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Contour presentation of long grain rice degree of milling and instrumental texture during cooking

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Abstract

Two long grain rice samples were milled for four different durations and cooked in excess water for various durations and in fixed water to rice ratio for 20 minutes. A uniaxial compression test was performed to assess cooked rice hardness and stickiness. Solid leach and moisture content of cooked rice was also determined. Results showed that milling significantly ($p < 0.05$) lowered milled rice protein and lipids and increased apparent amylose contents resulted in an increase in cooked rice hardness through affecting the ability of moisture to hydrate the core of rice kernels during cooking. Milling and cooking duration influenced total solid leached out during cooking. Solid leach was positively correlation with cooked rice moisture content and negatively with cooked rice stickiness. The decrease in the total solids leach out with the increase in cooking duration suggests a re-adsorption of these solid on the surface of cooked rice kernels thus sticky texture.

Introduction

Rice texture is a key indicator of rice quality as it affects cooked rice acceptance by consumers (Sitakalin and Meullenet 2000; Lyon *et al*., 2000). Unlike wheat, corn and oat, rice is consume largely as cooked whole grain, which is produced after de-hulling and milling processes, respectively. Cooking methods of rice vary widely. In general, most cooking methods of rice are subtle variations of two basic cooking techniques; (1) Excess or American method where rice is usually cooked in large amount of water then drained or (2) the Oriental method where rinsed rice is usually cooked in a measured amount of water; often twice the volume of rice (Crowhurst and Creed, 2001). However, for both cooking techniques, rice is usually cooked either in to the amount of water it can absorb during cooking or until the core of the grain is gelatinized to obtain an acceptable softness (Juliano and Perez, 1983; Kasai *et al*., 2005).

The effect of rice chemical composition, pre and post harvest practices on cooked rice functional properties have also been studied extensively (Juliano, 1985; Chrastil, 1992; Meullenet *et al*., 1999; Champagne *et al*., 1998; Srisawas and Jindal, 2007). During cooking of rice, especially in excess water, starch of rice absorbs moisture and swells. Continue heating result is starch gelatinization where starch is usually undergoes an order-disorder transition. Loss of bifringence and crystallanity, increase in viscosity of the suspension and leaching of soluble starch components is among the changes that occur to starch during gelatinization. Variation in rice chemical composition therefore may have impacts rice functional properties. For example, changes in rice chemical composition, disproportionate losses of lipids protein and minor components (Singh *et al*., 1998; Azhakanandam *et al*., 2000; Park *et al*., 2001) and the increase starch content of milled rice (Yoshizawa and Ogawa (2004), have impacts on cooked rice gelatinization (Okuda *et al*., 2007). Moreover, the amount of rice bran remaining on rice kernels after milling seems to play a key role in affecting rice quality characteristics including texture (Saleh and Meullenet, 2007).

Rice hydration during cooking considers as a key indicator of rice physicochemical properties and usually influenced by rice surface area and chemical composition (Yadav and Jindal, 2007). High amylose cultivars, for example, were indicated to have firmer and less sticky than low amylose cultivars. In addition, slender rice varieties, high in amylose, were indicated to uptake greater amount of water than short and rounder varieties, low in amylose, during cooking (Bergman *et al*., 2004). Water uptake by rice during cooking, in boiling water, was related to rice

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surface area Bhattacharya and Sowbhagya (1971). Others indicated that at boiling or at low cooking temperatures; the cooking rate and water uptake is actually depends on the interaction of rice chemical composition with water (Bergman *et al*., 2004). For this reason, Juliano and Perez (1983) suggested different water to rice ratio to cook rice with greater amylose content rice requiring larger amount of water to achieve an optimum cooking.

Although several researchers have studied the effect of water-to-rice ratio for rice cooking and resultant textural properties (Srisawas and Jindal, 2007) a universal way of selecting a water-to-rice ratio to obtain optimal cooked rice texture does not exist. Cooking of rice using fixed water to rice ratio, for example, raised some concerns of limiting the amount of water availability for rice kernels to absorb and affect leached amount of starch molecules and thus cooked rice texture attributes. In addition, there is lack of information on how cooking rice in excess amount of water affect its texture characteristics. Furthermore, no agreement exists among several researchers on the effect of solid leach out play during rice cooking (Bergman *et al*., 2004). Therefore, this study was initiated to investigate and graphically present the role moisture uptake, solid leach and degree of milling play in determining cooked rice instrumental texture attributes.

Materials and Methods

Rice sampling

Two long (Wells and CL-161) grain rice cultivar/hybrid harvested from Keiser, AR, at moisture contents (MC) of 16.0 and 21.2% (wet bases (wb)) respectively was used in this study. Wells and ClL-161 were selected as the most prominent variety and hybrids rice grown in the state of Arkansas. Rice samples were brought to the University of Arkansas Rice Processing Program laboratories in Fayetteville, AR, where the rice was cleaned (Carter-Day Dockage Tester, Carter-Day Co., Minneapolis, MN), and air dried at ambient temperature to a MC of ~12.5% wb. Dried rough rice samples were then stored in air-tight plastic storage containers at 22 ± 3°C for two months before milling.

Duplicate 150 g of each rough rice sample were de-hulled using a de-husker (THU-35, Satake, Hiroshima, Japan) and milled for 20, 30, 40 and 50 seconds using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, TX). A double-tray sizing device (GrainMan Machinery Mfg. Corp., Miami, FL) was used to separate whole from broken kernels. Only full rice kernels were used throughout this study.

Chemical composition

Milled rice surface lipid content (SLC) of each rice sample was determined in duplicate using a Soxtec system (Avanti 2055, Foss North America, Eden Prairie, MN) according to AACC method 30-20 (AACC International 1997) with modifications to the petroleum ether washing duration (from 30 to 20 min) as described by Matsler and Siebenmorgen (2005). In brief, 5 g of rice treatments were weighed into cellulose thimbles (Foss North America, Eden Prairie, MN); the thimbles and the head rice samples were pre-dried for 1 hr in an oven maintained at 100ºC. Subsequently, lipid was extracted from the samples utilizing 70 ml of petroleum ether (boiling point 35-60ºC; VWR, Suwanee, GA). The hot plate below the extraction cups was heated to 135ºC while the thimbles were immersed in the extraction cup solvent for a boiling duration of 20 min, then raised above the solvent and rinsed with petroleum ether condensate for 30 min. After rinsing, the extraction cups were removed from the Soxtec unit and placed into an oven maintained at 100ºC for 30 min to allow evaporation of the solvent. Samples were then placed in a desiccator at room temperature for approximately 30 min to cool before being weighed. The difference between the mass of the cups containing the extracted lipid and the original empty cup mass was then calculated to obtain the mass of the extracted lipid. SLC was expressed as the mass percentage of extracted lipid mass to the original rice treatment mass.

A cyclone sample mill (Udy, Fort Collins, CO) fitted with a 100-mesh sieve was used for grinding milled rice samples to obtain rice flour from each rice treatment. Protein content of milled rice flour was then determined on duplicate of each treatment using the Kjeldahl procedure, AACC method 46-11A (AACC International 2000). The protein content of rice flour was calculated by multiplying the nitrogen content by 5.95.

Analysis of the rice flour apparent amylose content was measured using the method described by Juliano (1971). One hundred ± 0.1 mg of dry rice flour samples were weighed and transferred into a 100-mL volumetric flask. Ethyl alcohol (1 mL) was added to wet the sample. Then 10 mL of 1N sodium hydroxide solution was added, swirled to disperse the sample, and allowed to rest ≈1 hr until the sample solution was completely clear. Then it was diluted to volume with distilled water, after which 2 mL of this dilution was pipetted to another 100-mL volumetric flask. Then 2.0 mL of 0.2% iodine solution (2.0 g of potassium iodide and 0.2 g of iodine diluted to 100 mL with distilled water) was added; the flask was filled to volume. This final solution was allowed to sit 30 min to fully develop color and then the amylase-iodine solution was analyzed calorimetrically at 620 nm using a Model 7230G spectrophotometer (Shanhai Analytical Instrument General Factory, China). Duplicated determinations were performed for each sample. Apparent Amylose content was expressed as a percentage of the rice flour weight.

Milled rice kernels dimensions

The dimensions (length, width, thickness, area, Circumference and Thru*Area) of milled rice kernels of rice (CL-161 and Wells) treatments (samples milled for various durations) were measured using a Satake rice image analyzer RIV 1A (Satake corporation Taito Ku Tokyo, Japan). One hundreds and fifty rice kernel was used for image analysis measurements. Rice kernels were placed on a feeding mechanism that individually delivered rice kernels on an imaging screen. Two CCD cameras were used to capture kernel images in binary form. During the image analysis measurements, one camera captured the image of the rice kernel from the top view measuring its length and width while a second camera captured the image of that rice kernel from the side view providing measurement for its thickness. A digitizing software program (v. 1.0A, RIA System) was used to capture the images and to automatically convert and record kernel dimensions into a text file (Counce *et al*., 2005).

Rice cooking

Rice was cooked using a miniature rice cooker consisting of a glass-cooking vessel (200 ml in volume and semi-spherical) with a glass top and a heating mantle (TM 102, Glas-Col, Terre Haute, IN), the temperature of which was regulated by a temperature controller (89000-10, Eutech Instruments, Pte Ltd, Singapore). One hundred ml water was preheated to boiling before the addition of 20 gram of milled rice. Rice was cooked for either 16, 18, 20 or 22 min to a maximum cooking temperature of 98.5±1°C, after which the excess water was drained. Another set of rice samples was cooked using in water to rice ratio of 2:1 (w/w) (W/R20) for 20 min. Cooked rice treatments were fluffed using a plastic fork and kept warm (50°C) using a temperature-controlled mantle for 5 min before texture measurements. The cooking conditions were identical for all rice treatments to eliminate differences in cooked rice textural properties due to the cooking method.

Starchy core of rice during cooking

The disappearance of cooked rice starchy core, during cooking, was evaluated using two glass slides. To perform this test, rice treatments was cooked for set durations after which five kernels, from each cook, was placed between two glass slides and compressed gently. Rice kernels core was examined, scanned and recorded. Rice treatments were cooked and the disappearance of rice kernels starchy core was examined in replicate.

Instrumental texture measurements

Cooked rice textural attributes were determined using a uniaxial single compression method using a Texture Analyzer (TA-XT2 plus, Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK). 10 whole cooked rice kernels were compressed using a 50-Kg load cell to leave a 0.3 mm gap between two compression plates at the bottom of the compression cycle. The maximum compression force was used as an indicator of cooked rice hardness while the adhesion energy measured during the upward travel of the compression plate was used as an indicator of cooked rice stickiness. Rice treatments were cooked in replicate and five measurements were taken for each cook. Cooked rice textural attributes were obtained using the Texture Exponent software (Stable Microsystems, version 1,0,0,92, Surrey, UK).

Cooked rice moisture content (MC)

MC of rice treatment was measured during cooking. Rice treatments were cooked, in excess water, for either 16, 18, 20 or 22 min after which approximately 5 g cooked rice was weighed, in triplicate, and dried at 130°C for 24 hours using a drying oven (Precision, Winchester, VA). Cooked rice MC was calculated as the percentage of moisture weight of cooked rice sample (wb). MC of rice samples cooked in water to rice ratio of 2:1 was also determined.

Total solids leach during cooking

The total amount of solids leached out during cooking was measured for each treatment. Rice samples were cooked for either 16, 18, 20 or 22 min in excess amount of water. Cooked rice was drained and approximately 10 grams of the cooking liquid was weighed, in triplicate, and dried at 130oC for 24 hours using a drying oven (Precision, Winchester, VA). The percentage of solids in the cooking gruels was then calculated.

Statistical analysis

Cooked rice texture measurements, MC and total solid leached out during cooking were averaged for each cook and regarded as a replicate. Analysis of variance (ANOVA) was performed using JMP (release 10.0 (SAS institute, Cary, NC). Least significant differences (LSD), at a 5% level of probability, were determined between instrumental texture measurements, solid leach and water uptake for each milling and cooking treatment.

Results and Discussion

Milled rice quality characteristics

Rice treatments were milled for 20, 30, 40 and 50 seconds to produce treatments of various milling degrees. Head rice yield (HRY) ranged from 53.10 to 55.17% and from 55.23 to 57.53% for CL-161 and Wells respectively. Although not significant ($P > 0.05$), HRY decreased with the increase in the degree of milling (Table 1). The decrease in HRY was a result of removing greater bran layer as well as the increased breakage in weak rice kernels as a result of milling for longer durations (Sun and Siebenmorgen, 1993; Siebenmorgen and Sun, 1994).

Milled rice SLC ranges from 0.18 to 0.44% for CL-161 and from 0.19 to 0.52% for Wells respectively (Table 1). Rice lipids are known to be localized on the outer caryopsis coat, aleurone, and subaleurone layers of rice kernels; therefore, milling for longer durations resulted in removal of greater amount of SLC. These results are in agreement with previous work by Saleh and Meullenet (2007).

Table 1 also shows the percentage of apparent amylose and protein contents of rice milled to various durations. AAC ranged from 23.93% to 24.95% and from 24.12% to 26.18% and protein content ranged from 7.26% to 7.68% and from 6.19% to 6.65% for Cl-161 and Wells, respectively. Milling to a lower SLC (i.e., greater milling degree) resulted in an increase, although not always significant ($P > 0.05$) in apparent amylose and a significantly ($P < 0.05$) decreased protein content. This is attributed to the removal of rice kernels outer most layers that are known to be rich in proteins. These results are in approval with Yoshizawa and Ogawa (2004) who reported a decrease in milled rice protein content with milling. The increase in AAC, on the other hand, was probably due to the disproportional losses of SLC and protein content due to milling. However, after reaching a milling ratio of 50% a constant protein content of milled rice were reported (Chen *et al*., 1999).

Milled rice dimensions

Rice surface was indicated to play a major part in affecting water uptake of rice during cooked rice (Bhattacharya and Sowbhagya, 1971), thus cooked rice texture properties. Minor and not significant ($P > 0.05$) kernels dimensions were used in this study. Thus results indicate that changes in rice functional characteristics were accredited for the most part to changes in rice chemical composition rather than dimensional changes due to milling.

Cooked rice firmness

Table 2 also shows cooked rice firmness of rice milled to various durations and cooked for 16, 18, 20, 22 or W/R_{20} min. Results showed that cooked rice firmness affected cooking and milling durations. For examples, the increase in rice degree of milling (i.e. decreasing SLC) and cooking significantly, ($P < 0.05$), produced softer rice than when lightly milled or cooked for short duration (Figure 1a). Milling for 50s and cooked for 22 min. produced the softest rice texture. Cooked rice firmness decreased from 81.0 to 68.5 N and from 79.9 to 76.8 N for CL-161 and Wells rice, respectively, when milled for 20 and 50s and cooked for 20 min. Cooking for longer duration resulted in softer rice texture.

We have indicated earlier that rice kernels surface area and chemical composition determines cooked rice moisture uptake, thus cooked rice texture. In the situation of cooking rice by putting it in boiling water; rice surface area probably plays a primary role affect cooked rice water uptake. In contrast, cooking rice in a rice cooker usually subjected to hydration temperatures lower than its gelatinization temperature (Bergman *et al*., 2004). In this case rice chemical composition/ interaction probably play the major role in determining cooked texture rice. Samples used in this study were cooked by putting certain amount of rice in a boiling known excess amount of water and all rice samples were cooked identically. Moreover, limited variation in rice kernels dimensions were reported, therefore, variation in cooked rice texture attributes were related foremost to the changes in their chemical composition as a result of milling. The decrease in firmness with milling agrees with previous work and was attributed to the restriction of moisture migration in rice kernels during cooking of lightly milled rice (Saleh and Meullenet 2007). Limited hydration of cooked rice kernels core during cooking appears to influence cooked rice firmness measurements. The negative correlation between cooked rice firmness and MC of rice during cooking, -0.86.and -0.84 for CL-161 and Wells respectively, provides more evidence of the significant role moisture uptake play in determining cooked rice firmness.

Table 1. Milled rice (CL-161 and Wells) HRY and chemical composition during milling for various durations [1, 2]

Cultivars	Milling (s)	HRY (%)	SLC (%)	AAC (%)	Protein (%)
CL-161	20	55.17 ᵃ	0.44 ᵃ	23.93 ᵃ	7.68 ᵃ
	30	54.13 ᵃ	0.33 ᵇ	24.04 ᵃ	7.47 ᵇ
	40	53.33 ᵃ	0.24 ᶜ	24.66 ᵃ	7.37 ᵇᶜ
	50	53.10 ᵃ	0.18 ᵈ	24.95 ᵃ	7.26 ᶜ
Wells	20	57.53 ᵃ	0.52 ᵃ	24.85 ᵃᵇ	6.65 ᵃ
	30	57.50 ᵃ	0.38 ᵇ	24.12 ᵇ	6.32 ᵇ
	40	55.87 ᵃ	0.27 ᶜ	24.92 ᵃᵇ	6.25 ᵇᶜ
	50	55.23 ᵃ	0.19 ᵈ	26.18 ᵃ	6.19 ᶜ

[1]HRY, SLC and AAC represent head rice yield, surface lipid content and apparent amylose content respectively
[2]Means of HRY, SLC, AAC and protein content of the same cultivar / hybrid milled to different durations with different letters are significantly ($P < 0.05$) different according to LSD

Table 2. Cooked rice texture, moisture content and solid leach during cooking of long grain rice samples (Wells and CL-16) milled to various degrees[1, 2]

Milling Durations (s)	CL-161 Hardness (N)	CL-161 Stickiness (N.s)	CL-161 Moisture Content (%)	CL-161 Solids (%)	Wells Hardness (N)	Wells Stickiness (N.s)	Wells Moisture Content (%)	Wells Solids (%)
	16 minutes							
20	89.88 ᵃ	7.11 ᵃ	68.43 ᵇ	1.26 ᵇ	94.85 ᵇ	8.72 ᵃ	70.26 ᵃ	1.43 ᵃ
30	90.06 ᵃ	7.63 ᵃ	70.38 ᵃ	1.08 ᶜ	95.00 ᵇ	9.54 ᵃ	70.48 ᵃ	1.46 ᵃ
40	89.70 ᵃ	8.35 ᵃ	70.55 ᵃ	1.28 ᵇ	102.21 ᵃ	11.06 ᵃ	67.11 ᵇ	1.35 ᵇ
50	91.99 ᵃ	9.26 ᵃ	69.73 ᵃᵇ	1.44 ᵃ	95.15 ᵇ	9.99 ᵃ	69.80 ᵃ	1.26 ᶜ
	18 minutes							
20	89.27 ᵃ	6.70 ᵃ	71.18 ᵇ	1.53 ᵃ	81.30 ᶜ	7.15 ᵃ	74.12 ᵃ	1.87 ᵃ
30	78.84 ᶜ	8.04 ᵃ	71.38 ᵃᵇ	1.26 ᵈ	87.32 ᵇ	7.84 ᵃ	70.97 ᵇ	1.49 ᶜ
40	77.78 ᶜ	8.05 ᵃ	71.01 ᵇ	1.30 ᶜ	98.04 ᵃ	10.08 ᵃ	69.69 ᵇ	1.32 ᵈ
50	84.22 ᵇ	8.22 ᵃ	71.84 ᵃ	1.46 ᵇ	82.05 ᶜ	8.42 ᵃ	72.36 ᵃᵇ	1.67 ᵇ
	20 minutes							
20	80.98 ᵃ	5.97 ᵃᵇ	72.50 ᵃᵇ	1.61 ᵃ	79.93 ᵃᵇ	7.58 ᵃ	75.53 ᵃ	2.05 ᵃ
30	78.30 ᵃ	6.79 ᵃ	71.30 ᶜ	1.30 ᵇ	82.91 ᵃ	8.20 ᵃ	73.05 ᵇ	1.75 ᵇ
40	71.15 ᵇ	6.84 ᵃ	71.63 ᵇᶜ	1.35 ᵇ	83.68 ᵃ	8.33 ᵃ	72.67 ᵇ	1.79 ᵇ
50	68.54 ᵇ	5.70 ᵇ	73.05 ᵃ	1.55 ᵃ	76.76 ᵇ	7.41 ᵃ	72.86 ᵇ	1.81 ᵇ
	22 minutes							
20	78.90 ᵃ	6.66 ᵇᶜ	73.59 ᵃ	1.83 ᵃ	82.58 ᵃ	7.73 ᵃ	74.54 ᵇ	2.02 ᵃ
30	69.77 ᵇ	8.33 ᵃᵇ	73.07 ᵃ	1.77 ᵇ	78.55 ᵃᵇ	7.58 ᵃ	74.64 ᵇ	1.56 ᶜ
40	68.06 ᵇ	9.50 ᵃ	72.71 ᵃ	1.48 ᵈ	80.09 ᵃᵇ	8.14 ᵃ	74.98 ᵃᵇ	1.83 ᵇ
50	63.91 ᶜ	5.27 ᶜ	73.97 ᵃ	1.63 ᶜ	76.40 ᵇ	8.76 ᵃ	75.38 ᵃ	1.73 ᵇ
	W/R_{20}							
20	99.30 ᵃ	7.30 ᶜ	67.73 ᶜ	NA	109.06 ᵃ	10.25 ᵃ	67.80 ᶜ	NA
30	88.10 ᵇ	8.79 ᵇᶜ	69.09 ᵃᵇ		103.84 ᵇ	8.85 ᵃ	69.36 ᵇ	
40	86.57 ᵇ	8.97 ᵇ	69.66 ᵃ		101.21 ᵇᶜ	9.73 ᵃ	68.33 ᵇᶜ	
50	85.35 ᵃ	11.03 ᵃ	68.21 ᵇᶜ		100.97 ᶜ	11.37 ᵃ	71.42 ᵃ	

[1] W/R_{20} and NA represents cooking of rice in water to rice ratio of 2: 1 for 20 minutes and Not Available results respectively
[2] Means of hardness, stickiness, moisture content and solid leach during cooking of the same cultivar / hybrid and cooking duration milled to different durations with different letters are significantly ($P < 0.05$) different according to LSD

In addition, milling was reported to decrease rice gelatinization temperature as a result of removing greater amount of the large starch granules, located in the outer layer. Small starch granules are usually localized in the center rice kernels (Okuda *et al.*, 2007). Large starch granules were indicated to exhibit high gelatinization temperature, more crystalline structure and more resistance of swelling and water penetration during cooking compared with smaller starch granules (Metcalf and Lund, 1985).

Cooked rice stickiness

Cooking of rice in excess amount of water had a stickiness values ranged from 5.27N.s to 9.50 N.s and from 7.15N.s to 11.06 N.s for CL-161 and Wells rice samples milled and cooked for various durations (Table 2). Stickiness of cooked rice in a water to rice ratio of 2:1 ranged from 7.30N.s to 11.03 N.s and from 8.85 to 11.37 N.s for Cl-161 and Wells respectively. Although not significant ($P > 0.05$), results pointed toward an increase in cooked rice stickiness with the increase in milling degree across cultivars and cooking water to rice ratio. Cooking duration however, resulted in a decrease in stickiness (Figure 1b).

The total amount of solids leached during cooking seems to play a major role in determining cooked rice stickiness. Cooked rice stickiness and total solids leached during cooking was negatively correlated with a correlation coefficient r of -0.52 and -0.79 for CL-161 and Wells samples respectively. This suggests a re-adsorption of the leached molecules, on the surface of cooked rice kernels, as a result of increased cooking water concentration (i.e., greater amount of moisture being transferred to hydrate rice kernels) with continue cooking. This probably resulted in a greater degree of a gel matrix formation surrounding rice kernels thus contributed to the increased cooked rice stickiness.

Stickiness of cooked rice are usually manifested by a sequence of event, based on the extent of occupation of spaces by water that is occurring during cooking and the interaction of rice chemical components (Adhikari *et al.*, 2001). Initially, where

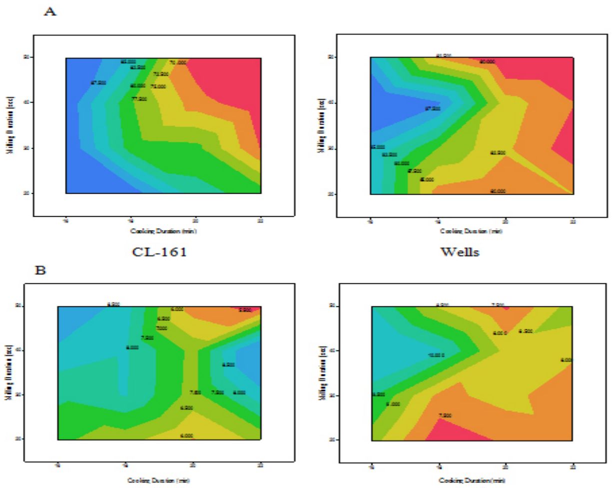

Figure 1. Contour plot of long grain cooked rice (CL-161 and Wells) hardness (A) and stickiness (B) as affected by milling and cooking duration

liquid occupied only part of the total space between rice kernels a strong liquid bridges resulting from pressure drop and an interfacial tension along the wetted surface, were indicated to develop. When spaces between food particles are completely filled by water, in case of rice during cooking, a negative capillary pressure is usually developed in the entire liquid space increasing the tensile strength of the wet particles (Papadakis and Bahu, 1992).

The increased stickiness with milling of rice samples cooked in a WR20 support a re-adsorption event of the leached molecules on the surface of cooked rice kernels, thus increase cooked rice stickiness. This agrees with Adhikari *et al.* (2001) who indicated a presence of immobile bridges, usually formed during heating food molecules. These bridges, upon drying, would eventually transform into solid bridges, creating a strong binding force between the particles, and believed be of starch and protein molecular bonds. The increase in cooked rice stickiness as a result of increased starch protein binding (Chrastil, 1990; Hamaker and Griffin, 1990; Hamaker and Griffin, 1993) supports this explanation.

Cooked rice MC

Table 2 presents cooked rice MC of rice samples milled to various durations. Results (i.e., ANOVA) indicated that cooking and milling duration have significant ($P < 0.05$) impacts on cooked rice MC. Moreover, cooked rice MC and cooking duration were highly correlated having a coefficient of determination (R^2) of 0.68. Significant interaction of milling and cooking duration ($P = 0.0030$ and 0.0023 for CL-161 and Wells respectively) was also reported. Results are presented in Figure 2 where for CL-161 samples, cooked rice starchy cores of samples milled for 50 seconds disappeared after cooking for 18 min compared to cooking for more than 20 min of samples milled for only 20 seconds (Figure 2). Similar resulted were reported for Wells samples (Figure 2).

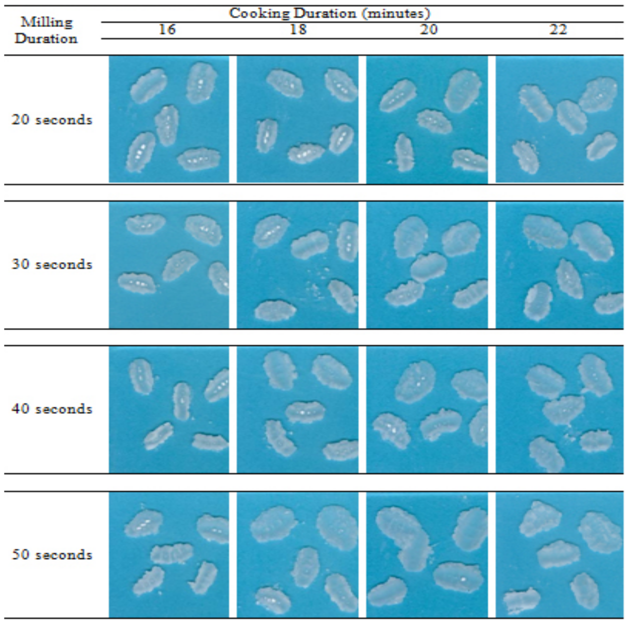

Figure 2. Cooking test of rice kernels of long grain CL-161samples milled to different degrees and cooked for various durations in excess amount of water

Moisture absorption by rice kernels during cooking are usually characterized by milled rice physicochemical properties such as amylose content, gel consistency, alkali spreading value, gelatinization temperature and protein content (Juliano and Perez, 1983; Metcalf and Lund, 1985; Juliano, 1993; Yadav and Jindal, 2007). Bhattacharya and Sowbhagya (1971) also related cultivar cooked moisture uptake to its surface area with a small degree to protein content and gelatinization temperature.

The removal of bran layers that are richer in proteins and lipids, compared to rest of the kernel seem to play a major role in restricting water uptake by rice kernels during cooking. This is in line with Juliano *et al.* (1965) and Yadav and Jindal (2007) findings that high protein rice require longer cooking and greater moisture compared to low protein rice and also with Bergman *et al.* (2004) and Juliano (1993) who reported that high amylose rice have higher capacity of absorbing moisture during cooking than lower amylose samples. This was also presented visually in Figure 2 and 3 where samples milled for longer durations (i.e., lower protein content) required shorter cooking duration to hydrate its starchy core. Lipids also indicated to have effects on restricting moisture uptake of rice during cooking through the formation of complexes with amylose and amylopectin (Eliasson and Krog, 1985, Seneviratne and Biliaderis, 1991; Hamaker and Zhang, 2003).

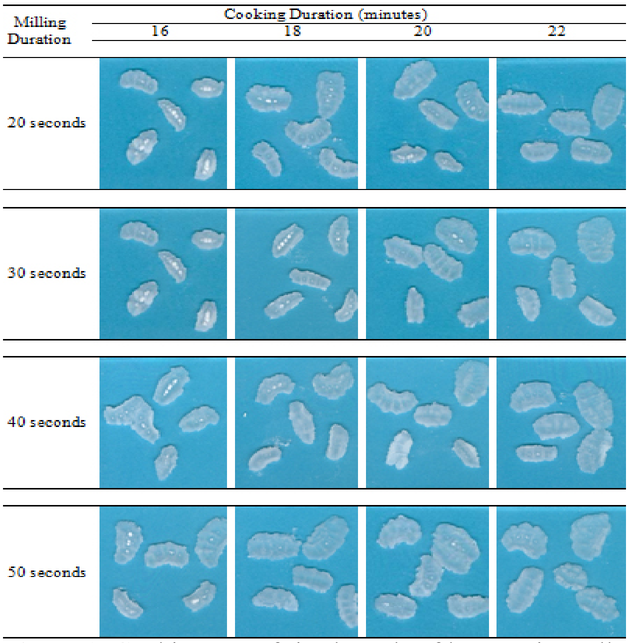

Figure 3. Cooking test of rice kernels of long grain Wells samples milled to different degrees and cooked for various durations in excess amount of water

Total solids leached during cooking

Table 2 presents the percentage of the total solids leached in the cooking liquid during cooking. Solid leached ranged from 1.07% to 1.83% and from 1.24% to 2.09% for CL-161 and Wells rice treatments respectively. Results indicated an increase in the total solid leach out with cooking, for similar milling duration, accompanied with an increase in cooked rice MC. This was attributed to the solubilization of more starch molecules as a result of continues heating. These results agree with Metcalf and Lund (1985) who reported a power function of the solid loss into the cooking gruel and cooking duration of rice.

Milling degree of rice also impacted the amount of solids leached out with a significant interaction ($P < 0.05$) between milling and cooking duration. During cooking, starch of the cooking rice kernel usually absorbs moisture and swells due to its gelatinization. Continue heating in the presence of water usually result in leaching of starch solids into the cooking gruel. This is probably the reason why soaking of rice at temperatures below that of starch gelatinization is recommended to minimize splitting of the kernel and the subsequent leaching of solids (Luh and Mickus, 1980).

Conclusion

Milling and cooking of rice to various durations affected cooked rice texture, solid leach and water uptake. Changes in cooked rice hardness due to milling and/ or cooking duration were related to the hydration of the rice kernel's core during cooking. Lightly milled rice samples resulted in lower MC of rice cooked for various durations, thus increased cooked rice hardness. The formation of protein–starch and lipid–starch complexes believed to restrict water absorption during cooking. Longer cooking duration resulted in greater MC of cooked rice producing softer rice. However, optimum cooking duration vary depending on rice type. Solids leached out during cooking depend on milling and cooking durations. Furthermore, adsorption of these solid components on the surface of cooked rice kernels believed to play a significant role in determining cooked rice stickiness. The increase in cooked rice moisture content during cooking was accompanied with an increase in total solid leach in the cooking water. Therefore, cooked rice moisture content and solid leach of rice when cooked in excess amount of water can be used as indications of optimum cooking of rice. Milled rice texture attributes can be controlled to some extent, depends on the consumer preference, by varying rice degree of milling.

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