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Direct observation and evaluation of cooked white and brown rice digestion by gastric digestion simulator provided with peristaltic function

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ABSTRACT

This study evaluates physical digestion for cooked white rice and cooked brown rice using a novel *in vitro* gastric digestion simulator (GDS). The GDS enabled direct observation of the disintegration of cooked rice in the presence of simulated human gastric peristalsis. The experiments confirmed a steep increase in the disintegration of cooked white rice during the initial 30 min, after which disintegrated contents slowly increased. However, the appearance of liquid phase had little effect on cooked brown rice up to 180 min digestion, likely due to the protective action of the bran layer. Our results indicated that cooked rice particles gradually disintegrated into smaller fractions, depending on the type of cooked rice. The present research uses GDS to provide a better understanding of solid food digestion.

1. Introduction

Human digestion in the gastrointestinal tract is a complex process that basically involves mechanical digestion and chemical digestion. During mechanical digestion, large foods are broken down into smaller pieces, which can subsequently be accessed by digestive enzymes. During chemical digestion, the enzymes secreted from different digestive systems break down large food molecules by hydrolysis, and the released nutrients can be used for body growth. Food disintegration occurs mainly in the mouth and stomach, whereas enzymatic digestion and the absorption of nutrients and water occur mainly in the small and large intestines (Kong & Singh, 2008). Recently, the effects of food texture and microstructural properties on human digestion have been of great interest to food scientists and nutritionists. Most gastric digestion studies focused on either clinical or medical purposes to clarify the role of food microstructural properties on the physiology of human digestion and nutrition (Marciani et al., 2000). Shaking flask and test-tube methods are commonly used for evaluating *in vitro* gastrointestinal digestion, due to easy simulation of the chemical environment in the gastrointestinal tract (*e.g.*, pH and digestive enzymes) (Hur, Lim, Decker, & McClements, 2010; McClements & Li, 2010). However, these methods do not enable simulation of a dynamic physical environment, such as peristaltic motion.

In the past, several research groups developed dynamic gastric and/or intestinal devices. Minekus, Marteau, Havenaar, and Huis in't Veld (1995) developed a multi-compartmental system that can simulate the dynamic conditions in the lumen of the stomach and small intestine. This device can be used to control the pH, temperature, and secretion of gastrointestinal fluids (Blanquet-Diot, Soufi, Rambeau, Rock, & Alric, 2009). Mercuri, Lo Curto, Wickham, Craig, and Barker (2008) designed a fully automated human gastric system that can simulate gastric secretion and emptying using a fixed outer cylinder with a movable inner cylinder to crush foods, eventually breaking them down by mechanical effect. These dynamic devices are very useful for analyzing chemical digestion but have difficulty detecting bulk solid foods due to the lack of the antral contraction wave that plays a major role in physical digestion. In recent years, a few simple gastric devices that focus mainly on physical digestion were developed. For instance, Kong and Singh (2010) designed a dynamic stomach model that can imitate continuous peristaltic movement of the stomach wall with similar amplitude and frequency of contraction forces as that reported *in vivo*. This device can also control gastric secretion and emptying to simulate the process of gastric digestion. Although this gastric device has provided valuable information about digestion

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in the stomach, the dynamic digestive process cannot be visibly observed due to the use of an untransparent latex vessel. Chen et al. (2011) proposed an *in vitro* gastric device comprised of a glass vessel and a spherical Teflon probe. This simplified device can provide mechanical force to gastric content by the upward and downward movements of the probe, while gastric content is compressed between the inflexible walls of the vessel and probe.

Recently, our group developed a new *in vitro* gastric digestion simulator (GDS) that can mimic peristaltic motion during gastric digestion and enables the direct observation of digestion in real time. The GDS consists of a gastric vessel, a roller system for inducing peristaltic motion, a temperature control system, and a transparent plastic chamber (Fig. 1). This simulator can quantitatively analyze and observe the disintegration of solid foods. Kozu et al. (2014) reported on the disintegration of Tofu as a solid food using the GDS, demonstrating the difference between particle disintegration using flask shaking experiments and that using the GDS. They also found that the type of Tofu can affect the ratio of each size fraction.

Rice is an important staple food worldwide and provides the primary dietary source of carbohydrates for more than half of the world's population. The rice grain is made up of various tissues. Brown rice is the part remaining after de-husking; it is comprised of an outer layer of bran and the inner endosperm and embryo. The bran contains pericarp and aleurone layers that are polished to obtain white rice. Brown rice, which is rich in nutrients and bioactive components, is a popular health product (Gani, Wani, Masoodi, & Hameed, 2012; Tian, Nakamura, & Kayahara, 2004). Some research on cooked rice digestion has been conducted either *in vitro* or *in vivo*. Han, Jang, and Lim (2008) analyzed the starch digestion rate of different cereals using pancreatic enzymes. These researchers addressed the role of dietary fiber contained in bran and found that white rice has a higher rate and greater extent of digestion than other types of rice. Lu, Cik, Lii, Lai, and Chen (2013) investigated the susceptibility of cooked rice to α-amylolysis using the *in vitro* digestion model with four types of rice cultivars. Their results indicated that amylose content can affect the textural properties and starch digestibility of cooked rice. Sun et al. (2010) examined the potential risk of diabetes in relation to the consumption of cooked white rice and brown rice by human trials. Their results suggest that most carbohydrate intake should come from whole grains rather than refined grains to help prevent diabetes. However, these results obtained using *in vitro* or *in vivo* digestion models did not indicate how cooked rice broke down during gastric digestion. Kong, Oztop, Singh, and McCarthy (2011) studied the physical changes in cooked rice during simulated gastric digestion. The diffusion of gastric juice into rice kernels was shown using magnetic resonance imaging (MRI). On the other hand, animal experimental methods can be also used for medicine and food. For instance, Bornhorst, Kostlan, and Singh (2010) determined the chemical and physical properties of the gastric contents containing cooked rice during digestion in the pig stomach. However, both MRI technology and animal experiment were not straightforward to handle, costly, and cannot be visibly observed in real time. All of the literature works using gastric simulators have not yet presented the important results on how rice particles in the gastric

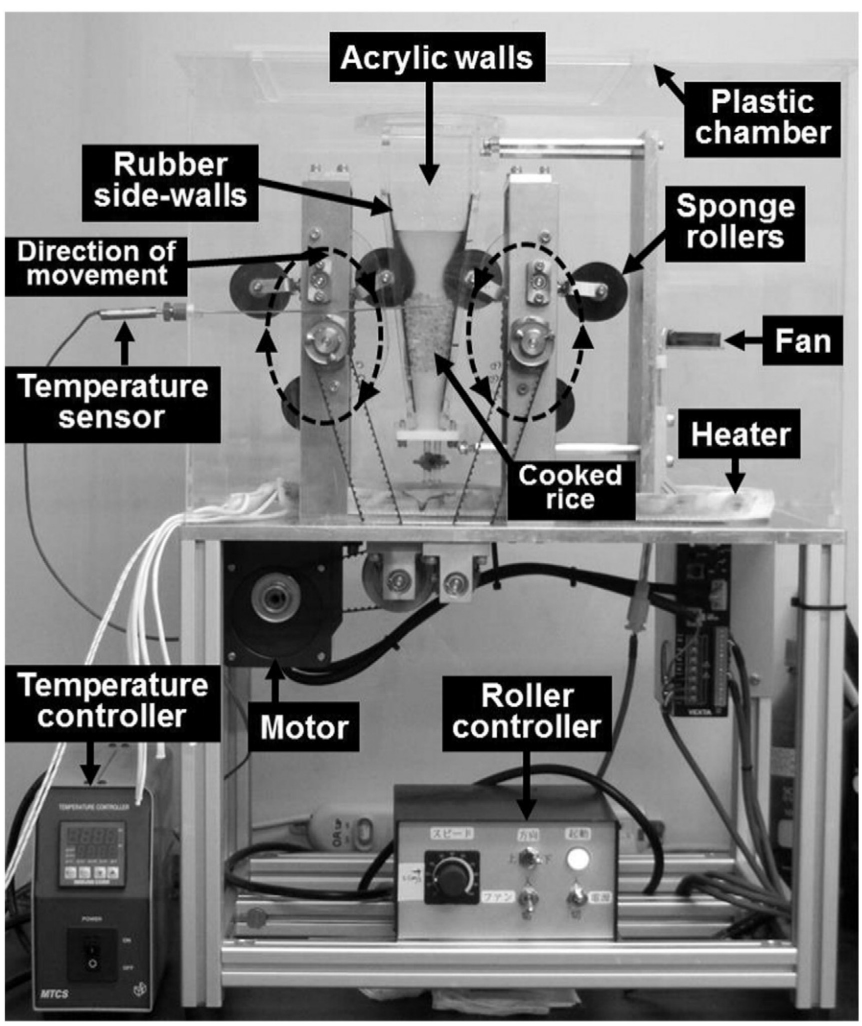

Fig. 1. Photograph of the experiment setup of the gastric digestion simulator (GDS) filled with cooked rice.