (1994)
7. Chung H-J, Lim HS, Lim S-T. Effect of partial gelatinization and retrogradation on the enzymatic digestion of waxy rice starch. J. Cereal Sci. 43: 353-359 (2006)
8. Goñi I, Garcia-Alonso A, Saura-Calixto F. A starch hydrolysis procedure to estimate glycemic index. Nutr. Res. 17: 427-437 (1997)
9. Lee JS, Shin HK. Correlation between glycemic index and *in vitro* starch hydrolysis of cereals. Korean J. Food Sci. Technol. 30: 1229-1235 (1998)
10. Lee Y-T, Chang H-G. The effect of heat treatments on *in vitro* starch digestibility and resistant starch of selected cereals. Food Sci. Biotechnol. 13: 810-813 (2004)
11. Hoseney RC. Minor constituents of cereals. pp. 81-101. In: Principles of Cereal Science and Technology. 2nd ed. American Association of Cereal Chemists, St. Paul, MN, USA (1994)
12. Yoo M-S, Lee Y-T. Pasting properties of crude β-glucan from spent brewer's yeast on wheat flour and starch. Food Sci. Biotechnol. 16: 485-488 (2007)