Effect of rice variety and milling fraction on the starch gelatinization and rheological properties of rice milk

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Abstract

This study aimed to investigate the rheological properties of rice milk produced from raw rice including rice varieties and milling fractions. Rice milk was prepared from two rice varieties, which were Arhent (long grain) and Bengal (medium grain) using brown, head and broken fractions of the two cultivars used. Gelatinization temperatures for each rice variety, milling fraction, and rheological behaviors of rice milk were examined. Flow behaviors of rice milk were significantly affected by the variety and milling fractions of raw rice. The different amylose to amylopectin ratios of the two varieties, the compositional differences and the subsequent impact on the gelatinization temperature of raw rice used in rice milk were the primary reasons for these differences. Rice milk prepared from Bengal showed greater consistency coefficients, showing a Newtonian flow behavior compared to the rice milk made from Arhent variety. Broken rice showed a potential to be as a raw material in the rice milk industry since it showed similar flow properties compared to the head rice (i.e. within the same variety).

Keywords: rice milk; rheology; rice variety; milling fraction.

Practical Application: Rheolocial properties of rice milk depending upon rice variety and milling fraction.

1 Introduction

Among consumers' needs, bringing nutritional benefit in combination with acceptability in food products is a significant opportunity for food industry (Jaenke et al., 2017). Nowadays consumers are increasingly concerned with health and thus health-oriented products using cereals are constantly being introduced in the market. Soy milk has been considered to be a carrier for these products in various parts of the world. However, allergies or bean-like taste associated with soy have been reported to limit the use of this type of products (Bevilacqua et al., 2016). The widespread acceptability of rice as a non-allergenic cereal allowed the substitution of rice for corn to make a product comparable in consistency and nutritional value to soy milk. A rice milk was referred to as a liquid extracted from rice due to its milk-like texture and functionality (Mitchell et al., 1988). Koyama & Kitamura (2014) also defined rice milk as a mixture of the mixed rice slurry and additional water at a solid:liquid ratio of 1:9, which was the solid:liquid ratio of standard milk. Rice milk is now commonly used as a nutritional beverage as an ingredient in soups and puddings as well as a substitute for milk.

Since starch is a key component in rice milk, the flow behaviors of rice milk are greatly dependent on the properties of rice starch. Although some information regarding the rheological properties or physical stability of rice slurries was introduced by Rani & Bhattacharya (1995) and Koyama & Kitamura (2014), this provided only the single point of viscosity of rice. Thus,

comprehensive research to understand the rheological behaviors of multi-component rice milk systems are necessary.

According to Joshi et al. (2015), rice exhibits a very wide range of rheological properties and cooking qualities depending on variety and type of rice, amylose content, and gelatinization temperature. Joshi et al. (2015) also stated that amylose to amylopectin ratio varied among different rice varieties and greatly affected the functional properties of starch. Therefore, it is evident that varietal differences in raw rice can impact end product qualities of rice-based food products including rice milk. However, the effects of such variables on the functional properties of rice milk are still under-investigated.

Besides the differences in variety, milling fractions such as brown, head, and broken rice within the same variety also exhibit different physicochemical properties (Payakapol et al., 2011). Traditionally rice milk is prepared from whole kernels of milled and brown rice. However, the large amounts of broken rice produced during the rice milling process can be utilized in rice milk production. Payakapol et al. (2011) reported differences between head rice and broken rice in hardness, alkali spreading value, and amylographic pasting properties. Authors further found that broken kernels exhibited lower peak and set back viscosity than the intact kernels. The reason for these functional differences between broken and head rice were attributed to the differences in relative amounts of amylose and

amylopectin. Such functional differences among varieties and milling fractions may impact on the rheological properties of rice milk. However, information on the rheological properties of rice milk from different rice sources, including varieties and milling fractions is now limited. Therefore, the preent paper provides a comprehensive study of the rheological properties of rice milk produced from various raw products, including rice varieties and milling fractions.

2 Materials and methods

2.1 Materials

Two rice varieties including Arhent (long grain) and Bengal (medium grain) were selected as the raw material. These two varieties were harvested at the University of Arkansas Rice Research and Extension Center in Stuttgart, AR at a moisture content of 13.5%. Rice was stored in plastic buckets at 4 to 6 °C. Prior to the rice milk preparation, the rice was kept in an equilibrium moisture content chamber for 3 days to achieve a moisture content of 12.5%. One-year-old rice samples of two cultivars were dehulled using a Satake rice machine (model THU, Satake Engineering Co., Ltd., Japan). It was then milled using a continuous miller (One pass rice whitening and caking machine, model MC-250, Satake Engineering Co., Ltd., Japan) to obtain milled rice with a degree of milling (DOM) of 84 using a milling meter (Type MM-IB, Satake Engineering Co., Ltd., Japan). The head rice and broken rice was separated using a shaking table (Grainman machinery, MFG Co., Miami, FL, USA). Brown, head and broken rice fractions of the two cultivars were then used in rice milk preparation. As far as cleaning dehulled or unhulled rice, unfortunately, exact information is unknown since the brown, head and broken rice fractions were directly obtained from the rice processing center for this experiment. However, all the rice fractions were processed based on commercial practices.

2.2 Preparation of rice milk

Rice milk was prepared with the slight modification of the mothod by Mitchell et al. (1988) as follows. Three batches of rice milk were prepared by soaking the rice fraction (i.e. brown, head, or broken) with de-ionized water for 2 h in a 1:3 ratio (rice to water) at room temperature (22 °C). Each sample of soaked rice was drained and ground with de-ionized water using a grinder (Warring Commercial grinder, Model CB10, Torrington, CT, USA) for 10 min until a smooth slurry was produced. Rice bran oil, sugar, and lecithin were added to the rice slurry, and this mixture was further blended for 3 min. The final slurry contained 8% rice, 3% sugar, 0.1% lecithin and 1% rice brain oil. Lecithin was added as an emulsifier in the system. The supernatants were filtered (USA standard testing sieve # 100, 150 μm) and then homogenized (Fisher Scientific homogenizer, Model 700, Pittsburgh, PA, USA) for 10 min. Each batch of rice milk was preheated to 72 °C separately on a gas stove. The preheated products were filled in glass bottles, and pasteurized at 72 °C for 20 min (Hot water splash pasteurizer, Food Process Equipment Co., USA).

2.3 Rheological measurements

Flow behaviors of the rice milk were tested using a rotational rheometer (Haake VT 550, Germany) equipped with a MVDIN measuring spindle (radius = 19.36 mm, height = 58.08 mm) at room temperature (22 °C). Samples (40 mL) were loaded into the cylindrical cup (radius = 21.0 mm). The samples were subjected to a shear rate that changed from 0 to 400 1/s over 3 min using a computer-controlled program (Rheowin Pro Data Manager version 2.84, Haake Mess Tech, Germany). The experimental data were fitted with the power law ($=k^n$) models where is shear stress (Pa), is shear rate (1/s), K is the consistency coefficient and n is the flow behavior index. The slope of the resulting curves described the apparent viscosity of the rice milk samples over this wide range of shear rates.

2.4 Measurement of gelatinization temperature

The gelatinization temperature of each milling fraction and rice variety was measured by Differential Scanning Calorimetry (DSC) (Perkin Elmer Pyris 1, U.S. Instrument Division, Norwalk, CT, USA). A portion of rice flour suspension (4.0 to 4.4 μg rice flour in 8 μL water) was sealed in stainless crucibles with a stainless steel lid. The sample was heated from 25 to 120 °C at 5 °C/min. An empty sealed crucible was run as a reference. The onset (T_o) and peak (T_p) gelatinization temperatures were measured in triplicates.

2.5 Statistical analysis

Rice milk from each rice source was prepared in three batches. Rheological properties of each batch of rice milk were analyzed in triplicates. The flow behavior parameters for each rice milk sample made from different rice sources were compared at a significance level of 0.05 in triplicates using one-way ANOVA followed by Tukey's test using JMP IN version 4.04 (SAS Institute Inc. Cary, NC, USA).

3 Results and discussion

3.1 Gelatinization temperatures for rice sources

As shown in Table 1, among the rice cultivars and milling fractions tested, Bengal head rice exhibited the lowest onset gelatinization temperature (70.7 °C), while Arhent brown rice displayed the highest temperature for the onset gelatinization (76.5 °C).

The primary reason for the different gelatinization temperatures of these rice varieties may be attributed to the amylose to amylopectin ratio of their starch. According to the apparent amylose contents estimated by the procedure described by Singh et al. (2000), Bengal variety contained low amylose contents compared to the Arhent variety. According to the Wang & White (1994), amylose consists of long linear chains with few branched chains, whereas amylopectin consists of highly branched short chains. Chung et al. (2011) and Srichuwong et al. (2012) indicated that shorter branch chains in amylopectin related to the gelatinization properties yielded a lower gelatinization temperature. Therefore, the lower gelatinization temperature in the Bengal rice can be attributed to the lower amylose content and

the presence of a greater number of shorter chain amylopectin branch chains compared to the Arhent variety.

The brown rice within the same variety showed a higher gelatinization temperature compared to the head rice (Table 1). The difference in gelatinization temperatures between brown and white head rice within the same variety can be attributed to the differences in the composition of the cellular materials within the specific layers of the rice kernel (Oli et al., 2014). For example, a DOM (degree of milling) of 84 was maintained in our milled rice samples. Marshall (1992) and Roy et al. (2011) found that partial removal of outer bran layer lowered the gelatinization temperature significantly. The layers of kernel removed during milling may include caryopsis coat, aleurone and subaleurone layers and part of starchy endosperm. Champagne et al. (1990) and Derycke et al. (2005) reported that waxy compounds present in the caryopsis coat may act as a water diffusion barrier and consequently resulted in higher gelatinization temperature. Research conducted by Derycke et al. (2005), and Xie et al. (2008) showed that the removal of protein and lipids, which were mainly present in the bran layer, reduced the gelatinization temperature. However, the removal of lipid or protein, by itself, had little effect on starch gelatinization temperature. Therefore, with these evidences, the higher gelatinization temperature in brown rice compared to milled head rice was to be expected. The end temperature followed the same trend as the onset and peak temperatures within for each rice variety.

3.2 Flow behavior index and consistency coefficient of rice milk

Results (Table 2) indicate that under the given processing conditions, rice milk made from various rice sources exhibited different flow behavior characteristics.

Mean flow behavior index values (n) for rice milk samples varied from 0.9 (Bengal broken) to 1.4 (Arhent head). The n of rice milk prepared from Arhent head rice was significantly different (p < 0.05) from that of Bengal broken, brown and head rice (Table 2). Rice milk from Arhent head, broken and brown rice showed a slight deviation from Newtonian behavior, showing n > l. This may indicate the presence of partially gelatinized starch according to the Rao (2014). This hypothesis was supported by the DSC gelatinization temperatures (Table 1). The onset temperature for Arhent head- rice and Arhent brown rice were 74.9 and 76.6 °C, respectively. The preheating temperatures applied during processing were below these temperatures and thus the gelatinization processing was not completed in the rice milk samples prepared from Arhent milled and brown rice. At these temperatures, granules were in the raw state and the volume fraction was low. According to Rao (2014), the value of n greatly depends on the extent of starch granule swelling. Therefore, it is clear that rice milk made from rice sources exhibiting varying gelatinization temperatures would result in final products with different state of granule swelling under a given heat treatment. This was the primary determinant of the differences reported in n values.

The consistency coefficient values (K) of rice milk samples (Table 2) ranged from 0.0003 (Arhent head) to 0.02 (Bengal head). Rice milk samples made from Bengal milled and broken rice did not show a significant difference in K. However, rice milk prepared from Bengal brown, and Arhent broken, milled, and brown rice were significantly (p< 0.05) different from that of rice milk made from Bengal broken and milled rice (Table 2). There were no significant differences among rice milk samples prepared from the different Arhent milling fractions. Payakapol et al. (2011) reported differences between head and broken rice in several properties including amylographic pasting properties. According to their findings, broken kernels exhibited lower pasting viscosities indicating lower swelling properties. However, our results did not show any difference in K of rice milk between head and broken rice within the same variety. It was believed that there was no difference in the relative amounts of amylose and amylopectin in head and broken rice.

Table 1. Gelatinization temperature by DSC according to rice types.

Rice type	Onset temperature (°C)	Peak temperature (°C)	End temperature (°C)
Bengal head	70.7 d[1] ± 0.1	75.4 d ± 0.1	82.2 d ± 0.1
Bengal brown	71.8 c ± 0.1	77.1 c ± 0.1	84.1 c ± 0.1
Arhent head	74.9 b ± 0.2	78.2 b ± 0.1	86.3 b ± 0.1
Arhent brown	76.5 a ± 0.1	79.8 a ± 0.1	88.4 a ± 0.1

[1]Different characters within a column mean significant difference at $P < 0.05$ by Tukey's test.

Table 2. Mean and standard deviation of consistency coefficient (K) and flow behavior index (n) values of rice milk prepared from different rice sources and fractions.

Rice source	Mean K (Pa.sn)	Mean n
Arhent head	0.0003 b[1] ± 0.03	1.40 a ± 0.03
Arhent broken	0.0015 b ± 0.12	1.20 a ± 0.12
Arhent brown	0.0005 b ± 0.06	1.40 a ± 0.06
Bengal broken	0.0200 a ± 0.01	0.90 a ± 0.01
Bengal brown	0.0040 b ± 0.07	1.00 a ± 0.08
Bengal head	0.0200 a ± 0.01	0.91 a ± 0.01

[1]Different characters within a column mean significant difference at $P < 0.05$ by Tukey's test.
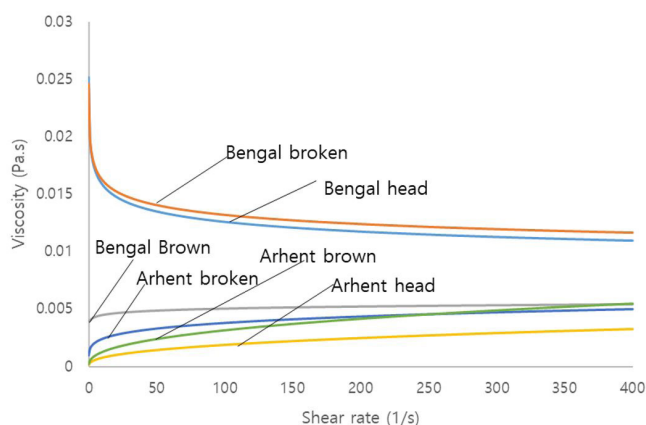
Figure 1. Effect of rice source on the viscosity of rice milk.

3.3 Viscosity of rice milk

Figure 1 shows the viscosity of rice milk prepared from different rice sources and fractions. There were distinct differences between samples for Arhent and Bengal varieties.

Rice milk from Bengal brown rice showed a lower viscosity compared to rice milk from Bengal broken and head rice. Rohman et al. (2014) have reported that milled rice (i.e., head) has more starch and lower lipid and protein content compared to brown rice within the same variety. They also found that the rate of viscosity increase with the degree of milling was higher for medium grain than for long grain cultivars. Therefore, rice milk made from Bengal milled rice would be expected to have higher viscosity compared to the other rice milk samples.

According to Barrera et al. (2013), swelling of starch granules determined the pasting behavior and rheological properties of a starch solution. Okechukwu & Rao (1995) reported that size distribution of starch granules greatly influenced the magnitude of consistency coefficient. Rao (2014) also have shown that swelling was a property of amylopectin and amylose and lipid actively inhibited swelling properties. During the gelatinization process, amylose leaches from starch granules affecting the viscosity of the continuous phase. Therefore, rice milk from Bengal variety would be expected to have a higher K than rice milk made from Arhent. In addition, one would expect the viscosity to be lower for brown and broken rice fractions (i.e., higher lipid content) than for head rice. However, the differences were not significant among broken, milled and brown rice fractions of Arhent. This is probably due to the fact that the preheating temperatures were lower than the gelatinization temperature. Lu & Luh (1991) reported that brown rice was consisted of surface bran rich in non-starch substances and contained 1.6 to 2.8% lipids and 7.8 to 8.3% proteins. The lipid and protein contents of brown rice were reduced to 0.3 to 0.5% and 6.3 to 7.1%, respectively, through milling process.

4 Conclusions

The rheological properties of rice milk were greatly affected by the variety and milling fraction of raw rice used in rice milk preparation. Rice milk prepared from Bengal had higher consistency coefficients showing a Newtonian flow behavior compared to the rice milk made from Arhent variety. Since broken rice showed similar flow properties compared to the head rice (i.e. within the same variety), it could be used as a raw material in the rice milk industry. However, sensory properties should be assessed to further justify this recommendation. The gelatinization temperature of the raw rice used in rice milk preparation appeared to have a significant influence on rheological behavior of rice milk. It was clear that gelatinization played an important role to convert the flow properties of rice milk from shear thinning to Newtonian or shear thickening. Further studies are required to understand the effect of preheating conditions on the flow behavior of rice milk. Since the cultivar and rice fraction used greatly influenced the flow properties of rice milk, processors need to pay close attention in selecting raw materials and processing conditions to yield desired flow properties.

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