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Nutritional and sensory profile of two Indian rice varieties with different degrees of polishing

S Shobana[1], **NG Malleshi**[1], **V Sudha**[1], **D Spiegelman**[2], **B Hong**[2], **FB Hu**[2], **WC Willett**[2], **K Krishnaswamy**[1], and **V Mohan**[1]

[1]Madras Diabetes Research Foundation & Dr Mohan's Diabetes Specialties Centre, WHO Collaborating Centre for Non-Communicable Diseases, International Diabetes Federation (IDF) Centre of Education, Gopalapuram, Chennai, India

[2]Departments of Nutrition, Epidemiology, and Biostatistics, Harvard School of Public Health, Boston, MA, USA

Abstract

Traditional hand-pounded rice has been replaced today with highly polished white rice in the Asian Indian diets. The study aimed to evaluate the nutritional as well as the sensory differences between the brown (0% polish) and the rice milled to different degrees of polish (2.3, 4.4 and 8.0%). Bapatla and Uma (red pigmented) varieties in both raw and parboiled forms were used. The protein, fat, dietary fibre, γ-oryzanol, polyphenols, vitamin E, total antioxidant activity and free radical scavenging abilities of the brown rice decreased while the available carbohydrates increased with polishing. Sensory attributes of the cooked rice samples (whiteness, grain intactness, fluffiness, firmness, stickiness, chewiness and the cooked rice aroma) were evaluated by trained panelists. Scores for branny taste and chewiness decreased with polishing. On the whole, brown rice of both the varieties was readily accepted by the well-informed sensory trained panelists.

Keywords

Brown rice; nutritional composition; available carbohydrates; oryzanol; antioxidant activity; chewiness

Introduction

Rice (*Oryza sativa*) is one of the most important and oldest food staples of India and other Asian countries. Rice was first mentioned during *Yajurvedic* (Achaya 2009) period (1500–

Correspondence: Vasudevan Sudha, Head, Department of Foods, Nutrition and Dietetics Research, Madras Diabetes Research Foundation and WHO Collaborating Centre for Non-Communicable Diseases, IDF Centre of Education, 4, Conran Smith Road, Gopalapuram, Chennai 600 086, India. Tel: + 9144 4396 8888. Fax: + 9144 2835 0935. sudhavasudev@yahoo.com; drmohans@diabetes.ind.in; Website: www.drmohansdiabetes.com; www.mdrf.in.

Declaration of interest: V.M., V.S., W.W.C. and S.D. designed the study. N.G.M. and S.S. led the data collection. S.S. wrote the first draft of the manuscript. H.B. and S.D. analysed the data and wrote the statistical analysis and results section. K.K. and H.F. reviewed the manuscript and contributed to the interpretation of data. All authors contributed to the revision and finalization of the manuscript. All authors declared that they have no duality of interest associated with this manuscript.

800 BC) of Hinduism. The total food grain production in India during the year 2008– 2009 accounts to about 234.47 million tonnes out of which rice production accounts to about 42% (99.18 million tones) (http://dacnet.nic.in/eands/latest_2006.htm). Historically, Indian diets are rich in carbohydrates and contribute to 60–70% of the total calories. Cereals continue to be the staple in Indian diets (Prema 2006); and in many parts of India, rice is the staple and main source of carbohydrates in the diet.

In the past, hand-pounded rice (retaining some of the bran and germ constituents) was consumed in India (Achaya 2009). However, today due to the advent of modern milling technology, which improved the yield of the head rice, the hand-pounded rice has been replaced extensively by milled (polished) rice. In this milling process, brown rice (whole grain, 0% polish) is milled to separate out the bran layer to produce polished white rice (refined grain) which is devoid of bran, germ constituents and contains only the starchy endosperm. A recent study has shown that the urban south Indians derived almost half of their calories from refined grain intake (Radhika et al. 2009).

Brown rice contains higher proportions of dietary fibre, polyphenols, γ-oryzanol, B vitamins and minerals compared to fully polished or white rice (Dinesh Babu et al. 2009). Most of these health beneficial nutrients are concentrated in the peripheral layers of the rice kernel (Juliano 1985; Itani et al. 2002) and are removed during polishing. Whole grain foods have been shown to improve insulin sensitivity and reduce the risk and incidence of type 2 diabetes (Fung et al. 2002; Pereira et al. 2002; Montonen et al. 2003; Sun et al. 2010). We have already reported that higher intake of refined grains was associated with insulin resistance, metabolic syndrome and type 2 diabetes among Asian Indians who habitually consume high-carbohydrate diet predominantly derived from polished white rice (Mohan et al. 2009; Radhika et al. 2009).

Today, brown rice and also the traditional hand-pounded rice are not readily available in the local market. Moreover, the information on the nutrient composition of brown rice and rice milled to different degrees of polish are also not available in ‘Nutritive value of Indian Foods’ published by the National Institute of Nutrition, Hyderabad, India (Gopalan et al. 2010). Hence, before promoting the benefits of whole grain consumption, it is important to generate information on the nutrient contents and sensory attributes of brown rice and brown rice milled to different degrees of polishing.

Accordingly, the nutrient content as well as the sensory attributes of brown rice (0% polish) versus rice milled to different degrees of polish (2.3, 4.4 and 8.0%) were studied with the following objectives: (a) to produce brown rice from a popular variety of white and a red-coloured rice variety commonly consumed in south India and to mill them to different degrees of polish in both the raw and parboiled forms; (b) to analyse the rice samples with different degrees of polish for their major nutrient and phytonutrient contents; (c) to study the differences in sensory profiles of these rice varieties following a standard protocol by trained panelists and (d) to study the sensory and nutritional differences between brown rice (0% polish) and rice with different degrees of polish (2.3, 4.4 and 8.0% polish). The study findings could help to design future intervention trials on the effect of whole grain (brown rice) on diabetes risk among overweight and obese adults. Moreover, the generated information could be helpful in planning nutrition education strategies to introduce brown rice in the population where rice is consumed as the major staple.

Materials and methods

Rice parboiling and milling

The paddy or the rough rice of Bapata (BPT) (white coloured) and Uma (red coloured) variety, commonly consumed in the states of Tamil Nadu and Kerala were procured from the National Seeds Corporation, Chennai, India, cleaned using rice destoner-cum-cleaner and used for the studies. A portion of paddy from both the varieties was parboiled following the conventional method of cold water soaking and dried to about 14% moisture content (Bhattacharya 1985). The parboiling as well as milling experiments was conducted at M/S Shanthadurga Rice Industries, Mundgod, Karnataka, India. Both the raw and parboiled paddy were cleaned to ensure that they were free from any foreign material and de-husked in rubber roll shellers. The de-husked rice (brown rice-0% polish) was used for de-branning or polishing (Figure 1). A portion of brown rice was polished in horizontal emery polishers to 2.3, 4.4 and 8.0% degree of polishing using standardized milling operations (USDA 1980).

Nutrient and phytochemical analysis

The raw and parboiled rice samples milled to different degree of polish (DOP) were pulverized in an Udy Cyclone mill to pass through 60 mesh (BSS) sieve and the whole meals were analysed for the proximate composition following the standard AACC (2000) methods. The dietary fibre (Asp et al. 1983) and γ-oryzanol (Seetharamaiah and Prabhakar 1986) contents of the rice samples were also determined. The available carbohydrate content of the rice samples was determined by enzymatic method adopted from the method described by Goni et al. (1996) with minor modifications and in brief, the defatted rice flour was gelatinized, subjected to sequential digestion with heat stable α-amylase, pepsin, pancreatic α-amylase and amyloglucosidase at appropriate pH and temperature. Finally, the digest was centrifuged and the reducing sugar content of the supernatant was estimated by the dinitro-salicylic acid method. The values were expressed as per cent (%) available carbohydrates. Soluble and bound polyphenols of the rice samples were extracted serially by methanol and 1% HCl methanol, respectively, at room temperature. Extracts were analysed for the polyphenol content by Folin–Ciocalteu's reagent method (Singleton and Rossi 1965). Characterization and quantification of vitamin E (tocopherols and tocotrienols) was carried out by reverse phase HPLC (Chen and Bergman 2005). The HPLC model CBM-10A Shimadzu system with RF 10 AXL fluorescent detector, LC 10 AT pump using shim-pack Prep-ODS(H) column (250 × 4.6 mm, 5 μm) using a gradient solvent system was used. The chromatograms were recorded and processed by the LC-10 A class software. The fluorescence detector was set at excitation and emission wavelengths of 298 and 328 nm, respectively.

Antioxidant activity

The total antioxidant activity (TAA) of the methanolic extracts of the rice samples were carried out using phosphomolybdenum reagent (Pilar et al. 1999) and the free radical scavenging ability (FRSA) of the methanolic extracts of the samples were carried out using the 1,1-diphenyl-2-picrylhydrazyl radical (DPPH) method of Bondet et al. (1997).

Sensory analysis

Cooking of rice samples—Pressure cooking, the common household method of rice cooking was chosen. Initially, the optimum ratio of rice to water was standardized and accordingly, 1:2.0 for brown raw and parboiled rice, and 1:2.8 for 2.3, 4.4 and 8.0% polished rice were used. Rice and water were taken in a cooking vessel of appropriate size and cooked in a pressure cooker (Prestige TTK Ltd, Tamil Nadu, India) (Table I). Later the cooked rice was transferred to a hot case and was taken up for sensory analysis.

Sensory evaluation by trained panelists—The sensory evaluation of the cooked rice samples were carried out by descriptive analysis methods consisting of formal procedures for assessing the specific attributes of a sample and rating their intensity on a suitable scale. The attributes included aroma, flavour, appearance and texture, separately or in combination. Sensory analysis, was carried out by trained panelists in the following phases: (1) selection of evaluation method suitable for descriptive analysis; (2) panel training – the panelists were trained on quantitative sensory evaluation of cooked rice; (3) Lexicon development – this was done by taking into account the various quality characteristics of cooked rice; (4) sensory evaluation under standard conditions and (5) data analysis – mean scores were calculated.

For the sensory analysis, four samples each of BPT raw, BPT parboiled and parboiled Uma red rice was evaluated in different sessions. Samples were evaluated in booth room maintained at a temperature of 22 ± 2° C under fluorescent lighting equivalent to daylight. The descriptors with definition (Lexicon) used for profiling of cooked rice is given in Table II. The panelists were asked to mark the intensity of attributes on a quantitative descriptive analysis scale (Tomlins et al. 2005), which consisted of 15 cm line scale wherein, 1.25 cm was anchored as low and 13.75 cm as high. The samples were blinded and served one by one in a random order and the panelists were asked to indicate the perceived intensity of each descriptor. Sensory evaluation was completed within 30 min of sample preparation.

Statistical analysis

The effect of the degree of polishing of both the rice varieties and their forms – BPT rice variety (raw and parboiled forms) and Uma red rice variety (parboiled form) on the macro-nutrient, dietary fibre content, γ-oryzanol, polyphenol content, TAA, FRSA and the sensory profile were assessed by the median score test for trend. First BPT variety raw white rice (8.0% polish) was compared to BPT parboiled white rice (8.0% polish) for the nutrient composition. We assessed whether any trend observed across the degree of polishing varied by rice variety and forms using a one-degree-of-freedom likelihood ratio test comparing the trends in each group compared. If either of these was significant, the *p*-value for the test for trend was given separately for each group. Otherwise, the best summary of the data assumes a common trend across the degree of polishing in both the raw and parboiled forms by rice varieties, and a single *p*-value is given overall. Robust regression methods were used to eliminate the need for the residuals to be normally distributed (Huber 1967). To quantify the magnitude of the association between each attribute and the degree of polishing, the percent change between 0 and 8.0% polishing is given for each attribute (if the data for 8.0% polishing is not available, the percent change between 0 and 4.4% polishing is given) for each rice variety. Second, the effect of the degree of polishing for Uma red rice was assessed separately. Finally, the overall difference between each attribute evaluated was compared to BPT parboiled rice.

Results

Effect of polishing on nutrient content by degree of polishing in BPT (both raw and parboiled forms) and Uma red (parboiled) rice varieties

The nutrient composition and dietary fibre contents in relation to the degree of polishing of the raw and parboiled rice of BPT variety and Uma red parboiled rice is presented in Tables III and IV, respectively. The overall nutrient compositions of the brown rice from BPT raw, BPT parboiled and Uma parboiled red rice were comparable and likewise the gross composition of the rice milled to different DOP was also comparable. Polishing significantly reduced the nutrient content of all quantities considered, including fat, dietary fibre, ash, γ-oryzanol, polyphenols, Vitamin E, TAA and FRSA, by between 30 and 90%, for all the rice samples considered, except for protein content which was significantly reduced by 20% through polishing and available carbohydrate, which increased significantly by 10%.

Overall, compared to BPT parboiled rice, the only differences observed were a significant 22% lesser bound polyphenols, 55% higher TAA and 26% lower FRSA in BPT raw rice and 42% greater bound polyphenols, and 67% lower TAA in Uma red parboiled rice (Table VII).

Effect of polishing on the sensory profile by degree of polishing in BPT (raw and parboiled) and Uma red rice varieties

Polishing significantly improved the grain intactness and fluffiness of BPT raw, parboiled, and Uma red rice varieties by 15–60% (Tables V and VI). Whiteness of the cooked rice samples increased significantly by 40–50% with increased polishing in the BPT raw and parboiled rice whereas, the redness decreased significantly by 70% in the Uma red rice. Polishing significantly improved the aroma of the BPT parboiled rice ($p < 0.0001$), and Uma red rice by 45–95% ($p < 0.001$), but had no effect on the BPT raw rice. Firmness increased significantly by 5–15% in the BPT parboiled and raw rice, respectively, but no effect was observed in the Uma red rice. Stickiness increased significantly by 45–60% in the BPT raw rice ($p < 0.0001$) and Uma red parboiled rice ($p < 0.0002$) but there was no effect in the BPT parboiled rice.

Branny taste decreased significantly by 40–70% with increased polishing for both the rice varieties ($p < 0.0001$). Chewiness decreased significantly by around 30% in the BPT raw ($p < 0.008$) and Uma red rice ($p < 0.0001$), but there was no effect in the BPT parboiled rice. Sweetness decreased significantly by 25% in the BPT parboiled ($p < 0.0006$) and Uma red parboiled rice ($p < 0.02$), but there was no effect of polishing found in the BPT raw rice.

It is noteworthy that decreased polishing did not detract from the overall quality (OQ) score for any of the rice varieties considered, and it therefore may be concluded that even unpolished rice is acceptable.

Comparison of the nutritional content and sensory profile of the rice samples

Overall, across the four levels of polish considered, BPT raw rice had about 20% significantly less bound polyphenols compared with BPT parboiled rice, while Uma parboiled red rice had about 40% significantly ($p < 0.03$) more bound polyphenols compared with BPT parboiled rice (Table VII). BPT raw rice had about 55% significantly more TAAs ($p < 0.05$) compared with BPT parboiled rice, while Uma red rice has about 70% significantly less TAAs ($p < 0.001$) compared with BPT parboiled rice. BPT raw rice ($p < 0.003$) and Uma red rice ($p < 0.001$) have about 25–40% significantly less FRSAs compared with BPT parboiled rice. Otherwise, in relation to protein, fat, available carbohydrate, dietary fibre, ash, γ-oryzanol, polyphenols other than bound, and tocopherols, there were no statistically significant differences observed between BPT raw rice or Uma red rice, relative to BPT parboiled rice.

Similarly, few overall statistically significant differences were observed between the sensory profiles of the rice samples (Table VII). The BPT raw rice was about 30% significantly more stickiness ($p < 0.001$) compared to BPT parboiled rice. The Uma red parboiled rice was about 15–35% significantly less chewiness, white and branny compared with the BPT parboiled rice, and 15–20% fluffier and improved aroma of the cooked rice. No difference in the overall sensory quality of the two rice varieties considered was observed.

Discussion

The study indicated that protein, fat, ash and dietary fibre contents decreases proportionately with higher DOP of rice with a concomitant increase in the available carbohydrate content. The study also highlights the significant reduction in phytochemicals with polishing of rice and this was seen across for both the BPT and Uma red rice varieties. Sensory evaluation by trained panelists revealed that with the given health benefits of whole grains such as brown rice, the sensory attributes of brown rice is as acceptable as other samples of rice with higher DOP.

Parboiling is commonly practiced in South India, for the processing of paddy. Parboiling hardens the endosperm and helps it to withstand the abrasion during milling or polishing and hence increases the head rice yield. Moreover, it helps in the retention of surface nutrients (Achaya 2009). In addition, the type and severity of parboiling can also induce retro-gradation and increases the resistant starch content (Lamberts et al. 2009) and possibly reduces the carbohydrate digestibility (Casiraghi et al. 1993; Larsen et al. 2000). A recent study among adults in south Indian city of Chennai had shown that parboiled rice is the most preferred rice (Radhika et al. 2010) and hence parboiled rice was considered in this study.

The nutrient composition of the samples indicates that polishing of the brown rice lowers its over all nutrient content substantially, especially in the fully polished rice (8.0% DOP). However, the extent of loss of nutrients was lower in rice milled to 2.3% DOP in both the rice varieties. Rice bran layers consist of non-starchy polysaccharides (cellulose and lignin), fat and dietary fibre. The aleurone layer and germ contains protein, fat and good amount of vitamins and minerals (Juliano 1985). Hence, the decrease in the protein, fat, ash and dietary fibre contents on polishing is more obvious as polishing removes the bran including aleurone and germ portions of rice kernel. This clearly indicates that, by judicious milling, most of the health beneficial nutrients of the rice kernels can be retained without affecting its cooking and sensory qualities.

The increase in the available carbohydrates proportionate to the degree of polishing may be due to the removal of bran, aleurone and germ portions leaving behind the starchy endosperm. The decrease in ash content with increased degree of polishing observed in the current study corroborates with the study results of Singh et al. (2000). Rice has good quality protein compared to other cereals (Juliano 1993) and is rich in branched chain amino acids such as leucine, isoleucine and valine. Moreover, rice fat is rich in essential *n*-6 fatty acids. In the rural Indian population, two-thirds of the *n*-6 fatty acid requirement is met by cereal– pulse-based diets (Gopalan et al. 2010). Recently, the dietary intake of the Indian population in rural areas have shown the protein inadequacy in several households (NNMB 2006) and the consumption of highly polished rice as staple without adequate amount of legumes may further worsen this condition.

Brown rice contains the number of micronutrients and phytochemicals such as polyphenols, γ-oryzanol, phytosterols, tocotrienols, tocopherols and carotenoids (Heinemann et al. 2008; Dinesh babu et al. 2009). Brown rice is richer in phenols than white rice (Hodzic et al. 2009). The Phenolic compounds are also known as antioxidants and are likely to have functional effects against oxidative damage and associated with reduced risk of chronic diseases such as diabetes and cardiovascular diseases (Adom and Liu 2002; Liu 2007). De-husked rice, especially red and black rice, which have pigmented bran are known to contain good proportions of polyphenols and possess higher antioxidant activity (Itani et al. 2002a) and in this study the Uma red rice showed higher polyphenol contents compared with white-coloured BPT variety. Moreover, the decrease in the total polyphenol content on polishing is not surprising as polishing removes the bran layers which are known to be a reserve of polyphenols in cereals (Naczk and Shahidi 2006). However, the polyphenol content of the 8.0% polished rice may be mainly contributed by the phenolic compounds present in the endosperm cell walls. Lower polyphenol contents for white-coloured rice varieties compared to those of coloured rice varieties have also been reported elsewhere (Finocchiaro et al. 2007). The BPT raw brown rice exhibited the highest TAA activity, whereas the BPT parboiled brown rice exhibited the highest FRSA amongst all the rice samples.

The γ-oryzanol is a mixture of ferulic acid esters of triterpene alcohols and sterols found mainly in rice (Xu and Godber 1999). It is reported to have number of health beneficial effects such as hypocholesterolemic, anti-atherosclerotic and antioxidant activity, and so on (Scavariello and Arellano 1998). Miller and Engel (2006) reported the γ-oryzanol contents for brown rice of European origin range between 26.2 and 62.7 mg/100 g sample and the present study showed similar results. The data also indicate that polishing to even 2.3% DOP drastically reduced the content, which suggests that the distribution of γ-oryzanol is mainly in the peripheral layers. These observations are in line with the observations made by Butsat and Siriamornpun (2010) who reported higher γ-oryzanol in bran fraction compared to the husk and endosperm.

The descriptive sensory analysis in this study indicated that chewiness decreased with increased degree of polishing. Similar observations have been reported by Park et al. (2001). This may be due to the presence of the bran constituents. Moreover, the increase in the whiteness score as well as cooked aroma, with increased degree of polishing may be due to the predominant starchy nature of the polished grains. The eating quality of rice has long been ascribed to starch. The panelists who participated in the sensory analysis of rice were food scientists, food technologists and nutritionists and they were formally trained for the sensory testing of rice samples and possibly due to this reason the overall acceptance scores of both brown rice and lower polished (less refined) rice samples were comparable as the panelists were aware of the benefits of whole grain consumption.

It is well established that refined grains (white rice) contain higher available carbohydrates and lower dietary fibre contents and their consumption leads to high glycaemic response, more insulin demand and increases the risk of type 2 diabetes (Liu 2002). In addition, reports also indicate that the substitution of whole grains including brown rice for white rice reduces the risk of type 2 diabetes (Sun et al. 2010). Our recent study has shown that, in urban south Indians, total dietary carbohydrates, glycaemic index (GI) and glycaemic load are associated with increased risk and dietary fibre with decreased risk for type 2 diabetes (Mohan et al. 2009). In general, the beneficial effect of dietary fibre from the whole grains may be mediated through less transit time and possibly less amount of carbohydrates being absorbed and thus less insulin demand (Cummings and Englyst 1987). A comparatively lower GI for brown rice compared to white rice has been reported by Panlasigui and Thompson (2006) and Atkinson et al. (2008). However, the difference in GI between brown and lower polished rice of BPT and Uma red rice varieties need to be evaluated in future studies.

It has also been documented that the insoluble fibre fraction of the pre-germinated brown rice was found to lower postprandial blood glucose concentration in *Wistar* rats (Seki et al. 2005). Qureshi et al.'s (2002) study indicated that the rice fibre concentrates decreased the hyperlipidaemia in individuals with type I and type 2 diabetes. These studies clearly indicate the health benefits of bran components of brown rice. Hence, it is highly desirable to switch over to brown rice to minimize the risk of insulin resistance, metabolic syndrome and type 2 diabetes. This may help in increasing the intake of good quality protein, dietary fibre and fat.

The study recommends sensory evaluation of the rice samples with different degrees of polishing in the community settings to further evaluate the results obtained in the current study with trained panelists. This extended work of study in the community setting has already been completed (Shubha et al. 2011).

Conclusion

In conclusion, the present study shows that brown rice is nutritionally superior to fully polished rice. The study also demonstrates that brown rice can be judiciously milled to retain most of the bran constituents and yet cooks similar to milled rice. Thus, brown rice and the rice with 2.3% DOP may be a good choice from the point of its nutritional health benefits and sensory quality parameters compared to the polished white rice (8.0% DOP), which is currently commonly consumed in India. This may serve as a potential dietary strategy to aid through appropriate culture specific nutrition education in improving the nutrition and health of people in general and in reducing the burden of metabolic disorders like diabetes in particular. Further research on GI testing of Indian rice varieties and randomized trials are needed to show the effect of brown rice consumption on risk reduction in chronic diseases such as diabetes.

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References

AACC. Approved methods of the AACC (10th ed.) moisture (method 44-19), protein (method 46-12), fat (method 30-25), ash (method 8-01). St Paul, MN, USA: American Association of Cereal Chemists; 2000.

Achaya, KT. The illustrated food of India A–Z. New Delhi, India: Oxford University Press; 2009.

Adom KK, Liu RH. 2002; Antioxidant activity of grains. J Agri Food Chem. 50:6182–6187.

Asp NG, Johansson CG, Hallmer H, Siljestrom M. 1983; Rapid enzymatic assay of insoluble and soluble dietary fibre. J Agri Food Chem. 31:476–482.

Atkinson FS, Foster-Powell K, Brand-Miller JC. 2008; International tables of glycemic index and glycemic load values: 2008. Diab Care. 31(12):2281–2283.

Bhattacharya, KR. Parboiling of rice. In: Juliano, BO, editor. Rice chemistry and technology. St Paul, MN: American Association of Cereal Chemists; 1985. 289–348.

Bondet V, Brand-Williams W, Berset C. 1997; Kinetics and mechanisms of antioxidant activity using the DPPHz free radical method. Lebensm-Wiss u-Technol. 30:609–615.

Butsat S, Siriamornpun S. 2010; Antioxidant capacities and phenolic compounds of the husk, bran and endosperm of Thai rice. Food Chem. 119(2):606–613.

Casiraghi MC, Brighenti F, Pellegrini N, Leopardi E, Testolin G. 1993; Effect of processing on rice starch digestibility evaluated by *in vivo* and *in vitro* methods. J Cereal Sci. 17:147–156.

Chen MH, Bergman CJ. 2005; A rapid procedure for analysing rice bran tocopherol, tocotrienol and γ-oryzanol contents. J Food Comp Anal. 18:139–151.

Cummings JH, Englyst HN. 1987; Fermentation in the human large intestine and the available substrates. Am J Clin Nutr. 45:1243–1255. [PubMed: 3034048]

Dinesh Babu P, Subhasree RS, Bhakyaraj R, Vidhyalakshmi R. 2009; Brown rice- beyond the color reviving a lost health food – A review. Am-Eur J Agro. 2:67–72.

Fung TT, Hu FB, Pereira MA, Liu S, Stampfer MJ, Colditz GA, Willett WC. 2002; Whole grain intake and the risk of type 2 diabetes: A prospective study in men. Am J Clin Nutr. 76(3):535–540. [PubMed: 12197996]

Finocchiaro F, Ferrari B, Gianinetti A, Asta CD, Galaverna G, Scazzina F, Pellegrini N. 2007; Characterization of antioxidant compounds of red and white rice and changes in total antioxidant capacity during processing. Mol Nutr Food Res. 51:1006–1019. [PubMed: 17639995]

Goni I, Garci-Diz L, Manas E, Saura-Calixto E. 1996; Analysis of resistant starch: A method for foods and food products. Food Chem. 56(4):445–449.

Gopalan, C, Rama Sastri, BV, Balasubramanian, SC. Nutritive value of Indian foods. Hyderabad, India: National Institute of Nutrition, Indian Council of Medical Research; 2010.

Heinemann RJB, Xu Z, Godber JS, Lanfer-Marquez UM. 2008; Tocopherols, tocotrienols, and γ-oryzanol contents in Japonica and Indica subspecies of rice (*Oryza sativa* L.) cultivated in Brazil. Cereal Chem. 85(2):243–247.

Hodzic Z, Pasalic H, Memisevic A, Srabovic M, Saletovic M, Poljakovic M. 2009; The Influence of total phenols content on antioxidant capacity in the whole grain extracts. Eur J Sci Res. 28:471–477.

Huber, P. The behavior of maximum likelihood estimates under nonstandard conditions Fifth Berkeley symposium on mathematical statistics and probability. Berkely, CA: University of California Press; 1967.

Itani T, Tamaki M, Arai E, Horino T. 2002; Distribution of amylose, nitrogen, and minerals in rice kernels with various characters. J Agri Food Chem. 50(19):5326–5332.

Itani T, Hideki T, Mitsuyoshi O, Kazunori F, Norio M. 2002a; A comparative study on antioxidative activity and polyphenol content of colored kernel rice. J Soc Food Sci Technol. 49(8):540–543.

Juliano, BO. Rice: chemistry and technology. 2. St Paul, MN: American Association of Cereal Chemists; 1985.

Juliano, BO. Rice in human nutrition. Rome: Food and Agriculture Organization; 1993.

Larsen HN, Rasmussen OW, Rasmussen PH, Alstrup KK, Biswas SK, Tetens I, Thilsted SH, Hermansen K. 2000; Glycemic index of parboiled rice depends on the severity of processing: Study in type 2 diabetic subjects. Eur J Clin Nutr. 54:380–385. [PubMed: 10822284]

Lamberts L, Gomand SV, Derycke V, Delcour JA. 2009; Presence of amylose crystallites in parboiled rice. J Agri Food Chem. 57:3210–3216.

Liu S. 2002; Intake of refined carbohydrates and whole grain foods in relation to risk of type 2 diabetes mellitus and coronary heart disease. J Am Coll Nutr. 21(4):298–306. [PubMed: 12166526]

Liu RH. 2007; Whole grain phytochemicals and health. J Cereal Sci. 46:207–219.

Montonen J, Knekt P, Jarvinen R, Aromaa A, Reunanen A. 2003; Whole grain and fibre intake and the incidence of type 2 diabetes. Am J Clin Nutr. 77:622–629. [PubMed: 12600852]

Mohan V, Radhika G, Sathya RM, Tamil SR, Ganesan A, Sudha V. 2009; Dietary carbohydrates, glycaemic load, food groups and newly detected type 2 diabetes among urban Asian Indian population in Chennai, India (Chennai Urban Rural Epidemiology Study 59). Br J Nutr. 9:1–9.

Miller A, Engel KH. 2006; Content of γ-oryzanol and composition of steryl ferulates in brown rice (*Oryza sativa* L.) of European origin. J Agri Food Chem. 54:8127–8133.

National Nutrition Monitoring Bureau (NNMB). Technical report: Diet and nutritional status of population and prevalence of hypertension among adults in rural areas. Hyderabad, India: National Nutrition Monitoring Bureau, National Institute of Nutrition; 2006.

Naczk M, Shahidi F. 2006; Phenolics in cereals, fruits and vegetables: Occurrence, extraction and analysis. J PharmBiomed Anal. 41:1523–1542.

Panlasigui LN, Thompson LU. 2006; Blood glucose lowering effects of brown rice in normal and diabetic subjects. Int J Food Sci Nutr. 57(3/4):151–158. [PubMed: 17127465]

Park JK, Kim AA, Kim KO. 2001; Effect of milling ratio on sensory properties of cooked rice and on physicochemical properties of milled and cooked rice. Cereal Chem. 78(2):151–156.

Pereira MA, Jacobs DR, Pins JJ, Raatz SK, Gross MD, Slavin JL, Seaquist ER. 2002; Effect of whole grains on insulin sensitivity in overweight hyperinsulinemic adults. Am J Clin Nutr. 75:848–855. [PubMed: 11976158]

Pilar P, Manvel P, Mignel AI. 1999; Spectrophotometric quantitation of antioxidant capacity through the formation of a phosphomolybdenum complex. Anal Biochem. 269:337–341. [PubMed: 10222007]

Prema R. 2006The double burden of malnutrition – Case studies from developing countries-India, FAO Food Nutrition Paper 84, Food and Agricultural Organization of the United Nations Rome.

Qureshi AA, Sami SA, Khan FA. 2002; Effects of stabilized bran, its soluble and fibre fractions on blood glucose levels and serum lipid parameters in humans with diabetes mellitus types I and II. J Nutr Biochem. 13:175–187. [PubMed: 11893482]

Radhika G, Van Dam RM, Sudha V, Ganesan A, Mohan V. 2009; Refined grain consumption and the metabolic syndrome in urban Asian Indians (Chennai Urban Rural Epidemiology Study 57). Metabolism. 58:675–681. [PubMed: 19375591]

Radhika G, Sathya RM, Ganesan A, Saroja R, Vijayalakshmi P, Sudha V, Mohan V. 2010; Dietary profile of urban adult population in South India in the context of chronic disease epidemiology [Cures – 68]. Public Health Nutrition. 12:1–8.

Scavariello EM, Arellano DB. 1998; Gamma oryzanol: An important component in rice bran oil. Arch Latinoam Nutr. 48(1):7–12. [PubMed: 9754398]

Seetharamaiah GS, Prabhakar JV. 1986; Oryzanol content of Indian rice bran oil and its extraction from soap stock. J Food Sci Technol. 23(5):270–273.

Seki T, Nagase R, Torimitsu M, Yanagi M, Ito Y, Kise M, et al. 2005; Insoluble fibre is a major constituent responsible for lowering the postprandial blood glucose concentration in the pre-germinated brown rice. Biol Pharm Bull. 28:1539–1541. [PubMed: 16079511]

Shubha K, Rani M, Sudha V, Wedick NM, Hu FB, Spiegelman D, Mohan V. 2011Perceptions about brown and lower polished rice: A quantitative study from southern India. J Am Dietetic Assoc.

Singleton VL, Rossi JA. 1965; Colorimetry of total phenolics with phosphomolybdic phosphotungstic agents. Am J Enol Vitic. 16:144–158.

Singh N, Singh H, Kaur K, Bakshi MS. 2000; Relationship between the degree of milling, ash distribution pattern and conductivity in brown rice. Food Chem. 69:147–151.

Sun Q, Spiegelman D, Van Dam RM, Holmes MD, Malik VS, Willett WC, Hu FB. 2010; White rice, brown rice and risk of type 2 diabetes in US men and women. Arch Int Med. 170(11):961–969. [PubMed: 20548009]

Tomlins KI, Manful JT, Larwer P, Hammond L. 2005; Urban consumer preferences and sensory evaluation of locally produced and incorporated rice in west Africa. Food Qual Prefer. 16:79–89.

USDA. US Department of Agriculture Science and Education Administration Agricultural Reviews and Manuals 9 ARM-W-12. Apr.1980

Xu Z, Godber JS. 1999; Purification and identification of components of γ-oryzanol in rice bran oil. J Agri Food Chem. 47:2724–2728.

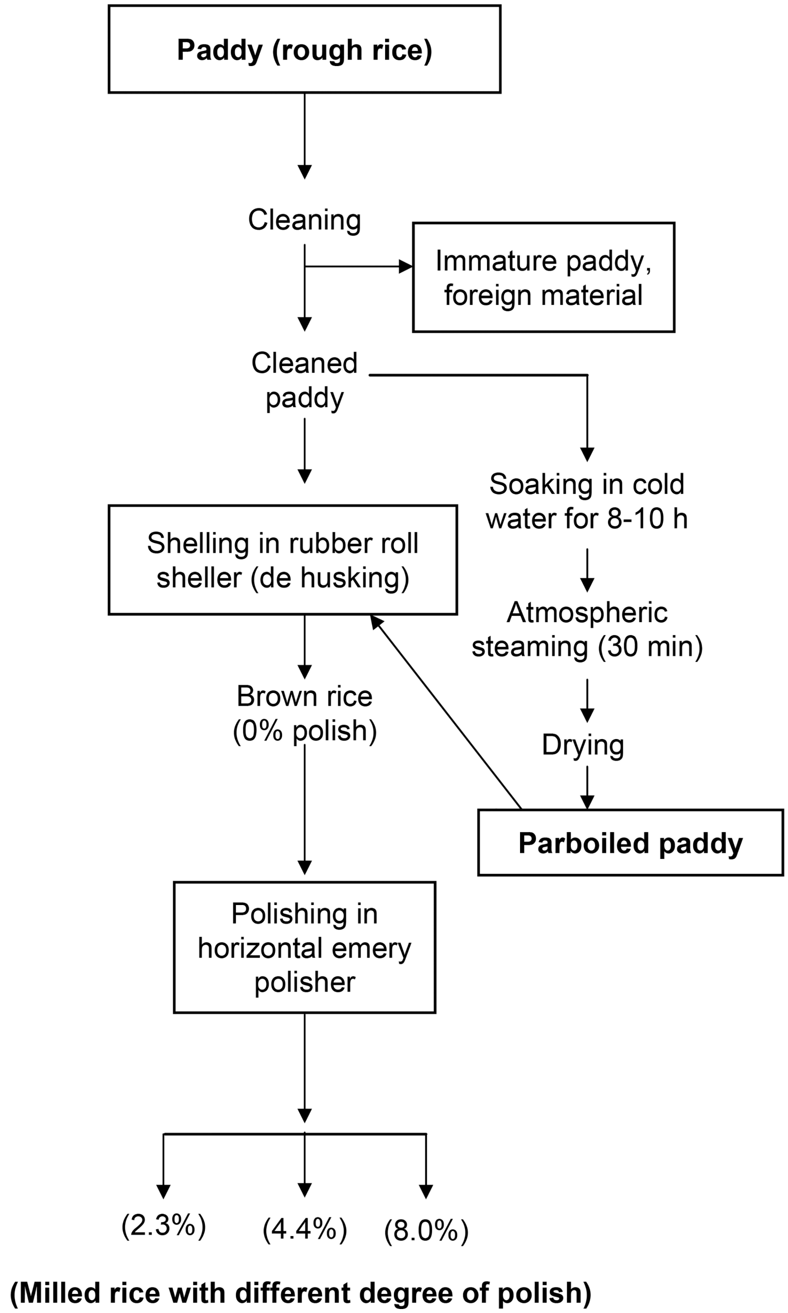

Figure 1.
Flow chart for rice milling.

Table I

Cooking characteristics.

Description of rice	DOP (%)	Uncooked rice mean weight[a] (g)	Cooked rice mean weight[a] (g)
BPT raw rice	0	100	316
	2.3	100	332
	4.4	100	330
	8.0	100	373
BPT parboiled rice	0	100	214
	2.3	100	243
	4.4	100	224
	8.0	100	327
Uma red parboiled rice	0	100	335
	2.3	100	353
	4.4	100	370
	8.0	100	397

[a]Mean of 6 days of cooking all the samples.

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Table II

Lexicon of sensory quality of cooked rice.

Term	Definition
Whiteness	The degree to which the sample is visually pure white
Grain intactness	The degree to which the grains retain the shape and form and the absence of cracked grain indicates high intactness
Fluffiness	Textural property manifested by an expanded and often distorted cellular structure. During cooking of rice, there is expansion in volume. This volume is explained in sensory terms as fluffiness. For example: Fluffiness is seen with smooth surface in case of parboiled rice and slightly less smooth surface in raw rice
Firmness	The force required to compress the cooked grains with molars
Stickiness	The degree to which the sample adheres to the palate
Chewiness	Textural property manifested by the readiness to break down to very small particles. Chewiness is relevant with brown (0% polished) raw and parboiled rice due to the presence of branny layer, needing more chews to masticate the cooked rice before swallowing
Aroma of cooked rice	A general term used to describe the aroma of cooked rice
Starch like	Aroma associated with cooked rice starch
Sweet	Basic taste associated with sucrose solution

Table III

Nutrients, dietary fibre, γ-oryzanol, polyphenol contents, vitamin E, TAA, and FRSA of raw and parboiled BPT rice milled to different DOP (g/100 g).

Parameter	BPT raw					BPT parboiled					
DOP	0%	2.3%	4.4%	8.0%	% Change[a] (P_{trend})	0%	2.3%	4.4%	8.0%	% Change[a] (P_{trend})	Overall P_{trend}
Moisture (%)	12.0 ± 0.2	12.0 ± 0.3	11.5 ± 0.3	11.4 ± 0.2	−5.0 (<.0001)	11.6 ± 0.4	11.0 ± 0.3	11.5 ± 0.3	11.5 ± 0.4	−0.9 (0.80)	
Protein (g%)[b]	7.8 ± 0.2	7.3 ± 0.2	7.0 ± 0.1	6.3 ± 0.3	−19	7.8 ± 0.2	7.3 ± 0.3	7.0 ± 0.3	6.4 ± 0.2	−18	<0.0001
Fat (g%)[b]	2.4 ± 0.1	2.2 ± 0.05	1.7 ± 0.1	0.7 ± 0.05	−71	2.6 ± 0.1	2.0 ± 0.2	1.6 ± 0.1	0.8 ± 0.05	−69	<0.0001
Available carbohydrate[c] (g%)[b]	71.3 ± 1.0	74.0 ± 0.9	77.1 ± 0.8	80.1 ± 0.7	+12	72.0 ± 0.7	74.3 ± 0.8	76.6 ± 0.9	79.0 ± 1.0	+9.7	<0.0001
Dietary fibre (g%)[b]	5.3 ± 0.3	3.7 ± 0.5	1.6 ± 0.4	1.0 ± 0.1	−81	5.0 ± 0.1	3.9 ± 0.2	2.5 ± 0.2	1.8 ± 0.2	−64	<0.0001
Ash (g%)[b]	1.1 ± 0.03	0.8 ± 0.06	0.7 ± 0.05	0.5 ± 0.03	−55	1.0 ± 0.09	0.9 ± 0.08	0.7 ± 0.1	0.5 ± 0.03	−50	<0.0001
γ-Oryzanol (mg/100 g)[b]	21.6 ± 1.9	12.4 ± 1.0	9.4 ± 1.8	3.6 ± 0.8	−83	24.6 ± 2.2	12.5 ± 1.0	10.5 ± 0.6	2.2 ± 0.3	−91	<0.0001
Soluble polyphenols (mg/100 g)[b]	34.9 ± 2.1	20.7 ± 1.7	10.6 ± 1.1	4.4 ± 0.7	−87	23.4 ± 1.8	16.3 ± 1.4	12.1 ± 0.9	4.3 ± 0.4	−82	<0.0001
Bound polyphenols (mg/100 g)[b]	35.2 ± 0.3	22.7 ± 0.6	19.4 ± 0.5	13.8 ± 0.6	−61	40.3 ± 1.5	27.6 ± 2.4	25.4 ± 2.4	21.0 ± 1.3	−48	<0.0001
Total polyphenols (mg/100 g)[b]	70.1 ± 2.3	43.4 ± 2.1	30.0 ± 0.9	18.2 ± 1.1	−74	63.7 ± 0.8	43.9 ± 1.3	37.5 ± 3.4	25.3 ± 1.7	−60	<0.0001
Vitamin E tocotrienols (mg/100 g)[b]	1.4 ± 0.08	1.3 ± 0.09	1.0 ± 0.04	0.4 ± 0.08	−69	1.4 ± 0.05	0.8 ± 0.03	0.4 ± 0.2		−74	<0.0001
Tocopherols[b]	0.6 ± 0.06	0.5 ± 0.02	0.2 ± 0.02	0.07 ± 0.05	−89	0.8 ± 0.03	0.2 ± 0.01	0.08 ± 0.01		−90	<0.0001
Total vitamin E (mg/100 g)[b]	2.0 ± 0.01	1.8 ± 0.08	1.3 ± 0.05	0.5 ± 0.01	−76	2.2 ± 0.01	1.0 ± 0.01	0.5 ± 0.03		−78	<0.0001
TAA[b,d]	10.8 ± 0.3	4.8 ± 0.2	4.4 ± 0.1	4.1 ± 0.2	−62	8.5 ± 0.3	4.7 ± 0.09	2.7 ± 0.2	1.5 ± 0.3	−83	<0.0001
FRSA[b,e]	27.0 ± 1.0	20.0 ± 0.6	16.0 ± 0.6	14.0 ± 0.6	−48	31.0 ± 0.6	27.0 ± 0.6	23.0 ± 0.6	21.0 ± 0.6	−32	<0.0001

[a] % Increase or decrease from 0 to 8–10% DOP or 4–5% DOP (if there is no available data for 8–10% DOP);

[b] The trend test for the DOP is not statistically significant between BPT raw rice and BPT parboiled rice;

[c] Measured directly, is the sum of starch and total free sugars (g available/100 g rice);

[d] TAA expressed as α-tocopherol equivalents/g;

[e] FRSA expressed as%of free radical scavenged (catechin equivalents).

Table IV

Nutrient, dietary fibre, γ-oryzanol, polyphenol contents, TAA and FRSA of Uma rice milled to different DOP (g/100 g).

Parameter	Uma parboiled				
DOP	0%	2.3%	4.4%	8.0%	% Change[a] (P_{trend})
Moisture (%)	11.7 ± 0.2	11.2 ± 0.5	11.3 ± 0.4	11.5 ± 0.2	−1.7 (0.65)
Protein (g%)	7.6 ± 0.3	7.2 ± 0.1	6.9 ± 0.3	6.4 ± 0.3	−16 (<0.0001)
Fat (g%)	2.3 ± 0.1	2.0 ± 0.1	1.6 ± 0.2	1.2 ± 0.1	−48 (<0.0001)
Available carbohydrate[b] (g%)	72.2 ± 0.9	75.1 ± 0.7	76.1 ± 0.6	78.0 ± 0.6	+8.0 (<0.0001)
Dietary fibre (g%)	4.5 ± 0.3	3.6 ± 0.2	2.8 ± 0.2	1.9 ± 0.2	−58 (<0.0001)
Ash (g%)	1.0 ± 0.05	0.9 ± 0.03	0.7 ± 0.06	0.6 ± 0.03	−40 (<0.0001)
γ-Oryzanol (mg/100 g)	29.0 ± 2.6	12.7 ± 1.7	8.3 ± 0.6	5.5 ± 0.7	−81 (<0.0001)
Soluble polyphenols (mg/100 g)	23.1 ± 1.4	13.9 ± 1.6	7.6 ± 0.5	5.2 ± 0.5	−77 (<0.0001)
Bound polyphenols (mg/100 g)	84.7 ± 5.2	43.6 ± 1.6	28.6 ± 0.2	22.7 ± 2.2	−73 (<0.0001)
Total polyphenols (mg/100 g)	107.8 ± 5.5	57.5 ± 1.0	36.2 ± 0.4	27.9 ± 1.6	−74 (<0.0001)
Vitamin E tocotrienols (mg/100 g)	2.1 ± 0.2	0.7 ± 0.09	0.3 ± 0.01		−85 (<0.0001)
Tocopherols	0.4 ± 0.03	0.1 ± 0.02	0.07 ± 0.02		−84 (<0.0001)
Total vitamin E (mg/100 g)	2.6 ± 0.2	0.8 ± 0.01	0.4 ± 0.03		−85 (<0.0001)
TAA[c]	2.9 ± 0.1	1.7 ± 0.1	1.0 ± 0.2	0.4 ± 0.03	−87 (<0.0001)
FRSA[d]	24.0 ± 1.7	17.0 ± 1.0	12.0 ± 0.6	10.0 ± 0.6	−58 (<0.0001)

[a]%Increase or decrease from 0 to 8–10% DOPor 4–5% DOP (if there is no available data for 8–10% DOP);

[b]Measured directly, is the sum of starch and total free sugars (g available/100 g rice);

[c]TAA expressed as α-tocopherol equivalents/g;

[d]FRSA expressed as % of free radical scavenged (catechin equivalents).

Table V

Sensory profile of raw BPT and parboiled BPT rice milled to different DOP.

Sensory attributes	BPT raw (DOP)					BPT parboiled (DOP)					Overall
DOP	**0%**	**2.3%**	**4.4%**	**8.0%**	**% Change[a] (P_{trend})**	**0%**	**2.3%**	**4.4%**	**8.0%**	**% Change[a] (P_{trend})**	**P_{trend}**
Whiteness[b]	6.8 ± 1.7	8.0 ± 1.2	9.1 ± 1.2	9.5 ± 0.7	+40	6.4 ± 1.2	7.7 ± 1.5	8.8 ± 1.4	9.4 ± 1.0	+47	<0.0001
Grain intactness[b]	7.0 ± 0.5	7.9 ± 2.0	8.6 ± 1.2	8.2 ± 1.1	+17	7.2 ± 0.4	8.1 ± 0.8	8.7 ± 1.4	9.1 ± 1.7	+26	0.0007
Fluffiness[b]	5.7 ± 0.6	7.1 ± 1.5	8.1 ± 0.9	8.8 ± 1.4	+54	5.9 ± 0.6	7.4 ± 0.9	8.2 ± 0.8	9.1 ± 1.9	+54	<0.0001
Firmness[b]	6.5 ± 0.3	7.3 ± 0.9	7.8 ± 2.3	7.4 ± 1.0	+14	7.6 ± 0.5	7.5 ± 1.0	7.7 ± 1.1	8.0 ± 0.6	+5.3	0.02
Stickiness	5.0 ± 0.9	5.1 ± 0.6	6.2 ± 0.7	7.3 ± 1.2	+46 (0.0001)	4.3 ± 0.7	4.7 ± 0.9	4.3 ± 0.5	4.2 ± 0.3	−2.3 (0.33)	
Chewiness	5.5 ± 1.8	4.6 ± 1.6	3.7 ± 0.3	3.8 ± 0.6	−31 (0.008)	5.8 ± 1.3	4.6 ± 0.9	5.1 ± 1.8	5.0 ± 0.8	−14 (0.35)	
Aroma of cooked rice	7.4 ± 0.8	8.9 ± 0.7	8.1 ± 1.9	8.5 ± 2.3	+15 (0.41)	4.6 ± 1.1	8.1 ± 1.4	8.1 ± 1.3	8.9 ± 1.8	+94 (<0.0001)	
Starch like	4.1 ± 1.0	5.2 ± 0.6	5.1 ± 0.6	4.9 ± 0.6	+20 (0.17)	4.1 ± 0.2	4.7 ± 0.8	5.4 ± 0.5	5.6 ± 1.4	+37 (0.005)	
Branny[b]	7.5 ± 1.9	5.2 ± 0.9	3.8 ± 0.5	3.6 ± 0.3	−52	7.4 ± 1.6	5.3 ± 0.5	4.8 ± 0.7	4.6 ± 0.4	−38	<0.0001
Sweet	5.3 ± 0.8	5.9 ± 2.4	5.3 ± 1.4	5.6 ± 0.9	+5.7 (0.77)	5.7 ± 0.6	5.3 ± 0.6	4.4 ± 0.8	4.4 ± 0.9	−23 (0.0006)	
OQ[b]	8.8 ± 1.1	9.4 ± 0.7	8.9 ± 1.0	9.2 ± 0.9	+4.5	9.0 ± 1.3	10.1 ± 0.4	9.4 ± 1.1	9.6 ± 2.0	+6.7	0.62

[a]% Increase or decrease from 0 to 8–10% DOP;

[b]The trend test for the DOP is not statistically significant between BPT raw rice and BPT parboiled rice.

Table VI

Sensory profile of parboiled Uma rice milled to different DOP.

Sensory attributes	Uma parboiled (DOP)				
DOP	0%	2.3%	4.4%	8.0%	% Change[a] (P_{trend})
Redness	10.0 ± 0.8	6.0 ± 1.4	4.1 ± 0.6	2.9 ± 0.4	−71 (<0.0001)
Grain intactness	6.3 ± 1.9	8.4 ± 0.9	9.4 ± 1.6	9.9 ± 1.1	+57 (<0.0001)
Fluffiness	6.9 ± 0.7	8.8 ± 1.3	9.5 ± 1.2	9.9 ± 1.1	+44 (<0.0001)
Firmness	7.5 ± 1.8	8.1 ± 0.9	8.8 ± 2.0	8.6 ± 2.4	+15 (0.25)
Stickiness	3.3 ± 1.4	2.9 ± 1.4	5.0 ± 2.0	5.2 ± 1.2	+58 (0.0002)
Chewiness	5.3 ± 1.1	4.4 ± 1.1	4.1 ± 1.6	3.6 ± 0.4	−32 (0.0001)
Aroma of cooked rice	6.6 ± 1.7	9.0 ± 2.3	9.9 ± 1.7	9.6 ± 1.5	+46 (0.001)
Starch like	5.1 ± 2.3	5.2 ± 2.2	5.4 ± 2.0	5.2 ± 2.2	+2.0 (0.94)
Branny	8.5 ± 1.9	4.0 ± 2.0	2.8 ± 0.6	2.7 ± 0.7	−68 (<0.0001)
Sweet	4.4 ± 1.4	5.8 ± 2.0	4.5 ± 1.5	3.3 ± 1.0	−25 (0.02)
OQ	8.8 ± 1.5	8.9 ± 2.4	9.7 ± 1.1	9.9 ± 1.9	+13 (0.13)

[a] % Increase or decrease from 0 to 8–10% DOP.

Table VII

Overall difference in nutritional and sensory profiles between rice groups.

	BPT parboiled	BPT raw			Uma parboiled		
Parameter	Mean ± SD	Mean ± SD	% Difference from BPT parboiled rice (95% CI)[a]	p-value[a]	Mean ± SD	% Difference from BPT parboiled rice (95% CI)[a]	p-value[a]
Nutrient and dietary fibre contents							
Moisture (%)	11.4 ± 0.4	11.7 ± 0.4	2.9% (0.3%, 5.5%)	0.03	11.4 ± 0.4	0.2% (−2.3%, 2.8%)	0.86
Protein (g%)	7.1 ± 0.6	7.1 ± 0.6	−0.4% (−6.5%, 6.2%)	0.91	7.0 ± 0.5	−1.4% (−7.0%, 4.7%)	0.65
Fat (g%)	1.8 ± 0.7	1.8 ± 0.7	−1.4% (−32%, 43%)	0.94	1.8 ± 0.5	7.3% (−20%, 43%)	0.63
Available carbohydrate[15](g%)	75.5 ± 2.8	75.6 ± 3.5	0.2% (−3%, 3.5%)	0.92	75.4 ± 2.3	−0.1% (−2.7%, 2.5%)	0.91
Dietary fibre (g%)	3.3 ± 1.3	2.9 ± 1.8	−23% (−51%, 20%)	0.25	3.2 ± 1.0	−0.5% (−26%, 33%)	0.98
Ash (g%)	0.8 ± 0.2	0.8 ± 0.2	−0.4% (−21%, 25%)	0.98	0.8 ± 0.2	4.9% (−14%, 28%)	0.63
Oryzanol and polyphenols contents, TAA, and FRSA							
Oryzanol (mg/100 g)	12.5 ± 8.4	11.8 ± 6.9	5.7% (−44%, 98%)	0.86	13.9 ± 9.6	24% (−33%, 129%)	0.49
Soluble polyphenols (mg/100 g)	14.0 ± 7.3	17.7 ± 12.1	14% (−36%, 102%)	0.65	12.5 ± 7.3	−11% (−45%, 45%)	0.65
Bound polyphenols (mg/100 g)	28.6 ± 7.7	22.8 ± 8.2	− 22% (−39%, −1.7%)	0.04	45.0 ± 25.4	42% (3.3%, 95%)	0.03
Total polyphenols (mg/100 g)	42.6 ± 14.6	40.4 ± 20.2	−11% (−37%, 25%)	0.50	57.4 ± 32.5	24% (−12%, 76%)	0.22
Vitamin E Tocotrienols (mg/100 g)	0.8 ± 0.4	1.0 ± 0.4	29% (−21%, 109%)	0.30	1.0 ± 0.8	−12% (−58%, 84%)	0.73
Tocopherols	0.4 ± 0.3	0.4 ± 0.2	5.1% (−53%, 133%)	0.90	0.2 ± 0.2	−36% (−71%, 44%)	0.29
Total vitamin E (mg/100 g)	1.2 ± 0.8	1.4 ± 0.6	20% (−28%, 100%)	0.49	1.3 ± 1.0	−19% (−61%, 67%)	0.56
TAA[c]	4.4 ± 2.8	6.0 ± 2.9	55% (0.6%, 140%)	0.05	1.5 ± 1.0	− 67% (−82%, −42%)	0.0001
FRSA[d]	25.5 ± 4.0	19.3 ± 5.2	− 26% (−37%, −13%)	0.0003	15.8 ± 5.7	− 41% (−52%, −27%)	< 0.001
Sensory profile							
White/red	8.1 ± 1.7	8.3 ± 1.6	3.6% (−7.3%, 16%)	0.53	5.7 ± 2.8	− 35% (−46%, −22%)	< 0.001
Grain intactness	8.3 ± 1.3	7.9 ± 1.4	−4.4% (−12%, 4.1%)	0.30	8.5 ± 2.0	0.7% (−9.8%, 12%)	0.91
Fluffiness	7.7 ± 1.7	7.4 ± 1.6	−3% (−13%, 8.5%)	0.60	8.8 ± 1.6	15% (4.1%, 27%)	0.006
Firmness	7.7 ± 0.8	7.3 ± 1.4	−6.5% (−13%, 1.0%)	0.09	8.3 ± 1.8	5.7% (−3.0%, 15%)	0.21
Stickiness	4.4 ± 0.6	5.8 ± 1.2	31% (18%, 44%)	< 0.001	4.1 ± 1.8	−15% (−29%, 1.4%)	0.07
Chewiness	5.1 ± 1.2	4.6 ± 1.5	−14% (−27%, 2.6%)	0.09	4.4 ± 1.3	− 16% (−28%, −1.2%)	0.04
Aroma of cooked rice	7.4 ± 2.2	8.2 ± 1.6	14% (−1.2%, 31%)	0.07	8.8 ± 2.2	20% (2.3%, 40%)	0.02

Parameter	BPT parboiled	BPT raw			Uma parboiled		
	Mean ± SD	Mean ± SD	% Difference from BPT parboiled rice (95% CI)[a]	*p*-value[a]	Mean ± SD	% Difference from BPT parboiled rice (95% CI)[a]	*p*-value[a]
Starch like	5.0 ± 1.0	4.8 ± 0.8	−2.2% (−12%, 8.3%)	0.67	5.2 ± 2.1	−1.1% (−16%, 17%)	0.90
Branny	5.7 ± 1.5	5.3 ± 2.0	−8.9% (−23%, 7.9%)	0.28	4.6 ± 2.8	− 29% (−43%, −11%)	0.003
Sweet	5.0 ± 0.9	5.5 ± 1.4	9.5% (−3.0%, 24%)	0.14	4.5 ± 1.7	−13% (−25%, 0.8%)	0.06
OQ	9.5 ± 1.3	9.1 ± 0.9	−4.1% (−10%, 2.3%)	0.21	9.3 ± 1.8	−3.2% (−12%, 6.0%)	0.48

[a]% Difference, *p*-value, and 95% CI were estimated from a regression model with log-transformed outcome;

[b]Measured directly, is the sum of starch and total free sugars (g available/100 g rice);

[c]TAA expressed as α-tocopherol equivalents/g.;

[d]FRSA expressed as % of free radical scavenged (catechin equivalents).