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ABSTRACT

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Rice is the leading cereal crop in Bangladesh. More than half of the world's population relies on rice as the major daily source of calories. Zn and iron are the most important elements, deficiency of which is a major cause for malnutrition. Ten advanced rice genotypes were selected to study their grain size, shape, nutritional properties and cooking qualities. Results revealed that amylose content ranged 20.75-23.93, Zn 11.32-21.18 ppm, Fe 5.52-14.64 ppm and protein 5.02-7.20% in the rice genotypes. The rice genotype TNDB showed the highest amylose (23.93 mg) and Zn (21.18 ppm) content. Fe (14.64 ppm) content was the highest in MV-20 and protein content in E-2 (7.20%). Kernel length breadth ratio ranged from 2.37 to 3.51 and 1000-grain weight of the genotypes was statistically similar.

Key words: *rice, grain, quality, zinc, iron, protein*

INTRODUCTION

Rice is the most important cereal and staple food which serve as major carbohydrate for more than half of the world population. Half of the world's population is suffering from one or more vitamin and/or mineral deficiency (World Food Program, 2015). More than three billion people are affected by micronutrient malnutrition and 3.1 million children die each year out of malnutrition (Gearing 2015) and the numbers are gradually increasing (FAO 2019; Johnson *et al*. 2011). Increase in literacy percentage and awareness of diet, people tend to be more health conscious and interested to have nutritionally enriched food. The quality of rice is an important character to determine the economic value in the export market and consumer acceptance. Protein energy malnutrition affects 25% of children where their dietary intake is mainly on rice and staple crops have low levels of essential amino acids (Gearing 2015). The amount of PC in rice is relatively low (8.5%) as compared to other cereals like wheat (12.3%), barley (12.8%) and Millet (13.4%) and an average of PC in milled rice is about 7 and 8% in brown rice. Rice supplies about 40% of the protein to human through diet in developing countries and quality of PC in rice is high, due to rich in lysine (3.8%) (Shobha Rani *et al*. 2006). Therefore, improvement of PC in rice grain is a major target for the plant breeders and biotechnologists. So far, by classical breeding effort, very limited success has been achieved because of the complex inheritance nature and the large effect of environment on protein content (Coffman and Juliano, 1987). According to Iqbal *et al*. (2006), more than 170 million children and nourishing mothers suffered from Protein-calorie malnutrition (PCM) in developing Afro-Asian countries. In comparison with meat, plant proteins are much less expensive and nutritionally imbalanced because of their deficiency in certain essential amino acids (EAAs). Iron and zinc micronutrients are the most important elements, deficiency of which is a major cause for malnutrition. More than half of the world population is suffering from bioavailable nutrient deficiencies particularly in developing countries (Seshadri 1997; Shahzad *et al*. 2014). The main reason of these deficiency occurred due to consumption of polished cereal based food crops as rice, wheat and maize (Pfeiffer and McClafferty, 2007). Modern high yielding rice varieties are poor sources of essential micronutrients like Fe and Zn (Zimmerman and Hurrel, 2002). On an average, polished rice has 2 mg kg^{-1}, while the recommended dietary intake of Fe for humans is 10–15 mg kg^{-1}. Therefore, globally more than 3 billion people were affected by Fe deficiency, particularly in developing countries (Graham *et al*. 1999; Welch and Graham, 2004). Pregnancy maternal mortality by anemia leads to 1.15 lakh deaths per year, resulting in 3.4 million disability-adjusted life-years (DALYs), has been recognized to Fe deficiency (Stoltzfus *et al*. 2004). Hence, improvement of Fe content in rice grain is necessary, which is a major challenge to the plant breeders. In plants, Zn plays a significant role in the biosyntheses and turnovers of proteins, nucleic acids, carbohydrates and lipids, with functional aspects as integral cofactor for more than 300 enzymes, coordinating ion in the DNA-binding domains of transcription factors and equally important as Fe and vitamin A (Marschner 1995). Males within the age bracket of 15–74 years require approximately 12–15 mg of Zn daily, while females within 15–74 years of age group need about 68 mg of Zn (Sandstead 1985). Generally, the content of Zn in polished rice is an average of only 12 mg kg^{-1}, whereas the recommended dietary intake of Zn for humans is 12–15 mg kg^{-1}(FAO 2001). About 17.3% of the global population is under risk of Zn deficiency and in some regions of the world, it is as high as 30% due to dietary inadequacy (Wessells and Brown, 2013). Therefore, to enhance the concentration of these micronutrients in rice grain could be possible as signified the presence of vast genetic potential of various rice germplasm by adapting appropriate genetic approaches. However, major attention to date has been paid on identification and development of genetically engineered rice grains with increased bioavailable contents of Fe and/or Zn. Recently, Indian Institute of Rice Research, Hyderabad has developed a genotype (IET 23832) that possesses high Zn (19.50 ppm). As the brown rice has higher amount of Fe and Zn, more than 70% of micronutrients are

lost during polishing (Sellappan *et al*. 2009) as they are located on the outer layer of the kernel. Martinez *et al*. (2010) found 10–11 ppm Fe and 20–25 ppm Zn in brown rice, while 2–3 ppm Fe and 16–17 ppm Zn was observed in milled rice.

Rice is the staple food and leading cereal crop in Bangladesh which is cooked and consumed as whole grain. Rice is the synonym for food in Bangladesh and had been the traditional source of carbohydrates and proteins since the prehistoric days (Shozib *et al*. 2017). Grain quality of rice is determined the factors such as grain appearance, nutritional value, cooking and eating quality (Juliano *et al*. 1990). The cooking qualities are amylose content, alkali spreading value, water uptake, volume expansion ratio and kernel elongation ratio. The gelatization temperature, gel consistency and amylase content are major traits, which are directly related to eating and cooking quality (Little *et al*. 1958). On the other hand, amylase content amylopectin structure and protein composition explained the difference in cooking quality of rice (Lisle *et al*. 2000). Coking quality is directly related to the physical and chemical characteristics of the starch in the endosperm. In this study, we have evaluated some cooking quality characters of land races of Bangladesh to assist in enlighting the consumers of the cooking quality of the land races they consume and help breeders for development of better quality rice.

Grain size and shape (length-width ratio) is a very stable varietal property that can be used to measure the varietal purity of a sample. The wide diversity of plant genetic resources provides opportunity for identifying micronutrient-rich genotypes for direct use or for genetic enhancement of staple crops using breeding strategies. The nutritional status and grain quality of rice is becoming more important. Considering consumer preference and market price, farmers aim is for the production of fine rice. In Bangladesh, cultivation of high yielding rice varieties has been increased and information of land races particularly nutritional statusisbecoming unknown. So, this study was undertaken to know size, shape of grains and nutritional properties and cooking qualities.

MATERIALS AND METHODS

Rice sample preparation

A total of 10 advanced rice genotypes (THDB, E-2, MV-20, MV-40, PNR-519, PNR-166, Kas80(C)(N)-10, Y12(8-1), Kasalat60(C)-1 and RM16-N-8) were collected from Bangladesh Institute of Nuclear Agriculture, Mymensingh, Bangladesh. The research was conducted in Crop Physiology Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh and Department of Agricultural Chemistry, Department of Biochemistry, Bangladesh Agricultural University, Mymensingh during 2020-21. The samples were manually cleaned to remove cracks kernels and the husk of the paddy was removed to get rice. Rice grains were grinded for analyzing.

Determination of kernel length and breadth

Ten randomly selected whole kernels of rice in three sets were taken and length and breadth of each grain was measured by using a slide calipers. The average value for each observation was considered as final reading. The length and breadth of rice kernel were expressed in millimeter (mm).

Determination of kernel length/breadth (L/B) ratio

The L/B ratio was calculated by dividing the average length by the average breadth of kernel. L/B ratio= Average length of the rice (mm)/ average breadth of the rice (mm). The scores are recorded for brown rice to evaluate the traits as genetic characteristics avoiding the effect of milling on size and shape. The rice grains were classified by standard evaluation system (SES) for rice (IRRI 1996).

Estimation of protein

Micro-Kjeldahl method was used for the estimation of total nitrogen in rice grain. Then total nitrogen was multiplied by conversion factor to obtained protein content.

Digestion: Powdered rice samples (0.2 g) taken in a 75ml Kjeldahl flask and 5 ml of concentrated H_2SO_4, 1 gm of digestion mixture was added. The flask was placed on digestion chamber and boiled until the mixture content becomes clear. The flask was cooled and the digested sample was diluted with distilled water.

Distillation: 25 ml of diluted digested samples was taken and 25 ml of 40% NaOH was poured into the flask slowly holding the flask about 45.angle and connected to the distillation set. The distillate was collected in a conical flask containing 10 ml of 2% Boric acid solution and 2-3 drops of mixed indicator.

Titration: Total distillate was titrated with 0.1N HCL and titration value was recorded.
Percentage of N was calculated by the following × formula:

% of nitrogen= (Ts-Tb) × normality of acid×0.014×100/weight of samples (g),
Where Ts= Titre value of the sample, Tb= Titre value of the blank
0.014= Milli equivalent weight of nitrogen
% protein= % of nitrogen × C.F.
C.F.= Conversion factor (5.5 for plant sample)

Sample preparation and determination of Zn and Fe

Collected samples were dried in an oven at 65°C for 24 hours and ground by a grinding machine after cooling. The prepared samples were then kept into plastic bottles until extract preparation. The plant extract was prepared by wet oxidation method using di-acid mixture following Singh *et al*. 1999. Exactly, 1.0 g of finely ground plant material was taken into a 250 ml conical flask and 10 ml of di-acid mixture (HNO_3: $HClO_4$= 2:1) was added to it. Then, it was placed on the electric hot plate for heating at 180-200°C until white fumes were evolved and subsequently cooled at room temperature. The digest was washed with distilled water repeatedly and filtered into a 100 ml volumetric flask through filter paper (Whatman No. 42) and the volume was made up to the mark with distilled water. Amaranth extracts were preserved separately in plastic bottles for subsequent chemical analysis.

The concentrations of Fe and Zn ions in the extracts were analyzed by atomic absorption spectrophotometer (AAS) (Model: SHIMADZU AA-7000) at the wavelengths of 248.3 and 213.9 nm, respectively as described by APHA 2012.

Determination of amylose content:

Amylose was determined following the method of Robyt and Whelan (1968). Accurately weighed 100 mg of powdered sample was taken and 1mlk of 95% ethanol and 9 ml of 1N NaOH were added and warmed for 5 min in water bath to gelatinize the starch. The content transferred in 100 ml volume with water cooled and brought to volume with water. 5 ml solution was taken into a 100 ml volumetric flask, 1 ml of acetic acid and 2 ml of iodine solution were added and made up to the volume with water, stirred and allowed to stand for 20 min before taking optical density at by spectrophotometer at 590 nm.

Preparation of standard curve:

100 mg of anhydrous potato amylose was dissolved in 100 ml of alcoholic NaOH (10 ml ethyl alcohol and 90 ml 1N NaOH). Portions containing 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75 and 2 mg of amylose transferred to 100ml flask. The solution was acidified with 1N acetic acid by adding 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4 ml respectively and color was developed using iodine solution. Optical density was taken at 590 nm in Spectrophotometer. The amylose content of the each sample was calculated from standard curve.

Calculation of amylopectin content:

Amylopectin is a calculated value which is obtained from the value of total amylose. % of amylopectin= 100-% of amylose (Jane *et al*. 1999).

Determination of volume expansion ratio:

Volume expansion ratio of raw milled rice and cooked rice was determined by water displacement method by using a measuring cylinder. A sample of 5 gm of rice grains poured into a measuring cylinder containing 15 ml of water and total volume was observed. The initial increase in volume after adding 5 gm of rice was recorded (Y) and soaked for 10 min. Rice grain sample was cooked for 20 min in a water bath at 90^0C. All the 5 gm of cooked rice were placed in 50 ml water taken in 100 ml measuring cylinder and the increase in volume of water was measured (X). The volume raise was recorded (X-50). Where, (X-50) is the volume of cooked rice (ml) and (Y-15) is the volume of raw rice (ml).

Determination of kernel elongation ratio (KER):

Kernel elongation after cooking and kernel elongation ratio (KER) was determined by Juliano 1971. In this method, 10 whole kernels after cooking (20 min in a water bath at 90^0C) was measured by using slide calipers and average kernel length was determined. Kernel elongation was calculated by dividing the average length of cooked kernel by the average length of the raw (uncooked) rice.

RESULTS AND DISCUSSION

The nutritional properties are shown in Table 1. Amylose content ranged 20.75-23.93, Zn 11.32-21.18 ppm, Fe 5.52-14.64 ppm and protein 5.02-7.20% in rice genotypes studied. THDB showed the highest amylose (23.93 mg) and Zn (21.18 ppm) content (Table 1). Fe (14.64 ppm) content was highest in MV-20 and protein content in E-2 (7.20%). Kernel length breadth ratio ranged from 2.37 to 3.51 and 1000-grain weight of the genotypes was statistically similar (Table 2). The results are in conformity of many researchers *viz*. Khatoon and Islam (2021, 2020a and 2020b), Maganti *et al*. (2019), Anjum and Hossain (2019), Ojha *et al*. (2018), Chukwuemeka *et al*. (2015), Martinez *et al*. (2010), Umadevi *et al*. (2010), Shipla (2010), Shipla and Sellappan (2010) and Shobha Rani *et al*. (2006).

Table 1. Nutritional properties of ten advanced rice genotypes

Genotype	Amylose(mg)	Amylopectin (mg)	Zn content (ppm)	Fe content (ppm)	Protein %
THDB	23.93a	76.07cd	21.18a	8.31ef	6.287b
E-2	22.67b	77.33cd	19.8b	5.527ef	7.20a
MV-20	22.17b	77.83c	16.70c	14.64a	6.30c
MV-40	21.97c	78.03b	19.66c	13.42b	6.07c
PNR-519	22.57b	77.43cd	16.80d	12.36c	5.27d
PNR166	21.53c	78.47b	14.95e	8.32cd	5.02d
Kas80(C)(N)-10	22.57b	77.43cd	18.96cd	5.98ef	6.07c
Y 12(8-1)	20.75d	79.25a	11.32ef	7.21de	5.26d
Kasalat60(C)-1	22.73b	77.27cd	14.92e	9.35d	5.18d
RM16-N-8	22.86b	77.14cd	16.01d	12.17c	5.93cd

Values having common letter(s) in a column do not differ significantly at 5% level as per DMRT

Table 2. Grain shape, size and cooking qualities of ten advanced rice genotypes

Genotype	Kernel length (mm)	Kernel breadth (mm)	Length /Breadth ratio	Volume expansion ratio	Kernel elongation ratio	1000-grain weight (g)
THDB	5.18bc	1.72ef	3.01b	2.84a	1.33a-d	21.82a
E-2	5.61b	1.71c	2.95b	1.85ef	1.25a-e	22.32a
MV-20	6.34a	1.90b	3.33a	2.37a-d	1.23a-e	22.07a
MV-40	6.06a	1.78c	3.40a	2.51ab	1.35a-d	22.63a
PNR-519	6.26a	1.78c	3.51a	2.45abc	1.15b-e	21.54a
PNR166	6.07a	1.89b	3.21a	1.98c-f	1.33a-d	23.02a
Kas80(C)(N)-10	5.82b	2.03a	2.69b	1.73ef	1.20a-e	23.03a
Y 12(8-1)	5.12bc	2.16a	2.37b	1.83ef	1.09de	24.30a
Kasalat60(C)-1	6.10a	1.87b	3.26a	1.89def	1.11cde	21.99a
RM16-N-8	5.93b	1.88b	3.15a	1.51f	1.21a-e	21.97a

Values having common letter(s) in a column do not differ significantly at 5% level as per DMRT

CONCLUSION

Amylose content ranged 20.75-23.93, Zn 11.32-21.18 ppm, Fe 5.52-14.64 ppm and protein 5.02-7.20% in the rice genotypes. The rice genotype THDB showed the highest amylose (23.93 mg) and Zn (21.18 ppm) content. Fe (14.64 ppm) content was highest in MV-20 and protein content in E-2 (7.20%).

REFERENCES

Anjum KI, Hossain MA (2019) Nutritional and cooking properties of some rice varieties in Noakhali region of Bangladesh. *Res. Agric. Livest. Fish*. 6(2), 235-243.

APHA, AWWA, WEF (2012) Standard Methods for the Examination of Water and Wastewater 22nd edn. Washington, USA. pp. 1-39.

Chukwuemeka AI, Kelechi AJ, Bernard A (2015) Cooking and physicochemical properties of five rice varieties produced in Ohaukwu local government area. *European J. Food Sci. Technol*. 3(1), 1-10.

Coffman WR, Juliano BO (1987) Rice. In: Olson RA, Frey KJ (eds) Nutritional quality of cereal grains: genetic and agronomic improvement. Agronomy monograph no. 28, American Society of Agronomy, Madison, pp 101–131.

FAO (2009) The state of food insecurity in the world 2009. FAO available at ftp://ftp.fao.org/docrep/fao/012/i0876e/i0876e.pdf

FAO/WHO (2001) Human vitamin and mineral requirements.Report of a joint FAO/WHO expert consultation Bangkok, Thailand.http://www.fao.org/docrep/004/y2809e/y2809e0m.htm

Gearing ME (2015) Good as gold: Can golden rice and other bio fortified crops prevent malnutrition? Science in the News, Harvard University.http://sitn.hms.harvard.edu/

Graham R, Senadhira D, Beebe S, Iglesias C, Monasterio I (1999) Breeding for micronutrient density in edible portions of staple food crops:conventional approaches. Fields Crops Res 60:57–80.

Iqbal A, Khalil IA, Ateeq N, Khan MS (2006) Nutritional quality of important food legumes. Food Chem 97:331–335.

IRRI (1996) Standard Evaluation System for rice. International Rice Research Institute, Los Banos, Philippines.

Jane J, Chen YY, Lee LF, McPherson AE, Wong KS, Radosavljevic M, Kasemsuwan T (1999) Effects of amylopectin branch chain length and amylase content on the gelatinization and pasting properties of starch. *Cereal Chem*. 76(5), 629-637.

Johnson AA, Kyriacou B, Callahan DL, Carruthers L, Stangoulis J, Lombi E, Tester M (2011) Constitutive over expression of the OsNAS gene family reveals single gene strategies for effective iron- and zinc-biofortification of rice endosperm. PLoS ONE 6(9):e24476

Juliano BO (1971) A simplified assay for milled rice amylose. *Cereal Sci. Today* 16, 334–340.

Juliano BO, Perez CM, Kaos M (1990) Grain quality characteristics of export rice in selected markers. *Cereal Chem*. 67:192-197.

Khatoon M, Islam MT (2020a) Grain shape, protein, zinc and iron content of rice land races in Bangladesh. *Int. J. Expt. Agric.* 10(2), 7-11.

Khatoon M, Islam MT (2020b) Amylose, amylopectin, volume expansion ratio and kernel elongation ratio of rice land races in Bangladesh. *Int. J. Sustain. Crop Prod*. 15(2), 1-3.

Khatoon M, Islam MT (2021) Grain quality, nutritional characters and cooking quality of rice genotypes including salt and drought tolerant varieties. *Int. J. Sustain Crop Prod*. 16(1), 1-6.

Lisle AJ, Martin M, Fitzgerald M (2000) A chalky and translucent rice grain differs in starch composition and structure of cooking properties. *Cereal Chem*. 77:627-632.

Little RR, Hilder GB, Dawson EH, Elsie H (1958) Differential effect of dilute alkali on 25 varieties of milled white rice.*Cereal Chem*. 35:111-126.

Maganti S, Swaminathan R, Parida A (2019) Variation in Iron and Zinc Content in Traditional Rice Genotypes.*Agric Res* (2019). https://doi.org/10.1007/s40003-019-00429-3

Marschner H (1995) Function of mineral nutrients: micronutrients. Mineral nutrition of higher plants, 2nd edn.Academic Press, London, pp. 347–364.

Martinez CP, Borrero J, Taboada R, Viana JL, Neves P, Narvaez L, Puldon V, Adames A, Vargas A (2010) Rice cultivars with enhanced iron and zinc content to improve human nutrition. In: 28th International rice research conference, 8–12 November 2010, Hanoi, Vietnam OP10: Quality Grain, Health, and Nutrition.

Ojha P, Chaudhary O, Subedi U, Karki R, Dongol DMS (2018) Milling, nutritional, physical and cooking properties of four Basmati rice varieties. *J. Nepal Agril. Res*. Council. 4:18-24.

Pfeiffer WH, McClafferty B (2007) Biofortification: breeding micronutrient-dense crops. In: Kang MS (ed) Breeding major food staples. Blackwell, Oxford Pingali PL, Hossain M, Gerpacio

Robyt JF, Whelan WJ (1968) Alyloses and their action on starch. Chapter 14 in: Starch and its derivatives. 4th ed. Radley JA, ed. Chapman and Hall Ltd., London.

Sandstead HH (1985) Requirements of zinc in human subjects. *J Am CollNutr* 4:73–82.

Sellappan K, Datta K, Parkhi V, Datta SK (2009) Rice caryopsis structure in relation to distribution of micronutrients (iron, zinc, b-carotene) of rice cultivars including transgenic *indica* rice. *Plant Sci* 177:557–562.

Seshadri S (1997) Nutritional anemia in South Asia. In: Gillespie S (ed) Malnutrition in south asia-a regional profile. In: UNICEF Regional Office for South Asia, pp.75–124.

Shahzad Z, Rouached H, Rakha A (2014) Combating mineral malnutrition through iron and zinc biofortification of cereals. *Compr Rev Food Sci Food Saf* 13:329–346.

Shipla JB (2010) Grain quality evaluation and organoleptic analysis of aromatic varieties of Goa, India.*J. Agril. Sci*. 2(3), 99-107.

Shipla JB, Sellappan K (2010) Grain quality evaluation of traditionally cultivated rice varieties of Goa, India. *Recent Res. Sci. Technol*. 2(6), 88-97.

Shobha Rani N, Pandey MK, Prasad GSV, Sudharshan I (2006) Historical significance, grain quality features and precision breeding for improvement of export quality basmati varieties in India. *Indian J Crop Sci* 1(1–2), 29–41.

Shozib HB, Hossain MM, Jahan S, Alam MS, Das SC, Alam S, Amin RB, Hasan MM, Malo R, Islam MR, Shekhar HU, Siddiquee MA (2017) Study of biochemical and cooking quality traits of major rice varieties of Bangladesh. *Malaysian Applied Biol. J*. 46(4), 55-62.

Singh D, Chhonkar PK, Pandey RN (1999) Soil plant water analysis: A Methods Manual. IARI, New Delhi, India. pp.72-86.

Stoltzfus RJ, Mullany L, Black RE (2004) Iron deficiency anaemia. In: Ezzati M, Lopez AD, Rodgers A, Murray CLJ (eds) Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors. World Health Organization, Geneva, pp.163–209.

Umadevi, Veerabadhiran MP, Manonmani S, Shanmugasundaram P (2010) Physico-chemical and cooking characteristics of rice genotypes.*Electronic J. Plant Breed*. 1(2), 114-123.

Welch RM, Graham RD (2004) Breeding for micronutrients in staple food crops from a human nutrition perspective. *J Exp Bot* 55:353–364.

Wessells KR, Brown KH (2013) Estimating the global prevalence of zinc deficiency: results based on zinc availability in national food supplies and the prevalence of stunting. PLoS ONE 7(11):e50568

World Food Programme (2015) Types of malnutrition. http://www.wfp.org/hunger/malnutrition/types

Zimmerman M, Hurrel R (2002) Improving iron, zinc and vitamin A nutrition through plant biotechnology. *Curr Opin Biotechnol* 13(2), 142–145.