



Development and Glycaemic Index Evaluation of Blue Pea Flower-Incorporated Millet-Based Extruded Breakfast Cereals

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Abstract

Background: The nutrition transition in India has increased dependence on ready-to-eat breakfast products, many of which are refined cereal-based and may produce rapid postprandial glycaemic responses. Millets and blue pea flower (*Crotalaria tinctoria*) and a value-added ingredient offer a relevant route to develop convenient breakfast cereals with improved carbohydrate quality, natural colour and functional value.

Objectives: To develop blue pea flower (BPF) incorporated millet and whey protein-based extruded breakfast cereals and evaluate the glycaemic index (GI) of the most acceptable formulation.

Methods: Breakfast cereals were formulated using ragi, kodri, whey protein concentrate and blue pea flower powder at 0% and 5%. Ten healthy adults aged 18-25 years participated in the GI study following ISO 26642:2010. After overnight fasting, participants consumed reference glucose and test portions providing 50 g available carbohydrate. Capillary blood glucose was measured at fasting, 15, 30, 45, 60, 90 and 120 minutes and incremental area under the curve was calculated by the trapezoidal method.

Results: The reference glucose produced a higher and sharper blood glucose peak than both cereal samples. The control cereal (0% blue pea flower) and the 5% blue pea flower cereal recorded GI values of 53 and 51, respectively; both were classified as low-GI foods.

Conclusion: The developed blue pea flower-incorporated millet breakfast cereal demonstrated low glycaemic potential despite extrusion processing. The product is relevant as a convenient, naturally coloured, millet-based functional breakfast option. Larger studies in metabolically at-risk groups are warranted before disease-specific claims are made.

Keywords: Blue Pea Flower, Breakfast Cereal, Extrusion, Glycaemic Index, Millet

Introduction

Breakfast is a key eating occasion that contributes to daily nutrient adequacy, appetite regulation and sustained cognitive and physical performance. In urban India, however, traditional breakfast patterns are increasingly being replaced by commercially available ready-to-eat (RTE) cereals and convenience foods. This shift has public health relevance because several RTE cereal products are based on refined starches, added sugars and intense processing, which may produce a rapid postprandial glucose response ^[1-4].

The glycaemic index (GI) is a standardised method of ranking carbohydrate-containing foods according to their ability to raise blood glucose after consumption. Foods with low GI are digested and absorbed more slowly and are useful in improving dietary carbohydrate quality [5-7]. Developing convenient low-GI breakfast products is therefore important in the context of rising obesity, insulin resistance and type 2 diabetes risk, particularly among young adults and working populations who often skip breakfast or depend on packaged options.

Millets are suitable base ingredients for such products because they are culturally familiar, climate-resilient and nutritionally valuable. Ragi (*Eleusine coracana*) and kodri/kodo millet (*Paspalum scrobiculatum*) contain dietary fibre, slowly digestible starch, minerals and polyphenolic compounds that may moderate glycaemic response [8,9]. In a human study on region-specific millet-based food mixes, traditional preparations such as dosa, mudde and roti showed low GI values of 37, 48 and 53, respectively and a 120-day intervention among prediabetic subjects reduced fasting blood sugar and HbA1c [10]. This supports the relevance of millet-led food product development for metabolic health.

Extrusion cooking is useful for producing attractive, shelf-stable RTE cereals, but it can also increase starch gelatinisation and enzymatic accessibility. Hence, the actual glycaemic effect of an extruded formulation must be measured rather than assumed [11]. Whey protein concentrate was incorporated in the present formulation to improve protein quality and food matrix structure, while millets provided the cereal base.

Blue pea flower (*Clitoria ternatea*), known in India as *Aparajita*, is valued as a natural blue colourant and as a source of anthocyanins, especially ternatins, along with other phenolic compounds [12-14]. Recent extrusion work using butterfly pea flower in breakfast cereals reported significant improvements in total phenolics, antioxidant properties, total dietary fibre and bowl-life characteristics, indicating its technological and functional suitability in cereal matrices [12]. A human crossover trial further showed that *Clitoria ternatea* flower extract, when consumed with sucrose, suppressed early postprandial plasma glucose and insulin responses while improving antioxidant capacity [15]. However, the wider antidiabetic evidence remains preliminary because available studies are dominated by animal models and short-term human trials [16]. This knowledge gap provides the rationale

for evaluating the GI of a blue pea flower-incorporated millet-whey extruded breakfast cereal using a standardized human protocol.

Objectives

To develop millet- and whey protein-based extruded breakfast cereals incorporating blue pea flower powder at 0% and 5%.

To determine the glycaemic index of the selected blue pea flower-incorporated cereal in healthy young adults.

Materials and Methods

Study design

This experimental product-development study was conducted in three phases: formulation and extrusion of blue pea flower-incorporated breakfast cereals; sensory screening to select the most acceptable formulation; and human glycaemic index evaluation of the selected product. The manuscript emphasises the GI evaluation phase while retaining essential product-development details for reproducibility.

Raw materials and formulation

Ragi flour, kodri flour, whey protein concentrate and dried blue pea flower powder were used as principal ingredients. Two cereal formulations were developed with 0% and 5% blue pea flower powder incorporation on a flour-blend basis. The 0% formulation served as the control, while the 5% formulation represented graded functional incorporation levels. Dry ingredients were blended thoroughly, conditioned with water up to approximately 10% of the total flour weight, double-sieved for uniformity and equilibrated in low-density polyethylene pouches at room temperature for 2 hours before extrusion.

Figure 1 presents the raw materials used for the development of Blue Pea Flower (BPF) incorporated extruded breakfast cereals. The major ingredients included ragi (*Eleusine coracana*), kodri (*Paspalum scrobiculatum*), whey protein concentrate-80, Blue Pea Flower (*Clitoria ternatea*), salt and vanilla extract. Ragi and kodri were selected as millet-based cereal ingredients, whey protein concentrate was incorporated to improve the protein quality and Blue Pea Flower was added as a natural colourant and bioactive ingredient.

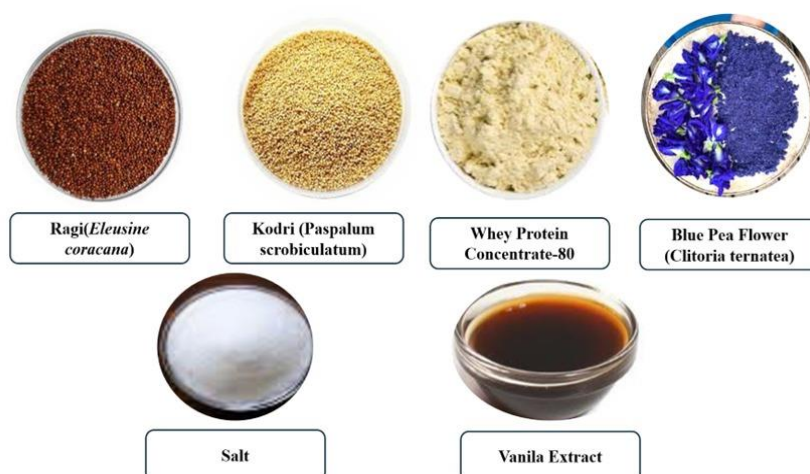


Fig 1: Raw Materials Used for the Preparation of Blue Pea Flower-Incorporated Extruded Breakfast Cereals



Fig 2: Extruded Breakfast Cereals Developed with Varying Levels of Blue Pea Flower Incorporation

Figure 2 shows the developed extruded breakfast cereals prepared with different levels of Blue Pea Flower incorporation, namely 0% and 5%. The 0% BPF formulation served as the control, while the 5% BPF formulation was developed to assess the effect of Blue Pea Flower

incorporation on the appearance and functional potential of the breakfast cereal. A visible change in colour was observed with increasing BPF levels, indicating successful incorporation of Blue Pea Flower into the extruded product.

Table 1: Formulation pathway and evaluation purpose

Formulation	Blue pea flower level	Purpose in study
Control cereal	0%	Baseline millet-whey extruded cereal
BPF-5 cereal	5%	Sensory-selected functional formulation

Extrusion processing

Extrusion was carried out using a co-rotating twin-screw extruder (BTPL lab model EB-10, Kolkata, India) with feeding, heating and die sections (Figure 3). The extruder barrel was approximately 3 feet long with a 40 mm diameter

and was fitted with temperature control, variable-speed motor and cutter assembly. The extrudates were dried in a hot-air oven at 100 deg C for 30 minutes to reduce residual moisture and improve shelf stability.



Twin Screw Extruded with the control Panel



Twin Screw Extruded with Feeder Assembly

Fig 3: Twin Screw Extruder with Control Panel and Feeder Assembly

Selection of formulation for glycaemic index testing

The two formulations (0% BPF and 5% BPF) were used for GI evaluation. The control cereal was also evaluated to understand whether blue pea flower incorporation altered the glycaemic response of the base millet-whey extrudate.

Participants

A total of 16 healthy adults initially consented to participate. Six withdrew during the study period; therefore, 10 participants completed the GI evaluation. Participants were male and female university students aged 18-25 years with

normal BMI. Inclusion criteria were normal BMI (18.5-22.9 kg/m²) and willingness to participate. Exclusion criteria included chronic disease, dietary supplement use, thyroid disorder, pregnancy or lactation, known allergy to milk protein or blue pea flower and unwillingness to continue participation. Written informed consent was obtained from all participants.

Evaluation of Glycaemic Index

Participants were tested in the morning after a 10–12 hour overnight fast. Following a two-day washout period, the alternate food was tested. Blood glucose responses were plotted and the incremental area under the curve (iAUC) was calculated using the trapezoidal method, following WHO/FAO guidelines (1998). The GI was computed using the formula:

$$\text{Area of trapezoid} = \frac{(\text{Increment}_1 + \text{Increment}_2)}{2} \times (\text{Time}_2 - \text{Time}_1)$$

Glycaemic index protocol

GI was assessed according to ISO 26642:2010 and FAO/WHO recommendations [6, 7]. Direct measurement was preferred because calculated GI values may differ from measured meal or product responses [18]. Participants reported in the morning after a 10-12 hour overnight fast. In the reference session, they consumed 50 g glucose dissolved in water. In test sessions, participants consumed portions of the control cereal and 5% BPF cereal standardised to provide 50 g available carbohydrate. The reference and test foods were consumed within 15 minutes and sessions were separated by a two-day washout period.

Capillary blood samples were collected by a trained technician at fasting and at 15, 30, 45, 60, 90 and 120 minutes

after consumption. Blood glucose response curves were plotted for the reference and test foods. The incremental area under the curve (iAUC) was calculated using the trapezoidal method, considering only the area above fasting baseline. The GI for each test food was calculated as:

$$\text{GI} = (\text{iAUC of test food} / \text{iAUC of reference glucose}) \times 100$$

The group mean GI was used for classification: low GI ≤ 55 , medium GI 56-69 and high GI > 70 [5, 6].

Statistical Analysis

Data were compiled and verified in Microsoft Excel. Descriptive statistics were used because of the small exploratory sample size. Participant characteristics and blood glucose values are presented as mean values, standard deviations or percentages, as applicable.

Ethical Considerations

Participation was voluntary and written informed consent was obtained. The research study received ethical approval from the Institutional Medical Ethics Committee of the Department of Foods and Nutrition, The Maharaja Sayajirao University of Baroda. Clearance was granted under Ethical Clearance Number: IECHR/FCS/M.Sc./10/2024/44

Results

Participant profile

The final sample comprised 10 healthy young adults; 70% were female and 30% were male. The mean age was 23.3 \pm 2.35 years. The mean BMI was 21.81 \pm 1.24 kg/m², indicating that the study group was within the normal BMI range. Mean fasting blood glucose values before reference and test sessions were comparable, suggesting stable baseline glycaemic status across testing days.

Table 2: Baseline profile of participants completing GI evaluation (n=10)

Variable	Result	Interpretation
Age (years)	23.3 \pm 2.35	Young adult group
Sex	Female 70%; Male 30%	Both sexes represented
Weight (kg)	54.7 \pm 5.37	Healthy adult range
Height (cm)	159.08 \pm 7.01	-
BMI (kg/m ²)	21.81 \pm 1.24	Normal BMI
Waist circumference (cm)	71.98 \pm 7.60	Within healthy range
Hip circumference (cm)	89.33 \pm 6.49	-
Waist-hip ratio	0.79 \pm 0.05	No central adiposity concern in group

Postprandial blood glucose response

The reference glucose produced a sharper postprandial rise, peaking at 173.4 mg/dL at 30 minutes. In contrast, the control cereal and 5% BPF cereal produced lower glucose

excursions, with peak values of 130.3 mg/dL and 126.5 mg/dL, respectively. The 5% BPF cereal also showed a faster decline after 45 minutes than the control cereal, suggesting a modestly attenuated glycaemic response.

Table 3: Mean blood glucose response after reference and test foods (mg/dL)

Time (minutes)	Reference glucose	0% BPF cereal	5% BPF cereal
0	89.0	88.9	86.3
15	140.2	120.2	117.5
30	173.4	129.5	126.5
45	159.5	130.3	120.5
60	146.3	124.2	112.1
90	126.3	105.3	105.3
120	107.3	97.5	97.5

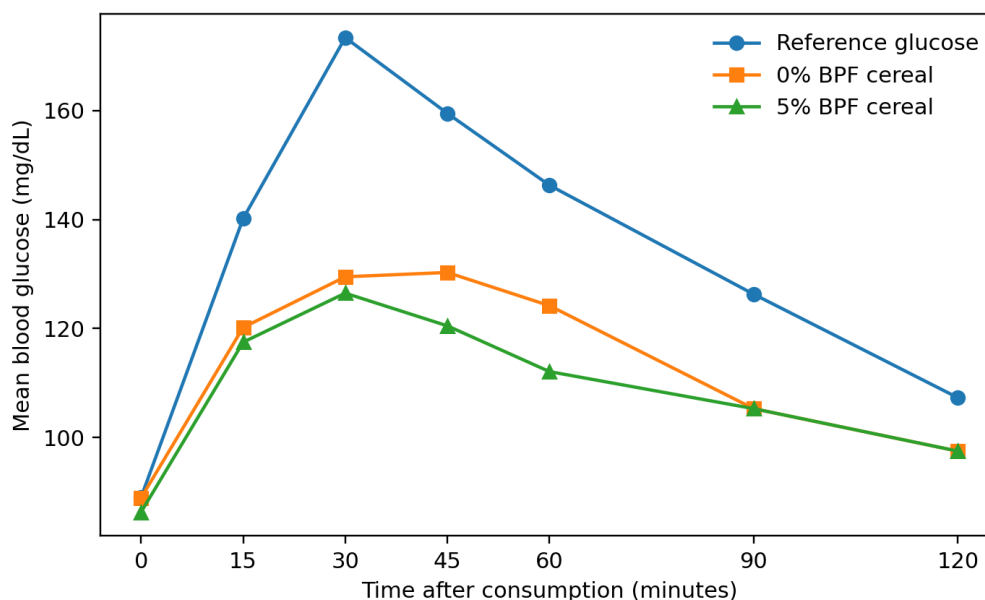


Fig 4: Postprandial blood glucose response curves for reference glucose, control cereal and 5% BPF cereal

Glycaemic Index of developed Breakfast Cereals

Both cereal products were classified as low-GI foods. The control cereal recorded a GI of 53, while the 5% blue pea flower-incorporated cereal recorded a GI of 51. The 5% BPF

formulation therefore showed an approximately 3.8% lower GI than the control cereal. Although the difference is modest, the finding is meaningful because the product retained low-GI status despite being an extruded RTE cereal.

Table 4: Glycaemic index classification of developed breakfast cereals

Product	Blue pea flower level	GI value	GI category
Control millet-whey extruded cereal	0%	53	Low GI
Blue pea flower millet-whey extruded cereal	5%	51	Low GI

Discussion

The present study demonstrates that a millet- and whey protein-based extruded breakfast cereal incorporating 5% blue pea flower powder can achieve low-GI classification in healthy young adults. This is the central finding of the work. It is nutritionally relevant because extrusion is often associated with starch gelatinisation, expansion and increased enzymatic accessibility, which can raise glycaemic response in cereal products [11]. The developed formulation appears to overcome this limitation sufficiently to remain within the low-GI category.

The low GI values observed in the present study are comparable with earlier millet-based human studies. Geetha *et al.* reported low GI values for millet food mix preparations, including roti with a GI of 53, which is identical to the control extruded cereal in the present study and also showed improvements in fasting blood sugar and HbA1c after dietary intervention in prediabetic subjects [10]. This strengthens the public health relevance of developing culturally compatible, millet-based breakfast products rather than relying only on refined commercial cereals.

Several formulation-level factors may explain the observed response. Ragi and kodri provide dietary fibre, resistant or slowly digestible starch fractions and polyphenolic compounds, all of which may slow digestion or glucose appearance in blood [8-10]. Whey protein concentrate may improve protein density and food matrix interactions, potentially moderating gastric emptying and postprandial glucose response. Blue pea flower contributes anthocyanins and phenolic compounds and serves as a natural colourant, giving the product both functional and sensory relevance [12-

14].

The inclusion of blue pea flower is also supported by recent extrusion literature. Singh *et al.* demonstrated that butterfly pea flower incorporation at 5% and 10% in extruded breakfast cereals significantly improved total phenolic content, antioxidant properties and dietary fibre, while the 10% formulation showed better retention of hardness, crispiness and crunchiness after soaking [12]. Although the present study selected 5% BPF on sensory grounds, the low-GI finding adds a human glycaemic dimension to the existing evidence on antioxidant enrichment and cereal functionality. Evidence on *Clitoria ternatea* and glycaemic regulation is promising but should be interpreted carefully. In a human crossover trial, *Clitoria ternatea* flower beverage consumed with sucrose suppressed early postprandial glucose and insulin concentrations and improved antioxidant markers [15]. A recent review concluded that animal studies show more consistent antidiabetic effects than human studies, while human evidence remains limited and largely acute [16]. Therefore, the present findings support functional food potential, not a treatment claim.

The finding has practical importance for public health nutrition. Breakfast skipping and dependence on packaged convenience foods are common among students and young working adults. A shelf-stable, attractive and low-GI RTE cereal can help bridge the gap between traditional nutrient-dense breakfasts and modern convenience-driven eating patterns. The product also aligns with interest in millets, locally relevant ingredients, natural colours and functional foods that can be positioned beyond calorie supply.

The 5% BPF cereal produced a slightly lower GI than the

control cereal, but the difference should be interpreted cautiously because the sample size was small and the study was conducted only in healthy young adults. The use of standardised GI methodology, fasting baseline measurement

and repeated postprandial sampling strengthens the study, while the inclusion of a control extrudate helps isolate the relevance of blue pea flower incorporation within the same millet-whey matrix.

Table 5: Alignment of present findings with selected literature

Literature evidence	Key finding	Relevance to present study
Geetha <i>et al.</i> [10]	Low-GI millet products (GI 37-53); FBS and HbA1c reduced in prediabetics.	Supports millet base.
Singh <i>et al.</i> [12]	BPF improved phenolics, antioxidant activity, fibre and bowl-life in extrudates.	Supports BPF extrusion.
Chusak <i>et al.</i> [15]	BPF with sucrose lowered early glucose and insulin response.	Supports acute glycaemic relevance.
Yunianto and Rosdiana [16]	Evidence is promising but mainly preclinical; human evidence remains limited.	Supports cautious claims.

This study has limitations. The final sample size was 10 participants, which is acceptable for exploratory GI testing but not adequate for subgroup analysis. Insulin response, glycaemic load, satiety and long-term metabolic outcomes were not assessed. The GI of the 10% BPF formulation was not evaluated because it was not selected through sensory screening. Future work should include larger samples, individuals with impaired glucose tolerance or type 2 diabetes, detailed nutrient composition, available carbohydrate verification, insulin response and storage stability-linked GI evaluation.

Conclusion

Blue pea flower-incorporated millet-whey extruded breakfast cereal was successfully developed and evaluated for glycaemic index. Both the control cereal and the 5% blue pea flower formulation were categorised as low-GI foods, with GI values of 53 and 51, respectively. The study strengthens the evidence that extrusion-based convenience foods can be reformulated using millets, milk protein and plant bioactives to improve carbohydrate quality. The findings are particularly relevant in the context of nutrition transition, breakfast skipping and the need for healthier RTE breakfast options. Further clinical and product-scale studies are required before disease-specific claims are made.

Future Research Recommendations

Evaluate the product in individuals with overweight, obesity, prediabetes or type 2 diabetes to assess metabolic relevance in target groups.

Measure glycaemic load, insulin response, satiety and incretin response for a broader metabolic profile.

Conduct detailed nutrient, resistant starch, dietary fibre, anthocyanin and antioxidant profiling after extrusion and storage.

Assess consumer acceptability, cost feasibility and scale-up potential for wider application in public health nutrition and functional food markets.

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Conflict of Interest: The authors declare no conflict of interest.

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