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Impact of cooking conditions on the properties of rice: Combined temperature and cooking time

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ABSTRACT

Changes in the properties of cooked rice under various cooking conditions were investigated. Waxy, low-, and high-amylose rice were subjected to treatment with different cooking temperatures (50, 70, 90 °C) for different cooking times (15, 30, 45 min). The results showed that cooking greatly increased the swelling behavior of waxy rice but decreased the swelling behavior and amylose leaching of low- and high-amylose rice. As the cooking temperature increased, rapidly digestible starch increased significantly for all rice products, whereas slowly digestible starch and resistant starch had a certain degree of reduction. Variation in the cooking time produced little effects on starch digestibility. Gelatinization temperature was positively correlated with temperature and time, whereas gelatinization enthalpy was negatively correlated with temperature and time. Pasting properties of all rice products decreased significantly as cooking temperature and time increased. The study showed that both cooking temperature and cooking time had significant impacts on the physicochemical properties and starch digestibility of waxy, low-, and high-amylose rice to various extents. Temperature had a more pronounced impact on the extent of change to the *in vitro* digestibility than did cooking time.

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1. Introduction

Rice, as a staple food on which billions of people live, is widely cultivated globally. Rice is a good source of nutrition and energy. However, it should be cooked before consumption to improve its hardness and eating quality [1]. Cooking is the process of rice starch gelatinization at higher cooking temperatures and times. Before cooking, soaking is commonly carried out to achieve a uniform water distribution and total starch gelatinization [2]. Generally, the standard ratio of water-to-rice for rice cooking ranges from 10:1 to 20:1. The excess water method is most commonly used in industrial rice cooking to maintain uniform heating in the flow. Changes occur in the properties of rice during cooking, i.e., water absorption and volume expansion. Altheide, et al. [3] found that water absorption in cooked rice was influenced by the cooking time, whereas the volume expansion of cooked rice had a relationship with the cooking temperature.

During cooking, rice starch undergoes water absorption, swelling, amylose leaching and gelatinization. Attaining a certain temperature within the rice is essential to start the process of starch gelatinization. Many studies have examined the impact of cooking temperature on rice starch gelatinization [4–6]. Cooking for a certain length of time is also a necessity for rice starch to absorb water and achieve complete gelatinization. Some studies have shown that the milling degree, amylose content, particle appearance, starch final gelatinization temperature and other factors can affect the required cooking time and can change the structure, texture and quality of rice [1,7,8]. Additionally, the influence of different heating temperatures and times on the physical properties of rice starch paste and the digestibility of heat-moisture treated maize starch have been studied, showing that heating temperature is the more vital factor in determining starch properties [9].

Physicochemical characteristics and starch digestibility are responsible for eating quality, processing characteristics and the end-use of cooked rice in industry. The different physicochemical characteristics of various types of rice may be correlated with differences in amylose content, grain size, and crystallinity [10–12]. Researchers have also attempted to correlate the physicochemical properties of cooked rice with cooking characteristics such as cooking duration and cooking methods [13,14]. During cooking, the dynamics of the solvation of starch and protein contribute to the alteration of physicochemical characteristics. Cooking time can also affect the digestibility of cooked rice to some extent.

The impacts of cooking temperature, cooking time and physicochemical properties on rice have been studied separately [8,13,15]. However, there is limited information on the impact of the combined treatments of cooking temperature and cooking time on the physicochemical properties and digestibility of rice. Additionally, there are

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few studies summarizing the mechanisms by which cooking temperature and cooking time affect rice physicochemical properties. Such studies would provide more information on the effects of cooking conditions on rice. The objective of this study was to investigate the impacts of cooking temperature and cooking time together on the physicochemical properties and starch digestibility of waxy, low-, and high-amylose rice.

2. Material and methods

2.1. Materials

Three rice cultivars were chosen for use: waxy rice (WR, YF4), low-amylose rice (LAR, QG), and high-amylose rice (HAR, LH6684). WR, LAR and HAR were purchased from Jiahao Gardening Company (Suqian, China). Amyloglucosidase (EC 3.2.1.3, 300 AGU mg^{-1}), pancreatin from porcine pancreas (EC 232.468.9, 228 USP mg^{-1}) and guar gum were supplied by Sigma Chemical Co. (St. Louis, MO, USA). Glucose assay reagent was purchased from Megazyme International Ireland Ltd. (Wicklow, Ireland). All chemicals and solvents were of analytical grade.

2.2. Chemical components analysis

The moisture content of the grains was calculated using the standard AOAC method [16]. The starch content was analyzed from ground rice flour using a GOPOD assay kit. The crude lipid content was determined by Soxhlet extraction following AOAC method 920.39C [17]. The protein content was determined using an auto Kjeldahl analytical instrument (FOSS Kjeltec 8400, Denmark). An amylose quantification kit (Megazyme, Ireland) was used to determine the amylose contents of the three cultivars.

2.3. Cooking treatment

The rice was dehusked and polished by an experimental rice milling machine (TM05C-C, Satake Manufacturing (Suzhou) Co., Ltd., China) to a milling yield of 90–91%. Broken kernels were removed from the grains.

The excess water method was used to cook the rice according to a previously described procedure with minor modifications [2]. First, 80 mL of distilled water was poured into a 250-mL beaker, then a lid was added and the beaker was incubated in a water bath for at least 1 h. A thermometer was used to monitor whether the water temperature in the beaker reached the set temperature. Milled rice samples (4 g) were weighed and immersed in 80 mL of distilled water in another beaker at room temperature for 30 min. Then, the water was decanted and the rice was poured onto filter paper. When the water bath temperature in the 250-mL beaker reached 50, 70 or 90 °C, the rice was added and timing was immediately started. A spoon was used to thoroughly stir the mixture every 5 min. The samples were removed from the water bath after a cooking time of 15, 30 or 45 min and immediately cooled with tap water for 30 s. The rice was drained of water and spread as a thin layer on an aluminum tray, frozen in a freezer at −20 °C and then freeze-dried. After two days, the dried samples were ground into powder and passed through a 40-mesh sieve. Then, the cooked rice flour was labelled and placed in a desiccator for storage.

2.4. Swelling power and solubility index

The swelling power (SP) and solubility index (SOL) of each sample were determined using a previously described procedure with minor modifications [14]. Cooked rice flour slurries (1.0 g db in 40 mL of distilled water) in 50-mL centrifuge tubes were thoroughly mixed by vortex, then kept in a water bath at 85 °C for 30 min. After cooling to ambient temperature, the tubes were centrifuged at 1000 $\times g$ for 20 min. The SP was estimated as the ratio of the weight of the wet sedimented gel to its dry weight. The SOL was expressed by drying the supernatant to a constant weight at 110 °C in a hot-air oven. Values were presented as the percentage of dried solid weight relative to the weight of dry cooked rice flour.

2.5. Amylose leaching

Cooked rice flour (20 mg, db) in distilled water (10 mL) was heated in a screw-capped tube at 85 °C for 30 min. After cooling to room temperature, tubes were centrifuged at 2300 rpm for 10 min. The aqueous solution (0.1 mL) was removed, and the amylose content was estimated as previously described by Varatharajan, et al. [18].

2.6. In vitro starch digestibility

The nutritional fractions of rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) in the cooked rice flour were determined according to the method of Englyst, et al. [19] with modifications. Cooked rice flour samples (550 mg, db) and distilled water (10 mL) were added to polypropylene screw-capped centrifuge tubes. Then, pepsin (0.1 g) and HCl (12 mol L^{-1}, 0.08 mL) were mixed into each tube and incubated at 37 °C for 30 min. Procine pancreatic a-amylase (4.5 g) was dispersed in 30 mL of distilled water and centrifuged at 3000 rpm for 10 min The supernatant was removed to a tube and mixed with 3.9 mL of amyloglucosidase. Following this, guar gum (50 mg), 15 glass beads (0.5 mm diameter), and 10 mL of sodium acetate buffer (0.25 mol L^{-1}, pH 5.2) were added to each tube. The tubes with cooked rice flour samples were incubated with the mixed enzymes at 37 °C in a shaking water bath. After 20 and 120 min of incubation, the hydrolyzate (0.5 mL) was removed and 20 mL of 80% ethanol was added to stop the reaction. The amount of released glucose was determined using a glucose oxidase assay kit. The contents of RDS, SDS, and RS in the cooked rice flour samples were analyzed according to the method by Englyst, Kingman and Cummings [19].

2.7. Determination of thermal properties

The thermal properties of the samples were determined using a differential scanning calorimeter (DSC) (TA 2910, TA Instruments, Wilmington, DE, USA). Samples (2 mg, db) were mixed with 6 μL of distilled water in an aluminum pan. The pan was hermetically sealed and equilibrated at room temperature for at least 2 h before the test, then heated at a rate of 5 °C min^{-1} from 30 °C to 110 °C, along with an empty sealed pan as a reference.

2.8. Determination of pasting properties

A Rapid Visco-Analyzer (RVA) (Newport Scientific, Warriewood, Australia) was used for the determination of pasting properties of the samples. Cooked rice flour samples (3 g, 140 g kg^{-1}moisture basis) were mixed with Milli-Q water in the RVA sample canister to obtain a total weight of 28 g. The mixture was stirred using a plastic paddle for at least 1 min. A programmed heating and cooling cycle was used, in which the samples were held at 50 °C for 1 min, heated to 95 °C over 7.5 min, and held at 95 °C for 5 min before cooling to 50 °C over 7.5 min and then being held at 50 °C for 2 min.

2.9. Statistical analysis

All analyses were determined at least in triplicate. Differences between the physicochemical properties and starch digestibility of the samples produced as a function of cooking temperature and cooking time were established using analysis of variance (ANOVA). Duncan's multiple range tests ($p < 0.05$) were carried out to analyze the differences. Statistical analysis was performed using Statistical Analysis System for windows (SAS Institute Inc., Cary, USA).

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