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Nutraceutically Enriched Rice Based Food to Mitigate Malnutrition in Bangladesh

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Abstract

Rice is the synonym for food in people residing in Ganga - Meghna - Brahmaputra basin area and has been one of the major traditional sources of carbohydrates and proteins since the prehistoric days. By the end of 2017, eighty-six high-yielding varieties (HYVs), including both inbreeds and hybrids, have been released by Bangladesh Rice Research Institute (BRRI). At present, total rice production (cleaned or milled rice basis) is about 34.8 MT, enough to satisfy the domestic requirement to feed more than 160 million population with the surplus of 2.06 MT. In contrast, there has been comparatively less progress on addressing the quality aspects of rice. Thus, emphasis should now be to focus on the grain quality and nutrition research towards rice grain nutraceutical properties to reveal its aptitude to combat with non-communicable diseases such as heart disease, cancer, diabetics etc. By the course of time, Grain Quality and Nutrition Division of BRRI has identified some promising nutraceutically enriched HYVs such as black rice, antioxidant enriched rice, low glycemic index rice, anti-depressive alias gamma amino butyric acid (GABA) enriched pre germinated brown rice and micronutrient enriched rice, specially zinc enriched rice. Since in Bangladesh, rice based processed food items are available namely flattened, popped and puffed rice to meet local demand as traditional food items, we assume that there is a potential scope to enhance nutraceutical enriched rice based food considering malnutrition mitigation and humanitarian relief operation into account. In this study we have formulated energy dense nutraceutical enriched rice based food formulation specially cake and biscuits having energy density ranging from 5.0 - 5.5 per 100g serving respectively. Rice based balanced and nutritious food intake may possibly reduce the amount of unprocessed whole rice consumption gradually. By attaining required dietary allowance, rice based food may help sustain food security in Bangladesh in a way to properly and effectively utilizing the rice grain. It will open diversified uses of rice and rice based food products in Bangladesh.

Keywords: *Antioxidant Enriched Rice; GABA Enriched Rice; Zinc Enriched Rice; Diabetic Rice; Low GI*

Introduction

Nutraceutical is defined as a food or part of a food that provides health benefits, including the prevention and/or treatment of a disease. The consumption of nutraceutical foods from cereals, vegetables, fruits, nuts, mushrooms, etc. play a pivotal role as curative and preventive measure of some non-communicable diseases (NCDs). Cereals such as wheat, maize, rice, oats, etc., are now employed in the preparation of foods that are similar in appearance to those of conventional foods and used in normal diets but have an added advantage

of aiding physiological functions along with providing nutrition. Eating habits can drastically reduce healthcare expenditures if individuals are to modify their diets based on an existing knowledge of nutrition. This study focuses on rice (*Oryza sativa* L.), one of the most consumed cereals in the world, with potentials of lot of nutraceutical values. Having versatile functional properties, rice as a food is unique, easily digestible, hypoallergenic and the source of quality protein. It is reported that human beings require at least 49 nutrients for their normal growth and development, and the demands for most of the nutrients are supplied by cereals, particularly rice due to its staple role [1]. Among these nutrients, mineral elements play numerous beneficial roles due to their direct or indirect effect in both plant and human metabolism and the deficiencies or insufficient intakes of these nutrients lead to several dysfunctions and diseases in humans. Malnutrition in Bangladesh is alarmingly high. According to FAO (2017) and World Development Indicators (WDI, 2016), 36.1%, 14.3% and 32.9% children under 5 years of age are suffering from stunting, wasting and underweight respectively in Bangladesh, with the prevalence of undernourishment (PoU) of about 24.4 million (15.1%) [2,3]. The national prevalence of zinc deficiency is 44.6 percent amongst preschool age children and 57.3 percent amongst non-pregnant non-lactating women [4,5]. It should be considered that adequate nutritional intake of Zn actually depends both on the amount of Zn in the diet and on its availability. Among many factors that affect the bioavailability of dietary Zn intake, phytate has been known well to decrease Zn bioavailability [6]. Absorption of Zn^{2+}, Ca^{2+}, Mg^{2+} and Fe^{2+} metals in the small intestine is therefore inhibited due to their chelation by phytate [7,8]. Estimation of molar ratio of phytate to minerals is a very important parameter for the understanding bioavailability of minerals. Shozib., *et al.* (2017) [9] surveyed a total of 68 high-yielding varieties (HYVs) in Bangladesh. They reported that BRRI dhan43 and BRRI dhan42, grown in uplands, have higher amounts of Zn at 38.4 $mgkg^{-1}$ and 27.0 $mgkg^{-1}$, respectively (based on 8.0 ± 0.5% degree of milling). BRRI dhan43 has other important minerals like Fe, Ca, P at concentration of 17.0 $mgkg^{-1}$, 68.1 $mgkg^{-1}$ and 2.5 mgg^{-1}, respectively. In support of bioavailability, molar ratio of phytic acid to Zn (PA/Zn); Fe (PA/Fe); Ca(PA/Ca) and P (PA/P) are found lower in BRRI dhan43 among all selected high Zn enriched HYVs by 3.56, 6.93,1.24 and 25.69 respectively followed by BRRI dhan42 (data not shown). Therefore, both BRRI dhan43 and BRRI dhan42 could be used as parental source for the development of micronutrient enriched rice (MER) breeding lines particularly for Aus (pre-monsoon or kharif-1) season. Up to now, BRRI has released four Zn enriched varieties: BRRI dhan62 (20 $mgkg^{-1}$) and BRRI dhan72 (22.8 $mgkg^{-1}$) for Aman (monsoon or kharif-2) season and BRRI dhan64 (24.0 $mgkg^{-1}$) and BRRI dhan74 (24.2 $mgkg^{-1}$) for Boro (dry winter or rabi) season. Type II diabetes is a major global health problem and its prevalence is increasing dramatically throughout the world, especially in Asia, including Bangladesh [10,11]. The escalating diabetes pandemic is largely a consequence of the shift away from traditional lifestyles and dietary patterns to increasingly sedentary behaviors. Epidemiological and clinical studies point to the adverse health consequences of foods and diets rich in carbohydrates which are readily and extensively digested [12-14]. The glycaemic index (GI) ranks foods on the basis of their propensity to raise blood glucose, thereby providing a relative measure of dietary carbohydrate quality. Lower GI foods and diets provoke only transient, moderate postprandial glycaemia and improve insulin sensitivity along with other endpoints of cardio-metabolic health in obese and overweight subjects as well as those with type II diabetes [15-20]. In 2017, Based on an *in vivo* experimental rat model study with 72 HYVs with un-parboiled milled or clean rice condition, Shozib., *et al.* [21] in 2017 reported that three HYVs, BR16, BRRI dhan46 and BRRI dhan69, are categorized as low GI rice (GI ≤ 55), 50 HYVs as intermediate GI rice (GI 56-69) and the rest 19 HYVs as high GI rice (GI ≥ 70). Due to its content of phenolic compounds that are able to inhibit the formation or reduction of the concentrations of reactive cell-damaging free radicals, thereby reducing the risk of coronary heart disease, rice has the potential to promote human health. In 2012, Dutta., *et al.* [24] reported that, among all tested HYVs of rice in Bangladesh, variety BR5 contains the highest total phenolic content (TPC), ferric reducing antioxidant power (FRAP) and total antioxidant capacity (TAC). In 2015, Shozib., *et al.* [25] showed how dietary administration of rice improves the antioxidant status in blood of the experimental long-evans rat. Pre-germinated Brown Rice (PGBR) alias germinated brown rice (GBR) enhances the bio-availability of nutrients by neutralizing phytic acid during the process of germination. PGBR has been found to be optimum for getting the highest non-essential amino acid such as gamma amino butyric acid (GABA), an inhibitory neurotransmitter content in brown rice [26]. The nutrients which have increased significantly include GABA, lysine, vitamin E, dietary fiber, niacin, magnesium, vitamin B_1, and vitamin B_6 [27]. PGBR has been reported to exhibit many physiological effects, including anti-hyperlipidemia, anti-hypertension, and the reduction in the risk of some chronic diseases, such as cancer, diabetes, cardiovascular disease, and Alzheimer's disease [28]. Muhammad., *et al.* (2017) [29] reported that, among the tested rice HYVs, BRRI dhan31 generates

elevated level of bioactive component, GABA at PBGR condition. Black rice is especially rich in anthocyanin pigments, phytochemicals, proteins, vitamins, minerals and antioxidant properties. In Bangladesh, Black rice (BRRI Black Rice, BBK1) has been found with low GI values for both brown and polished rice condition (48 and 51 respectively). BBK1 has high protein content of 9.5% and higher gamma oryzanol [30]. Other local black rice varieties, such as Gabura and BK10, are also very promising in this regard. Since World Food Program (WFP) of United Nations has a wheat based high energy biscuit (HEB) project operating all over the world, it is wisely to believe that there is a potential to utilize nutraceutical enriched rice flour based energy dense (ED) cookies too. HEBs provide 450 kilocalories of energy and at least 10 grams of protein per 100 grams. Since HEBs are containing high-protein cereals and vegetable fats, their high energy-to-weight ratio are procured by the WFP, for feeding disaster victims worldwide [39]. Considering the nutraceutical properties of rice into account, we aimed to proceed with rice-based food formulation in this study to introduce a potential option to address malnutrition, especially for vulnerable population, such as refugees, flood victims, undernourished children etc. Since there is no single scientific research on rice based energy dense food items formulation in Bangladesh, it is now high time to explore its potential for malnutrition mitigation through formulation of energy dense rice based food in Bangladesh. In this study, we aimed to formulate energy dense rice biscuit (EDRB) and energy dense rice cake (EDRC) at ED 5.6 and 5.0, respectively.

Materials and Methods

In this study, we selected 12 nutraceutical rice HYVs to prepare rice-based food formulation, i.e., as potential use of rice flour. All research activities were conducted at Grain Quality and Nutrition (GQN) Division of BRRI, Gazipur, Bangladesh.

Materials

A total 12 nutraceutically enriched BRRI HYVs including B5, BR16, BRRI dhan31, BRRI dhan42, BRRI dhan43, BRRI dhan46, BRRI dhan62, BRRI dhan64, BRRI dhan69, BRRI dhan72 BRRI dhan74 and local landraces such as Black rice (BBK1) flours were used to prepare rice-based food items. In 2016 - 2017, Aus (pre-monsoon or kharif-1) season varieties, namely BR16, BRRI dhan42 and BRRI dhan43, were grown at West Byed field of BRRI, Gazipur, Bangladesh. In the following Aman (monsoon or kharif-2) season, BR5, BRRI dhan31, BRRI dhan46, BRRI dhan62, BRRI dhan72 and BBK1 were grown and in the subsequent Boro (winter or rabi) season, BRRI dhan64 and BRRI dhan74 were grown in the same field. All rice varieties received BRRI recommended fertilizer doses for Aus, Aman and Boro seasons. Rice samples were collected from BRRI, GQN Division, and were sun dried to about 12% moisture content. Dehusked through dehulling using a Satake Dehuller, Satake Corporation, Japan. The resulting brown rice was polished by 10% removal of bran to get milled rice (the parts removed from brown rice, including pericarp, seed coat, embryo, and aleurone using a Satake Test Mill, Satake Corporation, Japan). Rice powder was prepared by grinding brown and milled rice in Udy Cyclone Mill (Udy Corporation, USA) to pass through 60 mesh net.

Approaches

We formulated our rice based products with several ingredients including un-parboiled milled rice flour (head rice flour) or broken rice flour, sugar, milk, duck egg, dates, nuts, vanilla essence, sagu powder (natural lubricating agent available in Bangladesh), butter, baking powder and rice bran oil (RBO). Since rice does not have gluten protein and it's very fragile in texture, we applied combination of sagu powder and dates to make the food dough compatible for uses in terms of softer, thicker and gaining elasticity. It resulted in preferable texture and crispiness. We also tried using brown rice flour but it resulted in hard texture, so we preferred to use un-parboiled milled rice or broken rice for formulation of rice-based products.

Moisture content of rice flour samples were determined by drying at 105^0C for overnight in an electric oven according to standard method of Association of Official Agricultural Chemists (AOAC) [33]. Standard micro Kjeldahl procedure of AOAC [34] was used for the determination of nitrogen, and crude protein was estimated by multiplying the nitrogen content by a factor 5.95. The crude fiber was estimated by the method of AOAC [33].

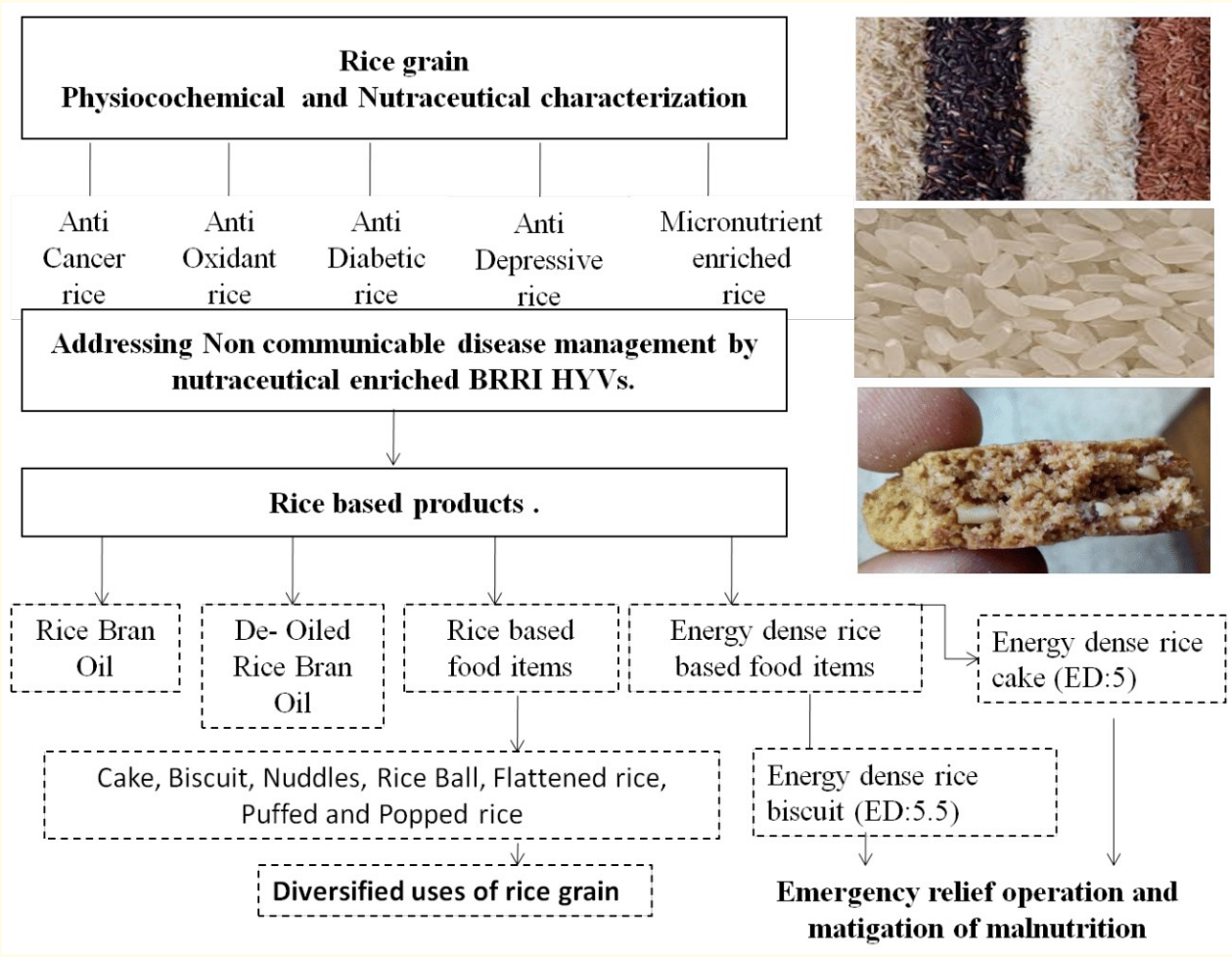

Figure 1: *Schematic diagram of GQN activities in BRRI, Gazipur, Bangladesh.*

Fat was extracted from the grounded rice samples with Chloroform: Methanol (2:1) solution. Fat was determined from the extract by the method of Choudhury and Juliano [35]. Samples were ignited at 550°C to burn off all organic materials. The inorganic material, which does not volatilize at that temperature, and estimated according to standard methods of AOAC [33]. The carbohydrate content of a sample was calculated by subtracting the percentage of other components (moisture, ash, fat, protein and fiber) of that sample from 100, and expressed as: carbohydrate (%) = 100 - (moisture + ash + fat + protein + fiber). Minerals such as Fe, Zn, Ca, Pb, Ni, As and Cd were estimated by the method of (AOAC) [34]. Estimation of phosphorus was carried out by measuring calorimetrically the blue color formed when the ash solution is treated with ammonium molybdate and the phosphomolybdate thus formed is reduced [36]. National Institute of Standards and Technology (NIST) reference material Rice flour NIST SRM 1568b [37] was used in mineral profiling of formulated rice based foods. We complied with BSTI (Bangladesh Standard Testing Institute) standards for biscuit formulation in Bangladesh.

Result and Discussion

Rice is an important source of energy, hypoallergenic, easily digested, and provides protein with higher nutritional quality. It has versatile functional nutraceutical properties, so rice-based low cost balanced, nutritious and safe diet formulation will able to address

malnutrition related problems of impoverished human population such as in Bangladesh. Since there are only a few reported nutraceutically enriched HYV rice varieties, such as antioxidant enriched BR5, diabetic rice BR16, BRRI dhan46 and BRRI dhan69, GABA-enriched pre-germinated BRRI dhan31 brown rice, Zn-enriched BRRI dhan42, BRRI dhan43, BRRI dhan62, BRRI dhan64, BRRI dhan72, and BRRI dhan74, energy dense (ED) rice-based nutritious and balanced safe food items are supposed to be available in Bangladesh in near future. Rice is a very good source of water soluble vitamins such as thiamine and riboflavin. BR5, BR16, BRRI dhan31, BRRI dhan43, BRRI dhan46 and BRRI dhan69 have thiamine (mg kg-1) and riboflavin (mg kg-1) levels of 8.0, 10.5, 8.4, 10.9, 7.5, 10.9 and 0.071, 0.075, 0.044, 0.064, 0.016, 0.060 respectively [31]. In order to prepare rice-based food we have multiple options of choosing rice flour from the below mentioned nutraceutical enriched BRRI HYVs (Table 1). In rice based food formulation, customer's preference must have to be considered according to their necessity and demand. In Bangladesh, we do not have evidence based processed food. Since cancer is one of the fast growing non-communicable disease (NCDs) at recent years in Bangladesh, anti-cancerous black rice based formulated foods might have immense potential (WHO, 2014). Considering the proximate analysis of rice (Table 2), among all tested HYVs in this study, it was found that black rice is the lowest carbohydrate (76%) containing rice variety. Cornejo., *et al*. [38] in 2015 reported that pre-germinated brown rice flour has some added advantage over wheat flour as it is characterized as gluten-free, low GI, increasing amount of anti-oxidant activity, protein, GABA, phytase content and decreasing level of fat and carbohydrate. Hence, pre-germinated BRRI dhan31 (12 mg 100 g-1 of GABA content) brown rice based food items has potential to make popular for a target population suffering from obesity, diabetics, hyperlipidemia, hypertension and Alzheimer's disease in Bangladesh. Nutraceutical-enriched rice HYVs can be used to provide multiple options based on consumer's preference. For instance, micronutrient-enriched (Zn and Fe) BRRI dhan43 and others reported Zn-enriched rice varieties might be suitable for preparing rice based products specially for malnourished population specially children under the age of five. In similar fashion, low GI indexed rice HYVs such as BR16 (52.4), BRRI dhan46 (53.1), and BRRI dhan69 (54.9) can be suitable as rice flour source to prepare rice-based food for diabetic patients in Bangladesh. A low GI diet has commonly been promoted as an effective way to help lose weight by controlling blood sugars and appetite. Considering the above situation into account, the low GI HYVs have potential to systematically combat non-communicable disease like diabetics in Bangladesh. In National Food Policy Plan of Action and Country Investment Plan Monitoring Report, 2016, Bangladesh government has argued for food security and nutrition targets of SDG2 by 2030 to eradicate hunger and free access to food especially vulnerable infants and malnourished children suffering from stunting, wasting and underweight in Bangladesh. Hence, energy dense rice based food has immense potential in this regard.

Rice flour from selected HYVs	Special properties
Black rice	Anticancer property enriched.
BR16, BRRI dhan46 and BRRI dhan69	Antidiabetic property enriched.
PGBR BRRI dhan31(GABA enriched)	Anti-depressive property enriched.
BR5	Anti-oxidant property enriched.
BRRI dhan74 and BRRI dhan64	Zinc enriched.
BRRI dhan43	Micronutrient enriched both Zinc and iron.

Table 1: *Selected Nutraceutical BRRI HYVs for rice based food formulation.*

Variety	*Protein	Moisture	Fat	Fiber	Ash	Starch
BR5	9.1	12.0	0.6	0.8	1.1	76.4
BR16	7.3	12.1	0.7	0.7	1.0	78.2
BRRI dhan31	8.9	11.8	0.6	0.8	1.1	76.8
BRRI dhan43	7.5	12.1	0.6	0.7	1.2	77.9
BRRI dhan46	8.1	12.3	0.6	0.8	1.0	77.2
BRRI dhan64	7.1	11.8	0.8	0.8	1.1	78.4
BRRI dhan69	8.0	12.0	0.7	0.7	1.0	77.6
BRRI dhan74	8.3	11.8	0.5	0.8	1.1	77.5
Black rice	9.5	12.2	0.6	0.7	1.0	76.0

Table 2: *Proximate analysis (in percentage) of few nutraceutical enriched BRRI HYVs.*

*Note: All parameters were analyzed at milled rice condition except protein.*Protein was estimated at brown rice condition.*

In this study, we have formulated energy dense rice biscuit (EDRB) and energy dense rice cake (EDRC) at ED 5.6 and 5.0 respectively (Table 3 and Table 4). Earlier in 2015, Shozib., *et al.* [32] reported few rice based food items such as rice ball (393 Calories $100g^{-1}$ serving; ED 3.93), rice biscuit (479 Calories $100g^{-1}$ serving; ED 4.79), rice plain cake (465 Calories $100g^{-1}$ serving ; ED 4.65) in an approach to create multiple options for diversified use of rice grain in Bangladesh. Since rice flour does not have gluten protein unlike wheat, so making dough is seeming difficult to get appropriate texture in reality. We tried several natural products to optimize its shape and texture such as sagu, a well-known lubricating agent, and dates; it enhances chewing properties rather than using xanthan gum (commercially available bacterial lyophilized powder).

Nutritional fact sheet	EDRB Per 100g
Zinc	1.50 mg
Iron	0.71 mg
Calcium	2.80 mg
Phosphate	8.5 mg
As	< 0.1 $mgkg^{-1}$
Pb	< 0.1 $mgkg^{-1}$
Cd	< 0.1 $mgkg^{-1}$
Ni	< 0.1 $mgkg^{-1}$
Carbohydrate	47.4g
Fat	36.0g
Protein	10.0g
Moisture	4.5g
Dietary fiber	2.0g
Energy	559 kcal
ED	5.6

Table 3: *Energy Dense Rice Biscuit (EDRB) formulated by GQN, BRRI, Bangladesh (Proximate analysis).*

Nutritional fact sheet	EDRC Per 100g
Zinc	1.15 mg
Iron	0.51 mg
Calcium	2.04 mg
Phosphate	7.5 mg
As	< 0.1 $mgkg^{-1}$
Pb	< 0.1 $mgkg^{-1}$
Cd	< 0.1 $mgkg^{-1}$
Ni	< 0.1 $mgkg^{-1}$
Carbohydrate	48g
Fat	30.0g
Protein	10.0g
Moisture	11.0g
Dietary fiber	1.0g
Energy	500 kcal
ED	5.0

Table 4: *Energy Dense Rice Cake (EDRC) formulated by GQN, BRRI, Bangladesh (Proximate Analysis).*

A major factor constraining accessibility of poor is price volatility. As the poor spend a relatively larger proportion of their income in basic stables, a sudden spike in price is equivalent to reduction in their real incomes. This will constrain their ability to acquire adequate quantity of staples. Considering this fact into account, our formulated products will not cost more than $0.10 USD for 100g serving which supposed to be cost effective. Rice-based formulated diets for children with moderate to acute malnutrition must have some important characteristics including high content of micronutrients, especially growth (type II) nutrients, high energy density (defined as the ratio of energy per weight of food), adequate high protein and fat content, low content of anti-nutrients, low risk of contamination, acceptable taste and texture, culturally acceptable, easy to prepare, affordable and available [42]. High energy density rice is most desirable for children with wasting, as they have an increased energy need for catch-up growth. The most important factor influencing energy density is the fat content, as the energy density of fat (9 kcal/g) according to the Atwater factors is more than double that of protein and carbohydrate (4 $kcalg^{-1}$). In a study with Peruvian malnutrition children, the energy density increasing from 1.0 $kcalg^{-1}$ to 1.5 $kcalg^{-1}$ showed significant impact on the energy intake per kilogram of body weight which increased by approximately 20% to 25% [43]. In a review of complementary feeding, nine studies comparing energy intake in malnourished children receiving diets with different energy densities were identified [44]. In six of the studies, energy intake was considerably higher when the children were given an energy-dense diet. In most of the studies, the level of the energy density in the low-energy-density diet was about 0.5 $kcalg^{-1}$ or lower. However, a study of 5 to 18-month-old malnourished children in Bangladesh compared a diet with an energy density of 0.92 $kcalg^{-1}$ with a diet of 1.47 $kcalg^{-1}$, and also found an increase (about 50%) in energy intake in the group on the energy-dense diet [45]. Low cost, nutritious and balanced rice based food items can be distributed in emergency situations such as flood relief program, earth quake disaster management, war engaged soldiers, refugee and social welfare related works such as improving health status of malnourished street children and climate change migrated population in Bangladesh. In the adverse situations, usually people suffer from inadequate intake of staples, and unavailability of fuel and cooking facilities. Hence, government as well as nongovernment organizations (GOs and NGOs) can distribute energy dense rice-based dry foods such as EDRC and EDRB to targeted population to provide preliminary boost up feeding. Since these products are both fat (> 30%) and protein (10%) enriched, we expect that these special products will soon be adopted in people's meal where adverse situations will arise. Since WFP has a successful integration of dry food products like wheat-based HEB to provide food supplements under emergency situations, rice-based products such as EDRB and EDRC may also have great potential under similar situations in Bangladesh.

Figure 2: *EDRB and EDRC HEBs formulated by GQN, BRRI, Bangladesh.*

As per the recent estimates by HIES-BBS, 2016, current per capita rice consumption ($gcapita^{-1}day^{-1}$ in Bangladesh is 367g which is still above the desirable intake of 350 $gcapita^{-1}day^{-1}$ [46]. Hence, a total of 367g cooked rice might generate around 477 calories but in the contrary, the new rice-based food formulation products might utilize only 30 - 35g of rice flour which eventually reduces rice uses by 10 times but still getting similar amount of energy through EDRC and EDRB generating 500 and 550 kilocalories, respectively. In the near future, GQN of BRRI will extend its research activities in human trials using the nutraceutically enriched rice-based products in association with Bangladesh University of Health Science (BUHS) especially to tackle type-II diabetic patients.

Conclusion

Rice is the most appreciated cereal crop to combat non-communicable diseases (NCDS) with its versatile nutraceutical properties embedded in it. In this study, we demonstrated that the formulation of nutraceutically enriched rice-based food items have potential to be popular among Bangladeshi people. This will pay a vital role to gradually reduce overall rice consumption and preferably help sustain food security in Bangladesh in a way to properly utilizing the rice keeping the required dietary allowance intact. In addition, nutraceutical rice-based food formulation for specific NCDs have potential for success in non-communicable disease management in Bangladesh.

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