Original Article

Effect of Gamma Irradiation on the 24-h Glycemic Responses of Parboiled Brown Rice Diets in Asian Indian Adults: A Randomized Cross-over Study

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Abstract

Background: The nutritional importance of brown rice (BR) is well established. Despite several nutritional benefits of BR, its consumption remains limited due to long cooking time and limited shelf-life. BR can be subjected to processing to improve shelf-life. Gamma irradiation is one such strategy, but it could induce changes in the grain and thus affect its glycemic properties. **Aims and objectives:** The aim of this study was to look at the 24-h glycemic response of irradiated and non-irradiated BR-based iso-caloric diets in Asian Indians. **Methods:** Fifteen (mean body mass index: 24 ± 2.6 kg/m^2) Asian Indian adults without diabetes, aged 25–39 years, participated in this randomized cross-over study. Iso-caloric diets were prepared with two varieties (ADT 43 and *Swarna*) of parboiled gamma-irradiated brown rice with 750–820 Gy dosage (IBR) and non-irradiated brown rice (NIBR). After the participants consumed these diets, 24-h glycemic responses were recorded using a continuous glucose monitoring system. The mean positive change from baseline glucose concentration was calculated as the incremental area under the curve (IAUC) for both the diets. **Results:** The percentage difference in 24-h average IAUC was 10% lower in the IBR diets when compared with NIBR diets, irrespective of the variety of BR (P = 0.56). In the case of ADT 43 rice variety, both IBR and NIBR diets showed similar IAUC (P = 0.68). However, the IBR of *Swarna* rice variety showed 21% lower IAUC when compared with the NIBR diet (P = 0.21). Comparing the IBR varieties, *Swarna* showed 21% lower IAUC than ADT 43 (P = 0.21), whereas between NIBR varieties, only 0.79% difference was observed between ADT 43 and *Swarna* (P = 0.93). **Conclusions:** Gamma irradiation of parboiled BR did not produce significant differences in the 24-h glycemic responses for BR-based diets. *Swarna* variety was better than ADT 43 with regard to glycemic response. Judicious application of radiation technology to BR varieties may help in shelf-life extension without affecting the glycemic properties.

Keywords: Brown rice, continuous glucose monitoring, gamma irradiation, glycemic response, IAUC, iso-caloric diet

Introduction

There is a rapid rise in diabetes rates in South Asian countries, particularly in India where white rice (WR) is consumed as a staple diet. Owing to the nutritional benefits of brown rice (BR), many urban consumers are willing to replace WR with BR.[1] BR has intact bran and germ constituents and is rich in B vitamins, tocopherols, tocotrienols, minerals, dietary fiber, functional lipids, essential amino acids, phytosterols, and phytochemicals such as phenolic acids, flavonoids, anthocyanins, proanthocyanins, gamma-aminobutyric acid, and

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γ-oryzanol and associated with a wide spectrum of nutrigenomic implications.[2] Phenolic compounds present in the bran are also associated with diverse human health benefits including anti-inflammatory, hypoglycemic, anticarcinogenic, anti-allergenic, and anti-atherosclerotic properties.[3]

Despite its high nutritional value, BR has a shorter shelf-life due to its higher fat content (presence of bran and germ) and also due to the accumulation of free fatty acids during storage in warm and humid conditions. Storage has the greatest effect on lipids and causes change in the metabolites in BR, wherein it is also susceptible to insect infestation, microbial contamination, and oxidative deterioration, thus affecting its quality.[4-6] Many researchers have experimented with different innovative storage technologies for BR such as pulse electric field, cold plasma, high pressure, infrared heating, ultraviolet-C radiation, high temperature fluidization, modified atmosphere packaging, and low temperature.[3] Gamma irradiation has been used as an ideal method for the preservation of rice grains and to reduce crop losses due to insect infestation and microbial damage[7] and has been adopted in several countries including India (FSSAI Guidance Note No. 7/2018).[8] Gamma irradiation is known to affect the physico-chemical properties of BR including cooking quality, amylose content, pasting property, and so on,[7,9-12] which influence the health benefits of BR particularly its glycemic property. Shu *et al.*[13] demonstrated the reduced rate of starch enzymatic hydrolysis and increased resistant starch content following irradiation in rice.

In 2020, according to the International Diabetes Federation, 90 million people in the Southeast Asian region have diabetes and of this, 74.2 million live in India. Slow-digesting foods and foods with high-resistant starch are preferred for population with diabetes as they have a positive impact on the glycemic control.[14] Several epidemiological and intervention studies support BR over WR.[15,16] Our earlier studies have shown that BR-based diets elicit lower 24-h glycemic responses when compared with WR-based diets.[17,18] We have also shown that in BR-based diets through a 3-month intervention study, there was a potential benefit on HbA1c and low-density lipoprotein reduction among participants with the metabolic syndrome and an elevated body mass index (BMI).[15] The physicochemical properties, shelf-life, and glycemic index (GI) of the parboiled BR (both irradiated and non-irradiated) were also assessed (data under publication). There is evidence from both CURES and prospective data (PURE) studies linking WR with type 2 diabetes (T2D).[19,20]

The glycemic properties of rice are influenced by multiple factors. The choice of rice variety and its processing and the form of food, meal composition, and so on influence digestion, absorption, and glycemic response and its associated physiological effects.[18,21-23] However, there are no reports on the glycemic properties of irradiated rice in general and parboiled BR in particular. In the current study, we have evaluated the 24-h glycemic responses of two Indian varieties of the gamma-irradiated parboiled BR-based iso-caloric diets in Asian Indian adults using a continuous glucose monitoring (CGM) system.

Materials and Methods

Study design

This study is a randomized cross-over study. The study protocol is given in Figure 1.

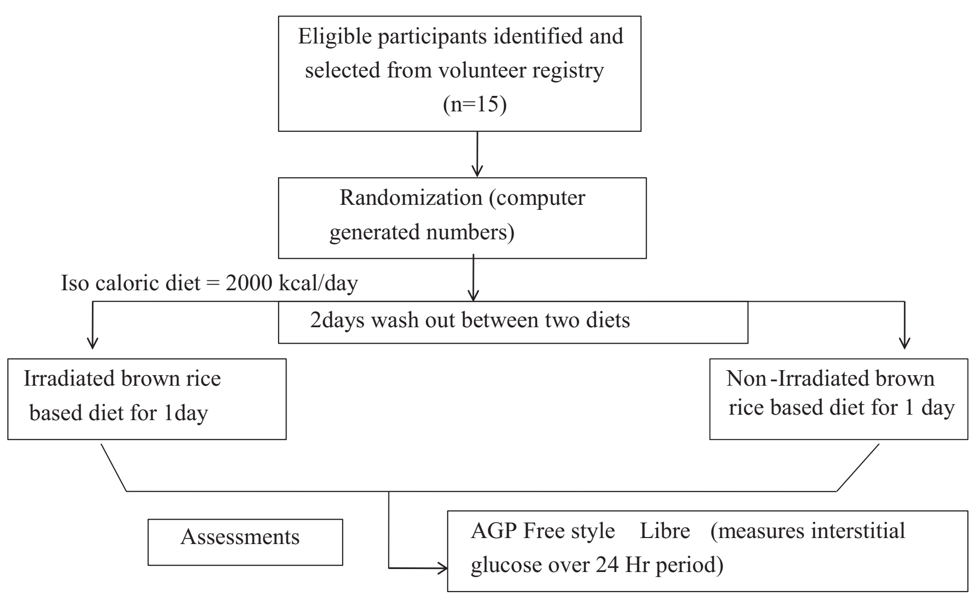

Figure 1: Study protocol

Subjects

Participants from a large volunteer registry maintained at our center were invited to participate in the study. Fifteen participants included both men and women in the age group of 25–45 years (from both the normal and overweight BMI categories) who were willing to participate in the study were screened for matching with inclusion and exclusion criteria. Inclusion criteria included both men and women in the age group of ≥ 25 to ≤ 45 years and willingness to participate. Exclusion criteria included pregnant or lactating women, participants with non-communicable diseases such as diabetes and cardiovascular diseases, and participants under medical therapy or following any special diet or allergic to BR.

Continuous glucose monitoring (CGM) protocol

Free Style Libre Pro Flash glucose monitoring system (an interstitial glucose monitoring system) sensor (pre-calibrated) was inserted on back of the upper arm of the participants. The sensor records the interstitial glucose values every 15 min for 14 continuous days (provides a total of 96 readings per day). Participants were given full details of the study protocol, and written informed consent was obtained from all volunteers prior to participation. The study was approved by the Institution Ethics Committee at Madras Diabetes Research Foundation (MDRF), Chennai, Tamil Nadu, India and further registered with the Clinical Trials Registry of India with the reference no. REF/2017/12/016372. The study was conducted according to the guidelines laid down in the Declaration of Helsinki.

Dietary intervention

Irradiated parboiled brown rice

Certified Indian paddy varieties ADT 43 and *Swarna* rice varieties were procured from Coimbatore, Tamil Nadu, India. The paddy varieties were parboiled by the cold water soaking and steaming method, dried, and shelled in a rubber roll sheller to obtain parboiled BR at the Indian Institute of Food Processing Technology, Thanjavur, Tamil Nadu, India. The BR samples were packed in polyester polypropylene 60 µm thickness pouches and heat-sealed manually and subjected to gamma irradiation using Cobalt^{60} source (at a dose of 750–820 Gy) at Innova Agritech Biopark, Bangalore, Karnataka, India. Non-irradiated BR served as control.

Planning of iso-caloric diet

The participants enrolled for the study were provided with iso-caloric breakfast, lunch, and dinner meals prepared from either irradiated ADT 43 or *Swarna* IR and corresponding NIR BR (control) varieties. All meals were standardized, prepared, and served at the test kitchen of MDRF. The diet menu plans for the control and test diets are shown in Table 1. Meals were prepared in accordance with the Hazard Analysis and Critical Control Point regulations. Dietitians regularly monitored cooking practices, facilities, storage, and dispatch of food. The nutrient composition of the test diets was calculated using EPiNU software [Table 2]. As it can be seen, there is no statistical difference in the nutrient contents between diets prepared using IBR and NIBR.

Participants were instructed to consume only the food and drink provided at the center and were advised to refrain from alcohol intake during the study period. Adherence to the study protocol was determined using 24-h dietary recall collected on both test and control diet feeding days.

Statistical analysis

Statistical analysis was performed using SAS software (version 9.2; SAS Institute, Inc., Cary, NC, USA). Data are presented as means with their confidence interval. The interstitial glucose response of the diets was assessed using the positive incremental area under the curve (IAUC) for both test and control diets. The first 14 readings on each feeding day were used as baseline

Table 1: Irradiated and non-irradiated BR diets menu* plan

Meal and time	Irradiated brown rice (IBR) diet		Non-irradiated brown rice (NIBR) diet	
	Main course and accompaniments	Quantity	Main course and accompaniments	Quantity
Breakfast (8.30–9.30 am)	IBR-*Idly*	250 g	NIBR-*Idly*	250 g
	Onion *Sambar*	130 g	Onion *Sambar*	130 g
	Mint *chutney*	35 g	Mint *chutney*	35 g
	Coffee with milk	120 mL	Coffee with milk	120 mL
Mid-morning (11–12.00 am)	Lemon juice	200 mL	Lemon juice	200 mL
Lunch (1.00–2.00 pm)	IBR *Sambar rice*	300 g	NIBR *Sambar rice*	300 g
	Onion/cucumber *raitha*	50 g	Onion/cucumber *raitha*	50 g
	Papad	5 g	*Papad*	5 g
Mid-evening (4.00–4.30 pm)	Tea with milk	120 mL	Tea with milk	120 mL
Dinner (8.00–9.00 pm)	IBR *dosa*	250 g	NIBR *dosa*	250 g
	Tomato *chutney*	100 g	Tomato *chutney*	100 g
Bed time	Apple	125 g	Apple	125 g

g, grams; mL, milliliters, no., numbers

*The menu was identical on all test days only with the exception of IBR and NIBR used values for IAUC calculation. The positive IAUC for each participant was assessed from the subsequent 82 interstitial glucose readings. The 24-h average IAUC was considered as the primary outcome of this study, based on the interstitial glucose measurements. The IAUC was standardized for missing interstitial glucose readings by dividing the outcome variable (IAUC) with the number of interstitial glucose readings available for each participant. The significant difference between groups, test vs. control diets (IBR vs. NIBR), was tested using the unpaired *t*-test.

Results

The 15 participants included 9 females and 6 males at a mean age of 31 years. Mean BMI was 24 kg/m^2.

Table 2: Average nutrient composition of the iso-caloric control and test diets

Nutrients	IBR-based diet		NIBR-based diet		*P*-value
	Mean	SD	Mean	SD	
Energy (in kcal)	2005	27	1996	7	0.70
Carbohydrate (in g)	348.3	0.5	349.5	0.8	0.21
Carbohydrate (% E)	69.5	1.0	70.0	0.1	0.54
Protein (in g)	57.1	0.4	56.9	0.3	0.60
Protein (% E)	11.4	0.2	11.4	0.0	0.98
Fat (in g)	23.5	1.2	23.8	0.1	0.83
Fat (% E)	10.6	0.4	10.7	0	0.66
Dietary fiber (g per 1000 kcal)	35.0	0.6	35.3	0.1	0.55

Table 3: Metabolic effect of irradiated brown rice (IBR) vs. non-irradiated brown rice (NIBR) (*n* = 15)

Outcome	No. of interstitial glucose observations (no. of participants)	ADT43 IBR	ADT43 NIBR	*Swarna* IBR	*Swarna* NIBR	IBR (ADT 43 and *Swarna*)	NIBR (ADT 43 and *Swarna*)	ADT 43 vs. *Swarna* IBR	ADT 43 vs. *Swarna* NBIR
Daily IAUC (mg-15 min/dL)[a] 24-h mean (95% CI)	69 (*n*=15)	240.8 (153.9, 327.6)	240.4 (143.4, 230.8)	188.3 (141.5, 235.0)	238.5 (163.0, 284.0)	214.5 (169.2, 259.8)	239.5 (207.7, 271.3)		
% Difference		0.2		21		10		21.0	0.79
P-value		0.68		0.21		0.56		0.21	0.93

CI = confidence interval

[a] Daily positive incremental area under the curve (IUAC) was measured using the interstitial glucose concentration from 7:00 am to the next day morning 6:45 am. The average interstitial glucose concentrations between 7:00 and 10:30 am were used as baseline values for IUAC concentration

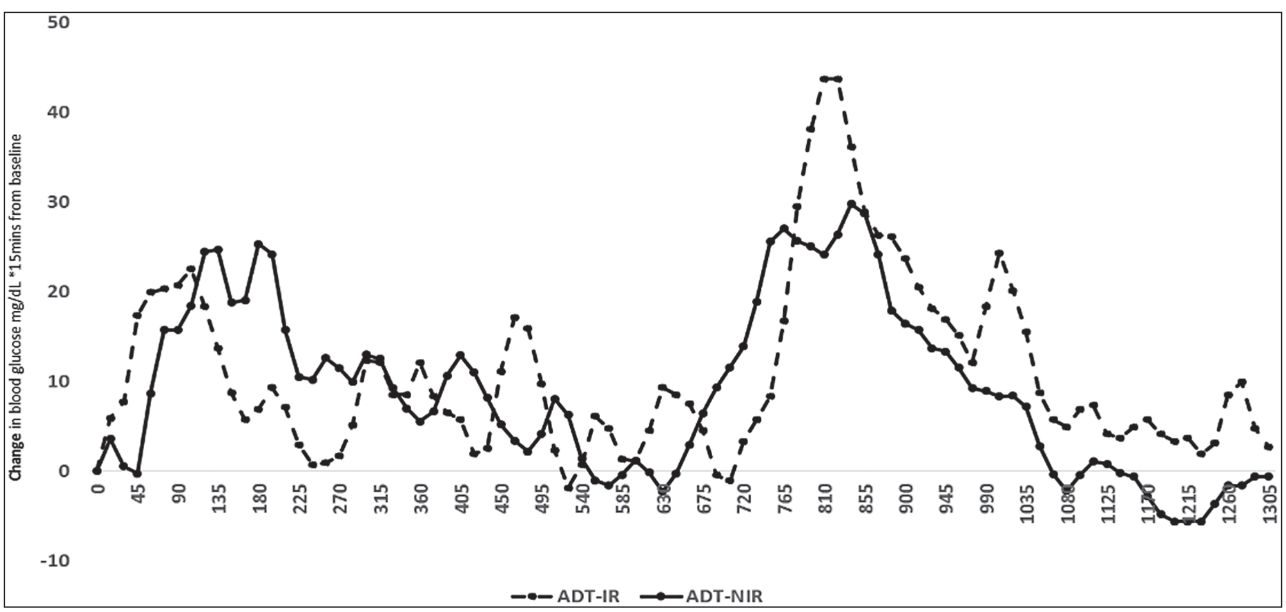

Figure 2: Change in blood glucose concentration observed for ADT 43 IBR vs. NIBR diets

Glucose response

The 24-h average glycemic responses of participants fed with diets prepared with two varieties of IBR and NIBR are presented in Table 3.

The diets prepared with ADT 43 BR whether irradiated or non-irradiated showed non-significant glycemic responses with only 0.2% difference (P = 0.68) [Figure 2]. Diet prepared with irradiated *Swarna* variety BR showed a 21% lower glycemic response (P = 0.21), compared with the diets prepared using non-irradiated *Swarna* variety BR [Figure 3]. Between the two IBR rice varieties, *Swarna* showed a lower IAUC [Figure 4]. Non-significant difference was observed between irradiated ADT 43 vs. *Swarna* BR (P = 0.21) and non-irradiated ADT 43 vs. *Swarna* BR (P = 0.93) [Figure 5]. The average glycemic response of the diet prepared using IBR was 10% lower (P = 0.56) than that of the diet prepared using NIBR, irrespective of the variety of BR used for preparing the diet [Figure 6].

Discussion

This study shows that diets prepared with IBR had statistically insignificant lower glycemic responses compared with NIBR (10% lower in the IBR diets). Non-irradiated versions of both the rice varieties (ADT 43 and *Swarna*) exhibited similar day-long glycemic responses,

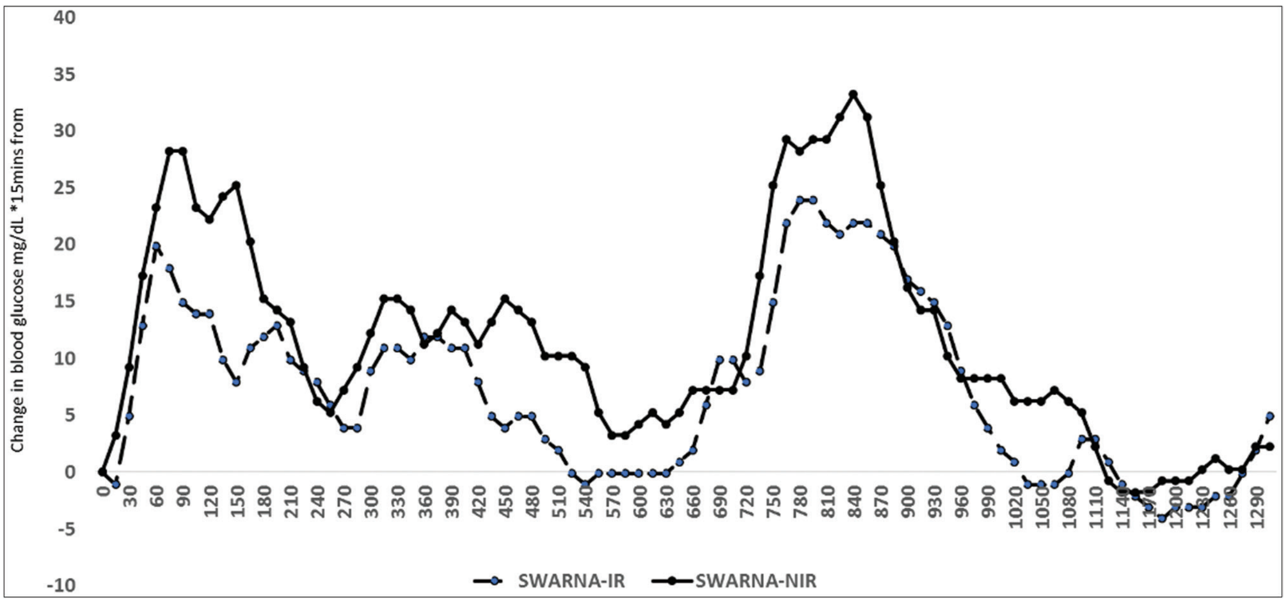

Figure 3: Change in blood glucose concentration observed for *Swarna* IBR vs. NIBR diets

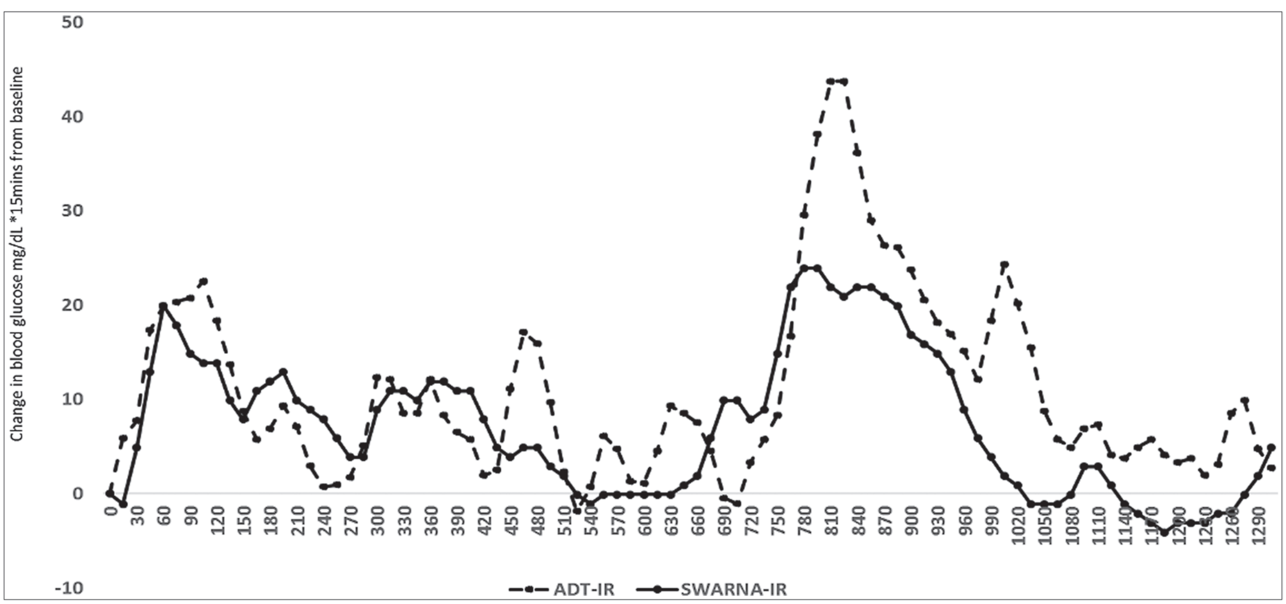

Figure 4: Change in blood glucose concentration observed for ADT 43 IBR vs. *Swarna* IBR diets

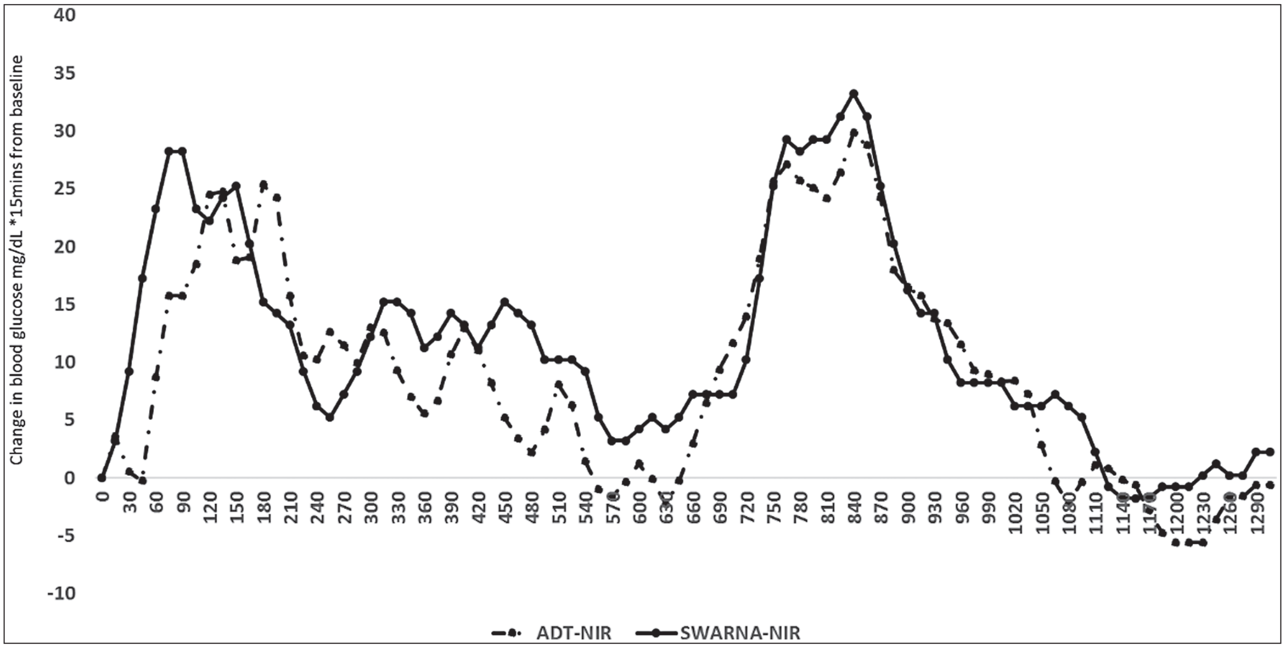

Figure 5: Change in blood glucose concentration observed for ADT 43 NIBR vs. *Swarna* NIBR diets

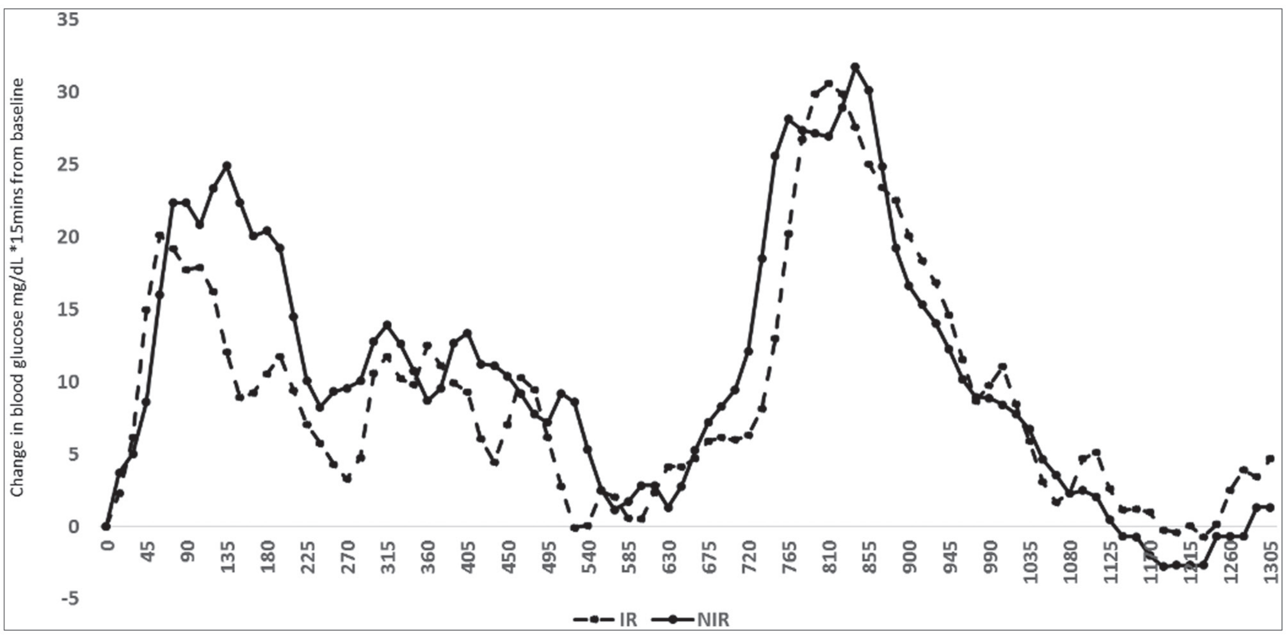

Figure 6: Change in blood glucose concentration observed for IBR vs. NIBR diets

whereas the irradiated versions of the two different rice varieties showed differences (although statistically insignificant). *Swarna* IBR-based diets showed a lower day-long glycemic response when compared with its non-irradiated version (*Swarna* NIBR) but was not statistically significant. Both the versions of ADT 43 variety of rice did not show any difference in the IAUC. These non-statistical differences are consistent with our previous GI studies of the rice varieties, which showed similar GI for the rice varieties taken up for the CGM study (data under publication).

Refined rice/WR is one of the major cereal staples of India, and nearly half of daily energy intake is derived from it. Epidemiological evidence indicates that consumption of WR was positively associated with T2D risk, whereas intake of BR was inversely associated.[15,24] Our previous randomized controlled trials[18] have shown higher 24-h glycemic and insulin responses for minimally polished rice (IAUC= 55.5 mg×5 min/dL) and WR-based diets (IAUC= 58.4 mg×5 min/dL) when compared with BR-based diets (IAUC= 34.7 mg×5 min/dL). Mohan *et al.*[17] used CGM technology to evaluate the effect of replacing WR with

BR or BR with legumes among obese Asian adults and reported lower 5-day average IAUC values (day-long glycemic response) and fasting serum insulin levels for BR-based diets.

BR is susceptible to insect and microbial infestation and susceptible to rancidity due to its higher fat content and so there is a need for safe and appropriate grain preservation techniques. Gamma irradiation (cold sterilization) is one such and can be an ideal method for preservation of rice to prevent insect infestation and microbial damage[17] and is adopted in several countries including India (FSSAI Guidance Note No. 7/2018).[8] However, gamma irradiation is known to affect the physicochemical properties of rice which may in turn increase the glycemic properties; hence, standardization of appropriate dosage of gamma irradiation is essential in order to preserve BR. Irradiation doses of 0.25–1 and 1.5–5.0 kGy, respectively, have been recommended by the FSSAI for insect disinfestation and reducing microbial load in cereals and their milled products (Radiation Processing of Food, Food Safety, and Standards-Food Products Standards and Food Additives Regulation, 2011).[25]

Parboiling process of BR has a better effect on blood glucose response than WR and BR.[26] During the parboiling process, the crystalline structure of the starch present in rice is transformed into an amorphous form.[27] Irradiation also changes the morphology of starch granules, i.e., alters amylose and amylopectin ratio in a dose-dependent manner.[28] A higher retrogradation in gamma-irradiated wheat starch was reported by Bhat and Karim,[29] and retrograded starch represents a significant source of resistant starch,[30] which is beneficial to T2D. Syahariza *et al.*[31] demonstrated a theory 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 becomes resistant to pancreatic amylase enzymatic hydrolysis releasing glucose slowly in blood. Khatun *et al.*[28] reported an increased amylose and amylose/amylopectin ratio significantly and decreased swelling and increased water solubility in Bangladesh rice variety BRRI Dhan 29 after treatment with 5 and 10 kGy. They also proved by an *in-vivo* experiment that this carbohydrate amendment leads to reduced GI.

In the present study, parboiled rice subjected to irradiation was used for the preparation of diet to evaluate the effect of irradiation on 24-h glycemic response. We have evaluated the effect of this dosage of irradiation on the nutritional, shelf-life, and glycemic properties of the parboiled BR used in this study (ADT 43 and *Swarna*), which indicated that this dosage caused non-significant differences in the nutritional and glycemic properties while prevented insect infestation (data under publication). The non-significant differences in the GI before and after irradiation corroborate with the current study findings of non-significant differences in the day-long glycemic response.

Thus, gamma irradiation can increase the shelf-life of BR without altering its glycemic properties. Strengths of this study include that this is the first study to demonstrate the day-long glycemic response of irradiated and non-irradiated parboiled Indian BR-based diets. The limitation of this study was not evaluating the effect of gamma irradiation on the day-long glycemic responses for the raw version of these BR varieties due to budgetary constraints.

Conclusion

The present study demonstrates that gamma irradiation (at the level of 750–820 Gy to parboiled BR, of both ADT43 and *Swarna* varieties) does not significantly alter the day-long glycemic response to BR-based diets. Processing of BR with irradiation technology can help in its preservation; gamma irradiation at lower dose can be utilized for the preservation of BR without affecting its glycemic properties. More studies with different levels of gamma irradiation on different varieties of BR can help to device irradiation protocols for the preservation of BR without affecting its glycemic properties. This would help to overcome the poor shelf-life issues of BR, which remains to be one of the important hurdles in popularization of BR in India, where WR (a major contributor of glycemic load of diets) is commonly consumed. This study can help to popularize BR as a healthy replacement choice for WR in this vulnerable Asian Indian population, which is currently facing an epidemic of T2D.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Authors' contribution

No competing financial interests exist. VM, VS, and SS conceived the concept. SS and MJ prepared irradiated parboiled brown rice under the guidance of SNJ. VS designed the intervention study and RG conducted the feeding trial. SS initiated the first draft of the manuscript and VS and SS interpreted the results. All authors contributed to the revision and finalization of the manuscript.

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