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Relationships between starch digestibility and gelatinization degree of cooked rice with structural change

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ABSTRACT

The effect of gelatinization degree during cooking on the digestibility of cooked rice was investigated through a simulated gastro-intestinal *in vitro* digestion technique. The changes in starch hydrolysis percentage during simulated digestion were evaluated as a cooked rice digestibility in this study. Polished medium, non-waxy rice grain was soaked into boiling water as a model cooking. The boiling time was set at 10 and 20 min to obtain two gelatinized degree samples. Slurry samples were prepared from the grain samples to examine the impact of structural change of rice grain. The kinetics of cooked rice digestibility showed that there was no significant difference in the equilibrium starch hydrolysis percentage between the grain boiled for 10 min as a partially gelatinized sample and the grain boiled for 20 min as a completely gelatinized sample. However, the large difference between raw and boiled samples was shown. It was also shown that the equilibrium percentage of slurry was larger than the grain, even if the gelatinization degree was the same. These results indicated that the rice digestibility would be less affected by cooking conditions related with starch gelatinization except for raw materials, but should be influenced on the masticatory conditions connected to structural changes in the grain.

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INTRODUCTION

Starch is a kind of polysaccharides mainly provided from cereals, and is a major resource of the vital energy for humans. A glycemic index (GI) is considered as one of the important objective indices for changes in blood sugar level in human body. The blood sugar level is varied after meal of which variation is different from carbohydrate resources even if the resources contain the equivalent amount of carbohydrate (Jenkins *et al*., 1981). Continuous consumption of high GI food may increase risk of obesity, cardiovascular diseases and type II diabetes (Jennie, 2007, Jenkins, 2007). Statistical studies have suggested the number of hypertension patients will increase from 972 million in 2000 to 1.56 billion in 2025 (Kearney *et al*., 2005), meanwhile the number of diabetes patients will also increase from 171 billion in 2000 to 366 billion in 2030 (Wild *et al*., 2004). Therefore, appropriate circumstances for not only medical care but also health maintenance through the meal must be considered and established.

Rice is regarded as one of the high GI foods (Murakami *et al*., 2006). Currently, production of low amylose cultivars of which cooked product shows soft and sticky attributes has been increased in Japan. These low amylose cultivars tend to have high GI property when they are cooked (Osawa and Inoue, 2007). Therefore, innovative researches and developments for GI control method have been necessary to decrease potential patients for metabolic syndrome like diabetes.

Zhang *et al*. (2006a, 2006b) and Jung *et al*. (2009) reported that raw starch or semi-cooked starch can be considered as low GI food resources to manage dietary for the patients, because GI is readily changed by gelatinization (Jaiboon *et al*., 2011). A structural property would also relate to starch hydrolysis (Bordoloi, *et al*., 2012), however there are few reports to investigate the effect of grain structural changes on the starch digestibility of cooked rice.

To examine digestibility of cooked rice with various gelatinization degrees for both slurry and grain, a simulated *in vitro* digestion technique was applied to both slurry and grain and changes in simulated starch hydrolysis percentage and kinetics during digestion process were investigated and evaluated in this study.

MATERIALS AND METHODS

Materials

Polished rice grain (Sunrice, Australian medium grain, white rice) was purchased at local store in Palmerston North, New Zealand and stored in a refrigerator at 4 °C before experiment. The initial moisture content of the sample grains was 14.1 ± 0.1% (w.b.). Apparent amylose content measured following modified Juliano's method (Juliano *et al*., 1981) was 23.7 ± 0.3% in dry material. The sample grain was examined within four months after purchase. A simulated gastric fluid (SGF) and a simulated small intestinal fluid (SIF) were prepared in accordance with the US pharmacopeia method (US pharmacopeia 2000).

Sample preparation

To obtain cooked rice grain samples with various gelatinization degrees, a model cooking method was applied to the polished rice grain (P) in this study. Two hundred grams of polished grain sample was simply soaked in 500 mL of boiling RO water. Soaking time in the boiling water for rice grain was regulated to produce various gelatinization degree samples. The gelatinization degree was confirmed by white core size in the compressed sample grains. Two glass plates were used as compressed apparatus for the tested grain. In this study, boiled grain with no white core, which was obtained by soaking in boiling water for 20 min, was defined as a completely gelatinized rice grain (CG). The grain soaked in boiling water for 10 min was also obtained and defined as a partially gelatinized rice grain (PG), which had small white core. The boiled sample rice grain was rapidly wrapped and cooled for 30 min under room temperature for further investigation. A part of grain samples was homogenized using household blender (HB605, Kenwood, Havant, UK) for 2 min to obtain slurry sample, which was generally used to determine the food digestibility.

In vitro digestion

A two-stage gastro-intestinal *in vitro* digestion model (Dartois *et al*., 2010) was arranged and employed in this study. Cooked rice grain and slurry samples were adjusted their starch contents by adding of RO water in the identical 500 mL jacketed glass reactors, and continuously agitated using magnetic stirrer in the reactor. Note that the grain samples were placed into a commercial mesh bag, in which grain samples can avoid directly contact with rotated magnetic stirrer bar and can be easily contacted with simulated digestive buffer. The reactor can be maintained its temperature at 37 °C during simulated gastric and intestinal digestive reactions by 37 °C of circulatory water.

The solution pH was adjusted to 1.20 ± 0.01 by addition of SGF, when the gastric process was regarded to start. The pH was continuously maintained during the process by addition of several concentrations (0.5, 1.0, 3.0 M) of HCl solution. After 30 min of gastric process, pepsin was inactivated according to the pH change to approximately 6.00 by addition of appropriate concentrations (0.2, 1.0, 3.0 M) of NaOH solution. To continue the small intestine process, SIF was added to the gastric reaction mixture. And then, the pH was adjusted to 6.80 ± 0.01 using NaOH or HCl solutions mentioned above.

Supernatants (0.5 mL) were collected to analyze the glucose content during the process at 5 min (G5) and 30 min (G30) of the gastric process, 5 min (I5), 30 min (I30) and 60 min (I60) of the small intestinal process. The glucose concentration was measured using D-glucose assay kit (GOPOD Format K-GLUK 07/11, Megazyme International) and spectrophotometer (GENESYS 10uv, Thermo Fisher Scientific, Waltham, MA). Results were represented as percentage of starch hydrolysis using below equations.

$$\%SH = Sh / Si$$
$$= 0.9 \times Gp / Si$$

where, %SH is a percentage of starch hydrolysis, Sh is an amount of hydrolyzed starch, Si is an initial amount of starch, and Gp is an amount of produced glucose. A conversion factor of 0.9 which was generally calculated from the molecular weight of starch monomer / glucose (162 / 180 = 0.9) was used (Goñi *et al*., 1997).

A first-order equation model referred to Goñi *et al*. (1997) as shown below was applied to describe the kinetics of starch hydrolysis.

$$C = C_{\infty} (1 - e^{-kt})$$

where, C corresponds to percentage of hydrolyzed starch at time t,

C_∞ is equilibrium concentration of starch in the simulated digestion process, k is the kinetic constant and t is time. Parameter estimation was carried out using the software, Igor Pro (ver. 4.01, Hulinks Inc. Tokyo, Japan).

Statistical analyses

Results were calculated as means ± standard deviations. Subsequently, Tukey's test, in conjunction with an analysis of variance (ANOVA) was used to determine significant differences among means, at an a priori significance level of P < 0.05 using R software (R Development Core Team, 2009).

RESULTS AND DISCUSSION

Figure 1 shows changes in starch hydrolysis percentage of rice slurry (a) and grain (b) samples with various gelatinization degrees during simulated *in vitro* digestion process. In the gastric process at G5 and G30, almost zero percent of hydrolysis was displayed both slurry and grain samples. The hydrolysis percentage increased after G30, which was in the small intestinal digestion process. The starch hydrolysis percentages of the slurry samples for P, PG and CG were sharply increased approximately 13, 49 and 56 % at I5, respectively. This result also indicated that the order of starch hydrolysis percentage at same digestion time was similar to the order of gelatinization degree. On the contrary, the grain samples for P, PG and CG show percent hydrolysis of 3, 15 and 15 %, respectively, which were comparatively lower than the slurry samples.

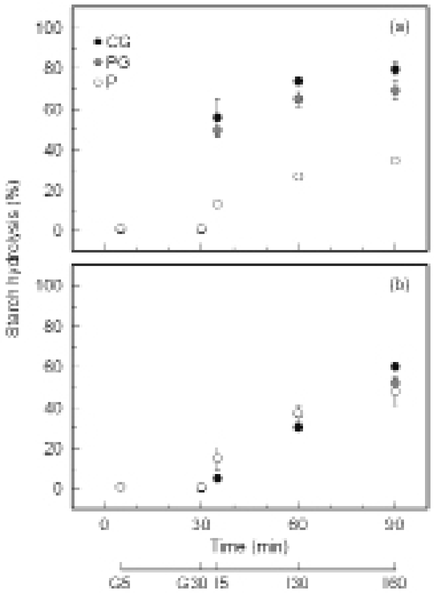

Figure 1. Changes in starch hydrolysis percentages of rice slurry (a) and grain (b) with various gelatinization degrees during simulated *in vitro* digestion process
P (polished), PG (partially gelatinized), CG (completely gelatinized). Error bars represent standard deviation (n = 3).

The calculated equilibrium starch hydrolysis percentage (C_∞) and the kinetic constant (k) of each gelatinized degree sample for slurry and grain are represented in Table 1. It was recognized that the equilibrium starch hydrolysis percentage increased with increase of sample gelatinization degree both in slurry and grain, although significant differences between PG and CG were not found. It was also shown that the equilibrium percentage for the slurry was larger than for the grain, even if the gelatinization degree was same. The kinetic constants for the slurry also increased with increase of gelatinization degree, though there were no significant differences for the grain which were sufficiently smaller than the slurry. Therefore, the structural properties of rice samples must be related with these differences between slurry and grain samples.

Table 1. Kinetics of starch hydrolysis for rice slurry and grain samples with various gelatinization degrees during simulated *in vitro* digestion process

		C_∞ (%)	k ×10^{-2} (min^{-1})
Slurry	P	32.4± 2.3 d	8.5 ± 1.0 b
	PG	66.8 ± 4.0 ab	26.9 ± 2.3 a
	CG	76.4 ± 2.4 a	26.8 ± 7.5 a
Grain	P	5.7 ± 0.5 e	9.6 ± 1.7 b
	PG	49.9 ± 8.1 c	5.8 ± 2.6 b
	CG	55.7 ± 8.6 bc	5.1 ± 2.6 b

Different letters in the same column indicate significant differences ($P < 0.05$) (n = 3). P (polished), PG (partially gelatinized), CG (completely gelatinized), C_∞ (equilibrium starch hydrolysis percentage), k (kinetic constant)

Bordoloi *et al.* (2012) reported that a shrinkage and wrinkle of foodstuffs during digestion were found on the tissue structure of cooked potato slice cell walls. Although the grain of *in vitro* digested samples in this study such as grains at I120 showed shrinkage because of low pH and digestive enzymatic treatment, their structural characteristics composed by cell wall matrix shown as pore-like structures were maintained. These results should be related with differences in the digestibility between slurry and grain samples including kinetic constant, which concerned digestion rate of starchy foods. Chung *et al.* (2006) confirmed that there was no differences in the equilibrium starch hydrolysis of waxy rice among various gelatinization degree samples. It was also found that there were no significant differences in the starch hydrolysis between PG and CG for the grain sample.

CONCLUSION

Differences in the *in vitro* digestibility between polished raw and cooked rice samples cooked by model cooking were found, although no significant differences between partially and completely gelatinized rice samples. The grain structural change should be more relational with rice digestibility according to comparison between grain and slurry sample. These results indicated that the rice digestibility would be less affected by cooking conditions related with starch gelatinization except for raw materials, but should be influenced on the masticatory conditions connected to structural changes in the grain.

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