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Research Paper

Gamma radiation application to rice: Reduced glycemic index in relation to modified carbohydrate observed in FTIR spectra

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ABSTRACT

This study was conducted with a popular, low price Bangladesh rice variety BRRI Dhan 29 with a view to possible carbohydrate modification targeting lower glycemic index using gamma radiation application. Irradiation process (5 and 10 kGy at a dose rate of 9.74kGy/h) altered amylose content, amylose/amylopectin ratio, swelling power, and solubility index. FTIR spectroscopy confirmed the changed molecular structures due to radiation application. Treatment with a dose of 5 and 10kGy caused increased amylose and amylose/amylopectin ratio significantly ($p < 0.02$). The highest amylose content was found in 10 kGy irradiated rice (30.20%) compared to unirradiated one (17.27%). Gamma radiation caused decreased swelling and increased water solubility in rice powder. These features of carbohydrate amendment in irradiated rice lead to reduced glycemic index as investigated with the in vivo experiments. Therefore, this study suggests gamma-irradiated rice (10kGy) is beneficial for diabetic subjects keeping lower blood glucose levels.

1. Introduction

Rice (*Oryza sativa*) is the staple food for over half of the world's population providing two-third of the total calorie supply as well as primary dietary sources of carbohydrates. The starch-based rice varieties or other carbohydrate foods can be classified or characterized according to the blood glucose raising potential (slowly or quickly) following ingestion, the indicator termed as the glycemic index (GI). The categorizations are: high ($GI \geq 70$), moderate (GI 56–69), or low GI ($GI \leq 55$). Foods with a high GI (release glucose rapidly) affect greatly physiological conditions relating to diabetes, obesity, and other metabolic syndromes. In the South Asian region, Bangladesh has the second largest number of adults with diabetes (5.1 million adults, 6.31%) (IDF Diabetes Atlas, 2013).

The glycemic response of rice is documented to be relatively high compared to other starchy foods. In the management of type 2 diabetes, it becomes common advice to take a limited quantity of rice because of its potential to raise blood glucose. However, the choice of rice variety and its processing are an important factor for digestion as well as producing glucose level in blood and its associate physiological effects. Limited studies reported the GI of Bangladeshi rice varieties. According to the project report of National Food Policy Capacity Strengthening Programme of Bangladesh (Md Zakir Hossain and Biswas, 2009), the glycemic index of ten rice varieties developed from Bangladesh Rice Research Institute (BRRI) was ranged from 49.87 to 74.2, while most of the varieties were within medium GI value (56–69). The glucose response effects at physiological state are attributed to starch (glucose polymer) composition (amylose and amylopectin) and starch nature (rapidly digestible and slowly digestible) of rice grains (Englyst, 1992). Variations in the GI of rice varieties depend on differences in the proportion of starch composition such as amylose and amylopectin content. Juliano et al. (1986) reported that varieties that contain a higher proportion of amylose (for example, 28%) have been shown to have a slower rate of digestion and produce lower glycemic and insulin responses. However, food processing treatments have various effects on the starch molecule and digestibility properties of rice. Consumers recently are concerned about foods with a low postprandial glycemic response because of having beneficial health effects.

Therefore, the applications of eco-friendly emerging technologies are of great importance for carbohydrate modification. Gamma radiation is a promising technology in food processing ensuring safety and shelf-life extension of food to make it available at any environmental crisis

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(Verma and Gautam, 2015; IFST, 2006). The application of gamma radiation is widely accepted as a non-thermal physical process to control insect infestation in rice. Ghanem et al. (2008) indicated that gamma ray caused degradation of aflatoxin B1 in rice and other corns significantly with the increase in the applied dose of gamma ray (4, 6, 10 kGy), and at 10kGy, the AFB1 degradation was highest (87.8%) in rice samples. Several dose-dependent studies reported the use of gamma radiation to modify structural changes of rice or other corn starch including the formation of cross-links by molecular alterations and thus reduce the digestibility of starch (Bhat and Karim, 2009; Chung and Liu, 2009). Also, the loss of granular structure and molecular fragmentation of starch due to radiation has been observed in another study (Yoon et al., 2010). Several investigations have been performed on rice to investigate gamma radiation-induced changes in carbohydrate composition and molecular arrangements relating to functional properties in different country (India, China, Taiwan, Brazil, etc.) rice varieties (Yu and Wang, 2007; Kumar et al., 2017; Frei et al., 2003). There is controversy among the results with varying radiation dose (2–20 kGy), rice variety, and botanical origin.

However, we are reporting for the first time to use of radiation facility in Bangladesh Atomic Energy Commission for rice processing. Bangladesh Atomic Energy Commission (BAEC) has been engaged for the last four decades in research and development activities in food irradiation with active participation in research projects under International Atomic Energy Agency (IAEA). Several food products including dried spices, fish, nuts, and fruits were commercially irradiated for domestic or export purposes with a Cobalt-60 gamma irradiator facility at Institute of Food and Radiation Biology, and Institute of Radiation and Polymer Technology according to the dose-effect guideline of IAEA. To facilitate commercialization and trade in irradiated foods, Bangladesh adopted in 1995, a specification for Authorization of Irradiation by Classes/Groups of Foods in line with the guidelines proposed by the International Consultative Group on Food Irradiation (ICGFI). Consumer acceptability tests conducted over the years under the joint FAO/IAEA project (IAEA-TECDOC-1219, 1998) did not reveal any untoward response to irradiated products. From that point of view, gamma radiation-induced molecular and functional changes in rice carbohydrates could be accepted for health beneficial role from rice consumption, particularly to diabetic subjects.

The present study has been conducted using a variety of BRRI-Dhan-29. This variety is very popular, widely consumed, and relatively cheaper (~0.59 USD/kg) in Bangladesh, but it has been reported as higher GI rice, 74.2 and 76.3 for parboiled and unparboiled category (Md Zakir Hossain and Biswas, 2009). Therefore, the study was planned with a hypothesis that the radiation processing might be effective in carbohydrate modification of that variety as well as a reduction in glycemic index. Several reference studies mentioned earlier reported that the doses of 4–10 kGy were found to be beneficial for stored grain with respect to microbial destruction (AFB1) and also cause carbohydrate changes. Therefore, the authors selected two dose (5 and 10 kGy) for radiation application for Bangladeshi rice on the basis of previous results. Since the amylose type starch plays a critical role in modifying rice quality, the methodology has been directed toward the radiation effect on the starch composition and molecular changes using Fourier transform infrared (FTIR) spectroscopy with a goal to formulate low glycemic food using gamma irradiated rice flour for diabetic and normal healthy subjects.

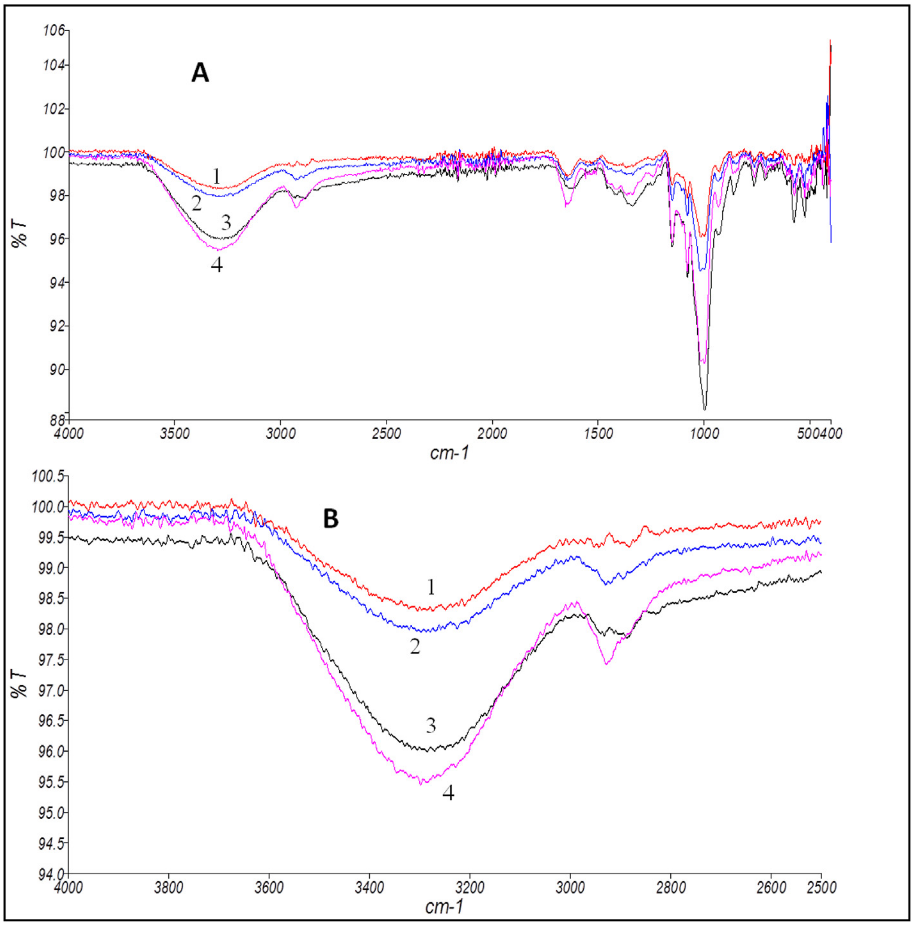

Fig. 1. FTIR spectra of control (unirradiated) and gamma irradiated rice with respect to standard starch: Control rice (1), 5.0kGy (2), Starch standard (3), 10kGy (4). The upper part (A) shows full spectra at a range from 400 to 4000 CM^{-1}. The lower part (B) is functional group region from 2500 to 4000 CM^{-1} indicates poly-hydroxyl groups and C–H stretching vibrations of unirradiated and gamma irradiated rice.

2. Materials methods

2.1. Rice sample and gamma irradiation

Rice grains of Bangladeshi cultivar BRRI-Dhan-29 were purchased from the super shop and local market to make several replicas. About 100 gm rice grains were packed in polyethylene bags and were subjected to gamma radiation doses of 5 and 10 kGy at a dose rate of 9.74 kGy/h (Ceric cerus DS-3) using Cobalt-60 gamma irradiator facility at Institute of Food and Radiation Biology of Bangladesh Atomic Energy Commission. The unirradiated samples served as control. Rice grains were powdered and analyzed within 5 days of radiation.

2.2. Fourier transform infrared (FTIR) spectroscopy

Native (unirradiated) and gamma irradiated rice powder samples were subjected to FTIR spectrometric analysis, a rapid, non-destructive technique to understand the fine molecular structure of rice starch in relation to functional groups. The infrared spectra were recorded on Perkin Elmer Spectrum Two FT-IR spectrometer (Perkin Elmer UATR TWO, USA) in the wavelength range of 4000–500 cm^{-1} with a resolution of 4 cm^{-1}. The measurements were averaged on 4 scans.

2.3. Determination of amylose content and amylose-amylopectin ratio

The amylose content in control and irradiated rice samples was determined based on the iodine-binding procedure as suggested by Juliano et al. (1981). Briefly, an alkaline solution of rice flour was prepared in 1M NaOH and an aliquot was subjected to reaction with iodine solution. The absorbance of the color complex product was measured at 620nm on the UV-Spectrophotometer (Shimadzu UV 1601, Japan). The amylose content of the rice samples was calculated (as a percent) based on a standard curve of potato starch amylose standards (Sigma Aldrich). Apparent amylose to amylopectin ratio (Am/Ap) was calculated founded on starch and amylose content as Am/Ap = [amylose content/(starch content-amylose content)]. Starch content was calculated (data not shown) using conversion factor (% starch = % reducing sugar × 0.9).

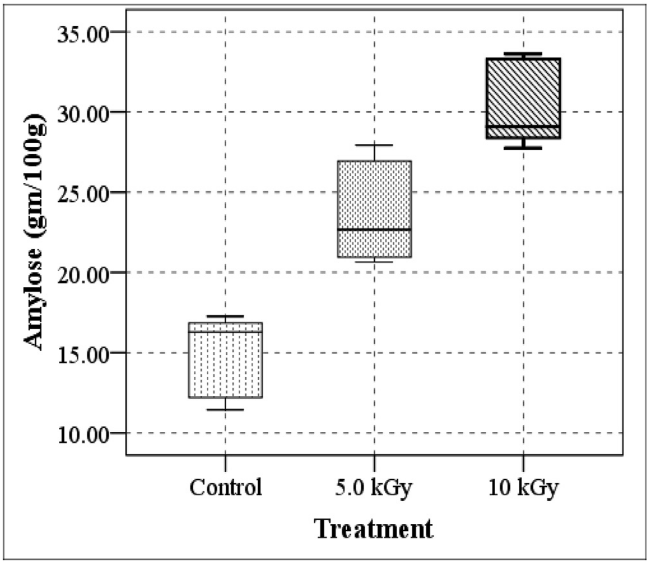

Fig. 2. Effect of gamma radiation application on amylose content of rice. Box plot drawn from SPSS statistical software shows the minimum to maximum ranges of amylose content obtained from replicate measurement in Control (unirradiated) and irradiated (5.0, 10 kGy) rice. Data represents the minimum, maximum, and median (horizontal line) values from 9 measurement and 3times radiation application.

2.4. Analysis of swelling and solubility index of rice powder

The swelling and solubility index of rice samples were determined according to Wani et al. (2014). Rice suspensions were prepared using distilled water in 50 mL centrifuge tubes and heated at 90 °C for 30 min. The rice starches become gelatinized and the tubes were centrifuged at 2200rpm for 15 min. The supernatants were withdrawn and placed in a pre-weighed petri dish for subsequent drying at 105 °C till constant weight. The remaining swollen sediments were also weighed. The solubility and swelling power were then calculated using the formula:

Solubility (%)= (weight of soluble matter in supernatant/ weight of sample) x100

Swelling power (%) = [weight of swollen matter/ {weight of sample x (100-solubility)}] x100

2.5. Measurement of glycemic index

Six-week-old Wister male rats were obtained from the Department of Biochemistry and Molecular Biology, Jahangirnagar University, Bangladesh. After acclimatization in a standard environment, a preliminary oral glucose tolerance test (OGTT) was performed after glucose ingestion (833 mg/kg body weight, equivalent to 50 g glucose/60 kg adult human) for all the rats (n = 20). Blood glucose was measured using a digital glucose meter (Glucoleader, Taiwan) collected from the tail vein at 0, 30, 90, and 120 min after feeding glucose solution. Then animals were fasted overnight and fasting glucose level was measured before oral gavages of test rice as suspension. Three rice (unirradiated, 5.0kGy, and 10kGy) suspensions were prepared by mixing rice powder (50 g carbohydrate equivalent) with hot water (80 °C) and keeping the mixture for sometimes to gelatinize so that the suspensions become uniform. Then, the rice solutions were fed orally through a gastric tube (30 mL/kg). Blood glucose was determined after 30, 90, and 120 min of test rice feeding. The blood glucose response curve and area under the curve (AUC) were calculated. The animal feeding test was conducted with formal ethical approval. Glycemic Index (GI) for control and irradiated rice was calculated from the incremental area under the curve (AUC) for 2 h of blood glucose response for each respective rice intake and with the AUC for glucose solution standard according to the method of Wolever et al. (1991), also reported by FAO/WHO (1997) using the following equation:

$$GI = \frac{\text{Incremental Area Under 2h blood glucose Curve for test rice}}{\text{Incremental Area Under 2h blood glucose Curve for glucose}} \times 100$$

2.6. Statistical analysis

The data reported are the average of triplicate observations. The data were subjected to one-way analysis of variance (ANOVA) with a significance level of 0.05 applying Tukey's test to determine the differences between the means using SPSS (version 24.0. Chicago, IL).

Table 1

Gamma radiation effect on starch composition and Physico-chemical properties of rice.

Rice sample	Amylose/ Amylopectin	Swelling index (g/ g)	Solubility index (%)
Control	0.25^{a}	10.23 ± 0.13^{a}	2.0 ± 0.7^{a}
5.0 kGy	0.51^{b}	9.49 ± 0.2^{ac}	5.33 ± 0.7^{b}
10 kGy	0.81^{c}	9.04 ± 0.61^{bc}	7.33 ± 0.22^{b}

Values are mean ± standard deviation. Different superscripts are significantly different at $p \leq 0.05$ among the rice samples studied.

3. Results and discussion

3.1. FTIR spectra on gamma radiation-induced molecular changes in rice

Natural (untreated) starch exists in rice endosperm as semi-crystalline granules consisting of two polysaccharides: amylose [linear polymer of α-(1,4)-linked d-glucopyranosyl units) and amylopectin [highly branched polymer of α-(1,4)-linked d-glucopyranosyl chains via α-(1,6)-glycosidic linkages]. Gamma radiation modifies the structure in both amorphous and crystal regions inducing physical and rheological changes in starch. The application of gamma radiation has been reported to generate free radicals that are capable of inducing molecular changes and cross-linking of rice starch (Bhat and Karim, 2009). Fourier transforms infrared (FTIR) spectroscopy has long been widely used as a useful technique to monitor structural changes in biopolymers. Thus, the possible structural modifications of rice starch due to the application of irradiation (5 and 10 kGy) have been observed under the FTIR spectroscopy. Fig. 1A presents the full spectral pattern of the unirradiated and irradiated rice in which the distinct differences in the spectral lines of rice samples were prominent. The FTIR spectra of all the rice samples were compared with the standard starch (Sigma Aldrich) to evaluate the IR pattern of the starch polymeric chain. The spectral region of the functional groups revealed that starch of unirradiated and irradiated rice showed almost a similar pattern without any remarkable changes which indicated that there was not any formation of a new type of chemical bonding. A broad IR band in the range of 3200–3400 cm^{-1} was due to the presence of poly-hydroxyl groups and C–H stretching vibrations were observed at IR band 2800-3000 cm^{-1} (Fig. 1B). In the fingerprint region, there were sharp bands at 1000 cm^{-1} (Fig. 1A) because of C–O bending vibrations and also there were significant spectral changes observed in the remaining region. By analyzing the IR band of a hydroxyl group, it was seen that the transmittance intensities of the spectra decreased and the value were 98.5%, 98%, 96.5%, and 96% for control, 5kGy, standard, and 10 kGy respectively. C–O bonding vibrations showed almost similar intensity patterns like hydroxyl groups and the intensities were 96%, 94%, 90%, 88% for control, 5kGy, 10 kGy, and standard respectively. In the region of 2500–4000 cm^{-1} and 400-1500 cm^{-1}, the transmittance intensities with 10 kGy decreased by the greatest margin as compared to the control rice whereas the changes of 5 kGy were not as prominent as 10 kGy. However, for both samples of 10 and 5 kGy, the variation of intensities had been significant ($p < 0.0001$) compared to the control rice. The results thus point out strong molecular reorganization in 10kGy irradiated rice compared to control and 5kGy rice. Byun et al. (2008) also found similar FTIR patterns and stretching vibrations at the functional group and fingerprint region of β-glucan before and after radiation treatment at 10kGy dose. The different spectral variation could be explained by the double effect of irradiation on starch polymers showing possible degradation of the glycoside bonds (at chain endings) and cross-linking of starch chains under oxygen in rice (Bhat and Karim, 2009). Hebeish et al. (1992) demonstrated that high dose gamma radiation (10–100 kGy at 6 kGy/h) caused significant enhancement of the carbonyl and carboxyl groups in maize and rice starch due to oxidative degradation of starch leading to structural changes brought about by irradiation. Moreover, the selection of radiation dose and dose rate might be considering factor toward diversified effect on the molecular arrangement or modification of rice or other corn starch affecting digestibility. Interestingly, the IR bands of 10kGy were in line with the standard starch (Sigma Aldrich) which indicated that the applied dose was approximately optimal to achieve similar functional characteristics to pure starch.

3.2. Effect of gamma radiation on amylose content of rice

The structural changes in irradiated rice are reflected in rice quality as well as the starch composition: the content of amylose (linear) and amylopectin (branched) glucose polymer. Both free and lipid-complexed amylose is the most important determinant for gelatinization properties and starch digestion leading glycemic index of rice (Frei et al., 2003; Lamberts et al., 2009). The amylose content of starches usually ranges from 15 to 35% with the intermediate (20–25% amylose) and high (25–33% amylose) (IRRI, 1985). The results in the present study on amylose content have been presented as a box plot to show the value range determined on each sample (Fig. 2). The amylose content in the Bangladeshi rice variety BRRI 29 varies from 11.45 to 17.27% collected from several sources ($n = 6$) and the average content found as 15.12 ± 2.4% (g/100 gm) in this study. The application of gamma radiation has a significant effect on the amylose content of rice in a dose-dependent manner. The data showed that amylose content in irradiated (5kGy and 10kGy) rice increased significantly ($p < 0.01$) compared to unirradiated rice as the doses of gamma radiation increased (Fig. 2). Treatment with 10 kGy gamma radiation resulted in the highest amylose content which ranged from 27.75 to 33.63% with an average content of 30.20% (Fig. 2). Such changes in starch glucose polymer after irradiation have been attributed to the splitting or deformation of glycosidic bonds as described by several researchers as reviewed by Bhat and Karim (2009). Studies have also shown that there is a decrease in the crystalline phase content and the distribution order of amylose and amylopectin in starch granules (Ciesla et al., 1991). In the present study, such structural changes induced by gamma radiation have been proved using FTIR. However, few kinds of research on rice from India, China, and Taiwan claimed decreased apparent amylose content of starch with an increase in irradiation dose (Kumar et al., 2017; Sung, 2005; Yu and Wang, 2007). The applied doses in those studies were high (5–20kGy) or low (up to 1kGy) but the dose rate in all cases used was lower (1kGy/h) compared to the present study (9.74 kGy/h). Therefore, it can be assumed that the applied dose rate might be a determinant in the modification of carbohydrate polymers. It has been widely reported that rice with low amylose content is more easily digested due to containing mostly rapidly digestible starch that increases blood sugar level rapidly after consumption and thus low amylose rice is not suitable for diabetic subjects (Riley et al., 2004; Lehmann and Robin, 2007). Whereas the starches with a high amount of amylose have also higher resistant starch due to confrontation to swelling in water and therefore cooked high-amylose rice have slower digestibility as well as nutritional benefits. The amylose content of rice also determines the starch molecular structure controlling the texture and sensory properties of cooked rice. In the present study, the 10kGy rice looked slightly brownish in solid form, however there was no color difference between unirradiated and irradiated rice suspension prepared at 80 °C for glycemic test in vivo as described in another section. It has been found that high-amylose rice varieties tend to have low palatability and fewer consumer preferences (Tao et al., 2019). Whereas rice with a high amount of amylopectin is very gelatinous and sticky once cooked and easily digested producing higher blood glucose levels. Therefore, it can be recommended that high-amylose rice can be used as 'rice flour' to prepare different types of bread, cake, and snacks as dietary management for diabetic subjects. Soong et al. (2015) reported reduced glycemic potency of oat and barley muffins containing greater amylose and fiber content rather than wheat and rice muffin.

3.3. Effect of radiation application on amylose to amylopectin ratio of rice

The ratio of amylose and amylopectin starch is the primary determinant of rice excellence. Both physical and chemical processing alters their ratios as well as digestive and nutritional properties. Therefore, the amylose: amylopectin ratio (Am/Ap) of rice affects the physiological response to blood glucose level (glycemic index). A high value of amylose and amylopectin ratio indicates a low glycemic index. Behall et al. (1989) reported that amylopectin led to a greater increase in blood sugar and insulin levels rather than the amylose effect. The present study observed a significantly higher Am/Ap in irradiated rice compared to the native one (Table 1). The ratios in control, 5kGy, and 10kGy rice are 0.25, 0.51, and 0.81 respectively. Hence, gamma irradiated rice could be beneficial

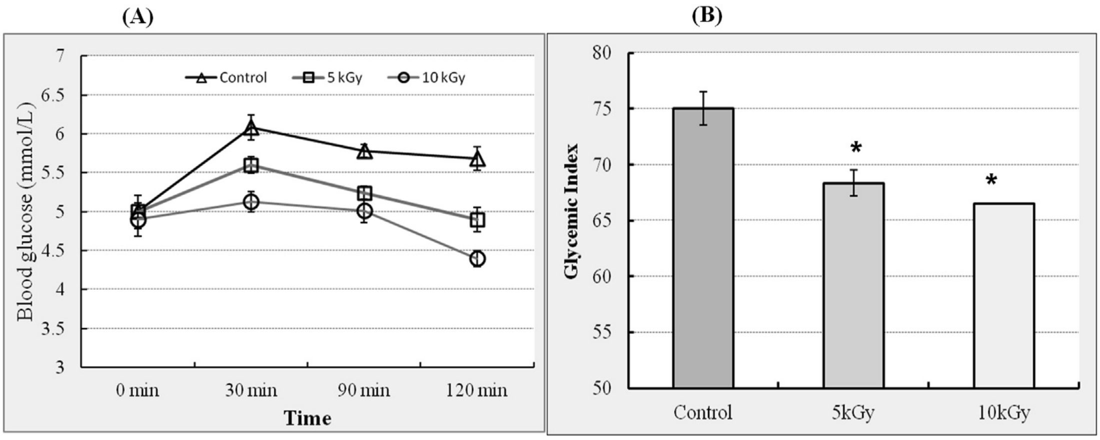

Fig. 3. Effect of irradiated and non-irradiated (control) rice consumption on blood glucose response (A) and glycemic index (B) in healthy Wistar rats ($n = 5$). The *sign indicates significant difference ($p < 0.02$) compared to control (unirradiated) rice GI.

for lowering blood glucose and can be used in the formulation of diets for diabetics. A comparative study on Indian long, medium, and short-grain rice (Dipnaik and Kokare, 2017) reported that long-grain rice had high amylase, low amylopectin content, and higher Am/Ap ratio (1.12) which results in significantly slower in vitro starch digestibility using salivary and pancreatic amylase enzymes. Thus, the ratio of amylose and amylopectin has been established as the indicator affecting the rate and extent of starch hydrolysis and hence the glycemic response of the food. Syahariza et al. (2013) determined the importance of amylose and amylopectin fine structures (degree and distributions of branch chain length) and starch digestibility in cooked rice grains. They found relationships of starch digestion rate with amylose content determined by size exclusion chromatography of cooked rice negatively and with a degree of branched chains positively. However, the observed Am/Ap values indicate the possible potential of gamma irradiated rice achieving low glycemic response as examined in our study in the consecutive section.

3.4. Gamma radiation effect on swelling power and solubility index of rice powders

The physicochemical characteristics like swelling and solubility have a significant role in starch digestibility. The interactions of the starch chains with hot water molecules are assessed by swelling and solubility index and this gelatinization manner is related to the crystalline and amorphous structure of starch molecules (Singh et al., 2004). Exposure of rice sample to gamma irradiation increased the solubility and decreased the swelling power with the increase of irradiation dose (Table 1). The 10kGy rice showed significantly ($p < 0.05$) higher solubility and lower swelling index compared to unirradiated rice. The changes in these physicochemical properties happen due to changes in the molecular organization within the starch granule after radiation treatment. Previous studies conducted on rheology and functional properties of starches isolated from five rice varieties from West Africa (Lawal et al., 2011) and 19 different varieties of Sri Lanka (Wickramasinghe and Noda, 2008) reported that the amylose content to be the foremost factor controlling gelatinization, pasting, turbidity, syneresis, and retrogradation of rice. Such that, low amylose starches gelatinize at lower temperatures and are easily digestible by enzymes. It was also assumed that lower amylose in the amorphous leads to reduced compactness in the starch granules resulting in higher swelling power and disorganization with heating. Sodhi and Singh (2003) suggested an inverse relationship between the amylose content of rice starches and their swelling ability. Among five cultivars grown in India, the rice having the lowest amylose contents (7.8%) had the greatest swelling abilities and those with the highest amylose rice had the lowest swelling ability whereas solubility was found to have a linear relationship with the amylose content. The previous references mentioned supporting the present study results found lower swelling power in gamma irradiated rice which contain higher amylose with a possibility to be less susceptible to gelatinize as well as to digestive enzymes since swelling of starch granules accelerate the enzymes to hydrolyze the starch chain. Swelling and gelatinization activities of wheat barley and maize starches have been found to be a property of their amylopectin content where amylose inhibits swelling, especially as lipid-complex form (Tester and Morrison, 1990). Cai et al. (2015) investigated the molecular structure (amylose content, amylopectin branch-chain content, and amylopectin branching degree) and crystalline structure of 10 normal Chinese rice starches with different amylose contents. They found that the gelatinization temperature and water solubility were significantly positively correlated with amylose content but significantly negatively correlated with amylopectin short branch-chain. In the same way, the swelling power, hydrolysis, and in vitro digestion were significantly positively correlated with short amylopectin chains, their branching degree, and relative crystallinity but significantly negatively correlated with amylose content and lamellar distance.

3.5. Effect of gamma radiation on rice glycemic index (GI)

As we found a significant increment of amylose content in irradiated rice, we expect this biochemical strategy to produce a low glycemic index in vivo. A clinical nutrition study by Miller et al. (1992) determined the glycemic index and insulin index values of 12 rice products ($n = 12$), found that the high amylose rice (28%) gave a lower glycemic as 64 and insulin index as 40 ($P < 0.01$) compared to the normal-amylose (20%) and thus identified the high-amylose rice varieties as potential in low-GI diets. Fig. 3 shows the glycemic index results of the present study. As expected rationally, gamma irradiated rice contributed to a low glycemic index compared to unirradiated rice (GI 75.02). The GI for 5kGy and 10kGy are 68.35 and 66.51 respectively. Thus the rice irradiated at 10kGy containing the highest amylose content (27.93–33.63%) produce significantly lower ($P < 0.05$) blood glucose levels at different time intervals (Fig. 3A) and lowest GI (Fig. 3B) measured in healthy Wister rats. A theory has been established by Syahariza et al. (2013) that amylose-type starch has a more linear flexible structure than amylopectin forming double helices after cooking as a result of retrogradation characteristics, and thus become resistant to amylase enzymatic hydrolysis releasing glucose slowly in blood. However, there was no significant discrepancy between the 5 and 10kGy rice GI. While the variation in amylose and FTIR pattern was thought to produce GI disparity between the irradiated rice, however, the in vitro data has not been reflected in vivo analysis in this case which might be owing to digestive bioavailability differences in experimental rats. Experiments on other country rice varieties found a comparable phenomenon. For instance, Frei et al. (2003) reported that among the six different rice cultivars of the Philippines, varieties with higher amylose content (26.9%) are associated with slower in vitro starch digestibility as well as estimated GI of 68–87.3% compared to those with lower levels of amylose content (9.8%) with higher GI (96.9%). A popular Indian Basmati rice (PB1121) was found to be high amylose (27.26%) variety with a high Am/Ap ratio (0.59), presence of stable amylose-lipid complex observed from the X-ray diffractograms (Kale et al., 2015). It has been suggested that the amylose-lipid complex II are crystallites having high melting temperature (>100 °C) for which degradation of starch becomes slower during digestion (Larsen et al., 2000) and thus the Basmati rice is determined as medium GI (58.41) variety, indicating its importance in diets of diabetics.

Conclusion

Gamma radiation of two doses of 5 and 10 kGy at a dose rate of 9.74 kGy/h altered amylose content, amylose/amylopectin content, swelling power, and solubility index in popular, low price Bangladesh rice variety BRRI Dhan 29. The changed molecular structures due to radiation application were observed through FTIR spectroscopy. The dose 5 and 10kGy caused increased amylose, amylose/amylopectin ratio, decreased swelling, and increased water solubility in rice. These carbohydrate modifications in irradiated rice lead to reduced glycemic index investigated in vivo experiments, suggesting gamma irradiated rice (10kGy) is beneficial for diabetic subjects keeping lower blood glucose levels. However, to acieve the taste and texture attribute of cooked irradiated rice, future human study is needed as public health research. Further study is therefore in consideration toward the effect of the irradiated rice consumption in ameliorating hyperglycemia related physiological disorders in human.

CRediT authorship contribution statement

Mst Afifa khatun: Conceptualization, Investigation, Writing - original draft, Formal analysis. **Md Razzak:** Methodology, Investigation. **Md Afzal hossain:** Methodology, Investigation. **Md Ashikur Rahman:** Investigation. **Ruhul Amin Khan:** Resources. **Roksana Huque:** Resources, Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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