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Milling breakage susceptibility and mechanical properties of parboiled brown rice kernels

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ABSTRACT

Parboiling, a hydrothermal treatment of paddy or brown rice, impacts both head rice yield and texture and nutritional characteristics of cooked rice. Here, milling breakage susceptibility of parboiled brown rice was investigated on both bulk and kernel level. Brown rice was parboiled by soaking at 40, 55 or 65 °C and steaming at 106, 120 or 130 °C. The breakage susceptibility and changes in starch and proteins of bulk samples were related to the properties of individual rice kernels. An increase in milling breakage susceptibility from 1% to 11% corresponded to a decrease in average bending force of individual kernels from 34.9 to 14.6 N. Furthermore, both white bellies and fissured parboiled rice grains were more breakage susceptible. Their average bending force was respectively 14.1 N and 17.6 N compared to an average of 39.6 N for intact parboiled rice grains. Whereas the level of proteins extractable with sodium dodecyl sulfate containing medium had no impact, the degree of starch gelatinization was critical in determining the presence of both white bellies and fissured parboiled rice grains. More in particular, complete starch gelatinization ensured the absence of white bellies and minimized fissuring in the parboiled end-product, thereby decreasing milling breakage susceptibility.

1. Introduction

Parboiling is a hydrothermal treatment, performed either on paddy (rough) rice or on dehulled (brown) rice. In the process, rice is soaked, steamed, and dried. Parboiling can considerably impact the texture, nutritional and color characteristics of cooked rice. In particular, cooked parboiled rice is firm, not sticky and contains higher levels of vitamin B_1 than raw white rice. Furthermore, it has a darker color and its flavor slightly differs from that of the unprocessed starting material. A proper execution of parboiling increases head rice yield (Bhattacharya, 2004; Buggenhout, Brijs, Celus, & Delcour, 2013; Delcour & Hoseney, 2010a). This is the mass percentage of rough rice that remains after milling as head rice (Cnossen, Jimenez, & Siebenmorgen, 2003), *i.e.* kernels that have at least three-fourths of the original kernel length (USDA, 2005). As head rice typically has twice or three times the economic value of broken rice, its yield is evidently of great importance for the rice industry.

Heat/moisture conditions during parboiling and the resulting structural changes in the major rice components largely determine the characteristics of the parboiled product. Process conditions increasing head rice yield may well reduce the sensory quality of the parboiled product. Therefore, from an industrial point of view, it is important to apply the most optimal processing conditions.

Despite some earlier research in the area, it is still not clear what determines the milling breakage susceptibility of parboiled rice. As head rice yield is determined by dehulling and milling a bulk of rice grains, it is difficult to establish which fraction of the bulk of rice grains breaks during milling. Nevertheless, both white bellies, *i.e.* parboiled rice grains with translucent outer layers and an opaque center, and fissured rice grains have been suggested to increase the milling breakage susceptibility of a bulk of parboiled rice grains (Bhattacharya, 1969; Bhattacharya & Swamy, 1967; Buggenhout, Brijs, & Delcour, 2013a; Mecham, Kester, & Pence, 1961). Our team recently suggested (Buggenhout, Brijs, & Delcour, 2013a) that the degree of starch gelatinization (DSG) can be related to the breakage susceptibility of the rice bulk. Both soaking and steaming conditions impact DSG during parboiling. The rice grain moisture content during soaking and severity of heating during steaming

Abbreviations: DSC, differential scanning calorimetry; DSG, degree of starch gelatinization; SDS, sodium dodecyl sulfate; SDSEP, level of extractable proteins in SDS containing medium; *T*, temperature.

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positively impact the DSG during the process (Biliaderis, Tonogai, Perez, & Juliano, 1993; Himmelsbach, Manful, & Coker, 2008; Manful, Grimm, Gayin, & Coker, 2008; Priestley, 1976).

Rice grains break during milling whenever the mechanical stresses of milling exceed the kernel strength. As such, increased knowledge on the characteristics impacting the mechanical strength of individual parboiled rice grains may help understanding the milling breakage susceptibility of parboiled rice grains. In contrast to what is the case for raw rice grains, limited research has been performed on the mechanical properties of individual parboiled rice grains, and the impact of parboiling conditions thereon. Islam, Shimizu, and Kimura (2004) showed that the average hardness (*i.e.* the bio-yield point in a compression test) of 25 parboiled rice grains increases by approximately 10–30 N with steaming temperatures (*T*) increasing from 90 to 100 °C. Furthermore, the average hardness increased with steaming times up to 60 min at 90 °C and up to 10 min at 100 °C. Saif, Suter, and Lan (2004) reported that the average ultimate tensile strength (*i.e.* the maximum stress a material can sustain before it is ruptured in a three-point bending test) of 25 rice kernels increases as a result of parboiling from 13.4 MPa to 50.2–60.6 MPa and from 9.2 MPa to 38.0–40.0 MPa, depending on the steaming time and rice cultivar used. Bello, Baeza, and Tolaba (2006) reported that the average rupture force of individual parboiled kernels, increases from 16.8 to 35.8 N when increasing heating time from 90 to 180 min at 85 °C. Likewise, when heating at 95 °C, the breaking force increases from 13.1 to 25.3 N with steaming time increasing from 45 to 75 min. The authors, however, did not explain why lower forces were obtained at higher heating *T*. Tempering for 24 h between soaking and steaming increased the breaking force from 77.5 − 83.6 N to 84.2–86.1 N, depending on the conditions used. Unfortunately, these results are based on only limited experimental data, which hardly reflect the variations in mechanical properties among individual rice grains.

While most research in the area has focused on characteristics of rice bulk, we here set out to study milling breakage susceptibility on both bulk and kernel level. To obtain parboiled rice samples with (i) different DSG and extents of protein aggregation, and (ii) varying levels of white bellies and fissured parboiled rice grains, brown rice was parboiled using combinations of three soaking and three steaming conditions and one standard drying step. The mass percentages of rice kernels breaking during milling of bulk samples were determined and related to the mechanical strength of individual rice grains comprising the bulk sample using a three-point bending test. The DSG and the level of proteins extractable with sodium dodecyl sulfate (SDS) containing medium (SDSEP) of bulk samples and their (non-)breakage susceptible rice kernel fractions were determined. The characteristics of the bulk were related to those of individual rice kernels, both in terms of breakage susceptibility and changes in starch and proteins.

2. Materials and methods

2.1. Rice samples

Brown rice (moisture content 12.0 g/100 g) of long-grain cultivar Puntal [dehulled in its country of origin (Spain), starch, amylose and protein contents of 84.6, 18.4 and 10.1 g/100 g (on dry matter basis) respectively] was obtained from Mars (Olen, Belgium). Moisture content was determined according to Approved Method 44-19.01 (AACCI, 1999). Starch content was calculated as 0.9 x the glucose level estimated by gas chromatography following acid hydrolysis and conversion to alditol acetates (Courtin, Roelants, & Delcour, 1999). Amylose content was determined colorimetrically according to Chrastil (1987) with slight modifications and expressed on rice dry matter content. Protein content was determined using an adaptation of the AOAC Official Method 990.03 (AOAC, 1995) to an automated Dumas protein analysis system (EAS, varioMax N/CN, Elt, Gouda, The Netherlands), using 5.95 as nitrogen to protein conversion factor. The mass percentage of chalky kernels did not exceed 1%.

2.2. Parboiling conditions

To obtain parboiled rice samples with (i) different DSG and extents of protein aggregation, and (ii) varying levels of white bellies and fissured parboiled rice grains, brown rice was parboiled on laboratory scale using soaking and steaming conditions outlined in Table 1 and in Buggenhout, Brijs, and Delcour (2013a). These conditions were chosen based on prior experience and contacts with industry. They take into account both breakage susceptibility and end-product quality (*i.e.* extent of deformation of the grains, color characteristics, and cooked rice quality).

A sample (650.0 g) was soaked in excess water at 40 °C for 60 min, 55 °C for 30 min and 65 °C for 60 min. Rice grain MCs at the end of soaking were 29.4 g/100 g (±0.2 g/100 g), 30.0 g/100 g (±0.1 g/100 g) and 33.6 g/100 g (±0.1 g/100 g), respectively. Soaking was performed in triplicate. After soaking, excess water was drained off, and the rice rested for 20–30 min. The soaked rice was then steamed in a cylindrical container in two steps. The first step was at 106 °C for 15 min. The *T*s and times of the second step were 106, 120 or 130 °C and 15 or 20 min, respectively. After steaming, the pressure was released and the hydrothermally treated samples were mildly dried on trays for 62 h at 27 °C (60% relative humidity) to avoid additional fissuring. The rice grain MC averaged ca. 14.0 g/100 g. The parboiled brown rice samples were stored in sealed plastic bags at 5 °C. As all steaming conditions were preceded by the same steaming step at 106 °C for 15 min, only the impact of the second steaming step is discussed.

2.3. Milling

Prior to milling, raw and parboiled brown samples were kept at 30 °C for about 24 h. The samples (200.0 g) were abrasively milled for 50 s in the presence of $CaCO_3$ (5.0 g) with a TM05C testing mill (Satake, Bredbury, UK). Mass percentages of broken rice kernels were determined in duplicate with an image analysis system (Camsizer, Retsch Technology, Haan, Germany) both before and after milling. In this study, we used the mass percentage of rice kernels breaking when milling rather than head rice yield to directly account for the percentage of broken rice kernels in the sample. It was calculated as follows:

Table 1
Soaking and steaming conditions during parboiling. The mentioned steaming conditions were preceded by a fixed steaming step at 106 °C for 15 min. The corresponding sample codes consist of the soaking and steaming temperatures.

Sample code	Soaking conditions		Steaming conditions	
	Temperature (°C)	Time (min)	Temperature (°C)	Time (min)
40 − 106	40	60	106	15
40 − 120	40	60	120	15
40 − 130	40	60	130	20
55 − 106	55	30	106	15
55 − 120	55	30	120	15
55 − 130	55	30	130	20
65 − 106	65	60	106	15
65 − 120	65	60	120	15
65 − 130	65	60	130	20