Original Article

Development and evaluation of nutritional, sensory and glycemic properties of finger millet (*Eleusine coracana* L.) based food products

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Background and Objectives: Finger millet (*Eleusine coracana* L.) (FM) is rich in dietary fibre and is therefore expected to elicit a lower glycemic response compared to other grains. However, there is little data on the glycemic properties of FM-based products. We evaluated the nutritional, sensory and glycemic properties of decorticated millet with lower polish (DFM-LDP), flakes (FMF), vermicelli (FMV) and extruded snack (FMES) (both FMV and FMES with 7-8% added soluble fibre). **Methods and Study Design:** The nutrient contents of the FM products were evaluated by standard AOAC (Association of Official Analytical Chemists) and AACC (American Association of Cereal Chemists) methods. Sensory evaluation was conducted monadically using a 9-point hedonic scale using untrained panel members. GI testing was conducted using a standardized validated protocol. The study was conducted according to the guidelines laid down by the Declaration of Helsinki, and was approved by the Ethics Committee of the Madras Diabetes Research Foundation. **Results:** The products had dietary fibre (DF) content between 5.8-15.6 g%. FMES was unique in having a very low fat content (0.17%). Evaluation of sensory perception revealed moderate acceptance of millet based products. The glycemic indices (GI) (mean±SEM) of the products were 84.7±7.7%, 82.3±6.4%, 65.5±5.1% and 65.0±6.6% for DFM-LDP, FMF, FMV and FMES respectively. **Conclusions:** DFM-LDP and FMF (purely finger millet based products) elicited higher glycemic responses. Comparatively, FMV and FMES (with added functional ingredients) exhibited medium GI values and, are healthier dietary options. It is possible to prepare FM products with lower GI by utilizing functional ingredients.

Key Words: decorticated finger millet, vermicelli, glycaemic index, dietary fibre, functional foods

INTRODUCTION

Finger millet (FM, *Eleusine coracana* L.) or Ragi forms the staple food for a large segment of the population in south Asian and African countries. This millet contains 65-70% starch, 11-12% dietary fibre, and has high levels of calcium (340-360 mg%).[1] Millet-based preparations are believed to elicit lower glycemic responses[2] and are therefore recommended for individuals with diabetes. While a number of FM- based products are now available, there is little scientific evidence to support their health benefits.

Varying study designs and methodological shortcomings make it difficult to draw conclusions from existing studies on the glycemic aspects of FM.[3,4] Also, very little information is available on the glycemic index (GI) of FM-based foods.[1,3] FM is used for the preparation of a variety of food products. Decorticated FM can be cooked like rice.[5] FM can also be used for the preparation of vermicelli and many other food products such as flakes and ready-to-eat extruded snacks.[3,6-10] There is a potential

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market for evidence based convenience products from FM. However data on the glycemic properties of the aforementioned products are not available. In the present study, we planned to study the glycemic properties of decorticated FM, flakes, vermicelli and a ready-to-eat snack, developed with functional ingredients using standard protocols.

METHODS

Raw materials, ingredients and food additives for the development of FM products

FM procured from the local market was pre-cleaned using de-stoner – aspirator. Defatted soya, resistant maltodextrin (NUTRIOSE FB06, Roquette, India), corn grits, onion powder, fenugreek, skimmed milk powder, Glyceryl mono stearate (GMS) and calcium carbonate ($CaCO_3$) were procured and kept in cold storage until use.

Preparation of decorticated finger millet with lower degree of polish (DFM-LDP)

Hydrothermal processing and decortication trials were conducted at PRS Foods, Kovilpatti, India (Figure 1).

Preparation of finger millet flakes (FMF)

FMF was prepared using a lab-scale experimental roller flaker (Murhopye Scientific Instruments, Mysore, India) (Figure 1).

Development of finger millet vermicelli (FMV)

FMV was prepared using a vermicelli machine (Amman Industries, Coimbatore, India) (Figure 1). Defatted soy and resistant maltodextrin (functional ingredient) were used in the formulation of FMV.

Development of finger millet based ready-to-eat high fibre, low fat extruded snack (FMES)

Extrusion trials were carried out at Sing Ventures, Chennai, India. FM flour was blended with fenugreek fibre, defatted soya flour, vegetable oil and spices and taken for extrusion (Figure 1).

Nutritional evaluation of the products

The nutrient contents (Table 1) of the FM products were evaluated by standard AOAC (Association of Official Analytical Chemists) and AACC (American Association of Cereal Chemists) methods. Available carbohydrates and total dietary fibre content of the sample were determined using Megazyme kit method (Megazyme Enzymatic Kit K-ACHDF 11/08, Ireland).

Sensory evaluation of finger millet based preparations

DFM-LDP, FMF, FMV prepared in the form of *upma* (a savory meal – a common Indian breakfast choice) and FMES as such was taken for the study. Sensory evaluation was conducted monadically using a 9-point verbal hedonic scale (1 = like extremely to 9 = dislike extremely) in a total of 30 randomly selected, untrained panels. Mean scores were calculated for data analysis.

GI testing

For study A (DFM-LDP, FMF, FMV in the form of upma), 16 healthy volunteers consumed 50 g available carbohydrate containing test portions, for Study B (FMES) 12 healthy volunteers consumed 25 g available carbohydrate containing test portions, The study participants were in the age group of 27.9±3.7 years, with a BMI of 20.5±1.4 (kg/m^2), They were recruited based on inclusion and exclusion criteria explained elsewhere.[11] The study was conducted according to the guidelines laid down by the Declaration of Helsinki, and was approved by the Ethics Committee of the Madras Diabetes Research Foundation. All participants gave written informed consent before participation. The trial was registered under Clinical trial registry of India (CTRI) and the reference number is REF/2016/04/011258.

After an overnight fast of 8-12 h, finger-prick capillary blood samples were obtained (Hemocue Glucose 201 + analyzer, Hemocue Ltd, Angelholm, Sweden) from all the participants. The reference/test foods were consumed immediately after this. The time of first bite in the mouth was set as time 0 and blood samples were taken exactly 15 30, 45, 60, 90 and 120 min later. The test foods were consumed in random order between the reference food sessions, with at least 2 days gap between measurements.[12] GI was calculated as mentioned in FAO/WHO.[13]

RESULTS

DFM-LDP had almost 60% lower dietary fibre content as compared to the native FM. Cooked upma samples had dietary fibre content in the range of 6.7-8.7 g% for all the three products, whereas the FMES has around 15.6 g% dietary fibre (Table 1).

The GI values for the DFM-LDP, FMF, FMV and FMES are shown in Table 2. The sensory scores are shown in Figure 2. The mean change in the glucose response curve for the reference and test foods is shown in Figure 3. There were no significant differences in the fasting blood glucose levels among the participants on all test days. DFM-LDP upma and FMF upma were of high GI category whereas the FMV upma and FMES were in the medium GI category. Age, sex, BMI, waist circumference, diet of the previous day to the test food testing and physical activity of the participants did not influence the GI of the FM products. The GI of DFM-LDP and FMF upma (without addition of functional ingredients) were not significantly different (p=0.83), similarly the GI of FMV upma and FMES (prepared with functional ingredients) did not differ significantly (p=0.80). The sensory scores revealed that all the products were moderately liked by the study participants. The texture of the FMES was liked very much for its crispy nature (Figure 2).

DISCUSSION

The study shows that finger millet based vermicelli and extruded snacks by virtue of their lower GI content are healthier options compared to refined wheat based vermicelli and commercially available snacks with higher fat content which are commonly consumed. GI values of decorticated FM have been reported previously. Shobana[14,15] reported a high GI for highly polished decorticated FM when served with dhal accompaniment (GI - 81) and in a formulation with legumes (GI - 93.4) respectively'. In the current study, minimal levels of polishing did not shift the GI of FM from high to medium category. GI of

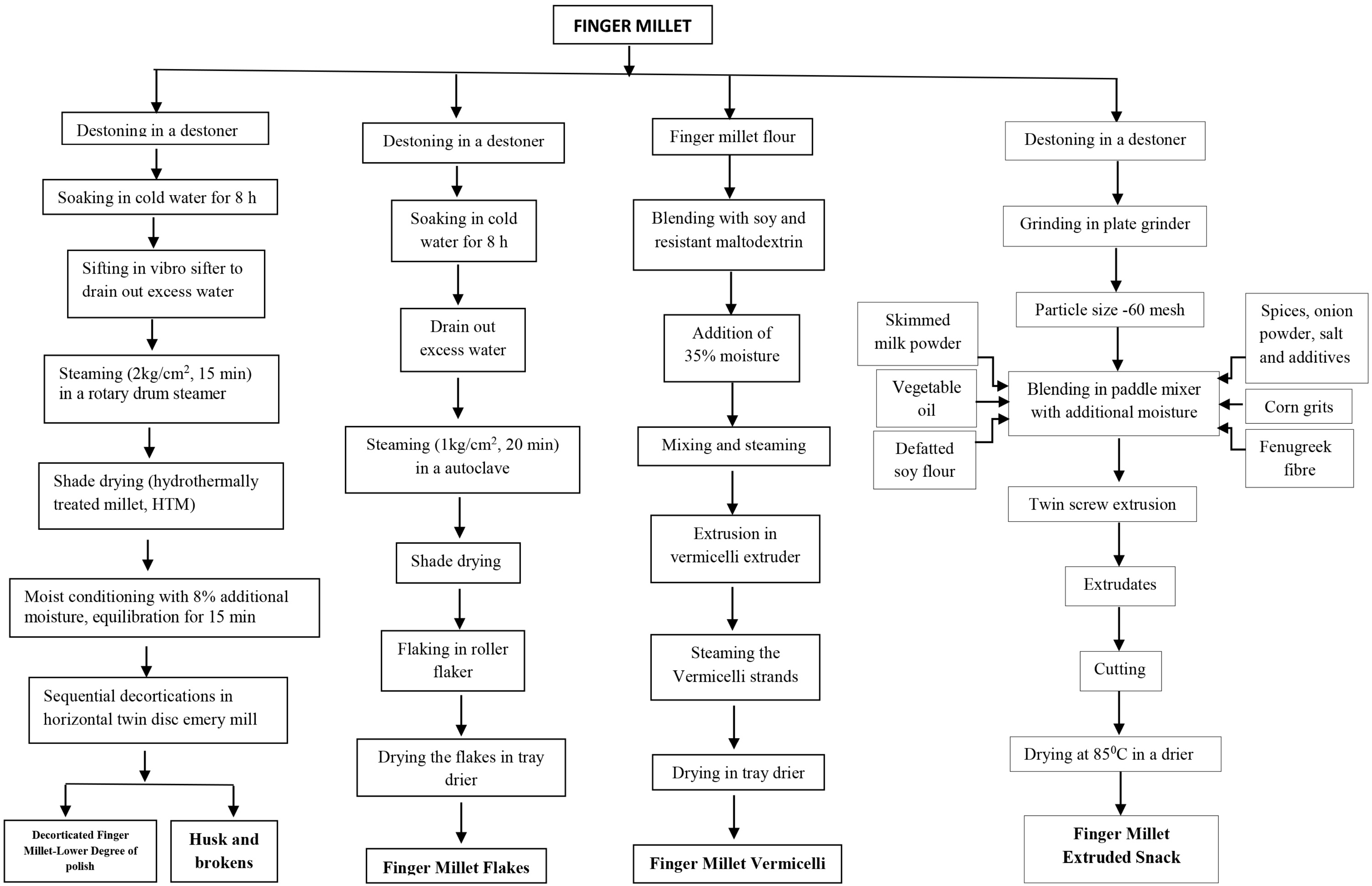

Figure 1. Flow chart for the preparation of finger millet based products.

Table 1. Nutrient composition of the control (commercial market samples) and finger millet based products (g/100 g)

Parameters	DFM-LDP	FMF	FMV	*p* value (between uncooked)†	DFM-LDP *upma*	FMF *upma*	FMV *upma*	*p* value (between cooked)‡	FMES
Moisture (g)	10.6±0.2	14.2±0.13	11.7±0.05	0.859	55.7±0.5	60.6±0.1	59.8±0.05	0.764	4.4±0.10
Protein (g) (N*5.95)	6.7±0.05	7.4±0.04	13.4 ±0.1	0.061	3.9±0.04	4.2±0.05	5.9±0.04	0.089	11.6±0.02
Total Fat (g)	0.9±0.2	1.2±0.01	0.6 ±0.02	0.333	2.3±0.10	2.0±0.1	2.1±0.04	0.879	0.6±0.02
Total Ash (g)	1.4±0.09	1.9±0.02	2.9±0.1	0.212	2.5±0.03	2.1±0.02	2.8±0.05	0.386	4.3±0.2
Dietary fibre (g)	5.8±0.05	12.3±0.15	13.6±0.1	0.567	6.7±0.03	7.9±0.03	8.7±0.07	0.407	15.6±0.1
Available carbohydrates (g)	74.4±0.3	62.7±0.9	57.7±0.1	0.478	28.7±0.10	23.0±0.03	20.4±0.03	0.469	63.2±0.02

DFM-LDP: Decorticated Finger Millet – Lower degree of polish; FMF: Finger Millet Flakes; FMV: Finger Millet Vermicelli; FMES: Finger Millet Extruded Snack
Values are mean ± SD; p value <0.05
†Uncooked is DFM-LDP, FMF, FMV.
‡Cooked is DFM LDP *upma*, FMF *upma*, FMV *upma*.

Table 2. Mean GI of finger millet products

Product	N	IUAC		GI		GI classification
		Mean	SEM	Mean	SEM	
DFM –LDP *Upma*	16	200	20.6	84.7	8.2	High
FMF *Upma*†	15	204	24.0	82.3	6.8	High
FMV *Upma*†	15	167	17.8	65.5	5.5	Medium
FMES	12	92.8	10.4	65	6.6	Medium

DFM-LDP: Decorticated finger millet with lower degree of polish; FMF: Finger millet flakes; FMV: Finger millet vermicelli; FMES: Finger millet extruded snack; SEM: standard error of mean.
†Outliers with >mean±2SD

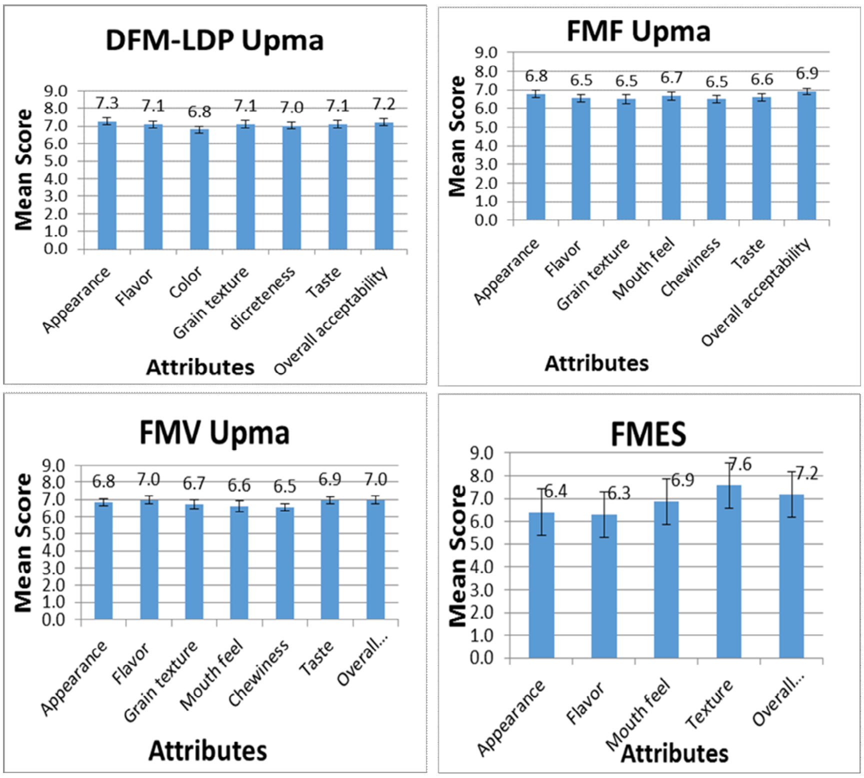

Figure 2. Sensory scores of finger millet based products. Data presented are mean scores±SE for sensory attributes based on a 9-point hedonic scale (1 = dislike extremely, 2 = dislike very much, 3 = Dislike moderately, 4 = Dislike slightly, 5 = Neither like nor dislike, 6 = Like slightly, 7 = Like moderately, 8 = Like very much, 9 = like extremely).

DFM-LDP cooked in the form of upma (GI - 85) was higher than the GI reported for highly polished decorticated FM served with dhal. It is likely that decortication, irrespective of the degree of polish, facilitates gelatinisation of the kernel starch during cooking due to loss of seed coat constituents. This clearly suggests that the integrity of the dietary fibre is important to impart the desirable functional benefits[16] like lower digestibility. This finding is similar to the observations of our earlier study on rice[17] where we found that rice with lower degree of polish elicited a glycemic response almost equivalent to fully polished white rice. Whole grains consumed without decortication are a healthier option compared to minimally polished grains in terms of glycemic response.

In the case of FMF, though the whole millet was flaked to retain the dietary fibre contents, the GI was high (82) which again can be attributed to fragile endosperm and subsequent higher gelatinization of starch and increase in the surface area during flattening, ultimately altering the grain matrix and enhancing susceptibility of starch granules to amylolytic enzymes. Grandfeldt et al[18] have shown that minimal processing of the grains and preparation of thicker flakes may be helpful in preparation of flakes with lower glycemic and insulinemic property. Studies in this direction may be helpful for preparation FMF with lower glycemic response.

Shukla and Srivastava[19] reported a low GI of 45 for the FM and wheat blend composite flour-based noodles compared to refined wheat flour-based noodles (62). In the present study, FM-based vermicelli with added resistant maltodextrin (RMD, soluble fiber) and defatted soya flour (to enhance protein) were in the medium GI category (65.5) similar to wheat vermicelli. The GI of vermicelli based on 100% FM flour alone was not determined in the current study as it is challenging to prepare it without gluten. RMD is low viscous soluble fibre, which is found to lower the glycemic response of carbohydrate containing foods,[20] hence RMD was included in the vermicelli formulation. Although several researchers have been working on FM, kodo millet based

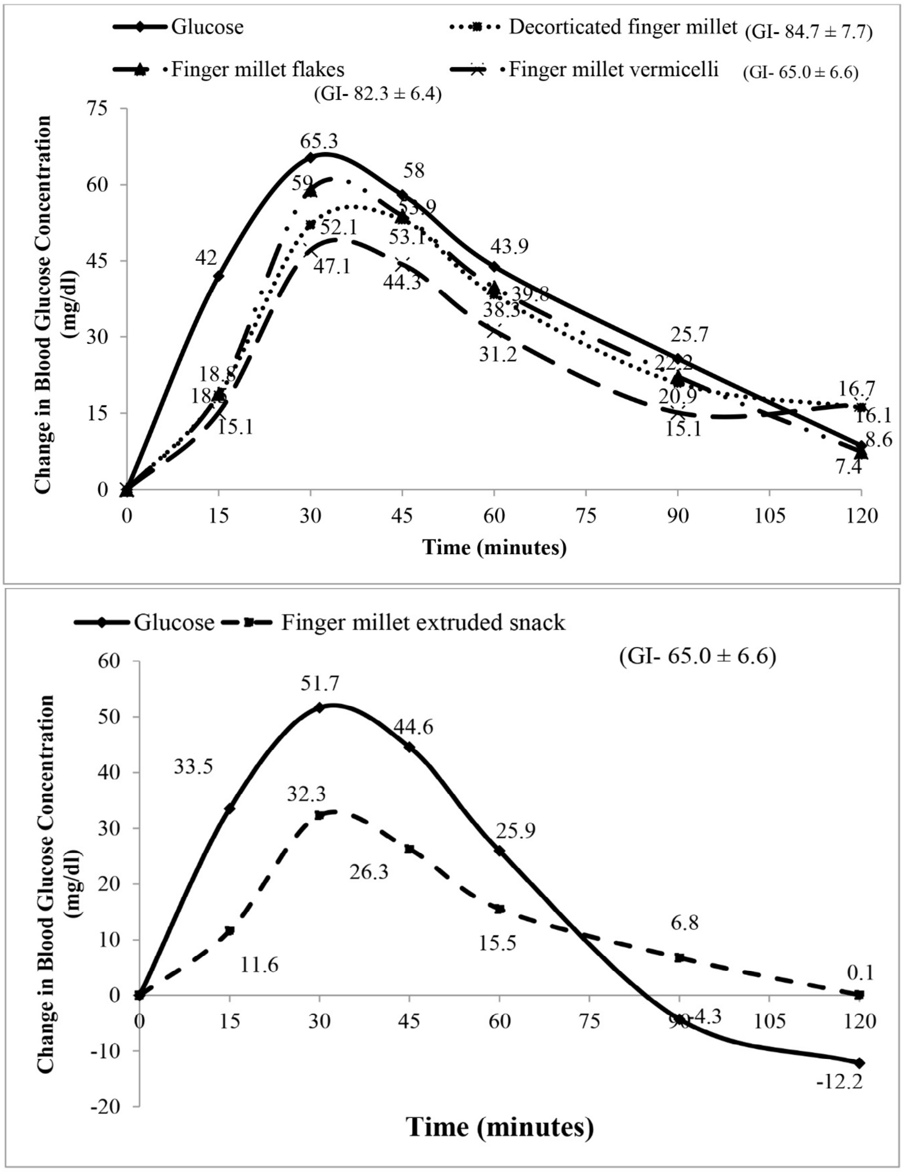

Figure 3. Change in blood glucose response to reference glucose and FM products.

noodles/pasta/vermicelli,[21,22] most of these formulations contained wheat. FMV prepared in the present study is unique in terms of being gluten free, and fortified with fibre and protein. Further formulation trials with different combinations of functional ingredients may be required to develop FM based vermicelli with good sensory and cooking properties and lower GI.

The preparation of ready-to-eat snacks from FM (adapting extrusion cooking technology) has been reported by Balasubramaniam et al,[8] and Seth & Rajamanickam.[9] To the best of our knowledge, there are no reports on the glycemic properties of FM based extruded snack. Commercial extruded snacks (maize based) are known to contain higher levels of fat (17-36 g%) and very low levels of fibre (0.17-4.14 g%). Consumption of 15 g of the FMES would give 2.3 g of dietary fibre. In the current study, efforts were taken to incorporate the spices and salt in the formulation itself before extrusion, thus eliminating the need for coating of the extruded snack, thereby leading to lower fat and higher fibre content (Table 1). Several studies have presented the beneficial effects of low GI, low GL diets on risk reduction for chronic diseases.[23] Evidence-based value-added products from FM with lower GI may be helpful in the prevention and management of diabetes and obesity. This study shows that nature of processing, ingredients and food matrix over and above the quality of dietary fibre, influence the glycemic response of FM-based products.

The study has a few limitations. FM based products were only moderately liked by the sensory panel and the products were developed based on only a few sets of formulations and trials. GI testing of control foods such as products made out of refined rice, wheat and FM products without added functional ingredients could not be conducted due to budgetary constraints. In addition, GI testing reflects only the glycemic property of the FM products and randomized clinical trials are needed to establish long-term benefits. However, the merits of the study are that it has utilized two FM products developed with func tional ingredients, and that it has evaluated the GI using validated protocols.

Conclusion

The present study showed that notwithstanding the widespread belief that finger millet lowers glycemic response, pure decorticated finger millet and finger millet flakes elicited higher glycemic responses. However, when appropriate functional ingredients known to lower the glycemic response were added, the GI values were lower and hence this may represent a healthier means by which FM can be included in the diet. Further formulation trials are required to prepare finger millet based products with good sensory attributes as well as favorable glycemic property. In addition, as GI provides information only on the 2 h glycemic response, long-term feeding trials to determine the health benefits of FM products is still warranted.

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AUTHOR DISCLOSURES

All authors declare that they have no duality of interest associated with this manuscript.

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Supplementary table 1. Anthropometric variables, sedentary activity, and nutrients intake of previous day's [24 h diet recall] of the study population

Description	Reference Mean±SD	DFM-LDP '*Upma*' Mean±SD	FMF'*Upma*' Mean±SD	FMV '*Upma*' Mean±SD	*p* value
Age (y)	27.9±3.7	27.9±3.7	27.9±3.7	27.9±3.7	0.796
Waist (cm)	73.7±7.2	73.7±7.2	73.7±7.2	73.7±7.2	0.144
BMI	20.4±1.5	20.4±1.5	20.4±1.5	20.4±1.5	0.37
Physical activity Sedentary (min/day)	269±138	278±199	278±246	456±269	0.665
Energy (kcal/day)	2185±738	2083±869	2041±618	1981±650	0.133
Protein (g/day)	69.8±31.3	71±54.9	65.1±34.9	62.3±32.8	0.080
Lipid (g/day)	66.2±34.4	68.2±51.4	65.7±35.8	60.5±39.3	0.212
Carbohydrate (g/day)	330±108	299±58	295±81.3	303±84.1	0.302
Dietary fibre (g/day)	27.9±15.7	24±10.4	21.8±10.3	23.9±14.7	0.364