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Postprandial glycaemic response of foxtail millet *dosa* in comparison to a rice *dosa* in patients with type 2 diabetes

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***Background & objectives*: Millets are rich source of dietary fibre and non-starchy polysaccharides with low glycaemic index (GI), hence can be used as a therapeutic diet. This study was conducted to estimate the effects of a millet-based *dosa* (foxtail *dosa*) compared to a rice *dosa* for breakfast on postprandial glucose levels in patients with type 2 diabetes mellitus (T2DM).**

***Methods*: The GI of rice *dosa* and foxtail millet *dosa* was estimated. A total of 105 T2DM participants were randomly selected for the study. The participants were on oral hypoglycaemic agents (OHA) and not on insulin. In this study, each individual served as their own control and experimental group. The postprandial increase in blood glucose was compared after a breakfast of rice *dosa* and millet *dosa*. Single and paired *t* test was used to note the change in blood glucose levels and the level of the significance.**

***Results*: The GI of foxtail millet *dosa* was 59.25 and rice *dosa* was 77.96. There was a significant reduction (P<0.001) in the postprandial glucose level of patients who consumed a millet-based *dosa* when compared to those who consumed a rice-based *dosa*. No significant reduction was observed in the fasting glucose levels.**

***Interpretation & conclusions*: The results suggested that replacing a rice-based breakfast item with a millet-based breakfast item lowers the postprandial blood glucose levels in T2DM patients. Thus, millets may have a protective role in the management of hyperglycaemia. Further studies need to be done in a systematic manner to confirm these findings.**

Key words Foxtail millet - glycaemic index - postprandial glucose levels - rice - type 2 diabetes

The global prevalence of diabetes was estimated to be nine per cent in 2014 among adults aged 18 years or more[1]. Diabetes has reached at an epidemic level, with around 366 million people with diabetes globally in 2011 and it is expected to increase to 552 million by 2030[2]. A WHO-ICMR study based on non-communicable diseases' risk factor surveillance showed that the prevalence of self-reported diabetes was 7.3 per cent in urban, 3.2 per cent in peri-urban and 3.1 per cent in rural areas[3]. The prevalence levels of diabetes and prediabetes were 10.4 and 8.3 per cent, respectively[4]. In 2012, an estimated 1.5 million deaths were directly caused by diabetes[5].

More than 80 per cent of diabetes deaths occur in low- and middle-income countries[5]. The need for implementation of effective dietary strategies in diabetes prevention and management has been emphasized by the success of diet and lifestyle changes in preventing diabetes in high-risk patients[6]. Another study confirmed postprandial hyperglycaemia as an independent risk factor for cardiovascular disease (CVD) in type 2 diabetes[7]. Postprandial hyperglycaemia produces oxidative stress, which, in turn, induces endothelial dysfunction and inflammation[8], all well-recognized risk factors for CVD. One dietary strategy aimed at improving both diabetes control and cardiovascular risk factors is the use of low glycaemic index (GI) diets[9].

Millets are small seeded grasses that grow well in dry zones as rain-fed crops, under marginal conditions of soil fertility and moisture in the semi-arid tropic region. These are highly nutritious, non-glutinous and non-acid-forming foods. Compared to polished rice, millets release a lesser percentage of glucose and over a longer period. This lowers the risk of diabetes[10]. Millet grains are considered superior among the major cereals with respect to protein, energy, vitamins and minerals. Besides, these are a rich source of dietary fibre, phytochemicals and non-starchy polysaccharides and reputed to have a low GI, and hence can be used as a therapeutic diet. This study was undertaken to assess the GI of a common Indian recipe (rice *dosa*) and a millet-based recipe (foxtail *dosa*). The aim was also to estimate the effect of a single change in the diet in any one meal with a low-GI food on the postprandial level of glucose in patients with type 2 diabetes mellitus (T2DM). The proximate principles of rice and foxtail millet *dosa* are given in Table I.

Material & Methods

Preparation of the rice- and millet-based dosa: For the preparation of the millet *dosa*, 90 g of unpolished foxtail millet was purchased from the local market along with 20 g of black gram pulses (*dal*), soaked for four hours and were ground with 90 ml of water. The batter was kept overnight for fermentation. The same recipe was followed for preparing the rice-based *dosa* with rice substituting the foxtail millet.

The final quantity of batter was weighed accurately. This weight (430g) of foxtail millet batter provided 36.4 g of available carbohydrate (CHO) while rice batter provided 77.0 g of available carbohydrate[13]. Hence, 290 g of foxtail batter and 140 g of rice batter were used to make two *dosas*. The participants were asked to consume both *dosas*. This quantity provided 50 g of available carbohydrate. The available carbohydrate was calculated by subtracting the total dietary fibre (TDF) which includes the soluble and insoluble fibre from the total carbohydrate present in 100 g of the test food. The available carbohydrate from black gram was constant in the two varieties of *dosa* as 20 g was used for both the recipes.

Reference food: White bread was chosen as the reference food[14] (purchased from the local bakery). The available carbohydrate was calculated by subtracting the TDF from total CHO. Therefore, 101 g of bread contained 50 g of available CHO.

Estimation of glycaemic index: Ten normal volunteers were selected and the reference sample and the test items were given with a two-day wash out period[14]. The average fasting blood glucose was 82 mg/dl (average of three different readings on three different days.) The participants were all females between the age range of 22-44 yr and body mass index (BMI) range of 23-28 kg/m^2. The purpose of the study was explained to each participant and written informed consent to participate in the study was obtained. They consumed two *dosas* such that these provided 50 g of carbohydrate and four slices of bread calculated for available carbohydrate[13].

After an overnight fast, finger prick blood samples were investigated at 0 (before test meal), 15, 30, 45, 60, 90 and 120 min[15]. The blood glucose

Table I. Proximate principles of rice *dosa*, foxtail millet *dosa* and white bread

Cereal grain	Protein (g/serving)	Fat (g/serving)	Minerals (g/serving)	Carbohydrate (g/serving)	Energy (kcal/serving)	Total dietary fibre (g/serving)
Foxtail millet *dosa*	15	4.0	3.5	69	354	20.7
White bread	7.8	0.7	-	51.9	245	2.51
Rice *dosa*	7.39	0.4	0.9	52.9	267	4.2

One serving=200 g
Source: Refs 11-13

levels at the specified time intervals were measured by glucometer[15,16] (Accu-Check meter, Roche, Switzerland).

The blood glucose concentrations after the test meal and reference food were used to draw a blood glucose response curve for the two hours period. The values at 75 and 105 min were obtained by extrapolation[15]. The incremental area under the curve (AUC) for each meal and reference food was calculated for each volunteer separately to reflect the total rise in the glucose concentration after eating the test and reference food[15]. The AUC was calculated using the general formula[14]. GI (%) was calculated as follows[15]:

$$GI = \frac{\text{Area under curve for 50 g CHO from test food}}{\text{Area under curve for 50 g CHO from white bread}} \times 100$$

Research design: The study was carried out at M.V. Hospital for Diabetes, Chennai, and the participants were enrolled over a period of eight months in 2014 and 2015 in the department of Diet and Nutrition of the Hospital. Ethical clearance was obtained from the Institutional Ethics Committee. The study protocol was explained to the participants and those who were willing to participate were enrolled in the study and written informed consent was obtained from each participant. A total of 105 participants with T2DM (M69:F36) visiting the M.V. Hospital for Diabetes, Chennai, India, who were never on insulin therapy but were on the same oral hypoglycaemic agents (OHA) for one year and whose blood glucose levels were above normal, were randomly selected for the study of an age group between 35 and 55 yr. The 105 eligible participants were randomly allocated to either rice or millet group on the first day and random sequences were generated using WinPepi software (New York, USA). The Figure represents the study design, the number of eligible participants and the number included for analysis.

Body weight and height were measured before the study and BMI was calculated. Waist and hip circumference of the participants were also measured. Duration of diabetes and information on educational status of the participants were collected using an open-ended questionnaire.

Each individual served as their own control and experimental group. At baseline, all participants were advised to report to the hospital in the fasting state and

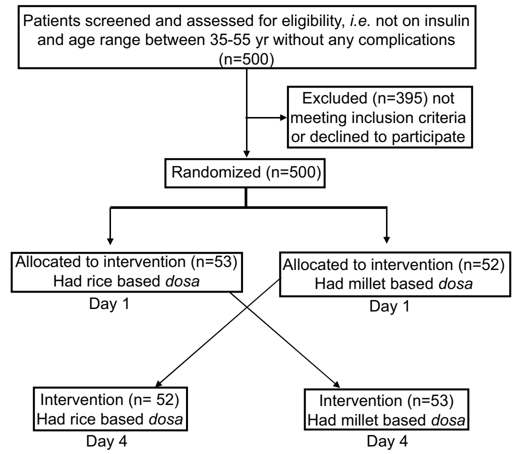

Figure. Flow chart showing the design of the study.

fasting blood glucose levels were estimated and then 53 participants consumed rice *dosa* and the rest consumed millet *dosa* for breakfast, and after one and half hours, the postprandial blood glucose levels were estimated. The blood glucose levels were estimated using the glucose oxidase-peroxidase method in the venous blood using BS 400 Mindray autoanalyzer (Diays Company, Germany). After two days of washout period, millet *dosa* was given to the first group and rice *dosa* to the second group and their fasting and postprandial glucose levels were estimated. Acceptability of the millet-based *dosa* was analyzed using organoleptic rating scale[17] with a score of 1-9. The organoleptic scale was given to every individual who participated in the study and they were asked to score the quality of the product based on the colour, flavour and taste of the product. Since the rice-based *dosa* is common recipe in everyday breakfast, the organoleptic score was not carried out to estimate the acceptability.

Statistical analysis: Statistical analysis was performed for the collected data using SPSS software version 19. (SPSS Inc. IBM, USA) The independent sample and paired *t* test were used to determine the changes in blood glucose levels.

Results

Of the 105 T2DM patients, 69 were male. The mean age of the participants was 49.3 ± 9.9 yr, mean height was 162.3 ± 8.6 cm, mean weight was 72.2 ± 10.4 kg and mean BMI was 27.4 ± 3.7 kg/m^2. The mean waist circumference of the female participants was 90.6 ± 9.2 cm and of the male was 96.6 ± 9.2 cm. The mean duration of diabetes was 4.2 ± 1.9 yr (Table II).

Table II. Baseline characteristics of the patients

Baseline parameters	Mean±SD
Age (yr)	49.26±9.903
Height (cm)	162.295±8.636
Weight (kg)	72.157±10.417
BMI (kg/m^2)	27.436±3.7396
Waist circumference (cm)	
Male	96.637±9.152
Female	90.594±9.248
Duration of diabetes (yr)	4.18±1.930
Family income per month (₹) (n%)	
<10,000	20.95
>10,000	79.04
Educational status (n)	
Schooling	40
Graduate	65

SD, standard deviation; BMI, body mass index

Demographic details revealed that 21 per cent of participants were in the lowest income group category and 79 per cent were in the middle- and high-income groups. Concerning the educational status, 40 per cent of participants had completed schooling and 65 per cent had done their graduation. The details are shown in Table II.

The acceptability of foxtail millet was evaluated using the organoleptic rating scale. Eighty nine per cent of the participants liked the product (score ≥6), <1 per cent neither liked nor disliked the product (score = 5) and about 9.5 per cent disliked the product (score ≤ 4).

Glycaemic index: The GI of millet-based *dosa* was 59.25 and that of rice-based *dosa* was 77.86. The study participants who consumed a millet-based *dosa* showed a significant reduction in their postprandial glucose levels when compared to the postprandial levels of those who consumed rice-based *dosa*. No significant differences were observed in the fasting blood glucose levels in both groups (Table III). The mean fasting blood glucose was similar in both the groups, and the postprandial values were significantly (P<0.001) higher in the rice group (Table III).

Discussion

The GI of the *dosa* prepared from foxtail millet was low. This may be due to the high levels of soluble dietary fibre in the millet. The TDF was reported to be 27.02 per cent, soluble dietary fibre 11.56 per cent and the insoluble dietary fibre 15.44 per cent[11]. It has been reported that the high viscosity of the soluble fibre delays digestion and absorption[18].

Table III. Fasting and postprandial blood glucose levels (mg/dl) in the study participants

Plasma glucose	Rice *dosa* (n=105)	Millet *dosa* (n=105)	*P*
Fasting blood glucose level	167.7±43.5	163.0±37.7	0.366
Postprandial glucose level	213.7±57.3	169.0±49.9	<0.001

Values are mean±SD

The glucose levels can be maintained to near normal with the help of dietary modification. It was observed in the present study that replacing rice-based *dosa* with millet-based *dosa* showed a significant reduction in the postprandial blood glucose levels. The results were in agreement with the previous study[19] which showed a 29 per cent decrease in the serum glucose level after consumption of millet-based *burfi*.

The incremental improvement in glycaemic control afforded by a low-GI diet can be compared with that achieved with other medical interventions such as OHA or insulin[20]. One of the potential effects of low-GI diets is to reduce insulin secretion in patients with type 2 diabetes and to reduce daily insulin requirements in patients with type 1 diabetes[21,22]. Wolever *et al*[21] observed a 30 per cent reduction in urinary C peptide levels in patients with type 2 diabetes on a low-GI diet, indicating reduced endogenous insulin demand. After supplementing only one meal with a lower GI food in the meal, namely breakfast in the present study, the participants showed a reduction in their glycaemic profile. A similar result in the use of low-GI foxtail millet biscuits has been reported[23].

The high-soluble dietary fibre content has been found to reduce gastric emptying and absorption of glucose after a meal, resulting in improved glucose tolerance. The soluble dietary fibre component has been reported to decrease the activity of digestive enzymes, thus resulting in incomplete hydrolysis of carbohydrates, protein and fats and delaying absorption[18]. There was a weak but significant correlation between the amount of TDF per 50 g carbohydrate portion of food and GI according to Wolever[24]. Cellulose content of the food was the best predictor of the GI of the food[24]. Foxtail millet contains

8.0 g/100 g of crude fibre and rice has 0.2 g/100 g of crude fibre[13]. The TDF in foxtail millet has been reported to be 27 per cent[11] while rice contains only 4.1 per cent[13]. Low-GI diets favourably influence postprandial metabolism, lowering insulin resistance and lipid and clotting parameters. Together these metabolic effects may explain the long-term benefits of low-GI diets on CVD observed in large cohort follow up studies[25].

The metabolic effects relate to the rate at which glucose is absorbed from the small intestine. A reduced rate of glucose absorption after the consumption of low-GI carbohydrate foods will reduce the postprandial rise in gut hormones (*e.g.,* incretins) and insulin. The prolonged absorption of carbohydrate seen over time will maintain suppression of the free fatty acids (FFAs) and the counter regulatory responses, while at the same time achieving lower blood glucose concentrations. Over time, with the reduction in FFA concentrations and the rise in the respiratory quotient with tissue insulinization, glucose is withdrawn from the circulation at a faster rate. Consequently, blood glucose concentrations return towards baseline despite continued glucose absorption from the small intestine. The rise in peak postprandial blood glucose is therefore, reduced together with the incremental blood glucose area above baseline[22].

It has been suggested that obesity is related to GI or glycaemic load[26-28]. Studies on altering GI and load have indicated that if the GI and load of the first meal is lower, less food is consumed in the subsequent meal[28,29]. The use of GI is encouraged as a way to improve the quality of carbohydrates consumed[30] and use of GI is of particular benefit for controlling glycaemia, lipids and weight[9].

Our study had several limitations. The sample for the present study comprised only 105 patients with T2DM visiting a hospital for diabetes. This sample was only a small portion of all patients with diabetes limiting the generalization of findings. The study was limited to a one-time individual postprandial response to a single meal consisting of low-GI food. Hence, a long-term effect of consumption of millet *dosa* on blood lipid profile and glycosylated haemoglobin (HbA_{1c}) in T2DM patients would be beneficial. Another limitation of the study was that the available carbohydrate was estimated using the difference method.

In conclusion, our study indicated the potential benefits of foxtail millet in the diet therapy for patients with diabetes. However, there is a scope to explore the potential benefits of millets in the management of metabolic disorders through long-term feeding interventions. If used on a long-term basis, it could be beneficial in controlling lipid profile as well as the HbA_{1c} levels in such patients.

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***Conflicts of Interest*:** None.

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