ORIGINAL ARTICLE

Glycemic Index of a Novel High-Fiber White Rice Variety Developed in India—A Randomized Control Trial Study

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Abstract

Background: White rice, a common Indian staple, has a high glycemic response and is associated with high risk of type 2 diabetes. The aim of this study was to compare the Glycemic Index (GI) of a newly developed high-fiber white rice (HFWR) with that of commercial white rice (WR).

Materials and Methods: HFWR was developed using biochemical screening approaches and classical plant breeding techniques. The GI of HFWR was determined using a validated protocol in 30 healthy participants in the year 2013 and repeated in a subsample of 15 participants in the year 2014; the results were compared with the value for WR. The incremental area under the curve was calculated geometrically by applying the trapezoid rule for both reference food (glucose) and the test foods (HFWR and WR). Proximate principles along with dietary fiber, resistant starch, and amylose content were analyzed using standardized methods.

Results: The dietary fiber content of HFWR was fivefold higher (8.0 ± 0.1 vs. 1.58 ± 0.17 g%), resistant starch content was 6.5-fold higher (3.9 ± 0.2 vs. 0.6 ± 0.03 g%) ($P < 0.001$), and amylose content was significantly higher (32.8 ± 1.1 vs. 26.0 ± 0.2 g%) ($P < 0.001$), compared with WR. HFWR was found to be of medium GI (61.3 ± 2.8), whereas WR was of high GI (79.2 ± 4.8). Overall, HFWR had 23% lower GI compared with WR ($P = 0.002$).

Conclusions: The new HFWR variety can be considered as a potentially healthier alternative to commercial WR in rice-eating populations, on account of its lower GI and high fiber content.

Introduction

NONCOMMUNICABLE DISEASES SUCH AS type 2 diabetes and cardiovascular disease currently represent the leading cause of morbidity and mortality throughout the world, including developing countries, where communicable diseases had hitherto held sway.¹ The explosive increase in noncommunicable diseases in developing countries has been attributed to changes in diet and physical activity levels wrought by economic development, industrialization, and

urbanization.² Among dietary factors, the role of dietary carbohydrates, particularly the quantity and quality of the staple cereal, has received widespread attention with respect to risk of noncommunicable diseases.

The Glycemic Index (GI) of a food (reflecting the relative rate of digestibility of the available carbohydrates of the food compared with a reference food [usually glucose])⁴ is an important measure of the quality of carbohydrate.⁵ Diets high in GI have been shown to increase the risk for chronic diseases like cardiovascular disease and type 2 diabetes because

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of their impact on blood glucose and insulin levels.^{6,7} In contrast, low GI diets have several health benefits such as decreasing plasma glucose levels, plasma insulin demand, and levels of inflammatory markers.^{8–10}

Rice (*Oryza sativa*) is the staple food of more than half of the world's population (mainly the Asia Pacific region and some parts of the Americas and Africa) and provides 20% of the world's dietary calorie supply.¹¹ Most of the rice consumed today is in the form of refined white rice (WR), which consists almost wholly of the endosperm (90% starch) and is virtually devoid of bran and germ,¹² with less than 1% dietary fiber (DF).¹³ Use of high GI refined WR^{14,15} has been shown to be associated with the metabolic syndrome and type 2 diabetes in cross-sectional and longitudinal studies in several western and Asian populations.^{16–19}

Use of whole grains such as brown rice, which contains not only more DF but also micro- and phytonutrients, would appear to be a healthier alternative to reduce the glycemic response and thus the risk of type 2 diabetes and other non-communicable diseases.^{2,8} Unfortunately, consumer awareness regarding the health benefits of brown rice is low, and it suffers from certain limitations like poor shelf life, longer cooking time, and poor sensory attributes compared with WR.^{20,21} Therefore development of a rice variety with high amounts of DF and lower GI, but retaining the consumer-friendly characteristics of WR, is the need of the hour.

We therefore attempted, in collaboration with agricultural scientists from South India, to identify WR varieties with improved glycemic profiles using advances in agriculture and biotechnology. Our efforts have culminated in the discovery of a novel high-fiber WR (HFWR) variety with improved nutritional and glycemic properties. The present study reports on the GI of the HFWR and compares it with that of commercially available WR.

Materials and Methods

Development of a new high-fiber rice variety

The high-fiber rice variety was developed after 5 years of research by using classical “marker assisted” plant breeding for introgression of various mutations and biochemical screening approaches, and a patent for the methodology used to prepare the rice has been applied for (application number 3126/CHE/2013). The popular South Indian rice variety *Ponni* was chosen as the starting point. The breeding program did not involve the use of genetic engineering/gene transformation technologies. We tried to increase the DF by raising the nondigestible starch (resistant starch [RS]) content of rice grains, through structural modification of amylopectin by deploying a set of induced mutations leading to down-regulation of enzymes necessary for chain length extension of amylopectin in the rice endosperm. The resulting enhancement of DF mainly as RS was unaffected by subsequent polishing and also did not affect the cooking quality.

The HFWR was also tested over three seasons across three location to assess the variability of RS content due to soil conditions and agricultural practices, and no significant differences were found in its composition. The GI of HFWR was tested during two different harvest periods—after the first harvest (*Kharif*) in 2013 and after the second harvest (*Rabi*) in 2014. The commercial WR used as a control was of the *Ponni* rice lineage during both the GI studies.

Food composition analysis

The macronutrient composition and available carbohydrate content were determined in triplicates using the 2000 AACC standard²² and enzymatic kit methods (Megazyme International, Bray, County Wicklow, Ireland), respectively. The amylose content was measured using the International Organization for Standardization ISO 6647 method.²³ The RS content was estimated using the Megazyme kit method (adapted from the 2002 AOAC standard).²⁴ The total DF was estimated using the AOAC 991.43 standard.²⁵

Participants

Thirty healthy volunteers between 18 and 45 years of age were recruited from the volunteer registry for the GI study of HFWR in 2013. In the year 2014, GI testing of the second harvest HFWR was done in a subsample of 15 healthy volunteers. A randomized controlled crossover study design was used in both the trials. Participants were excluded if they were under-/overweight, not willing to participate in the study, or on any special diet, had any family history of diabetes, were suffering from acute or chronic illness, had any food allergies, or were on any medications (Fig. 1). Anthropometric measurements including height, weight, and waist circumference were taken in the fasting state using standardized techniques as described elsewhere.²⁶

Ethical considerations

Participants were given full details of the study protocol and the opportunity to ask questions. All gave written informed consent before participation. The study was conducted according to the guidelines laid down in the Declaration of Helinski and was approved by the Institutional Ethics Review Committee of Madras Diabetes Research Foundation, Chennai, India.

Study protocol

This study was conducted using the internationally recognized GI protocol³ recommended by the Food and Agriculture Organization/World Health Organization⁴ in 1998, which has been validated in an interlaboratory study.²⁷

Volunteers visited the GI Testing Centre of the Madras Diabetes Research Foundation on the test day in the morning after a 10–12-h overnight fast. An interviewer elicited details regarding meals over the previous 24 h, physical activity, smoking, alcohol, and consumption of caffeine-containing drinks using a validated questionnaire and ensured that the volunteers maintained their usual diet and physical activity schedules (Supplementary Tables S1 and S2; Supplementary Data are available online at www.liebertonline.com/dia) and refrained from smoking and alcohol during the study period. The participants were informed about the study foods beforehand, and informed consent was taken from them prior to starting the study. Participants were randomized using computer-generated randomized tables and were given the test food accordingly. The reference food trial was performed at the first, last, and middle of the sequence of the test foods.

Test and reference food

HFWR and WR diets providing 50 g of available carbohydrate (63.6 g of uncooked rice) were given as test foods. Fifty-five grams of dextrose (glucose monohydrate) dissolved in

FIG. 1. Participant flow diagram. BMI, body mass index; GI, glycemic index; HFWR, high-fiber white rice; WR, white rice.

200 mL of water was used as the reference food [Glucon-D® glucose powder; Heinz India (P) Ltd., Mumbai, India]. The pressure cooking method was used for the test food preparation as this is the most popular and conventional method used in this population. Uncooked rice providing 50 g of available carbohydrate (HFWR, 67 g; WR, 65 g) was used (rice-to-water ratio of 1:2) for common WR and HFWR. The rice was pressure-cooked (three whistles), and cooking time for WR and HFWR was 30 and 32 min, respectively. The test food recipe was standardized in the in-house test kitchen during each GI testing. Volunteers were given 200 mL of water along with the test food, and an extra 200 mL was given during the subsequent 2 h.

Blood glucose measurement

All participants underwent 3 days of testing with the reference food and 2 days with the test food in random order with at least a 2-day gap between measurements so as to minimize carryover effects. Blood glucose was measured using the HemoCue® Glucose 201+ analyzer (HemoCue Ltd., Ängelholm, Sweden) and an automatic lancet device (Accu-Chek® sensor; Roche Diagnostics GmbH, Mannheim, Germany). Participants were encouraged to warm their hands to increase the blood flow, prior to the administration of the finger prick.

The fasting capillary blood sample was obtained before consumption of the food. Volunteers immediately consumed the reference/test food containing 50 g of available carbohydrate. The first sip or bite was set as time 0, and blood samples were taken at 15, 30, 45, 60, 90, and 120 min.

Calculation of the GI

In total, 30 participants were recruited, of whom two individuals dropped out of the first study. Additionally, four participants in the HFWR rice group and three in the WR

group whose GI was greater than the mean ± 2 SD were considered as outliers and excluded. Hence data of 24 and 25 volunteers for the HFWR and WR groups, respectively, were included in the GI analysis for the first harvest GI testing study. For the second harvest GI testing study, all the 15 participants were included in the analysis.

The incremental area under the curve (IAUC) values of the blood glucose test and reference foods were calculated geometrically using the trapezoid rule, ignoring the area below the fasting baseline.¹ The mean and SEM values of the IAUC for the reference and test food were calculated. The GI value was calculated with the following equation, and the mean of the resulting value was the GI of the test food:

$$\text{GI value of test food (\%)} = \frac{\text{Blood value IAUC value for test food}}{\text{IAUC value of reference food}} \times 100$$

Statistical analysis

Statistical analysis was performed using SPSS software (version 20.0; SPSS, Inc., Chicago, IL). Data are given as means with their SEs. The significance of differences in GI and in IAUC of HFWR and WR was tested using the Mann-Whitney U test (*t* test). Using linear regression, the effects of age, sex, body mass index, and waist circumference on the GI and IAUC were analyzed for the test foods. Statistical significance was set at $P < 0.05$.

Results

The nutrient compositions of the newly developed HFWR and WR are shown in Table 1. The available carbohydrate, protein, and fat content were significantly lower in HFWR compared with WR ($P < 0.001$). The total DF content of

TABLE 1. NUTRIENT COMPOSITION OF HIGH-FIBER WHITE RICE AND WHITE RICE

Nutrient	Raw		P value ^a
	HFWR	WR	
Moisture (g)	11.0±0.5	10.0±0.6	0.05
Available carbohydrate (g)	75.1±0.9	77.1±0.6	<0.001
Protein (g)	8.0±0.1	9.4±0.2	<0.001
Fat (g)	0.3±0.04	0.8±0.1	<0.001
Ash (g)	0.7±0.04	0.4±0.01	<0.001
Total dietary fiber (g) ^b	8.0±0.1	1.58±0.2	<0.001
Resistant starch (g)	3.9±0.2	0.6±0.03	<0.001
Amylose (g)	32.8±1.1	26.0±0.2	<0.001

Values are for 100 g of uncooked rice.

^aThe Mann–Whitney U test was used to test significance. $P < 0.05$ was considered to be statistically significant.

^bDietary fiber inclusive of resistant starch.

HFWR, high-fiber white rice; WR, white rice.

HFWR was fivefold higher (8.0 ± 0.1 vs. 1.58 ± 0.17 g%), RS content was 6.5-fold higher (3.9 ± 0.2 vs. 0.6 ± 0.03 g%) ($P < 0.001$), and the amylose content was significantly higher (32.8 ± 1.1 vs. 26.0 ± 0.2 g%) ($P < 0.001$), compared with WR.

The GI of HFWR and WR was estimated twice—first among 30 healthy participants in the year 2013 and then in a subsample of 15 participants in the year 2014 (Table 2). The average body mass index of the study participants was 22.3 ± 0.5 and 20.6 ± 0.4 kg/m² for Studies 1 and 2, respectively. Age, sex, body mass index, and waist circumference did not differ significantly between the study groups. There was no significant difference in the macronutrient consumption and physical activity levels of the study participants (Supplementary Tables S1 and S2).

The mean IAUC and GI of HFWR and WR are shown in Table 3 and Figure 2. The HFWR showed medium GI in both the studies with no significant differences in the mean IAUC ($2,943 \pm 296$ vs. $2,989 \pm 394$ mg $\times$ min/dL; $P = 0.84$) or GI (59.4 ± 3.6 vs. 64.4 ± 4.4 ; $P = 0.28$) between the two studies done 1 year apart. Similarly, the GI of WR did not differ significantly between the two studies (80.6 ± 6.5 vs. 77.0 ± 7.6 ; $P = 0.81$). Taking the average of Studies 1 and 2, HFWR was

TABLE 2. DEMOGRAPHIC/ANTHROPOMETRIC CHARACTERISTICS OF PARTICIPANTS IN THE TWO GLYCEMIC INDEX STUDIES

Characteristic	Study 1, 2013 (n = 25)	Study 2, 2014 (n = 15)	P value ^a
Female [n (%)] ^b	12 (48)	8 (53.3)	0.45
Age (years) ^c	27.9 ± 0.9	26.7 ± 1.0	0.83
BMI (kg/m ²) ^c	22.3 ± 0.5	20.6 ± 0.4	0.06
Waist circumference (cm) ^c			
Male	83.0 ± 1.7	80 ± 1.9	0.40
Female	73.6 ± 1.7	68.1 ± 1.5	0.12

^aSignificance was tested using the Mann–Whitney U test for continuous variables and the χ^2 test for categorical variables. $P < 0.05$ was considered significant.

^bNumber of participants (percentage female).

^cData are mean $\pm$ SD values.

BMI, body mass index.

categorized under the medium GI category (61.3 ± 2.8), and its GI was found to be 23% lower ($P = 0.004$) compared with WR (79.2 ± 4.8), which was classified as high GI. The IAUC of the HFWR ($2,961 \pm 231$ mg $\times$ min/dL) was also lower than the WR ($3,370 \pm 226$ mg $\times$ min/dL; $P = 0.009$).

Discussion

We report here on the development of a unique HFWR variety that has significantly higher DF and lower GI even after polishing. The present study has followed the internationally recognized GI protocol³ recommended by the Food and Agriculture Organization/World Health Organization⁴ in 1998 and validated by Henry et al.²⁷ in 2008. The new HFWR showed 23% lower GI compared with the control *Ponni* WR. We believe that widespread adoption of HFWR can help to improve the health of populations, by enhancing the quality of the staple dietary cereal.

Several factors influence the GI of foods, including processing, preparation, and cooking methods, the physical form of the food, the type of sugars and starch in the food, and other factors such as the presence of DR and antinutrients and the ripeness or maturity of the food.²⁸ The medium GI of our HFWR may be attributed to the high DF content of this rice, which was fivefold higher than that of WR. The high DF of HFWR may be due to its high amylose and long-chain amylopectin content, which in turn results in high RS.²⁹ The glucose chains of amylose starch are more bound to each other by H⁺ bonds, making them less available for amylolytic attack compared with amylopectin, which has many branched chains and larger surface area.³⁰ Although two earlier developed mutant WR specimens from *Japonica* varieties in Korea also reported high fiber and amylose content (4.8 g% fiber and 33.96 g% amylose), they were not commercially successful because of the poor gelatinization, low swelling ability, and increased hardness.^{31,32} Our HFWR appears more promising in this respect.

The ability of DF to reduce the glucose response of food is related to induction of satiety-related hormones like glucagon-like peptide-1, ghrelin, leptin, gastric inhibitory polypeptide, and peptide YY.^{4,33} DF induces production of short-chain fatty acids, which act as an external energy source and increase the secretion of satiety-related hormones via G-protein-coupled receptors from the L-cells. These hormones bring about a decrease in postprandial glucose and insulin responses.³⁴

Earlier attempts at developing and testing high-fiber rice varieties have shown mixed results. Yusof et al.³⁵ estimated the GI of commercially available brown rice, WR, and high-fiber rice in 10 healthy individuals in Malaysia. This study, surprisingly, showed that both WR and high-fiber rice were in the high GI category (81 and 87, respectively). Although no description of the high-fiber rice was provided, the rice apparently needed to be cooked for longer duration (35 and 40 min), which might have possibly led to higher degree of gelatinization, eliciting higher GI responses despite the higher fiber content.

Rapid industrial development and urbanization have led to increase in consumption of processed and refined foods, such as highly polished WR, which are low in DF and high in GI and are thus detrimental to health. This is more alarming in some ethnic groups like South Asians who have an increased

TABLE 3. MEAN INCREMENTAL AREA UNDER THE CURVE AND GLYCEMIC INDEX OF HIGH-FIBER WHITE RICE AND WHITE RICE

	HFWR			WR			Average of the two studies		
	Study 1	Study 2	P value ^a	Study 1	Study 2	P value ^a	HFWR	WR	P value ^a
Number of participants	24	15	—	25	15	—	39	40	
IAUC (mean $\pm$ SEM)	2,943 $\pm$ 296	2,989 $\pm$ 394	0.84	3,383 $\pm$ 298	3,346 $\pm$ 380	0.933	2,961 $\pm$ 231	3,370 $\pm$ 226	0.009 ^b
GI (mean $\pm$ SEM)	59.4 $\pm$ 3.6	64.4 $\pm$ 4.4	0.283	80.6 $\pm$ 6.5	77.0 $\pm$ 7.6	0.812	61.3 $\pm$ 2.8	79.2 $\pm$ 4.8	0.004
GI category	Medium	Medium		High	High		Medium	High	

Glucose was defined as having a reference Glycemic Index (GI) of 100.

^aSignificance was tested using the Mann–Whitney U test. $P < 0.05$ was considered significant.

^bAdjusted with reference (glucose) incremental area under the curve (IAUC).

HFWR, high-fiber white rice; WR, white rice.

susceptibility to insulin resistance and diabetes and who derive nearly 70% of their total calories from these food sources.³⁶

Brown rice, being a whole grain (unpolished), has a DF of 5.3 g%.¹³ Our rice (HFWR), despite being polished WR, showed a DF content of 8.1 g%, mainly as nondigestible starch and some remnant bran constituents. However, HFWR, being a WR, may not contain bran micro- and phytonutrients as in brown rice.³⁷

The International GI table³⁸ shows a wide range of GI for brown rice, from 45 to 87, falling into all the three GI categories (low, <55; medium, >55–69; and high, >70; on a scale of 100 being the GI of glucose), which may be due to the varietal differences and processing methods. In total, 12 different brown rice varieties with low to medium GI values, including pregerminated, parboiled, and steamed processed rice, were reported in the International GI table. Despite such GI values, brown rice has several challenges for its practical use. This includes poor consumer acceptance, as it is per-

ceived as being an inferior quality of rice due to its color and sensory properties. Moreover, there are problems associated with short shelf life²⁰ and longer cooking time.

HFWR not only has an inherent high DF and a lower GI (which is similar to brown rice), but it is also indistinguishable from WR with respect to sensory properties. Therefore it is not surprising that HFWR has gained wide acceptance, as is evident from its widespread availability in supermarkets across South India. Our HFWR is likely to be of benefit not only to consumers in India, but also to those in countries such as China, Japan, Korea, and other nations where rice is consumed as a staple. These countries make up more than 70% of the world's population and nearly the same proportion of the world's people with diabetes. Use of HFWR has the potential to improve the health of people in this region by improving the quality of the diet due to the beneficial effects of higher fiber content and lower GI.

FIG. 2. Mean blood glucose response of test food high-fiber white rice (HFWR) (circles) and white rice (WR) (triangles) compared with glucose (reference) (diamonds). GI, Glycemic Index.

This study has several strengths. First, an international standardized GI analysis method was used to study the glycemic properties of the HFWR. Second, the testing was done in successive years to rule out seasonal variations. The novelty of the HFWR is another significant strength. The small sample size and short duration of the study are the limitations of the study.

Conclusions

We report on a newly developed HFWR that has lower GI and excellent sensory and other characteristics compared with WR. Switching from the current high GI WR to HFWR could help to reduce overall dietary GI and the glycemic load. Further studies on HFWR for its physicochemical and structural properties to correlate with its glycemic properties are underway. The health implications in the prevention and control of chronic diseases like diabetes, obesity, and cardiovascular diseases are obvious. However, long-term supplementation trials are needed to see its potential metabolic benefit, such as its effects on serum lipids and other metabolic markers.

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Author Disclosure Statement

No competing financial interests exist.

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