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Improvement in nutritional attributes of rice using superheated steam processing

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ABSTRACT

Superheated steam (SS) was used for the stabilization of lightly milled rice (LMR), and the nutritional properties of the LMR stabilized by SS (SS–LMR) were assessed. SS processing did not cause the loss of non-starch nutrients (fat, protein, ash and dietary fibre) or promote the oxidation of unsaturated fatty acids in LMR. SS processing significantly increased the total phenolic content and antioxidant activity of LMR probably by enhancing the extractability and release of bound phenolic acids. However, SS processing moderately disturbed the long- and short-range structures of starch, and thereby increased the starch digestibility of LMR. Compared with well milled rice (WMR), SS–LMR had a higher antioxidant activity, higher contents of non-starch nutrients and phenolics, and slower starch digestion rate. From a health perspective, SS processing could be considered a suitable method for the stabilization of LMR and the resultant SS–LMR may be a potential alternative to WMR.

1. Introduction

Rice (*Oryza sativa*) is the staple food for half of the world's population and it is widely consumed in the form of well milled rice (WMR; Fig. 1D). The WMR was obtained by removing the entire bran layer from brown rice (Fig. 1B), leaving only the starchy endosperm (Wu et al., 2014). Non-starch nutrients and nutraceuticals such as proteins, minerals, dietary fibre, fatty acids and phenolic compounds are largely concentrated in the bran layer (Das & Singh, 2015; Martini, D'Egidio, Nicoletti, Corradini, & Taddei, 2015; Monks et al., 2013; Walter et al., 2013). These bioactive phytochemicals have been shown to provide desirable health benefits beyond basic nutrition by reducing the risk of chronic diseases (Rebello, Greenway, & Finley, 2014). However, brown rice with an intact bran layer is rarely consumed owing to its inferior cooking quality and short shelf life (Wu et al., 2014). Our previous study (Wu et al., 2016)

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Abbreviations: SS, superheated steam; LMR, lightly milled rice; WMR, well milled rice; SS–LMR, stabilized LMR of which peroxidase was inactivated by 120 °C SS; HA–LMR, stabilized LMR of which peroxidase was inactivated by 120 °C hot air; DBR, degree of bran retention; d.b., dry weight basis; WXRD, wide angle X-ray diffraction; ATR-FTIR, attenuated total reflectance-Fourier transform infrared spectroscopy
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demonstrated that the inner aleurone layer of rice bran only had a marginal influence on rice cooking quality, and theoutermost cuticular layer adversely impacted cooking quality. Partial removal of the cuticular layer from brown rice by lightly milling is adequate to achieve similar cooking quality with WMR and retain most of the bran layer (Wu et al., 2014, 2016). It was also suggested that the shelf life of the resultant lightly milled rice (LMR; Fig. 1C) could be extended by inactivation of peroxidase in LMR grain using superheated steam (SS). The desirable physical and sensory properties of LMR, including required cooking conditions, appearance, texture and microstructure, were well preserved after SS processing (Fig. 1E) (Wu et al., 2014). However, information about the effect of SS processing on the chemical composition and potential nutritional attributes of LMR is still lacking, including fatty acid composition, antioxidant activity, phenolic compounds and the molecular structure and digestibility of starch.

Thermal processing can lead to an appreciable loss in bioactive phytochemicals, but this is not always the case (Dewanto, Wu, & Liu, 2002; Kim, Kang, & Gweon, 2013). The effect of thermal processing on fatty acids and phenolic compounds depends on processing methods, food source, oxygen, moisture content, and thermal history (Barakat & Rohn, 2014; Huang, Ho, & Fu, 2004; Wang, He, & Chen, 2014). In addition, thermal processing may affect starch digestibility by altering the distribution of starch fractions (rapidly digestible starch, slowly digestible starch, and resistant starch). The alteration of starch fractions upon thermal processing is closely related to the molecular structure and phase transition of starch, which can be monitored by long- and short-range structure analysis (Chung, Lim, & Lim, 2006; Zavareze & Dias, 2011). Generally, severe molecular structure change and phase transition (e.g. gelatinization) can substantially increase starch digestibility (Chung et al., 2006), which may be undesirable from a nutritional standpoint. Thermal processing at restricted moisture and/or low temperature only causes limited molecular structure change and phase transition (Zavareze & Dias, 2011), thus may suppress the increase of starch digestibility.

SS is a novel thermal processing technology suitable for food applications. High heat penetration and an oxygen-free environment are the major advantages of SS, which lead to rapid heating and reduced oxidative degradation reactions during processing (Anto, Bv, Gc, & Hebbar, 2014). In our previous study, we showed that the desirable physical and sensory properties of LMR were well preserved when the SS processing conditions were optimized: restricted moisture content (~14%), relatively low temperature (120 °C) and short treatment time (2.5 min) (Wu et al., 2014). In the current study, we investigated the influence of SS processing on the chemical composition and nutritional attributes of LMR. In addition, the properties of the LMR stabilized by SS (SS–LMR) were compared with those of the more conventional WMR to establish the potential advantages of this novel processing method. Hot air processing is not a suitable method for the stabilization of LMR because it induces severe fissures in LMR grain (Fig. 1F) (Wu et al., 2014). However, we compared the properties of SS stabilized LMR (low oxygen) with those of hot air stabilized LMR (high oxygen) so as to provide some information about the role of oxygen levels on the quality of the rice produced.

2. Materials and methods

2.1. Materials and chemicals

Paddy (*Oryza sativa L. ssp. Japonica*, *cv.* Kongyu-131) was harvested in 2012 (Qingan, Heilongjiang, China) and obtained from China Oil & Foodstuffs Corporation (Xinyu, Jiangxi, China). Immediately after the paddy arrived, it was vacuum-packed and refrigerated at 4 °C until use.

All fatty acid methyl ester (FAME) standards were purchased from Nu-Chek Prep, Inc. (Elysian, Waterville, MN, USA). Glucose oxidase/peroxidase diagnostic kit was purchased from Megazyme Inc. (Wicklow, Leinster, Ireland). The HPLC grade acetic acid and acetonitrile were purchased from Merck Inc. (Darmstadt, Hessen, Germany). All other chemicals and reagents, including 2,2′-azino-bis (3-ethylbenzthiazoline -6-sulphonic acid) (ABTS) and 2,4,6-tripiridyl-S-triazine (TPTZ), were purchased from Sigma-Aldrich Inc. (St. Louis, MO, USA).

2.2. Sample preparation

The schematic diagram of rice sample preparation is shown in Fig. 1. Four samples were prepared and used in this study, namely lightly milled rice (LMR), two processed LMR (HA–LMR and SS–LMR), and well-milled rice (WMR). To obtain LMR and WMR, the paddy was dehusked by a rubber roll type husker (THU-35A, Satake Inc., Japan) and milled 25 s and 120 s, respectively, to remove 3% and 10% by weight with a laboratory polisher (TM 05, Satake Inc., Tokyo, Japan). To prepare HA–LMR and SS–LMR, the native LMR grains were treated by hot air and SS, respectively, in a laboratory scale apparatus designed and manufactured by the Food Engineering Center of Nanchang University as described previously (Wu et al., 2014). In brief, the temperature and the velocity of flow of hot air and SS were adjusted to 120 °C and 1.00 m/s, respectively, then allow the processing chamber to preheat for 10 min. After that the native LMR grains were scattered on the sample tray in monolayer and inserted into the processing chamber. The shortest times required for hot air and SS to inactivate peroxidase in LMR grain were 3.5 and 2.5 min, respectively (Wu et al., 2014). HA–LMR and SS–LMR represented the stabilized LMR of which peroxidase was inactivated by 120 °C hot air and SS in the shortest time respectively. It is generally accepted that the bran layer comprises ~10% of rice grain by weight (Wu et al., 2014). Therefore, the bran layers of LMR, HA–LMR, SS–LMR and WMR were removed by ~30, ~30, ~30 and ~100%, respectively, because their grain weights were reduced by 3, 3, 3 and 10%, respectively, by milling as mentioned above. According to this, the degree of bran retention (DBR) for LMR, HA–LMR, SS–LMR and WMR were ~70, ~70, ~70 and ~0%, respectively.

2.3. Proximate analysis and energy value

Moisture contents of rice samples were determined by a moisture analyser (Hr83, Mettler Toledo Inc., Kusnacht, Switzerland). The crude fat, protein ($N \times 5.95$), ash and dietary fibre (soluble, insoluble and total) were determined according to the AACC (2000) method 30-20, 46-13, 08-01 and 32-07 respectively. Total carbohydrate was estimated by subtracting the sum of