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Nutritionally important starch fractions and estimated glycemic index of selected South Indian rice varieties

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ABSTRACT

The nutritionally important starch fractions and *in vitro* starch digestibility index (SDI) were studied in three commercially available rice varieties and a millet which were subjected to four different cooking methods to validate the claim of low glycemic index. The Hydrolysis index was analyzed to compute Estimated Glycemic Index (EGI) and correlated with SDI. In addition, carbohydrate profile, amylose content, the degree of gelatinization and ultra-structural analysis were also done. The starch fractions differed according to the cooking methods. Samples with high Rapidly Available Glucose (RAG) showed higher Starch Digestibility Index (SDI). The SDI ranged from 17-46, samples cooked by pressure and steaming method had higher SDI. The degree of gelatinization (DG) correlated with total starch (TS) content. The Estimated Glycemic Index ranged from 53-65 categorizing them as medium GI foods. The nutritional properties of rice starch fractions are of immense interest due to their digestion characteristics (slowly digested and absorbed) and therefore, the identification of foods with low glycemic index and low RDS and SDI values could be useful for target population.

Introduction

Rice (*Oryza sativa*), being one of the staple cereals among Asian population and particularly in the dietaries of South Indians, is of specific interest in the dietary management of diabetes, due to its high glycemic response (Jenkins et al.,1982). Over the centuries, the evolution and expansion of technology in rice processing has witnessed a substantial change in its production. Industrial processing of rice includes extrusion, milling and parboiling, while the domestic processing methods include boiling, steaming and pressure cooking, which is the process of cooking food under high pressure steam, employing water or a water-based cooking liquid, in a sealed vessel known as a pressure cooker. High pressure limits boiling and permits cooking temperatures well above 100 °C to be reached. The physico-chemical properties of rice are influenced by several processing methods including gelatinization of rice which, in turn, influences the rice starch digestibility and ultimately the glycemic response. The glycaemic response of rice varieties is reported to be relatively high, ranging from 64 to 93 (Miller et al., 1992).

Rice comprises 70% to 80% of carbohydrate as starch, which is digested and absorbed slowly that favours the dietary management of metabolic disorders like diabetes (Wolever andMehling, 2002). However, it varies enormously in different starchy foods (Jenkins and Buckley, 1988). Alternatively, a detailed analysis of digestion variability of different rice starches is pivotal in treating type II diabetes (Urooj et al., 2000). Predicting *in vivo* glycemic response, using *in vitro* starch hydrolysis methods, is widely recommended (Englystand andHudson, 1996; O' Dea et al., 1981). Methods to determine *in vivo* glycemic response are tedious and costly. However, predictable GI (Estimated Glycemic Index) values are easier and time saving, therefore can be used as a screening tool to measure the *in vitro* glycemic index. In recent times, several processed rice varieties are

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*Corresponding author E-mail: asnau321@gmail.com commercially available with claims of low glycemic response and are suggested for use by diabetics. It is observed that the consumption of rice is restricted by diabetics either as a personal choice or on the clinician's advice. The locally available finger millet (*EleusineCoracana*) in South Karnataka region is recommended for consumption instead of the / more than rice due to its nutritional claims of lower starch digestibility. Our studies on the digestibility of *Eleusinecoracona* (*in vitro* and *in vivo*) have negated the assumptions that the finger millet elicits low glycemic response and has low starch digestibility compared to rice (Urooj et al., 2006; Roopa et al., 1998). Furthermore, the high SDI of the millet could be decreased by blending it with cereals and pulses (Aarthi et al., 2003). Foxtail millet (*Setariaitalica*), traditionally called Navane rice in the region, is a millet widely grown in India and is popular for its reported health benefits on blood glucose and lipid profile (Lee et al., 2010). Singh et al. (2011) reported on the effective supplementation of foxtail millet on lowering serum glucose, serum lipids and glycosylated hemoglobin in type 2 diabetics. On the contrary, the research on the starch digestibility of foxtail millet has reportedly been limited. The incorporation of foxtail millet in selected Indian food preparations resulted in lower SDI (Soumya D Rao and AsnaUrooj, 2005).

In South India, rice is consumed almost daily, using different cooking methods. The effect of this practice on starch digestibility in six rice varieties was investigated in an earlier study (Rashmi et al., 2003). However, no data have been reported on the starch digestibility of commercially available rice varieties which were used by diabetics for their low glycemic index. Therefore, the current study was undertaken to evaluate the impact of various processing methods on starch fractions and *in vitro* starch digestion in three commercial rice varieties and one millet variety, reported to have low GI. The hydrolysis index (HI) was also analysed to calculate the estimated glycemic index (EGI).

Materials and methods

Samples and processing treatments

Three rice varieties and millet suggested for use by the diabetics were selected. They were India Gate Brown rice (IGB), Mangalore Kerala Parboiled rice (MKP), TGR Dia rice (TGR) and foxtail millet - Navane rice (NAV). These were processed by 4 different cooking methods- pressure cooking, open vessel, straining and steaming. All the samples were purchased from the local market of Mysuru, Karnataka, India, cleaned and stored in air tight containers until further use. The standard conditions for cooking were followed as per our earlier study (Rashmi et al., 2003).

Sample preparation

All the grain samples were grounded into powder in a homogenizer and then vacuum packed in polyethylene bags after passing through a 60-mesh sieve (250μm) and stored at 4 ºC before further analysis.

Chemicals and enzymes

All the chemicals were of analytical grade. Amyloglucosidase solution from *Aspergillusniger*, Pancreatin porcine (Sigma Aldrich, Fluka analytical products), Liquimax Glucose (InstaMIX) GOD-PAP Trinder's method, Avecon Health care Pvt, ltd.HP.

Methods

Using controlled enzymatic hydrolysis with pancreatin and amyloglucosidase, the samples were analyzed for the nutritionally important starch fractions which include rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS). In order to derive Starch Digestion Index (SDI), rapidly available glucose (RAG) was also measured. In addition, amylose content, the degree of gelatinization and Estimated Glycemic Index (EGI) were analyzed in the samples using standardized protocols discussed below. The cooked samples were subjected to ultra-structural studies and were evaluated for the sensory acceptability as well.

Starch fractions

Nutritionally important starch fractions – rapidly digestible starch (RDS), slowly digestible starch (SDS), Resistant Starch (RS) along with Rapidly Available Glucose (RAG) were estimated as described by (Englyst et al., 1992) methods. The values for different starch fractions of Total Starch (TS), RDS, SDS and RS were obtained by combining the values of G20, G120, and FG and TG as follows:

$$\boldsymbol{TS = (TG - FG) \times 0.9}$$

(TG = Total Glucose, FG = Free Glucose)

$$\boldsymbol{RDS = (G20 - FG) \times 0.9}$$

(G20 = measured glucose after 20 minutes of incubation,
G120 = measured glucose after 120 minutes of incubation).

$$\boldsymbol{SDS = (G120 - G20) \times 0.9}$$

$$RS = TS - (RDS + SDS)\ \boldsymbol{OR}\ (TG - G120) \times 0.9$$

The Starch Digestion Index (SDI) was also calculated using the equation:

$$\text{SDI}=\frac{RDS}{TS}\times 100$$

Amylose content

Amylose content was determined by the colorimetric method as described by Juliano (1981). 1mL of 95% ethanol and 9mL of 2MNaOH were added to the samples (100mg) and these mixtures were made up to 100 mL with distilled water. Furthermore, these solutions were measured for the absorbance at 620 nm by adding 2.0 mL of 0.2% iodine solution (Electronics India 2306 -Vis spectrophotometer, Labmatrix Manufacturers, India). Potato starch was used as a standard (calibration curve) to estimate the amylose content.

Degree of gelatinization

The degree of gelatinization (DG) of all the cooked samples was measured based on the starch-iodine complex reaction (Wootton et al., 1971).

Estimated Glycemic Index

Estimated Glycemic Index of the samples was calculated by determining the Hydrolysis Index (HI) on dry weight basis and as per the standard method (Goni et al., 1997).
The Hydrolysis Index (HI) was calculated as -

$$HI=\frac{\text{Glucose120 min released from 100g test sample}}{\text{Glucose120 min released from 100g of reference sample white bread}}\times 100$$

$$EGI=39.71+0.549\ \times HI$$

Ultra structural observations

Tungsten filament secondary electron detective Spectrum Electro Magnetic (S- 3400N, Hitachi Science Systems, LTD., Japan) operating at an accelerating voltage of 2.00 KV instrument was used and images at 1000X magnification scale were observed.

Statistical analysis

All the experiments were carried out in triplicates (n=3) and expressed as mean ± SD. The level of significance was set at ($p<0.05$) and the data was subjected to one-way ANOVA, followed by Tukey's post-hoc multiple comparison test among the samples and the method of cooking. Linear correlations were calculated between starch fractions and its related attributes using SPSS package (SPSS 16.0 version for windows, Inc.).

Results and discussion

Cooking methods, sensory attributes and the degree of gelatinization

Four different methods were adopted for cooking the samples and the evaluation of their cooking characteristics. Based on the processing method used, the time required to cook the samples and the amount of water absorbed by the samples also differed. Consequently, the cooked weight and cooking time also varied among the samples which ranged from 7 minutes (pressure cooking) to 40 minutes (straining). Straining and open vessel cooking methods required longer cooking time and more water than pressure cooking method. This difference could be attributed to the high temperature under high pressure employed for the cooking method and also to the differences in post-harvest processing treatments to which the samples have been subjected. The cooking methods adopted for this study influenced the physico-chemical properties of the rice varieties, which suggests that these properties also may be the reason for the difference in starch fractions (Juliano and Betchel, 1985).

The samples were also subjected for the sensory evaluation by a panel of 30 semitrained members using a score card and the attributes studied were the textural characteristics (doneness, grain texture and stickiness and overall acceptability). The processing method prioritizing a lower sensory score has resulted in higher acceptability of the grain variety. TGR sample cooked by the straining method had higher appearance acceptability compared to other varieties. The textural parameters were desirable in all the varieties ranging from very soft to grainy consistency. All samples cooked by open vessel method were rated acceptable for the chewiness attribute. It was also observed that, though the cooking characteristics varied according to the sample and method of processing used, all the varieties were highly acceptable by the panelists indicating the suitability of the cooking methods used in this study.

The degree of gelatinization attained with different cooking methods varied from 50 to 84 % with significant differences ($p< 0.05$, Table 1). The DG of MKP in steaming method was the least (50%) compared to the the highest DG (84%) in pressure cooked NAV variety. The differences in amount of water used have influenced the degree of hydration in all four cooking methods, which again has altered the extent of gelatinization. In this study, the pressure-cooking method resulted in maximum gelatinization in all the samples.

Table 1. Degree of gelatinization in the processed samples (%)

	Method of Cooking				
Samples	**Open Vessel**	**Pressure Cooking**	**Straining**	**Steaming**	**Mean**
MKP	56	66	53	50	56.32^{a}±6.66
IGB	57	70	55	60	60.43^{b}±6.65
NAV	74	84	73	67	74.66^{c}±7.34
TGR	63	65	56	58	60.40^{b}±4.17
Mean	63^{r}	71^{s}	59^{q}	59^{p}	62.95±5.79

*MKP- Mangalore Kerala parboiled rice, IGB- India Gate Brown rice, NAV- Navane, TGR-TGR-dia-rice. Calculated values with the same superscript(s) in a row or column are significantly different at ($p<0.05$).

Table 2. Total starch content and fractions in the processed rice varieties (g/100 g fresh basis)

Cooking Method* **	**MKP***	**IGB***	**NAV***	**TGR***	**Mean****
Rapidly Digestible Starch (RDS)					
A	9.61	8.37	8.82	9.08	8.97^{a}
B	10.96	8.54	9.76	10.53	9.95^{c}
C	7.49	9.08	8.65	8.07	8.32^{a}
D	9.16	8.28	9.49	9.43	9.09^{b}
Mean**	9.31^{r} ±1.43	8.57^{p}±0.36	9.18^{q}±0.53	9.28^{r}±1.01	±0.67
Slowly Digestible Starch (SDS)					
A	2.06	10.11	4.65	5.64	5.62^{d}
B	1.81	7.20	3.47	4.79	4.32^{c}
C	3.61	2.93	1.29	7.33	3.79^{b}
D	1.45	4.81	2.26	4.50	3.26^{a}
Mean**	2.23^{p}±0.95	6.26^{s}±3.10	2.92^{q}±1.46	5.57^{r}±1.27	±1.01
Resistant Starch (RS)					
A	25.98	22.22	5.22	26.84	20.07^{c}
B	15.37	26.74	13.29	23.40	19.70^{b}
C	15.21	28.45	12.11	27.88	20.91^{c}
D	14.41	26.24	7.60	27.14	18.85^{a}
Mean**	17.74^{q}±5.51	25.91^{r}±2.64	9.56^{p}±3.79	26.32^{s}±1.99	±0.86
Total Starch (TS)					
A	37.66	43.17	19.28	44.55	36.17^{c}
B	29.85	45.46	28.00	41.33	36.16^{c}
C	28.00	43.63	23.41	46.38	35.36^{b}
D	26.63	42.25	20.20	44.09	33.29^{a}
Mean**	30.54^{q}±4.93	43.63^{r}±1.35	22.72^{p}±3.94	44.09^{s} ±2.09	±1.35

*MKP- Mangalore Kerala parboiled rice, IGB- India Gate Brown rice, NAV- Navane, TGR- TGR dia rice. **Mean values carrying different superscript letters in a row and column differ significantly ($P \leq 0.05$) ***Method A, Open Vessel cooking method; B, Pressure Cooking method; C, Straining method and D, Steaming method.

Table 3. Rapidly Available Glucose (RAG) and the Starch Digestion Index (SDI) of cooked rice varieties (g/100 g fresh basis)*

		Samples				
Starch fractions	**Method of Cooking****	**MKP**	**IGB**	**NAV**	**TGR**	**Mean**
RAG	Method A	10.68	9.30	9.81	10.09	**9.97^{b}**
	Method B	12.18	9.49	10.85	11.71	**11.06^{d}**
	Method C	8.33	10.09	9.62	8.97	**9.25^{a}**
	Method D	10.18	9.21	10.55	10.48	**10.11^{c}**
	Mean	**10.34^{q}±1.59**	**9.52^{p}±0.40**	**10.21^{q}±0.59**	**10.31^{q}±1.13**	**±0.74**
SDI***	Method A	25.52	19.38	45.79	20.38	**27.77^{c}**
	Method B	36.71	18.78	34.85	25.47	**28.95^{b}**
	Method C	26.75	20.81	36.95	17.39	**25.48^{a}**
	Method D	34.4	19.59	46.96	21.38	**30.58^{d}**
	Mean	**30.85^{r}±5.54**	**19.64^{p}±0.85**	**41.14^{s}±6.13**	**21.16^{q} ±3.34**	**±2.15**

MKP- Mangalore Kerala parboiled rice, IGB- India Gate Brown rice, NAV- Navane, TGR- TGR dia-rice. ***SDI= (RDS/TS) x 100. **Method A, Open Vessel cooking method; B, Pressure Cooking method; C, Straining method and D, Steaming method. Any two mean values bearing different superscript letters in a row and in a column differ significantly ($P \leq 0.05$).

Table 4. Amylose content of raw and processed samples (g/100 g)

Sample	**Amylose content of raw sample (%)**	**Amylose content (%) of processed samples**				
		Open Vessel	**Pressure Cooking**	**Straining**	**Steaming**	**Mean**
MKP	23.89	19.80	18.94	15.60	18.46	18.2 ±1.47
IGB	26.95	23.62	21.03	13.92	19.68	19.56 ±0.86
NAV	34.54	25.18	24.09	21.36	25.39	24.05 ±1.39
TGR	25.73	20.36	18.42	16.17	18.90	18.46 ±2.60
Mean	27.78	22.24	20.62	16.76	20.60	20.06±0.76

Nutritionally important starch fractions

The nutritionally important starch fractions in the samples subjected to different cooking methods are presented in Table 2. Controlled enzymatic hydrolysis method was used to measure the starch content in foods which were further classified into RDS, SDS and RS for the nutritional purposes. The glucose released was measured colorimetrically by using a glucose oxidase kit. The values for the starch fractions varied significantly ($p<0.05$) depending on the method of cooking. Straining method resulted in lower RDS (8.32%) values in all samples while pressure cooking method resulted in higher RDS (9.95%) values. SDS was found to be inversely related to RDS values and varied among the samples, with MKP variety (2.23%) lower value and IGB variety (6.26%) having a higher value for SDS compared to other samples. Samples cooked by steaming and open vessel methods resulted in low RDS and high SDS values, a desirable attribute in the dietary management of diabetes. Total starch content varied significantly ($p<0.05$) according to the varieties and method of cooking, ranging from 22.72 to 44.09%. Steaming method resulted in the lowest amount of TS content (33.29%). Among the samples, NAV (22.72%) showed significantly lower TS content compared to the other varieties. A lower proportion of starch measured as RDS is often associated with foods with low levels of RAG (Englyst et al., 1992). Digestibility of starch is of great importance to human health. The gelatinization of starch granules is a result of cooking of starchy foods, especially rice. The identification of foods with low RDS and SDI values and the effects of factors influencing the starch fractions are a topic of continuous research because of increased attention for starchy foods and the nutritional advantages of starches that are slowly digested and absorbed.

RAPIDLY AVAILABLE GLUCOSE (RAG) and STARCH DIGESTIBLE INDEX (SDI)

Table 3 represents the RAG and SDI values of all the samples according to the cooking methods. Significantly lower RAG values were observed for the straining method and on the contrary, pressure cooking and steaming methods resulted in significantly ($p<0.05$) higher RAG values (11.06 and 10.11, respectively) as compared with the other cooking methods used in the study. The amount of glucose that can be expected to be rapidly available for absorption after a meal is represented as RAG values. These values are related to the foods based on the eating habits and include both RDS and free glucose. Therefore, they are helpful in predicting glycemic responses (Englyst et al., 1996).

RAG values and the method of cooking influence the measure of relative rate of starch digestion i.e SDI (Fig. 1). Thus, in the present study, steaming and pressure-cooking methods resulted in higher RAG and corresponding SDI values. Samples cooked by straining method gave lower RAG and SDI values. As expected, pressure cooking and open vessel cooking resulted in significantly ($p<0.05$) higher RAG values in all samples.

Commercial rice varieties IGB and TGR showed comparable SDI, significantly lower ($p<0.05$) than other two varieties used in the study. Thus, SDI ranking of sample grains varied over a wide range depending on the method of cooking.

SDI in varieties according to the methods of cooking is as follows:

Open Vessel: NAV > MKP >TGR >IGB
Pressure Cooking: MKP> NAV> TGR > IGB
Straining Method: NAV>MKP> IGB> TGR
Steaming Method: NAV > MKP >TGR >IGB

Amylose content

The amylose content analyzed in both raw and cooked rice varieties is presented in Table 4. The mean amylose content varied significantly ($p<0.05$) between the samples and the processing methods employed. The results indicate that the selected varieties could be categorized as medium – amylose content rice as the mean value was 20.06 ± 0.76 ($p<0.05$). Among the cooking methods, steaming method showed significantly lower amylose content than other processing methods. However, it was interesting to note that the amylose content differed between raw and processed samples. This variation could be due to the processing methods which effect the re-distribution of starch fractions and its digestibility. In addition, *in vitro* starch digestion and glycemic responses are influenced by the amylose content (Goddard et al., 1984). Starch gelatinization is the process of breaking down the intermolecular bonds of starch molecules in the presence of water and heat, allowing the hydrogen bonding sites (the hydroxyl hydrogen and oxygen) to engage more water. This bonding irreversibly dissolves the starch granules in water where water acts as a plasticizer. The gelatinization characteristics differ in grains and relate with the protein and amylose content, granule size, molecular weight and structure of starch granule (Whistler, 1984 and Annison et al., 1994).

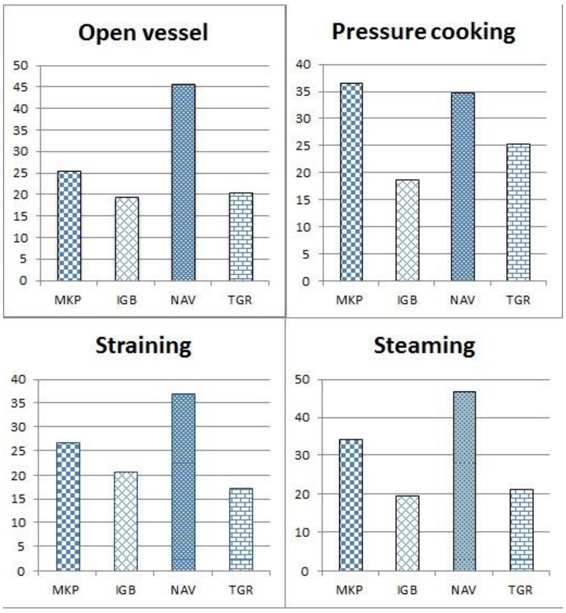

Fig. 1. Comparison of Starch Digestibility Index of samples according to methods of cooking. Note: MKP- Mangalore Kerala parboiled rice, IGB- India Gate Brown rice, NAV- Navane, TGR- TGR dia-rice.

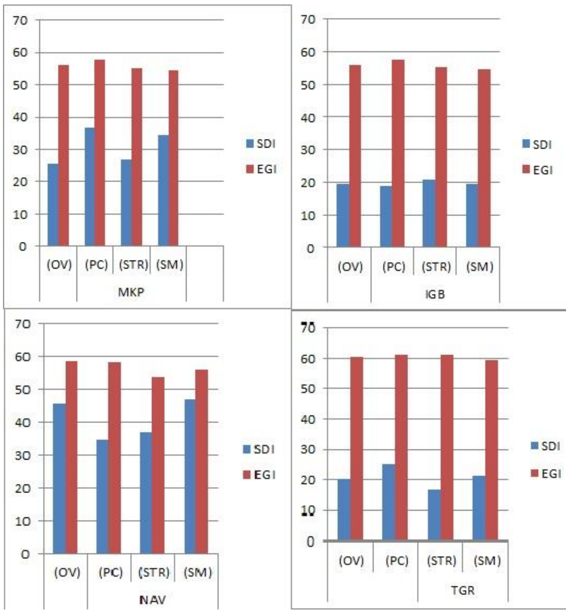

Fig. 2. Relation between SDI and EGI of the processed samples. **Note:** MKP- Mangalore Kerala parboiled rice, IGB- India Gate Brown rice, NAV- Navane, TGR- TGR dia-rice. SDI – Starch Digestibility Index, EGI- Estimated Glycemic Index.

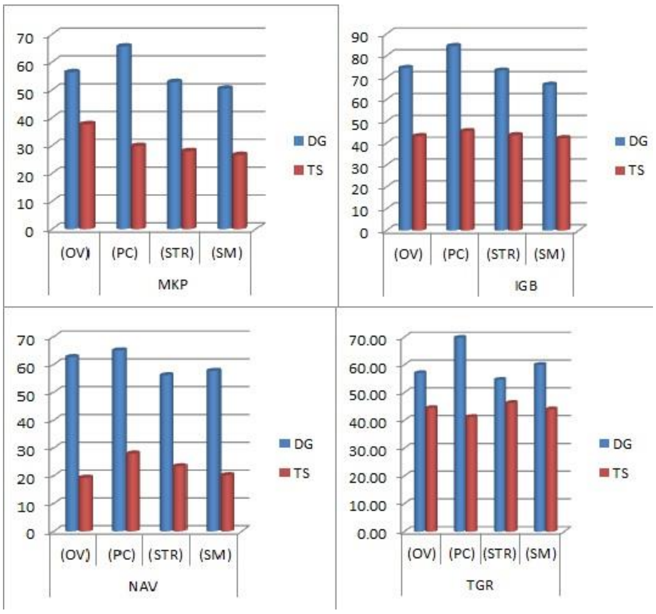

Fig. 3. Relationship between Degree of gelatinization (DG) and Total Starch (TS) among samples
Note: MKP- Mangalore Kerala parboiled rice, IGB- India Gate Brown rice, NAV- Navane, TGR- TGR dia-rice.

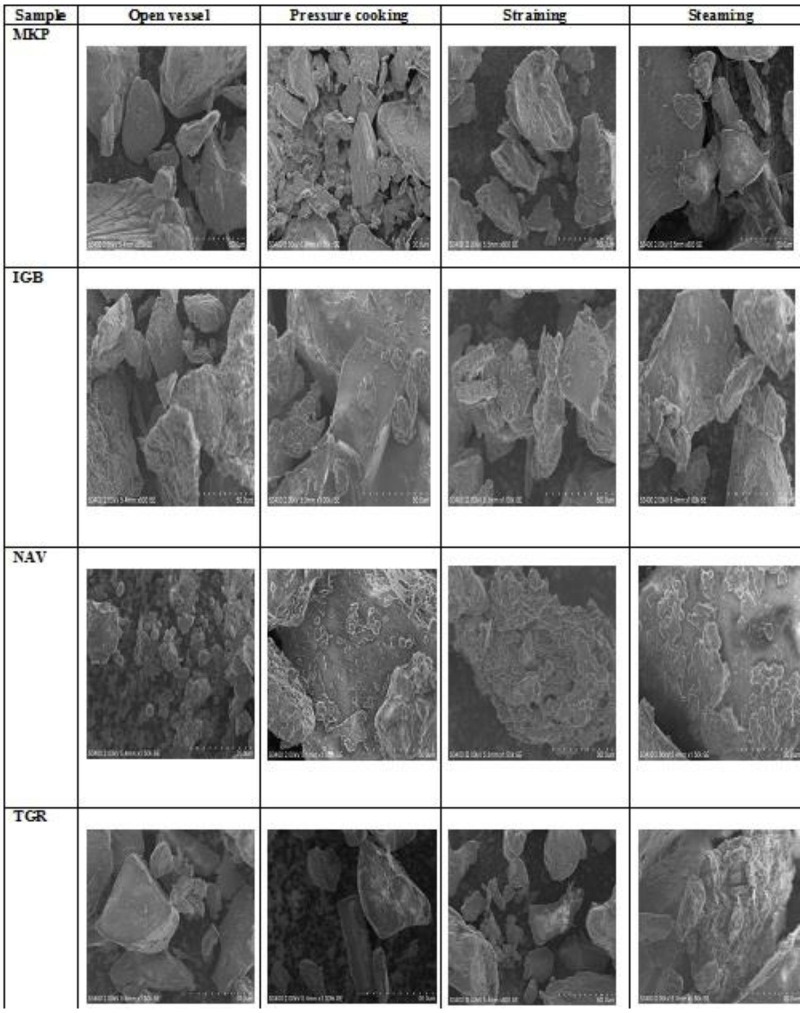

Fig.4. Scanning Electron Micrographs (SEM) of differently processed samples at 1000X magnification
Note: MKP- Mangalore Kerala parboiled rice, IGB- India Gate Brown rice, NAV- Navane, TGR- TGR dia-rice.

Table 5. Estimated Glycemic Index (EGI) of the rice samples

Cooking Method**	MKP	IGB	NAV	TGR	Mean
A	56.09	65.65	58.62	60.37	60.18±4.05
B	57.64	61.81	58.28	61.23	59.74±2.09
C	55.30	56.56	53.67	61.33	56.72±3.30
D	54.61	58.10	56.21	59.27	57.05±2.06
Mean	55.91±1.30	60.53±4.06	56.70±2.28	60.55±0.96	

*MKP- Mangalore Kerala parboiled rice, IGB- India Gate Brown rice, NAV- Navane, TGR- TGR dia rice.
**Method A, Open Vessel cooking method; B, Pressure Cooking method; C, Straining method and D, Steaming method.

Estimated Glycemic Index (EGI) of the samples

The Estimated Glycemic Index of the samples (Table 5) was calculated based on Hydrolysis Index which was compared with white bread as standard. In general, carbohydrates are ranked on the basis of their relative ability to release glucose into blood compared to pure glucose and white bread (Jenkins et al., 1984) and that is generally termed as Glycemic Index (GI). The EGI ranged between 53 and 65 for all samples, categorizing them as medium Glycemic Index foods. Higher mean EGI (60%) was observed for the samples cooked by open vessel method comparable with other methods and among the rice varieties IGB and TGR had higher mean EGI. Rice carbohydrates show moderate level of glycemic index (GI) value, which is an important indicator fortype-2 diabetic individuals prone to co-morbidities.

Relationship between starch fractions, SDI, RAG and EGI

A significant positive correlation between RDS and RAG (r=0.99, p<0.01) and between SDI and EGI (R=0.64, P<0.05) was observed. An inverse relation was seen between RDS and SDS (r = -0.22, p<0.01). Although RAG showed a positive correlation with SDI, it did not reach statistical significance (r=0.33). It was noticed that the EGI increased as the SDI of the various samples increased. Similar trend in values of EGI and SDI was observed for different cooking conditions (Fig. 2). The glycemic index (GI) and resistant starch (RS) content have been established as important indicators of starch digestibility. The higher the SDI value, the higher the EGI. In this aspect, *in vitro* RDS, SDS, RS values are reported to reflect the rate of starch digestion *in vivo* (Englyst et al., 1992; Hon’s et al., 1996).

These results imply that cereals / millets with higher SDI and EGI values may elicit higher blood glucose response level. Screening foods for EGI is a viable method compared to the *in vivo* studies. In this study, although the commercial rice varieties IGB and TGR showed the higher EGI (60%), they can be classified as intermediate GI foods. Many studies on rice starch digestibility categorize it as high GI food (Bjo¨rck, and Eliasson., 1996; Jenkins et al., 1984; Miller et al., 1992). In contrast, this study reveals that certain rice varieties and grains subjected to specific processing methods (parboiling etc.) can alter the starch digestibility and thus decrease glycemic index. Likewise, GI values higher than 100 have previously been reported for millets (Jenkins et al., 1984), but the low EGI values exhibited by foxtail millet (53-58), irrespective of cooking methods, is of much interest for further research (Bravo et al., 1998, Goni et al., 1997; Jenkins et al., 1984).

A relationship between Degree of gelatinization (DG) and Total Starch (TS) was observed (Fig. 3). It was observed that the increase in TS content was associated with the DG, irrespective of the sample and the cooking method employed. This may be probably due to the higher availability of starch with higher degree of gelatinization. Gelatinization is generally defined as the hydration and irreversible swelling of the granule, which is concomitant with the destruction of molecular order, melting of starch crystals and starch solubilization. During gelatinization, starch granules close the cracks present in the endosperm leading to consolidation of the grains (Bauer et al., 2004; Ituen et al., 2011). Gelatinization is affected by heating starch granules in water, leading to granule swelling, eventually yielding a viscous paste which can be used in food products (Rohaya et al., 2013).

Ultra structural studies

Granule morphology of starch samples after cooking by different methods were viewed at 5.4mm 1000X SE resolution, using Scanning Electron Micrograph (Fig 4). Significant variations in the ultrastructure and continuous rigid matrix among the samples were observed by the cooking methods as evident by SEM results. And accordingly, widely dispersed and ruptured granules of starch were visible in the samples. These ruptured granules formed the collective masses of protein-starch complexes which were visible in the samples employed with different processing treatments, as evident in the SEM. The inter-granular spaces among the samples showed a loose network, but with more darkened spaces in between, indicating the formation of starch-protein complex layer which might prevent the effective diffusion of amylase to hydrolyze the starch. In all the samples cell wall had ruptured during the grinding process and both intact and damaged starch granules surrounded by protein matrix were visible. In the present study, the four varieties were not similar in granular size. The raw rice TGR and millet NAV had smaller granular size compared with the MKP parboiled rice and IGB varieties. Pressure cooked samples showed a high degree of granule deformation and folding. In agreement with the particle size distribution, results showed that the granules were larger in size. Most granules had collapsed indicating a high degree of gelatinization, granule diffraction and intense cell rupture in the processed samples. The differences in swelling power and water solubility of starch are the resultant alterations in morphological structures of these granules (Singh et al., 2001). In the present study, these differences might be attributed to the different morphology, granule size, molecular structure, crystallinity and botanical source of the samples used. Thus, the study of the granular morphology of the samples helps in the understanding of interactions between starch, proteins and other factors affecting the starch digestibility.

Conclusion

This is the first study attempting to validate the nutritional claims of the commercially available rice varieties in the context of dietary management of diabetes. The results appear to be useful, as the selected rice varieties could be categorized as medium EGI foods, thus improving prospects for the consumption of these varieties compared to the commonly available grains. However, the EGI values need to be confirmed by *in-vivo* studies in both healthy and type 2 diabetic subjects before recommending them to the target population. In the present study, samples cooked by steaming method exhibited all attributes considered beneficial in the management of type-2 diabetes.

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