Original Article

Effect of Gamma Irradiation on Shelf Life, Nutritional, and Glycemic Properties of Three Indian Brown Rice Varieties

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Abstract

Brown rice (whole grain, BR) has lower glycemic index (GI), is a healthy replacement for white rice (WR). However, BR has a short shelf life, is susceptible to pest infestation. Gamma irradiation is a safe approach to prevent the latter. This study examines effect of gamma irradiation on the physical, cooking, nutritional, shelf life and glycemic properties of three Indian parboiled BR. Parboiled BR of ADT-43, BPT-5204, and *Swarna* rice varieties were packed in polyester and polypropylene pouches (60 µ thickness) and subjected to gamma irradiation [750–820 Gy] (IR). Appropriate controls without irradiation (NIR) were maintained. Irradiation did not induce major changes in the physical and nutritional properties, except for resistant starch which significantly increased after irradiation in ADT-43 and BPT-5204. Irradiation reduced the cooking time, increased loss of solids in the cooking water and decreased apparent water uptake (particularly in BPT-5204). IR varieties exhibited longer shelf life (8–9 months) compared to 6 months shelf life of NIR varieties. The shelf stability of IR *Swarna* rice was superior in terms of delayed rancidity development compared to all other rice. All BR samples exhibited the ranking of 'like moderately' in the sensory acceptability tests at 6 months of storage and scores decreased subsequently. Irradiation did not affect GI [all showed medium GI, except a high GI for IR BPT 5204] and helped in shelf life extension of parboiled BR by preventing insect infestation.

Keywords: Brown rice, chronic disease, glycemic index, storage, whole grain

Introduction

Healthy eating advocacy from various national and international bodies emphasises consumption of whole grains for prevention of chronic diseases like type 2 diabetes (T2D). Brown rice (BR) is superior to white rice (WR) in terms of higher levels of dietary fibre, proteins, vitamins, minerals and phytochemicals with nutraceutical properties.[1] BR can be a healthier alternative to WR and has been shown to be beneficial in overweight Indians with metabolic syndrome (MS).[2]

Diabetes is increasing in epidemic proportions in India and globally. As of 2021, more than 74 million people are affected with diabetes in India. WR, a carbohydrate rich cereal staple is extensively consumed and provides almost 50–70% daily calories in India.[3,4]Several studies have shown that WR exhibits high glycemic index (GI)[5-7] and glycemic load (GL) which contributes to increased risk of MS, and T2D in the Asians worldwide.[4,8] In addition, genetically, Asian Indians have higher propensity for diabetes and, hence use of such cereal staples could further

Received: 03-August-2022, **Revised:** 14-September-2022, **Accepted:** 15-September-2022, **Published:** 21-December-2022

Access this article online

Quick Response Code:

Website: www.journalofdiabetology.org

DOI: 10.4103/jod.jod_83_22

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How to cite this article: Shanmugam S, Mathiyazhagan J, Parthasarathy V, Jeevan RG, Gayathri R, Karthikeyan P, *et al*. Effect of gamma irradiation on shelf life, nutritional, and glycemic properties of three indian brown rice varieties.J Diabetol 2022;13:368-76.

accentuate the epidemic of diabetes and cardiovascular disease.[9]

Parboiled BR-based diets elicit a lower glycemic response as compared to minimally polished rice as well as WR.[7,10] However, it has poor cooking, sensory[11] and storage properties when compared to WR.[12] BR has intact bran and germ and contains higher levels of fat; therefore, it is more prone to rancidity and insect infestation during harvesting, processing, storage and distribution.[13] To enhance storage life, chemical fumigation is being advocated, but toxic residues may remain after such fumigation.[14] Irradiation is regarded as a superior method for disinfestation of stored commodities including cereals and pulses as compared to thermal and chemical fumigation methods.[15] The World Health Organization (WHO) has reported that no adverse effects of feeding irradiated foods to animals and further concluded that the irradiation of foods in accordance with established good manufacturing practices raises no unresolved questions of safety.[16] Foods like pulses, fruits and vegetables, spices, sea food and animal foods are nowadays being routinely irradiated. Codex Alimentarius Commission and the WHO have adopted standards for irradiation of foods, and these are practiced in more than 42 countries.[17] In India, the Food Safety Standards Authority of India (FSSAI) has issued a guidance note on the safety of irradiated foods (Guidance Note No. 7/2018, FSSAI, https://archive.fssai.gov.in/home/FSSAI-Guidance-Notes.html accessed on 21.5.20) and the regulations on radiation processing have been notified under Food Safety and Standards (Food Products standards and Food Additives) Amendment Regulations, 2016. Irradiation doses of 0.25 to 1KGy and 1.5 to 5.0 Kgy respectively has been recommended by FSSAI for disinfestation and reducing microbial load in cereals and their milled products.[18]

While subjecting BR to gamma irradiation for improving its storage life, it is important to ensure that its glycemic properties are not affected, so that its benefits for the population vulnerable to diabetes are retained. Such studies are scarce in India. Hence, the current study aims to evaluate the effect of gamma irradiation on the physical, nutritional, shelf life, cooking, sensory and glycemic properties of three Indian parboiled BR varieties.

Materials and Methods

Preparation of parboiled brown rice

Certified Indian paddy varieties ADT-43, BPT-5204 and *Swarna* varieties were procured from Texcity Biosciences, Pvt Ltd., Coimbatore, Tamil Nadu, India. These varieties are widely grown across Tamil Nadu; ADT-43 is a short duration crop while BPT 5204 is a long duration crop and have medium slender grain type. *Swarna* is high yielding and known to have lower GI.[19] The paddy varieties were cleaned and soaked in cold water for 20h and steamed for about 20 minutes at atmospheric conditions followed by drying in sun initially followed by shade drying to 14% moisture content.

The dried material was shelled in rubber roll sheller (this method of shelling does not damage the bran layer) to obtain parboiled BR (PBR) availing the facilities at the Indian Institute of Food Processing Technology, Tanjore, India.

Irradiation

Irradiation dosage optimization studies carried out at Food Irradiation Processing Laboratory division, BARC, Mumbai, showed that the rice irradiated at higher doses than 1 KGy became slimy and sticky on cooking. Hence, a dose of 750 to 850Gy (suggested by the irradiation facility which operates in ranges and has to be below 1 KGy) was used to irradiate rice samples using Cobalt^{60} source at Innova Agritech Biopark, Bangalore, Karnataka, India. Rice samples were packed in polyester polypropylene 60µ thickness pouches, heat sealed manually and the packed samples were irradiated (as irradiation is a sterilization process, packed samples were subjected to irradiation). Appropriate controls (without irradiation) were maintained.

Shelf-life testing

Nutrient contents of the samples were determined prior to storage. The samples were stored at ambient conditions and were withdrawn at monthly intervals (until the samples developed rancidity assessed by rancid odor and FFA) and analyzed for moisture and free fatty acid (FFA) content, and examined for pests and rancid odor. Sensory evaluation was carried out on quarterly basis till end of the storage studies which was planned for 1 year (at ambient storage).

Determination of physico-chemical properties

The control (non-irradiated, NIR) and irradiated BR rice (IR) samples were analyzed for physical parameters like length, breadth, L/B ratio, thousand kernel weight, true density and bulk density and evaluated for cooking characteristics, such as minimum cooking time, apparent water uptake, volume expansion and solid loss.[20]

The moisture content was determined by gravimetric method (drying at 130°C for 2 h to constant weight) and the protein, fat and ash contents were determined according to AOAC methods (AOAC 984.13; AOAC 920.39and 923.03 respectively). The FFA content was determined according to IS: 548 (Part I), 1964 [Revised 14th reprint 2007]. Dietary fibre, available carbohydrate and resistant starch (RS) contents were determined using Megazyme kit (Megazyme, Ireland). Amylose content was estimated according to ISO 6647-1:2007 method.

Sensory evaluation of cooked rice samples

Evaluation was conducted at baseline, and third, sixth and ninth month of storage using a 9-point verbal hedonic scale (1 = like extremely to 9 = dislike extremely) method for acceptance of the cooked samples under standard conditions by 15 regular rice consuming panelists. The cooked (30 g) samples, after cooling to room temperature, were given to the panelists on different occasions along with a sensory questionnaire (self-administered) and mean scores for the overall acceptability were considered for data analysis.

Glycemic index testing

The GI study was approved by the institutional ethics committee and further registered with the clinical trials registry of India (REF/2017/12/016372). The study was carried out following the guidelines laid down in the Declaration of Helsinki. Written informed consent was obtained from the panelists prior to participation.

Fifteen healthy volunteers consisting of males and females without diabetes, in the age group of 20-45years were recruited from the volunteer registry of the Glycemic Index Testing Centre at the Madras Diabetes Research Foundation (MDRF), Chennai, India. The GI was determined using internationally recognized GI protocol by FAO/WHO[21] as per the recommended guidelines by international dietary carbohydrate task force for GI methodology[22] and International Standards Organization, 2010; ISO 26642-2010,[23] which have been validated and published elsewhere.[24] Subjects were excluded if the body mass index (BMI) was >23.0 kg/m^2 or >25.0 kg/m^2.[25] Use of any special diets for therapeutic or other purposes, family history of diabetes, chronic illnesses like CVD, hypertension, cancer, etc., pregnancy and lactation, history of food allergy, concurrent use of any medications and fasting blood glucose value >5.6 mmol/L (100 mg/dL) were considered as exclusion criteria. Anthropometric measurements including height, weight and waist circumference were measured in the fasting state using standardized techniques. All the subjects gave written informed consent before participation. Interviewer administered questionnaire to capture 24hr dietary recall and physical activity was administered to the study participants. They were also instructed to follow a similar meal pattern that they usually take on the days prior to the administration of the test foods. They were also requested to refrain from intense physical activity, smoking and consumption of alcohol during the entire study period.

All the rice samples with 1:1.75 rice: water ratio was pressure cooked for 15 min (20 min for *Swarna* variety alone) and served. The serving size was calculated from the available carbohydrate content of the respective cooked PBR. Fifty-five g of dextrose (glucose monohydrate- Glucon-D glucose powder, Heinz India (P) Ltd., Mumbai, India) dissolved in 200 ml of water served as reference food.[22]

Fasting capillary blood samples (after a 10–12 h overnight fast) were taken twice at an interval of less than 5 minutes before consumption of food and the baseline value taken as a mean of these two values. Hemocue 201+ Glucose analyzer (Hemocue Ltd, Sweden) was used as the tool for the measurement of blood sugar. Further, the participants were administered the test food and the first capillary blood sample was taken exactly at 15mins and subsequent samples at 30, 45,60,90 and 120 min. Volunteers were provided with 200 ml of water along with the test food and additional 200 ml was given during the subsequent 2h.

The GI was calculated as the incremental area under the blood glucose response curve of 50g available carbohydrate portion of the test food expressed as a percent of the response to the same amount of carbohydrate from the reference food (glucose) taken by the same volunteer.

Statistical analysis

Statistical analysis was performed using SAS software (version 9.0; SAS Institute, Inc., Cary, NC). The significance of difference between the different rice varieties and between the irradiated and non-irradiated rice samples was tested using ANOVA and independent ‘t’ test respectively. The significance of difference in the overall acceptability scores of NIR and IR rice samples of each variety from baseline and duration of storage and between NIR and IR samples (of each variety) was assessed using independent ‘t’ test. Intra-individual variation of the three reference (glucose) tests was assessed by determining CV%. Participants with more and less than 30% of CV for reference glucose were considered as outliers. Out of 15 participants in the GI study, 3 subjects were removed as outliers. Thus, the data of 12 volunteers were included in the final analysis. One volunteer with CV <30% was removed as outlier for all the test foods, 1 volunteer was removed for irradiated BPT 5204 and ADT43 brown rice test foods and 1 for non-irradiated *Swarna* brown rice test foods and hence were not included in the analysis. Data are shown as means with standard errors. Shapiro–Wilks test revealed normal distribution of the data. The significance of difference in GI of test foods was tested both by Mann-Whitney U test (IR BR vs NIR BR between the same varieties) and ANOVA between different varieties of IR and NIR rice. Using linear regression, the effects of age, sex, BMI and waist circumference on the GI and IAUC were analyzed for the test foods. Statistical significance was set at $p<0.05$.

Individual GI was calculated according to the method recommended by FAO/WHO.[21] The Incremental Area under the Curve (IAUC) of blood glucose for the reference and test food were calculated geometrically using the trapezoid rule, ignoring the area below the fasting baseline.[21,24] The mean and standard errors (SE) of the IAUC for the reference and test food were calculated. GI value was calculated by expressing each subject's IAUC after the test food as a percentage of the same subject's mean reference IAUC. The group mean was the GI of the respective test food.

Results

BR varieties (both IR and NIR forms) differed significantly in physical properties (1000 kernel weight, length, breadth, thickness and bulk density) ($P < 0.001$) [Table 1]. *Swarna* variety had the highest 1000 kernel weight, breadth, thickness and bulk density while ADT 43 was longest and had the highest L/B ratio. Gamma irradiation did not cause any major change in the physical parameters within the BR varieties, except that there was significant reduction in thickness in BPT 5204 variety ($P = 0.001$).

The cooking time ranged between 36 to 39 minutes which decreased to 33 to 37 minutes after irradiation. Significant reduction in cooking time upon irradiation was observed in BPT-5204 and *Swarna* varieties [Table 1]. The differences in apparent water uptake during cooking between the NIR samples of the three varieties were not maintained post irradiation. Similarly, loss of solids during cooking showed significant difference in NIR and IR between different varieties ($P = 0.003$ and $P = 0.01$ respectively) and increased after irradiation.

In the NIR state, the protein content of the rice varieties ranged between 8.4–9.6% which increased after irradiation except *Swarna* variety, and BPT 5204 variety showed the highest protein content (9.45%). Upon irradiation, mineral content increased in ADT 43 and in *Swarna* variety. In the NIR state, *Swarna* rice contained highest available carbohydrate (71.6%) as compared to 70.7 and 71.4% in other two varieties; after irradiation, the content significantly decreased in BPT and *Swarna* varieties while it (non-significantly) increased in ADT 43 variety. Among the rice samples, *Swarna* contained highest dietary fibre (DF) (5%) and the DF content increased in ADT 43 and *Swarna* rice varieties on irradiation. The resistant starch (RS) content ranged from 0.3 to 0.8 g%, it increased by 1.5 to 2.5 fold on irradiation in all three varieties.

The amylose content of the rice varieties ranged between 21–24 g%; however, upon irradiation, the amylose contents decreased in *Swarna*, increased in ADT 43 and remained unaltered in BPT 5204 variety [Table 1].

The moisture and FFA levels and the appearance of insect infestation in the stored NIR and IR brown rice samples are shown in [Figure 1a and b] respectively. The moisture content of the stored samples was well within safe storage levels (10–12.8%) throughout the study period. The FFA content of all the rice varieties both NIR and IR increased after 4 months of storage; the levels varied

Table 1: Physical properties, cooking characteristics and nutrient composition of the control and irradiated parboiled brown rice varieties (mean ± SD)

Parameters	ADT-43		*p*-value	BPT-5204		*p*-value	SWARNA		*p*-value	*p*-value among all varieties	
	NIR	IR		NIR	IR		NIR	IR		NIR	IR
Physical properties											
1000 Kernel weight(g)	14.09±0.34	13.93±0.12	0.467	12.66±0.10	12.74±0.13	0.576	15.87±0.07	15.96±0.07	0.003	<0.001	<0.001
Length(mm)	5.9±0.07	5.92±0.08	0.748	5.38±0.08	5.46±0.11	0.178	5.4±0.1	5.42±0.08	0.704	<0.001	<0.001
Breadth(mm)	1.88±0.08	1.98±0.08	0.141	1.88±0.08	1.86±0.11	0.748	2.14±0.05	2.16±0.05	0.621	<0.001	<0.001
L/B Ratio	3.14±0.159	2.99±0.140	0.261	2.86±0.163	2.94±0.234	0.513	2.52±0.094	2.51±0.085	0.766	<0.001	<0.001
Thickness (mm)	1.59±0.05	1.58±0.06	0.238	1.58±0.05	1.55±0.04	0.001	1.68±0.05	1.69±0.04	0.337	<0.001	<0.001
Bulk Density(g/ml)	0.847±0.008	0.849±0.003	0.729	0.847±0.002	0.846±0.008	0.885	0.898±0.005	0.897±0.009	0.944	<0.001	<0.001
Cooking characteristics											
Cooking time (min)	37.3±0.20	36.8±0.1	0.082	35.6±0.2	33.4±0.26	0.002	39.1±0.81	36.7±0.1	0.031	<0.001	<0.001
Apparent water uptake during cooking (g/g)	4.8±0.1	4.7±0.1	0.225	5.2±0.1	4.6±0.1	0.009	4.5±0.1	4.6±0.1	0.225	<0.001	0.421
Loss of solids during cooking (%)	2.26±0.05	2.33±0.05	0.296	2.13±0.05	2.26±0.05	0.05	2.03±0.05	2.43±0.05	0.020	0.003	0.01
Nutrient composition (g/100g)											
Protein (g%)	8.56±0.19	8.66±0.11	0.5	9.45±0.22	9.64±0.17	0.1	8.55±0.13	8.41±0.11	0.38	0.001	<0.001
Fat (g%)	2.7±0.17	2.35±0.16	0.19	2.42±0.18	2.47±0.14	0.77	2.95±0.13	3.23±0.12	0.001	0.01	<0.001
Ash (g%)	1.38±0.01	1.54±0.02	0.001	1.31±0.01	1.30±0.01	$	1.32±0.01	1.45±0.02	0.005	<0.001	<0.001
Amylose (g%)	21.23±0.16	22.52±0.24	0.005	21.37±0.18	21.37±0.25	0.98	24.18±0.11	22.43±0.19	<0.001	<0.001	0.001
Available carbohydrate (g%)	70.68±0.23	71.23±0.14	0.06	71.44±0.10	71.07±0.16	0.008	71.56±0.21	70.88±0.15	0.006	0.002	0.07
Total dietary fibre (g%)	4.81±0.13	4.86±0.24	0.83	4.79±0.06	4.29±0.20	0.07	5.16±0.12	5.26±0.10	0.19	0.009	0.002
Resistant starch (g%)	0.32±0.09	0.81±0.16	0.02	0.36±0.12	0.59±0.10	0.03	0.48±0.01	0.73±0.17	0.14	0.155	0.27

$ No statistics were computed

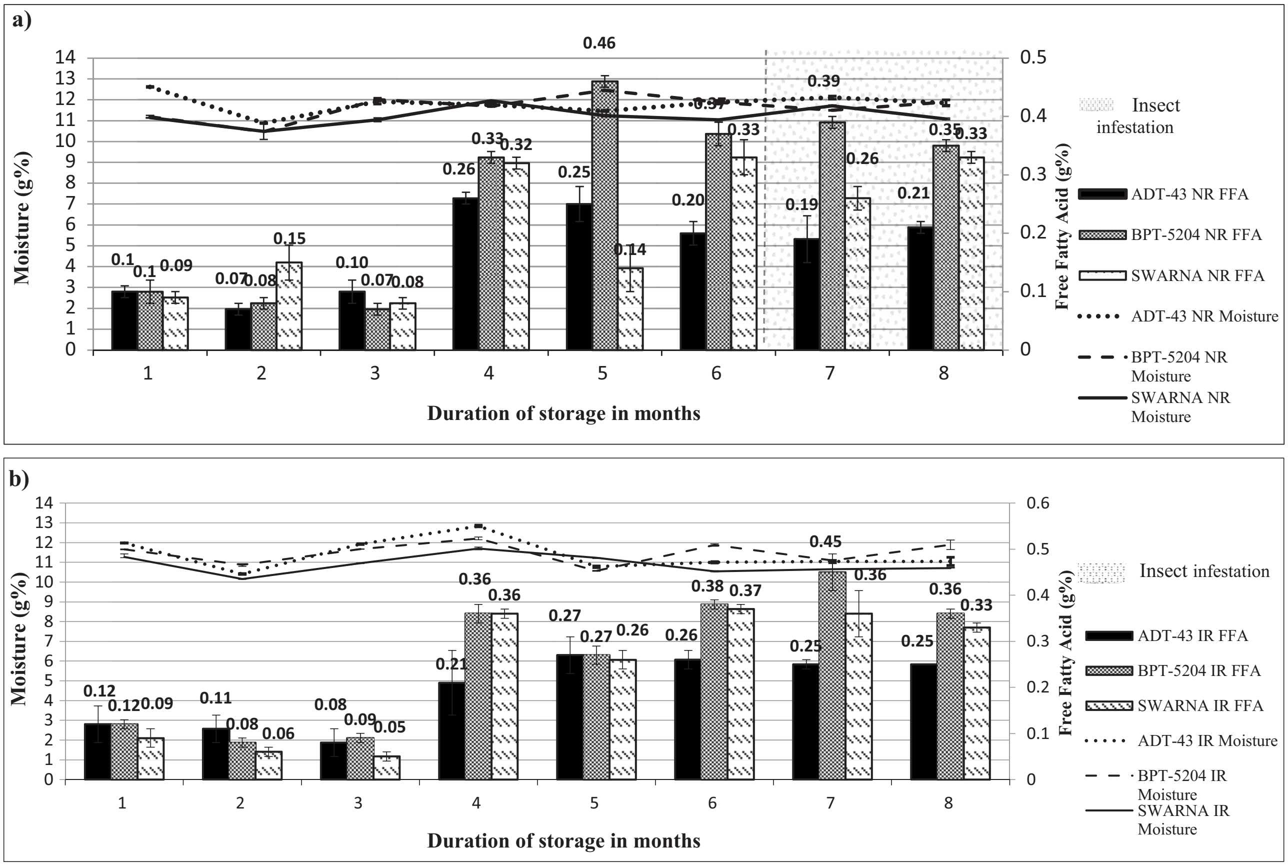

Figure 1: Effect of gamma irradiation and storage on the shelflife properties (moisture, free fatty acid, pest infestation) a). Control (NIR) brown rice varieties. b). Irradiated (IR) brown rice varieties

between varieties, the values fluctuated and did not show a consistent increase with storage time. *Sitophilus oryzae* (rice weevil storage pest) was noticed in NIR samples in the 7th monthofstorage, whereas the IR samples were free from insect infestation during the storage period. Rancid odor started appearing in all the NIR samples after 6th month of storage and the intensity was severe during the 8thmonth of storage. In contrast, the IR samples showed rancidity only in the 8thmonth of storage (IR ADT and BPT 5204) and the 9th month of storage (*Swarna* variety). The sensory acceptability scores are shown in [Table 2]. The sensory evaluation of the cooked rice samples showed that the overall acceptability was of "like moderately" category till 6thmonth of storage (for IR and NIR samples of all rice varieties). The study indicated that irradiation did not affect the overall acceptability of the cooked rice at baseline. The sensory acceptability of all the rice samples was comparable till 3 months of storage, however, the scores started dropping after 6 months for all the samples (scores showed "like slightly" category) except in IR *Swarna* (which remained in the "like moderately" category). The scores at 8 months of storage were in the "dislike slightly" and "neither like nor dislike" category, except for IR *Swarna* which only dropped into the "like slightly" category. The storage study was terminated after 9 months of storage as all the samples were rancid. The storage study indicated that the IR samples of ADT 43 and BPT 5204 could be stored for 8 months packed in polyester polypropylene 60 µ thickness pouches at ambient conditions, while IR *Swarna* could be stored in the aforementioned storage conditions for 9 months.

Glycemic properties

The GI values of the plain cooked BR are shown in [Table 3] and [Figure 2a, b and c]. Both NIR and IR varieties fall in medium GI except IR BPT 5204(GI=72), which fell in high GI category. The GI of all the NIR varieties ranged from 67 to 69. Among IR varieties (GI ranged from 68 to 72), ADT 43 showed the least (GI= 68) and BPT 5204 showed the highest value (GI=72). Irradiation did not produce any significant changes to the GI of any of the rice varieties. The GI values were not influenced by age, sex, diet and physical activity level of participants.

Discussion

The study reports for the first time, the changes in physical, cooking and nutritional properties, shelf life and glycemic properties of three Indian parboiled BR varieties following irradiation. We show that irradiation is not associated with any significant changes in physical properties, nutritional values and glycemic properties in any of the three BR

Table 2: Development of rancidity and sensory acceptability (overall acceptability score) in the control (NIR) and irradiated (IR) parboiled brown rice samples during storage

Brown rice varieties	Baseline	Duration of storage in months							
		1st MConth	2nd Month	3rd Month	4th Month	5th Month	6th Month	7th Month	8th Month
Rancidity									
ADT-43 NIR	X	X	X	X	X	X	✓	✓	✓
ADT-43 IR	X	X	X	X	X	X	X	X	✓
BPT-5204 NIR	X	X	X	X	X	X	✓	✓	✓
BPT-5204 IR	X	X	X	X	X	X	X	X	✓
SWARNA NIR	X	X	X	X	X	X	✓	✓	✓
SWARNA IR*	X	X	X	X	X	X	X	X	X
Overall sensory acceptability									
ADT-43 NIR	7.3±0.97$	-	-	7.2±1.15	-	-	6.1±0.75	-	4.5±0.7$
ADT-43 IR	7.2±0.95@	-	-	7.0±1.46	-	-	6.6±1.09	-	5.5±0.8@
BPT-5204 NIR	7.1±1.08*	-	-	7.0±0.53	-	-	6.0±0.98	-	4.7±0.7*
BPT-5204 IR	7.0±1.89^	-	-	7.0±0.95	-	-	6.7±1.32	-	5.2±0.7^
SWARNA NIR	7.4±2.1&	-	-	7.3±0.53	-	-	6.5±0.89	-	6.5±0.6&
SWARNA IR	7.2±1.32#	-	-	7.2±0.58	-	-	7.1±1.04	-	6.9±0.7#

X- not rancid, ✓ rancid

#Overall acceptability presented as mean scores ± SE for sensory attributes based on a 9-point hedonic scale (1 = *dislike extremely,* 2 = *dislike very much,* 3 =*Dislike moderately,* 4 = *Dislike slightly,* 5 = *Neither like nor dislike,* 6 = *Like slightly,* 7 = *Like moderately,* 8 = *Like very much,* 9 = *like extremely*).

$, @, *,^ P<0.05 significantly lower overall acceptability from baseline and 8 months of storage in ADT 43, BPT 5204 NIR and IR (within each variety, NIR/IR)

&,# P >0.05 non-significant differences in overall acceptability from baseline and 8 months of storage in *Swarna* NIR and IR samples (within NIR/IR)

Table 3: Glycemic Index (GI) [Mean±*SEM] of control and irradiated parboiled brown rice varieties at baseline

Test and reference food	Non-irradiated (NIR) brown rice			Irradiated (IR) brown rice			*P* value NIR Vs IR
	IAUC (mg/dl*min)	Glycemic Index (%) [Mean±SEM]	GI category	IAUC (mg/dl*min)	Glycemic Index (%) [Mean±SEM]	GI category	
Glucose	4925.8±390.3	100		4925.8±390.3	100		
ADT43	3450.4±344.6	67.3±6.0	Medium	3713.9±359.8	67.7±6.1	Medium	0.928
BPT5204	3468.5±286.9	67.4±4.6	Medium	3889.9±305.4	72.0±5.0	High	0.740
SWARNA	3492.1±229.2	68.8±8.6	Medium	3713.9±359.8	68.9±5.1	Medium	0.786
#Between varieties p Value	0.781	0.983		0.652	0.916		

*The significance of difference between NIR and IR GI of same variety of rice tested using Mann-Whitney U test

#The significance of difference between different varieties of either NIR and IR rice varieties were tested using ANOVA

*SEM: Standard Error of Mean

varieties studies. However, we did observe minor changes such as reduction in the cooking time, loss of solids in the cooking water and decreased apparent water uptake (particularly in BPT-5204). Irradiation prevented insect infestation and improved the shelf life of parboiled BR from 6 to 8 months.

Both international and national studies have shown that the wholegrain consumption provide various health benefits including diabetes risk reduction.[2] Earlier studies have proved the advantage of using BR over WR.[13] Mohan *et al.*,[10] and Shobana *et al.*,[7] demonstrated that parboiled BR showed lower GI and rice-based diets prepared out of it showed lower day long glycemic response as compared to parboiled WR. However, widespread adoption of BR in the Asian Indian diet is hampered not only by consumer perceptions involving sensory and cooking properties of BR such as prolonged cooking time and chewy texture but practical considerations such as also poor shelf life and proneness to rancidity.

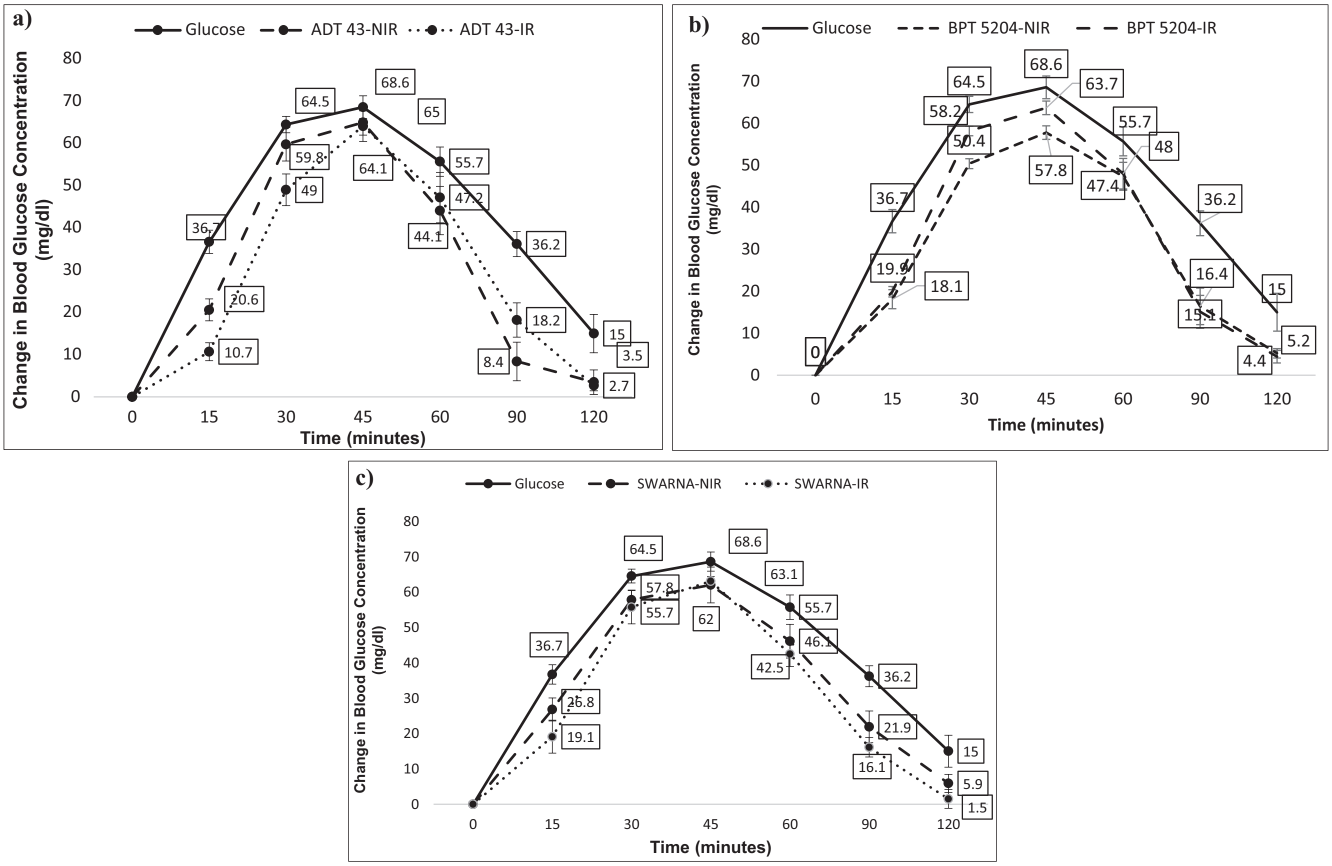

Figure 2: Mean change in glycemic response of control (NIR) and irradiated (IR) brown rice varieties. a). ADT 43. b). BPT 5204. c). Swarna

Radiation technology is a physical, safe, environmentally clean, non-invasive, economic and efficient technology and can be applied to wide range of food products.[17] Radiation interferes with the development of reproductive organs, and affects reproduction of insects[26] and destroys micro-organisms by damaging the cell membrane, metabolic enzymes, DNA and RNA thereby retarding growth and replication. Irradiation is, therefore, an attractive option for improving the shelf-life of food products including BR varieties.

However, if irradiation were to adversely affect the glycemic and nutritional profile of BR, the whole purpose of the exercise would be defeated. Our findings are therefore of importance as they show that irradiation is not associated with any significant differences in the physical and nutritional properties of BR.

We show a small but significant decrease in cooking time for *Swarna* and BPT-5204 varieties following irradiation. Sabularse *et al.*,[27] reported a similar decrease (1–2 min) for raw BR irradiated at 1 KGy and attributed the reduction to the disruption of grain matrix during irradiation. Reduction of cooking time is a desirable change since it can improve the acceptability of BR among consumers.

Our results show no increase in water uptake of grains following irradiation, except for the BPT 5204 variety. Increased water uptake in IR BPT 5204 could probably attributed to the varietal effect (BPT 5204 developed fissures in the grains after parboiling in contrast to other varieties with the same method of parboiling) and consequences of irradiation.

Our results show that at the irradiation doses used (750–820 KGy), there was no major change in the solid content of BR varieties. Increased solid loss from BR with increasing irradiation dose in BR has been observed by Sabularse *et al.*,[27] who attributed this feature to the degradation/modification of amylose and amylopectin constituents as well as rice grain structure, which in turn aid in the release of grain components such as soluble starch and proteins in cooking water. It is possible that the lower doses of irradiation used in our study led to less disruption of the grain matrix, thereby leading to less loss of solids. Gamma radiation at 5 and 10 kGy of Bangladesh rice variety BRRI Dhan 29 caused decreased swelling and increased water solubility in rice powder.[28]

Following irradiation, there was a significant decrease in available carbohydrates in BPT 5204 and *Swarna* varieties with non-significant differences in the dietary fibre contents. There was also a significant increase in RS contents of BPT 5204 and ADT 43 varieties; this could be attributed to effect of gamma irradiation on the carbohydrates constituents leading to interconversion of available to non-available carbohydrates (dietary fibre and resistant starch). Similar results have been reported by Shu *et al.*,.[29] Sabularse *et al.*,[30] reported a lower level of damaged starch with 1 KGy irradiated BR as compared to control and attributed it to the formation of gluco-amylase and amylase resistant starch due to molecular rearrangements in starch after irradiation. This may be the reason for increase in RS content observed in our present study. Khatun *et al*,[28] treated Bangladesh rice variety BRRI Dhan 29 with a dose of 5 and 10kGy and reported increased amylose and amylose/amylopectin ratio significantly which will be beneficial for diabetic subjects by keeping blood glucose levels lower.

Development of rancidity is a major problem during storage of rice. Parboiled rice seems to be more susceptible to this phenomenon, possibly on account of disruption of fat globules within the rice grain during the process of parboiling. This fat is exposed to atmospheric oxygen and gets oxidized, contributing to the rancid odor (oxidative rancidity). Hydrolysis of fat by insect lipases (following infestation) can also lead to rancidity. Rancidity affects the sensory properties of rice and reduces consumer acceptability. Our results show that IR varieties of brown rice were less prone to develop rancidity than the NIR varieties, and were therefore associated with better sensory perception among consumers. While two of the IR varieties did develop rancidity, this occurred much later than with the NIR varieties and could be attributed to oxidative rancidity rather than infestation-mediated effects. Use of a laminate packaging material with good gas barrier properties which is compatible with the appropriate level of gamma irradiation may help to improve the shelf life of IR BR further. The extended shelf life of the third IR variety (*Swarna*) is interesting and deserving of further study.

An irradiation dose of 0.25 to 1KGy and 1.5 to 5.0 KGy has been recommended by FSSAI for disinfestation and reducing microbial load in cereals and their milled products respectively.[18] The insecticidal properties of irradiation are well established, and it has been reported that for complete destruction of *Sitophilus oryzae* is achieved with 16 krad,[26] at 1 KGy[31] and at 0.5 KGy.[32] However, for microbial decontamination, irradiation doses higher than1KGy may be required which may affect the sensory and physico-chemical attributes of rice. Our results are therefore of interest as they show that pest infestation can be prevented, at least for time periods corresponding to the duration of our study, using much lower doses of irradiation.

As our population has traditionally consumed WR, the sensory acceptability scores of BR even at baseline were no higher than the "like moderately" category. Reasons for such low scores could be the chewy texture, dull color and typical sensory properties of BR. The decrease in the scores in stored samples are expected, and could be attributed to the biochemical and oxidative changes to the fat components in storage, packaging material (which provides barrier from the environment) and storage conditions (room temperature storage). The IR BR samples, however, retained these scores for longer than the NIR samples, probably on account of lower propensity for development of rancidity. Even among the IR varieties, *Swarna* parboiled brown rice had higher acceptability scores at baseline and throughout the study. More studies are required with different irradiation dosage, packing and storage conditions to arrive at optimal conditions for preserving parboiled BR with superior properties.

There are some limitations to the study. The study did not employ different doses of irradiation, packaging laminates and storage conditions so as to determine the minimal dose of irradiation and other optimal conditions to preserve parboiled BR with superior nutritional and glycemic properties.

Conclusions

Gamma irradiation at a dose of 750–820 Gy did not show major changes in the physical properties of parboiled ADT-43, BPT 5204 and *Swarna* variety BR packed in polyester and polypropylene (60 µ) pouches. Irradiation prevented insect infestation and delayed rancidity and did not cause a significant change in GI. More studies on the methods of parboiling, irradiation dosage and alternate packaging options are required to determine the optimal conditions and to extend the shelf-life stability of parboiled BR without affecting its unique nutritional, sensory and glycemic properties. Long shelf life is of great benefit for public distribution of rice through government channels.

Acknowledgment

The authors thank the Board of Research in Nuclear Sciences (BRNS), Government of India, for sponsoring the study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Authors disclosure statements

SS and SNJ conceived the concept and designed the study. SS and MJ conducted the parboiling studies and packing of the rice samples. MJ carried out the irradiation, nutrient analysis and shelf-life testing. PV and RG coordinated the GI testing. PV, PB and PK carried out the statistical analysis. RG guided the nutritional analysis. SS, SNJ, NGM and VS interpreted the study findings and

SS drafted the manuscript. SNJ, VS, NGM, KK, RGJ, RMA, UR, VM reviewed the manuscript and helped in finalization of the manuscript. All authors declare that they do not have any conflict of interest.

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