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Assessment of quality of minor millets available in the south Indian market & glycaemic index of cooked unpolished little & foxtail millet

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***Background & objectives*: Millets are widely marketed as healthier alternatives to white rice (WR). This study was conducted with two aims: firstly, to look at the nature and quality of minor millets available in the Chennai market and secondly, to estimate the glycaemic index (GI) of unpolished forms of the two most widely available minor millets, *i.e.* little (LM) and foxtail millet (FXM).**

***Methods*: A market survey was conducted of 100 food stores in four zones of Chennai, south India. Morphological features of market millet samples were compared with that of unpolished millets under stereo-zoom microscope, and the claims declared on the pack were evaluated. A consumer perception survey was conducted among 20 minor millet-consuming female homemakers. Finally, the GI of unpolished LM and FXM was evaluated using a validated protocol in 12 healthy volunteers.**

***Results*: Forty eight brands of minor millets were available, with LM and FXM being the most common. Most of the millet samples were identified as highly polished grains using stereo-zoom microscope. The product labels were misleading and showed no scientific backing for claims mentioned on the label. Most participants (12 of 20) were unaware of the fact that millets can also be polished like rice. Both LM and FXM exhibited high GI (88.6±5.7 and 88.6±8.7, respectively).**

***Interpretation & conclusions:* The availability and knowledge regarding unpolished millets was low. Both LM and FXM exhibited high GI. Hence, substituting millets for WR might be of limited benefit considering the glycaemic property in the prevention and management of chronic non-communicable diseases such as T2DM.**

Key words Diabetes - foxtail millets - glycaemic index - little millets - market survey - rice

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Faulty dietary patterns have been postulated to play a major role in the exponential increase in diabetes prevalence in India[1]. The Asian Indian diet is characterized by a high glycaemic load (GL) and glycaemic index (GI), primarily on account of the nature of the cereal staple namely white rice (WR) in south India[2] and milled and refined wheat in north India. Intake of diets with high GI and GL has been found to be associated with increased risk for type 2 diabetes mellitus (T2DM) and metabolic syndrome in Asian Indians[2,3].

Some of the commonly consumed WR varieties have been reported to have high GI[4]. While wholegrain foods such as brown rice (BR) and wholegrain wheat are healthier alternatives, there are several barriers to their widespread use[5,6]. Consumer acceptance of BR is poor[7,8] while wheat is culturally not a main cereal staple in the southern region of India and cannot be consumed by persons with gluten allergy. Moreover, rice and wheat cultivation are water intensive and not eco-friendly. Therefore, there has been interest in alternative grains which can grow under adverse agro-climatic conditions and are nutritionally superior to rice and wheat.

Millets refer to a group of small-seeded, annual cereal grasses that are considered as healthier alternatives to refined cereals on account of their presumed higher fibre content and lower GI and GL. Minor millets such as foxtail millet (FXM) (*Setaria italica*), proso millet (PM) (*Panicum miliaceum*), little millet (LM) (*Panicum sumatrense*), kodo millet (KM) (*Paspalum scrobiculatum*) and barnyard millet (BM) (*Echinochloa esculenta*) contain higher amount of dietary fibre compared to polished WR[9]. Although millet-based preparations have been believed to have superior glycaemic properties, the evidence is equivocal[10], with some groups having shown high GI for finger millet-based preparations[11]. The present study was aimed to assess the availability of minor millets in the metropolitan area of Chennai, a city in southern India and to look at consumer awareness regarding these millets. We also evaluated the GI of pressure-cooked unpolished LM and FXM.

Material & Methods

Market survey and product evaluation: A market survey was carried out to represent the four zones (North, South, East and West) of Chennai in January 2017. Randomly, a total of 100 retail outlets selling minor millets were included. The outlets were selected so as to include supermarkets, hypermarkets, organic stores, grocery stores and pharmacies, where minor millets are usually sold. The number of brands available for each millet was estimated, and the information provided on the product label was evaluated. Unpolished millets (100% wholegrain with intact bran and germ) were obtained from dehusked millets. The morphological features of the millets (polished or whole grain in terms of intactness of bran and germ) were evaluated using physical examination as well as stereo-zoom microscopic examination (using SZM-LED 2 stereo-zoom microscope, Optika, Italy).

Consumer perception survey: A telephonic interview using a semi-structured qualitative questionnaire was conducted in January 2017 among 20 consumers of minor millets (purposive sampling), and the responses were recorded. The questionnaire was designed to capture the demographic details of participants, such as age; the kind of market where the grocery shopping is done and the dietary habits in general and use of millets in particular by the whole family or selected family member; the reasons behind buying and not buying millets and also awareness about polished and unpolished forms of millets and the method adopted to identify them while buying. All the participants were female homemakers between the ages of 40 and 50 yr.

Nutrient evaluation of unpolished little millet (LM) and foxtail millet (FXM): The nutrient content of the unpolished LM and FXM (single sample source, procured from Earth 360, Kadiri, Andhra Pradesh) was determined by standard Association of Official Analytical Chemists (AOAC) methods[12], whereas the available carbohydrate and dietary fibre content were determined using Megazyme K-ACHDF 06/14 kit (Megazyme, Ireland which is based on the AOAC Official Method 991.43 and AACC Method 32-07.01).

Glycaemic index (GI) testing: The GI testing was done during December 2017 to March 2018. This study was conducted using Internationally recognized GI protocol[13] and guidelines recommended by the International Dietary Carbohydrate Task Force for GI Methodology and ISO (2010)[14,15], which have been validated and published elsewhere[16]. The study was conducted at the GI Testing Centre of Madras Diabetes Research Foundation (MDRF), Chennai, India. The procedure used in this study was in accordance with International standards for conducting ethical research in humans and was approved by the Ethics Committee of MDRF. All volunteers gave informed written consent. The trial was also registered with the Clinical Trials Registry of India (CTRI/2018/05/014043).

Eligible participants were both men and women, aged 20-45 yr with body mass index (BMI) 18.5 to 22.9 kg/m^2, with no family history of diabetes and not on any medications or treatment for any chronic disease. A total of 20 volunteers (males=10 and females=10) were screened as per inclusion and exclusion criteria[17] and 15 of them were recruited for the study from the GI volunteer registry of MDRF. However, due to personal reasons, three of the 15 volunteers dropped out and hence the study was completed with 12 volunteers. Sixty seven per cent (n=8) of the study participants were females. The mean age (yr) was 26.5±5.12, height (cm) 162.8±9, weight (kg) 55.4±8.3, BMI (kg/m^2) 20.8±1.0, waist circumference (cm) 74.8±5.5, blood pressure (systolic) 102±13 mmHg and (diastolic) 67±10 mmHg. All participants underwent three days of testing with the reference food and one day with the test foods in random order with at least two days gap. On each test day, the volunteers visited the GI testing centre in the morning after a 10-12 h overnight fast. A questionnaire on the previous meal (24 h recall), physical activity, smoking, alcohol and caffeine-containing drinks was administered. Volunteers were given 200 ml of water along with the test food. The time of first bite in the mouth was set as time 0 and capillary blood samples were taken at 15, 30, 45, 60, 90 and 120 min post ingestion of the test foods containing 50 g available carbohydrates (FXM, unpolished plain uncooked - 78 g, LM, unpolished, plain uncooked - 80 g). Both the millets were cooked without salt in the pressure cooker, FXM was cooked in ratio of 1:1.5 water and LM in the ratio of 1:1.25. Fifty grams of glucose dissolved in 200 ml of water was used as the reference food. The test foods containing 50 g of available carbohydrates from LM and FXM (cooked LM 171.3 g and FXM 183.8 g) and the reference food were ingested within 12-15 min.

Statistical analysis: Statistical analysis was performed using SPSS software (version 20.0; SPSS, Inc., Chicago, IL, USA). Of the 15 healthy volunteers, 12 completed the study (dropouts n=3). Individual GI was calculated as per FAO/WHO[13] recommendations. The incremental area under the curve (IAUC) of blood glucose for the reference and test food was calculated geometrically using the trapezoid rule, ignoring the area below the fasting baseline. The mean and standard errors of the IAUC for the reference and test food were calculated. GI value was calculated by expressing each participant's IAUC after the test food as a percentage of the same participant's mean reference IAUC. The mean of the resulting values was taken as the GI of the respective test food.

GL of test foods = GI × available carbohydrate in g/100

Data were shown as mean with standard error unless otherwise stated. The significance of difference between the GI of FXM and LM was tested using paired *t* test. Using linear regression, the effects of age, sex, BMI and waist circumference on the GI and IAUC were analyzed for the test foods. The significance of difference between nutrient composition of both uncooked and cooked millets was tested using independent *t* test.

Results

Market survey

Availability: Of the 100 outlets selected, 35 per cent of shops were from the south zone, 29 per cent from the west, 25 per cent from the east and 11 per cent were from the north. Of the outlets visited, 46 per cent were supermarkets, 41 per cent were organic stores, nine per cent were hypermarkets and four per cent were pharmacies. A total of 48 brands of millets were identified. However, no single brand was selling all the varieties of minor millets at the time of the market evaluation. LM and FXMs were the most widely available choices as a maximum of 43 of 48 brands were selling these two minor millets followed by kodo millet (41 brands) and barnyard (38 brands). Only 21 brands were selling proso millet (Table I).

Nutritional label information: Health and nutritional claims were stated on 19 of the 48 brands, but none of the brands mentioned whether these minor millets were in the polished or unpolished form. Nutritional information was available on the pack for 10 brands of BM, 13 of LM, 14 of KM, 13 of FXM and four of PM. The ranges of the nutritional content values declared on the packs are shown in Table II. Some of the brands declared very low dietary fibre content (1-2%) possibly indicating that the pack contained polished forms of these millets. The remainder of the brands declared a dietary fibre content in the range of 8.8-14.7 g per cent. The fat content of the millets ranged between 1 and 6 g per cent, and the protein content, between 6 and 12.7 g per cent. Some of the brands had very high

Table I. Number of brands selling polished and unpolished minor millets in market

Millet	Total number of brands selling the millet	Number of brands selling polished millets (%)	Number of brands selling unpolished millets (%)
Barnyard	38	36 (94.7)	2 (5.2)
Little	43	40 (93.0)	3 (6.9)
Kodo	41	37 (90.2)	4 (9.7)
Foxtail	43	39 (90.6)	4 (9.3)
Proso	21	21 (100)	Nil

Table II. Range of nutrients provided by brands for each millet (g/100 g)

Description	Barnyard millet		Little millet		Kodo millet		Foxtail millet		Proso millet	
	Market sample	IFCT	Market sample	IFCT	Market sample	IFCT	Market sample	IFCT	Market sample	IFCT
Energy (KJ)	1312.1±114.5	-	1338.9±206.9	1449.2±19.2	1354.3±100.3	-	1544.1±176.0	-	1354.3±100.3	-
Protein (g)	9.8±2.2	-	8.6±1.4	10.1±0.5	12.4±0.3	-	11.2±1.7	-	12.4±0.3	-
Fat (g)	3.4±1.4	-	4.1±1.7	3.9±0.4	1.05±0.1	-	3.3±1.3	-	1.05±0.1	-
CHO (g)	64.1±9.5	-	68.2±6.7	65.6±1.2	70.2±0.3	-	71.0±11.0	-	70.2±0.3	-
Dietary fibre (g)	11.4±2.1	-	7.2±2.0	7.7±0.9	2.15±0.1	-	6.9±2.2	-	2.15±0.1	-
Fe (mg)	15.5±3.7	-	8.2±3.1	1.3±0.4	0.8±0.0	-	4.6±4.9	-	0.8±0.0	-
Ca (mg)	20.0±14.4	-	17.9±10.2	16.1±1.5	-	-	33.3±15.5	-	-	-
Vitamin B1 (mg)	0.1	-	0.3	0.3±0.04	-	-	0.6	-	-	-

Data presented as mean±SD. SD, standard deviation; IFCT, Indian food composition tables; CHO, carbohydrates; Fe, iron; Ca, calcium

carbohydrate content (almost 95%). Wide variation existed between brands with respect to the iron and calcium content (Table II). In most cases, the claims of being wholegrain were not appropriate as majority of the grains were highly polished and lacked bran and germ. The GI values and the source of the same were not indicated for many of the products claimed to be lower GI.

Microscopic evaluation of commercial millets: The millet samples manually de-hulled had a smooth and glossy appearance with intact bran and germ constituents (Fig. 1A, C, E, G and I). Unpolished FXM was golden yellow and KM was brownish, while the others were off white. PM and KM had bigger kernel sizes compared to BM, LM and FXM. The continuous bran and germ constituents were visible in all the unpolished millets. In contrast, many of the market millet samples were highly polished and whitish, with absence of bran and germ (Fig. 1B, D, F, H and J). A typical groove was observed in the germ portion of the grain, indicating the absence of germ. Market FXM alone was mildly yellowish with a rough texture, indicating partial retention of bran layers (Fig. 1D). Very few brands contained unpolished millets, the details of which are shown in Table I. The market parboiled millets were brownish with translucent appearance and there was complete loss of bran layers. In many of these, retention of minor proportions of germ was observed. White belly was observed in the parboiled KM samples (Fig. 1M).

Consumer perception survey: Of the 20 participants, 12 (60%) were unaware of the fact that millets can also be polished like rice. Only eight participants (40%) were aware that unpolished millets are healthier. Of the 12 unaware participants, seven (58.3%) were willing to switch to unpolished millets after the benefits were explained to them (data not shown). Of the 20 participants, 17, 16, 14, 19 and one participants consumed barnyard, little, kodo, foxtail and proso millet, respectively. Seven participants consumed millet daily and the rest (13) consumed occasionally. Of the 20 participants, the average

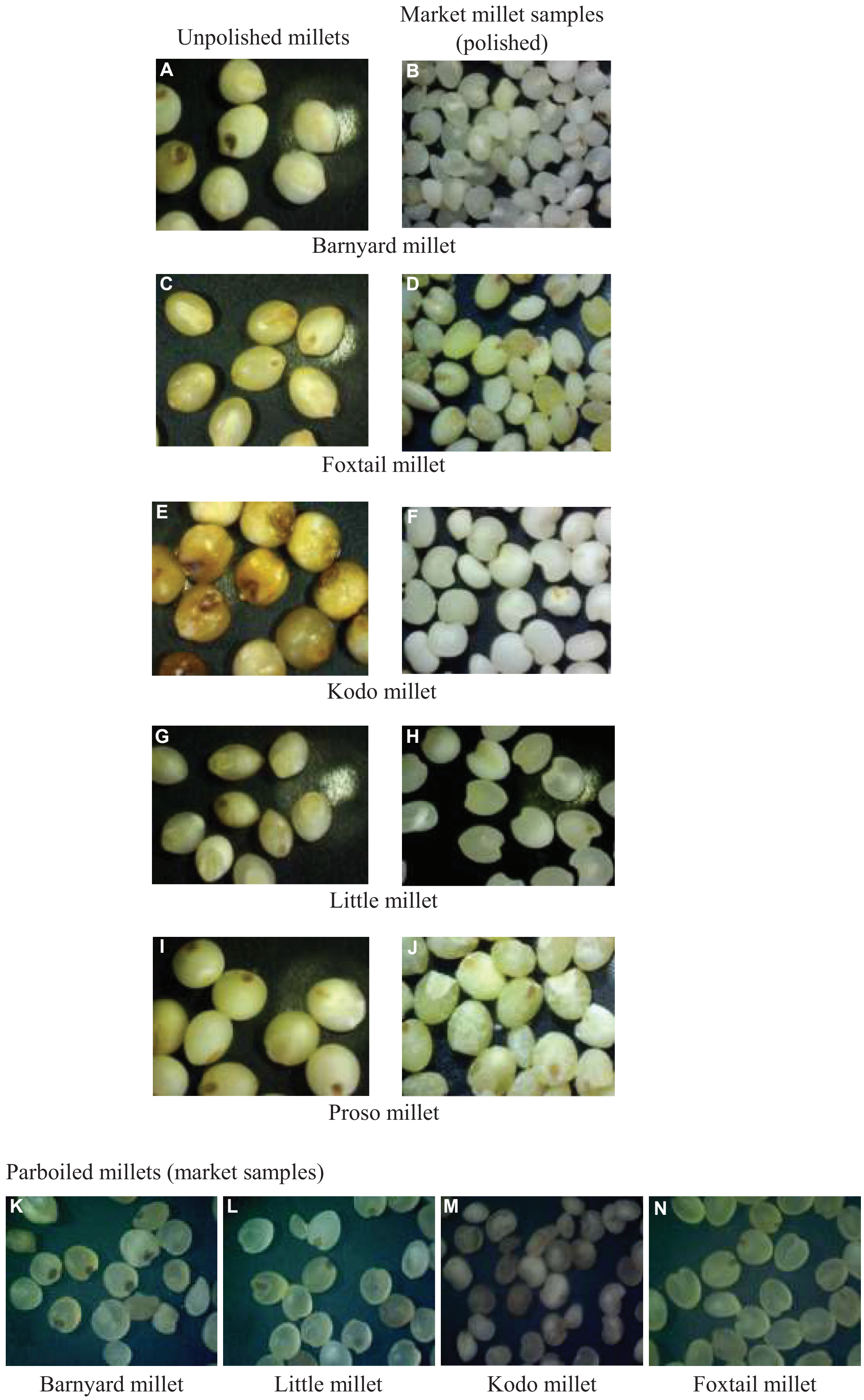

Fig. 1. Stereo-zoom microscopic images of unpolished millet and market minor millet raw and parboiled samples.

millet consumption per month for a family was 1-2 kg for 17 participants, 2-3 kg for two participants and 5-6 kg for one participant.

Nutrient composition of unpolished LM and FXM: The protein and available carbohydrate content were found to be higher in FXM (14.7±0.4, 64.4±0.4 g/100 g) when compared to LM (13.4±0.5, 62.33±1.0 g/100 g), but the fat and total dietary fibre values were higher for LM. The detailed nutrient compositions of millets are given in Table III.

Glycaemic index (GI) of pressure-cooked unpolished LM and FXM: The GI of pressure-cooked unpolished LM and FXM was high, 88.6±5.7 and 88.6±8.6, respectively. The mean IUAC was 3953.8±365.6 mg/dl/min for LM and 3765.8±268.9 mg/dl/min for FXM. The GL of pressure-cooked unpolished LM and FXM was 44.3 mg/dl/min available carbohydrates in grams (per serving size providing 50 g available carbohydrate) for both the millets (Table IV). The mean change in capillary blood glucose concentration after consumption of millets compared to reference glucose is given in Figure 2.

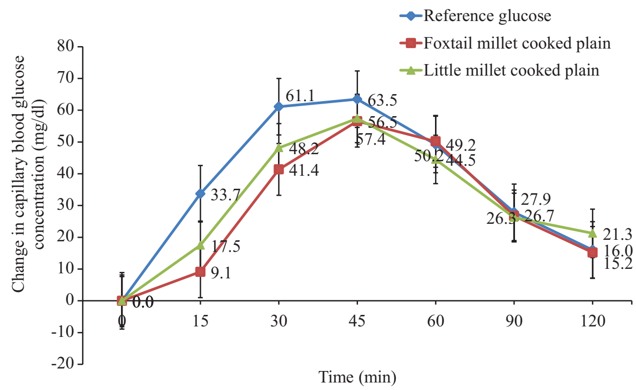

Fig. 2. Mean change in capillary blood glucose concentration of pressure-cooked little and foxtail millet compared to reference glucose.

Table III. Nutrient composition of unpolished little millet (LM) and foxtail millet (FXM) (g/100 g)

Parameters	Uncooked FXM (g/100 g)	Uncooked LM (g/100 g)	Cooked FXM (g/100 g)	Cooked LM (g/100 g)
Moisture	9.9±0.1***	10.8±0.1	60±0.0	57±0.0
Ash	1.1±0.1	1.7±0.1	0.5±0.1	0.8±0.1
Protein	14.7±0.4*	13.4±0.5	6.2±0.1	6.3±0.1
Fat	3.6±0.1**	4.4±0.2	1.5±0.1	2.1±0.1
Available carbohydrate	64.4±0.4*	62.3±1.0	27.4±0.1	29.4±0.3
Total dietary fibre	8.1±0.2**	9.2±0.2	3.5±0.1	4.3±0.1

*P**<0.05, **<0.01, ***<0.001 compared to LM. Data presented as mean±SD (n=3)

Table IV. Mean incremental area under the curve (IAUC) and glycaemic index (GI), glycaemic load (GL) of little millet (LM) and foxtail millet (FXM)

Millet variety	n	IAUC mg/dl min for reference food* (mean±SEM)	CV % for reference food (mean±SEM)	IAUC mg/dl min for test food* (mean±SEM)	GI (mean±SEM)	GI classification	GL (per serving size providing 50 g available carbohydrate) mg/dl/min available carbohydrates in grams
Little	12	4644.4±1353.9	17.4±4.3	3953.8±365.6	88.6±5.7	High	44.3
Foxtail	12			3765.8±268.9	88.6±8.6	High	44.3
WR (BPT variety)*	-	5009.2±460.2	18±2.8	3981.1±438.5	82.5±8.8	High	41.3
BR (BPT variety)*	-			2936.2±278.0	58.7±2.1	Medium	29.4

*In-house data. Significance of difference between rice and millets were tested using Mann-Whitney U-Test. BR vs. FXM *P*=0.02; BR vs. LM *P*<0.001; WR vs. FXM *P*=0.586; WR vs. LM *P*=0.446. BPT, Bapatla; CV, coefficient of variation; SEM, standard error of mean; WR, white rice; BR, brown rice

Discussion

This study reports on the nature of small millets (little, foxtail, proso, barnyard and kodo millet) available in Chennai market and also on the GI of pressure-cooked unpolished forms of the most commonly available millets namely LM and FXM. The millets which were available in Chennai market were predominantly in the polished form. Even the unpolished LM and FXM showed high GI in the present study.

The nutrition labels did not provide information on whether the millets were whole or in the polished form. The packaging carried claims such as diabetic friendly, whole grain and low GI, although the scientific basis for these claims was not mentioned. Our earlier study has shown the deleterious effects of even minimal degrees of polishing on the glycaemic properties of rice[17]. Similar or even poorer results can be expected when millets are used in their polished form as their grains are smaller in size compared to WR, a factor that has shown to increase glycaemic responses[18]. We have earlier shown that even minimal polishing of finger millet leads to very high glycaemic responses (GI=84.7)[11].

Among cereals, millets are unique for their richness in calcium, dietary fibre, polyphenols and protein[19]. The fibre content of whole grain millets has been shown to range from 19.1 to 30.8 per cent. The protein content of minor millets was also found to be higher than major millets such as sorghum and pearl millet[20]. The nutritional values provided on the labels were lower. This is another indication that the commercially available millets are marketed in the polished form, as polishing has been shown to decrease the fibre and protein content[21].

Under microscope, many of the market millet samples were whitish and lacked glossy appearance, indicating that they were highly polished. The translucent and duller appearance of the parboiled millets may be due to gelatinization of starch during hydrothermal processing and the inner penetration of bran pigments during parboiling. Bran retention observed in the BM and KM may be due to harder texture of the parboiled millets and also the ability of the hardened millets to retain the bran layers during the milling process. The white belly observed in the parboiled KM may be due to the presence of un-gelatinized starch core in the grains after parboiling as is the case reported for parboiled rice[22].

To understand the glycaemic properties of minor millets, the GI of pressure-cooked unpolished LM and FXM was evaluated. Both pressure-cooked LM and FXM exhibited high GI. This could be due to the nature of starch (millets are known for lower amylose content)[23] and the chewy nature of unpolished millets (higher chewing time may lead to finer particle size of the cooked grain and hence higher surface area of the bolus presented for amylolytic digestion). Higher chewing time has shown higher glycaemic responses in the case of rice[24], and this could apply for millets also. This clearly indicates that being a whole grain alone may not be sufficient to qualify for a low/lower GI and there are several other factors which may play a role.

There are no reports on the GI of unpolished pressure-cooked FXM and LM; however, there are some studies on the GI of other millets. Ugare *et al*[25] reported a low GI for dehulled barnyard millet and heat-treated barnyard millet. They mentioned that the reduction in GI could be due to development of resistant starch during the heating and cooling cycles that the millet was subjected to. In contrast, Mani *et al*[26] reported a GI of 68±8 for plain pressure-cooked kodo millet. The glycaemic properties of millet-based preparations vary widely, with a lower GI of 17.6 reported for foxtail millet and barnyard millet based *upma* preparation containing legumes and fenugreek[27]. The same authors reported a GI of 35 and 23 for foxtail, barnyard millet '*dokhla*' and foxtail millet '*laddu*'. Patil *et al*[28] reported a GI of 52.1 for LM in the form of flakes *upma* and attributed this to formation of resistant starch during partial gelatinization and melting of starch during steaming of grains. However, due to variations in GI testing methodologies adopted by different researchers, it is difficult to make direct comparisons.

The GL of pressure-cooked unpolished millets was similar to plain cooked WR (BPT variety) and higher than BR. Choosing a whole grain cereal staple with lower glycaemic properties would be the best option (to lower the GL) in a population at high risk of T2DM such as south Asians who consume high-carbohydrate meals. Millets have been advocated as healthy alternatives to WR and refined wheat in this population[29]. However, our results showed that commonly available minor millets (even in the unpolished form) had high GI and high GL similar to plain cooked WR. Plain cooked BR seems to be a comparatively healthier choice in terms of lower glycaemic properties[5,17]. Frequent consumption of fibre depleted minor millets in larger quantities can, in the long term, increase the GL of diets and consequently the risk for insulin resistance, obesity, T2DM and cardiovascular diseases.

The strength of our study included a market survey of minor millets in supermarkets, organic stores, pharmacies and departmental stores across all parts of Chennai city. The main limitation of the study was that nutrient evaluations of the market samples were not carried out. Also, as the millets showed high GI even in the unpolished form, we did not evaluate the GI of polished pressure-cooked LM and FXM. Consumer perception survey was carried out with only 20 women due to limited time period of the study as well as the budgetary constraints and this might not be a representative sample size for each zone of the city.Further, satiety of the test millets was not measured in this study.

In summary, unpolished minor millets were virtually unavailable in the markets in Chennai. Most of the millet samples available were highly polished and depleted of bran and germ as evident through microscopic evaluation. The nutritional and functional claims made by the various brands of millets were found to be unsupported by scientific evidence and were misleading. The consumer perception survey indicated unawareness of the polishing of millets. Hence, awareness on the polishing, morphological features and nutritional aspects of millets is required to empower the consumers for making appropriate nutritional choices.

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Conflicts of Interest: None.

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