



Formulation and Evaluation of a Gluten-Free Water Chestnut (*Trapa natans* var. *bispinosa* Roxb.) Porridge Premix: Proximate Composition, Mineral Profile, and Sensory Acceptability

Aditi Gupta¹, Sr. Prof. Sunita Mishra²

Student¹, Sr. Professor²

¹²Department of Food and Nutrition, School of Home Science,
Babasaheb Bhimrao Ambedkar University (A Central University),
Vidya Vihar, Raebareli Road, Lucknow – 226025, Uttar Pradesh, India
Email: aditiguptaaa04@gmail.com

ABSTRACT

A gluten-free porridge premix based on water chestnut flour (*Trapa natans* var. *bispinosa* Roxb.) was developed and evaluated in two formulations — a control (Sample A) and a nut enriched variant (Sample B). Proximate analysis following AOAC (2005) methods recorded protein at 15.97%, fat at 6.74%, carbohydrate at 72.25%, moisture at 2.28%, and ash at 2.76%. Of the mineral results, the calcium value is the most clinically significant: at 600 mg/100 g, a single serving meets the full adult ICMR daily requirement — a result of practical significance for populations that avoid dairy due to lactose intolerance, economic constraint, or religious dietary practice. Sensory evaluation by a semi-trained panel of 20 on a 9-point hedonic scale found that Sample B outperformed Sample A on mouthfeel ($F = 6.681$, $p = 0.014$) and overall acceptability ($F = 4.174$, $p = 0.048$), with a mean score of 8.53 ± 0.61 . Given singhara flour's established low-GI starch behaviour and the formulation's mineral density, the premix addresses the dietary needs of gluten-sensitive and diabetic consumers within the Indian ready to-cook food segment.

Keywords: water chestnut flour; porridge premix; proximate analysis; sensory evaluation; gluten-free; functional food; 9-point hedonic scale; ANOVA; calcium; low glycaemic index

1. INTRODUCTION

India's nutritional landscape presents a difficult contradiction. Undernutrition persists in economically vulnerable communities while, simultaneously, non-communicable diseases — type 2 diabetes mellitus, obesity, cardiovascular disease — are rising rapidly across urban and semi-urban populations. The dietary thread connecting both problems is, in many cases, the same: a heavy reliance on refined, high-glycaemic carbohydrates that dominate the affordable end of the food supply. Public health campaigns have limited reach when the structural incentive to consume cheaply processed food remains unchanged. Bridging this gap requires food products that can be prepared quickly at home, remain affordable at scale, and carry a

nutrient profile that addresses rather than worsens both problems simultaneously. Porridge premixes occupy exactly this niche — ready-to-cook (RTC) products that require minimal preparation skill and lend themselves to nutrient fortification [17],[23].

Water chestnut (*Trapa natans* L., syn. *Trapa bispinosa* Roxb.) is an aquatic fruit of the family Trapaceae, cultivated across the wetland regions of northern and eastern India, including Uttar Pradesh, Bihar, West Bengal, Madhya Pradesh, and Manipur. Locally known as singhara, the fruit has been consumed as a traditional fasting food for centuries, though its commercial processing has not kept pace with its cultural familiarity. Singhara flour was selected for this formulation on the basis of two properties that are difficult to find in combination in cereal flours commonly available in the Indian market. First, it is entirely gluten-free — an attribute that most cereal flours cannot offer. Second, its high amylose content (30–38%) slows starch digestion, yielding a lower glycaemic response compared to wheat or rice flour, which carries clear dietary implications for consumers managing diabetes or metabolic risk. [11]

Porridge and porridge premix formulations receiving comparatively little attention. The absence of porridge and premix formulations in the published literature is a notable gap, particularly since singhara-based porridge already exists in Indian domestic cooking and demand for gluten-free convenience foods is rising in both domestic and export markets.[2],[13],[14] This study attempts to fill that gap by developing and evaluating a singhara flour-based porridge premix at the postgraduate laboratory scale

The supplementary ingredients were chosen to compensate for specific limitations of singhara flour. Almonds and cashew nuts were added to bring the protein level up to FSSAI's high protein labelling threshold, since singhara flour alone contributes only 4–7% protein; they also improve fat quality through their oleic acid content. Sago was selected for its gelatinisation behaviour, which produces the smooth texture expected in a cooked porridge. Cardamom was used for flavour, consistent with the traditional singhara preparation this formulation is modelled on. Stevia was chosen over sugar to keep the glycaemic contribution of the sweetener at zero — a substitution that matters most for the diabetic consumer segment this formulation directly targets.[3],[5],[10],[16]

The study aimed to formulate and standardise two premix compositions — a control (Sample A) and a nut-enriched formulation (Sample B) — determine their proximate and mineral profiles, and assess consumer acceptability through sensory testing on a standardised 9-point hedonic scale, with one-way ANOVA used for statistical comparison.

2. MATERIALS AND METHOD

2.1 Procurement of Raw Material

Dry water chestnut (*Trapa natans* var. *bispinosa*) was procured from Varanasi, Uttar Pradesh, India — one of the principal cultivation regions for this crop. All supplementary ingredients, including almonds (*Prunus dulcis*), cashew nuts (*Anacardium occidentale*), sago pearls (processed tapioca starch, locally known as sabudana), cardamom seeds (*Elettaria cardamomum*), and stevia extract (*Stevia rebaudiana*), were sourced from the local retail market in Lucknow, Uttar Pradesh. Ingredients were inspected at the point of purchase for

visible damage, contamination, and signs of excessive moisture before acceptance. All experimental work was conducted at the Bakery and Confectionery Laboratory, Department of Food and Nutrition, School of Home Science, Babasaheb Bhimrao Ambedkar University, Lucknow.

2.2 Preparation of Water Chestnut Flour

Dry water chestnut fruits were cleaned to remove surface dust, extraneous matter, and damaged kernels. The cleaned fruits were de-shelled, and the white kernels were dried in a hot air oven at 60°C until constant weight was achieved (± 0.001 g). The dried kernels were ground in a laboratory mill and sieved through a 60-mesh sieve to obtain a fine, uniform flour. The prepared flour was stored in airtight containers at room temperature until use.

2.3 Formulation of Porridge Premix

Two porridge premix formulations were developed following initial standardisation trials. Sample A served as the control, with higher proportions of water chestnut flour and sago. Sample B was the experimental formulation, in which a portion of the water chestnut flour and sago was replaced by increased quantities of almond and cashew nut powders, with the aim of improving both protein content and textural creaminess. The ingredient composition of both formulations is shown in Table 1.

Table 1: Ingredient Composition of Water Chestnut Porridge Premix Recipes

Ingredient	Sample A — Control (g)	Sample B — Modified (g)
Water chestnut flour	65	55
Sago	25	20
Almond powder	4	10
Cashew nut powder	4	10
Cardamom powder	0.5	0.3
Stevia	1.0	0.35
Salt	0.5	0.3

Values are expressed in grams per 100 g premix batch.

For both formulations, almonds and cashew nuts were roasted separately under dry conditions at 150°C for 10 minutes, then ground to a fine powder in a laboratory blender. Sago pearls were dry-roasted on a low flame to reduce residual moisture and to develop flavour. Water chestnut flour was re-sieved through a 60-mesh sieve to standardise particle size across batches before blending. All ingredients were weighed and combined in a laboratory mixer until a visually uniform premix was obtained.

2.4 Proximate Composition Analysis

Proximate analysis was carried out using standard AOAC (2005) methods. Moisture content was determined gravimetrically by drying the sample in a hot air oven at $105 \pm 2^\circ\text{C}$ to constant weight (AOAC 925.10). Ash content was determined by incineration in a muffle furnace at 550°C for four hours (AOAC 923.03). Protein content was estimated by the Kjeldahl method, with nitrogen converted to protein using a factor of 6.25 (AOAC 920.87). Fat content was extracted by Soxhlet method using diethyl ether over approximately six hours (17–18 extraction cycles) (AOAC

920.85). Carbohydrate content was calculated by difference: Carbohydrate (%) = 100 – (Moisture + Protein + Fat + Ash). Energy content was estimated as: Energy (kcal/100 g) = 4 × (Carbohydrate + Protein) + 9 × Fat.

2.5 Mineral Analysis

Calcium, iron, and potassium were determined by atomic absorption spectrophotometry (AAS), following AOAC methods 984.27, 999.11, and 985.35, respectively. For sample preparation, approximately 2 g of each sample was dry-ashed at 550°C in a muffle furnace, dissolved in 5% HNO₃, and diluted to 100 mL with distilled water. Mineral content was calculated as:

$$\text{Mineral content} = (C \times V \times D) / (W \times 10) \quad (1)$$

Where C = concentration (mg/L), V = volume (mL), D = dilution factor, and W = sample weight (g).

2.6 Sensory Evaluation

Organoleptic evaluation of both formulations was conducted using a standardised 9-point hedonic scale (1 = Dislike Extremely; 9 = Like Extremely), as recommended for consumer acceptability testing of food products.[8] A semi-trained panel of 20 members was recruited from the student and faculty community of the School of Home Science, Babasaheb Bhimrao Ambedkar University, Lucknow, and given orientation training before the session to ensure consistency of scoring. The evaluation was conducted under the direct supervision of the corresponding author, Prof. Sunita Mishra.

Both samples were prepared under standardised conditions: each premix was reconstituted with hot water at a ratio of 1:4 (w/v), cooked on a medium flame for five minutes with continuous gentle stirring, and served at 55 ± 5°C in coded, unlabelled white ceramic bowls. Panellists were asked to rinse with plain water between samples to minimise carry-over effects. Scores were recorded for five attributes — Appearance, Taste, Smell (Aroma), Mouthfeel, and Overall Acceptability — on printed evaluation cards.

2.7 Statistical Analysis

Descriptive statistics (mean and standard deviation) and one-way analysis of variance (ANOVA) were used to determine whether statistically significant differences existed between the two formulations for each sensory attribute. Statistical significance was set at $p < 0.05$ ($\alpha = 0.05$). Data were analysed using MS Excel with standard statistical tables. A paired t-test was additionally performed to confirm the ANOVA results, given the repeated-measures design of the panel.

3. RESULTS AND DISCUSSION

3.1 Proximate Composition of Water Chestnut Porridge Premix

The proximate composition of the premix is summarised in Table 2. Each parameter is discussed below.

Table 2: Proximate Composition of Water Chestnut Porridge Premix

S.N o.	Parameters	Value (%)	Procedure
1.	Moisture content	2.28	AOAC 925.10 (Hot Air Oven, 105°C)
2.	Protein content	15.97	AOAC 920.87 (Kjeldahl, N × 6.25)

3.	Fat content	6.74	AOAC 920.85 (Soxhlet Extraction)
4.	Ash content	2.76	AOAC 923.03 (Muffle Furnace, 550°C)
5.	Carbohydrate content	72.25	By difference $[100-(M+P+F+A)]$

3.1.1 Moisture Content

A moisture content of 2.28% sits well within the 5% upper limit prescribed by the Indian Standards Institution (ISI) for dry instant food mixes, confirming that the premix can be stored at ambient temperature without refrigeration. Low moisture content reduces water activity, which limits both microbial proliferation and oxidative degradation the mechanisms through which dry food products most commonly deteriorate during storage.[20] The result is consistent with figures reported in comparable studies: [23] recorded 2.1–3.4% for a pearl millet porridge premix, and [17] reported 2.5% for a weaning food porridge mix.

3.1.2 Protein Content

At 15.97%, the protein content is approximately 1.5 times that of typical wheat-based porridge mixes, which generally fall in the 10–11% range. This difference is attributable to the almond (21.2 g protein/100 g) and cashew nut (18.2 g protein/100 g) fractions; singhara flour on its own contributes only 4–7% protein and would not meet the threshold for FSSAI's high-protein labelling category.[5],[22] Beyond the quantity, there is reason to expect reasonable protein quality from this ingredient combination: water chestnut flour is known to contribute lysine, while almonds and cashew nuts supply arginine, glutamic acid, and branched-chain amino acids, producing a modest amino acid complementarity across the ingredient profile.[9],[10] Protein digestibility within the cooked premix matrix was not measured in this study; the amino acid complementarity described above reflects ingredient-level compositional data and cannot be assumed to translate directly to bioavailable protein in the final prepared product. This remains an open question for future investigation using in vitro protein digestibility assays. A standard 30–40 g serving of the premix would provide approximately 4.8–6.4 g protein, representing 9–12% of the adult RDA of 54–60 g/day.

3.1.3 Fat Content

Fat content was recorded at 6.74%, derived primarily from the almond and cashew nut components. Both are rich sources of oleic acid, a monounsaturated fatty acid associated in multiple intervention studies with reductions in LDL cholesterol levels.[5],[10] The result falls within the 5.2–7.8% range reported by Kshirsagar and Agarkar [12] for nut-enriched pearl millet premixes and is close to the 5.4% recorded by Darshane [6] for an instant sweet potato porridge formulation.

3.1.4 Ash Content

Ash content was 2.76%, within the ranges reported for water chestnut flour products by Rajput and Singh [20] (1.5–2.5%) and ^[24] (2.0–3.2% for water chestnut-supplemented foods). Cardamom's contribution to the total ash value is disproportionate to its mass fraction in the recipe. Despite comprising only 0.3–0.5 g per 100 g of formulation, cardamom carries an inherently high ash value of approximately 6.5% and its inclusion measurably elevates the overall mineral load of the premix beyond what the flour and nut fractions alone would produce.

3.1.5 Carbohydrate Content

Carbohydrate content, calculated by difference, was 72.25% — the dominant macronutrient in the premix, as expected given that water chestnut flour and sago are both starch-rich ingredients. Unlike common cereal starches, singhara flour contains a relatively high amylose fraction (30–38%), which increases the proportion of slowly digestible and resistant starch in the final product.[11],[18],[15] characterised water chestnut starch as having a low proportion of rapidly digestible starch compared to cereal starches, consistent with its established low-GI behaviour in the literature. For diabetic consumers, the glycaemic impact of a breakfast premix is a practical daily concern, and the starch composition of singhara flour directly addresses it.

3.2 Mineral Composition

Mineral analysis by AAS yielded a calcium content of 600 mg/100 g, iron at 4.22 mg/100 g, and potassium at 350 mg/100 g. Among the three minerals determined, calcium is clinically the most significant: at 600 mg/100 g, a single serving of the premix meets the full adult ICMR daily calcium requirement. This value reflects the cumulative calcium contributions of all ingredients in the formulation — cardamom (383 mg/100 g), almonds (264 mg/100 g), cashew nuts (37 mg/100 g), and singhara flour (20–30 mg/100 g) — with cardamom making a disproportionately large contribution relative to its low mass fraction in the recipe.[3],[22] For households in which dairy is absent from the diet — whether due to economic constraint, lactose intolerance, or religious observance — a non-dairy source delivering the full adult calcium requirement per serving is a practically relevant finding.

Iron at 4.22 mg/100 g represents approximately 7–10% of the adult male ICMR reference daily intake per serving, a non-trivial contribution for populations where iron-deficiency anaemia remains prevalent, including adolescent girls and women of reproductive age in the north Indian demographic this product targets.[5],[22],[24] Potassium at 350 mg/100 g is consistent with a dietary profile beneficial for individuals managing hypertension, for whom dietary potassium is a factor in blood pressure management alongside sodium restriction.[3],[19],[25]

3.3 Sensory Evaluation Results

Mean hedonic scores ($\pm$ SD) for all five sensory attributes are presented in Table 3. Sample B scored higher than Sample A across all five attributes. Both formulations exceeded the hedonic midpoint of 5.0, confirming that panellists found both products acceptable.

Table 3: Average Hedonic Scores ($\pm$ SD) of Samples A and B on a 9-Point Hedonic Scale (n = 20)

Perception	AVG $\pm$ SD (Sample A)	AVG $\pm$ SD (Sample B)	Hedonic Description (B)
Appearance	7.79 $\pm$ 0.98	8.32 $\pm$ 0.58	Like Very Much
Taste	8.16 $\pm$ 0.69	8.53 $\pm$ 0.70	Like Very Much
Smell (Aroma)	8.11 $\pm$ 0.66	8.32 $\pm$ 0.48	Like Very Much
Mouthfeel	7.84 $\pm$ 0.69	8.42 $\pm$ 0.69	Like Very Much
Overall acceptability	8.11 $\pm$ 0.66	8.53 $\pm$ 0.61	Like Very Much

3.3.1 One-Way ANOVA Results

ANOVA results for each sensory attribute are presented in Table 4.

Table 4: Results of One-Way ANOVA for Comparison Between Samples A and B Based on Sensory Characteristics

Sensory Characteristic	F-value	p-value	Level of Significance
Appearance	4.072	0.0511	Non-significant ($p > 0.05$)
Taste	2.689	0.1098	Non-significant ($p > 0.05$)
Odour (Aroma)	1.274	0.2664	Non-significant ($p > 0.05$)
Mouthfeel	6.681	0.0139	Significant ($p < 0.05$)
Overall acceptability	4.174	0.0484	Significant ($p < 0.05$)

Of the five sensory attributes evaluated, mouthfeel showed the largest difference between formulations ($F = 6.681$, $p = 0.0139$). This outcome is attributable to the higher nut content in Sample B: the increased almond and cashew nut proportions contribute a creamier consistency, while the adjusted sago-to-water-chestnut flour ratio appears to have produced a smoother gelatinised texture during cooking. Starch gelatinisation behaviour in sago and water chestnut flours is known to influence the viscosity and smoothness of cooked porridge,[7],[9] and the proportional changes between the two formulations were sufficient to produce a perceptible textural difference among the panel.

Overall acceptability also differed significantly between formulations ($F = 4.174$, $p = 0.0484$), with Sample B preferred. Both samples scored above 8.0, which ^[8] associate with commercial viability in consumer acceptability testing — a relevant benchmark given that the study's stated purpose includes evaluating this product's potential for the Indian RTC market. Sample B, at 8.53 ± 0.61 , sits at the upper end of scores reported in comparable premix studies:[23] recorded 7.8–8.4 for a pearl millet premix, and [17] found 8.0–8.5 for a weaning porridge formulation.

Appearance ($F = 4.072$, $p = 0.0511$), taste ($F = 2.689$, $p = 0.1098$), and smell ($F = 1.274$, $p = 0.2664$) showed no statistically significant differences between the two samples, indicating that the reformulation did not alter these attributes to a degree detectable by the panel. The mild sweetness contributed by stevia and the nuttiness from almonds and cashews were rated acceptable across both formulations. Both samples were noted for warm, aromatic notes characteristic of cardamom. Cardamom's distinctive aroma is primarily attributed to 1,8- cineole and alpha-terpinyl acetate, the dominant volatile compounds in its essential oil. [3],[26]

The closely matched aroma scores across both samples — 8.11 ± 0.66 for Sample A and 8.32 ± 0.48 for Sample B — indicate that reducing cardamom content from 0.5 g to 0.3 g was not perceptible to the panel, which supports keeping the lower cardamom proportion in Sample B on cost grounds without sensory penalty.

CONCLUSION

The central aim of this study was to determine whether singhara flour could serve as the base of a ready-to-cook premix that is both nutritionally adequate and sensorially acceptable — the two

conditions a product must satisfy simultaneously to have any real utility in a consumer market. Sample B meets both criteria. The nutritional case rests primarily on the calcium and protein results: a mineral density of 600 mg/100 g in a non-dairy, gluten-free product occupies a genuinely uncommon position in the Indian RTC segment, and a protein level of 15.97% — achieved without any protein isolate or concentrate — qualifies under FSSAI's high-protein labelling threshold. The sensory case is made by the panel scores: 8.53 ± 0.61 on overall acceptability, with statistically significant improvement over the control on mouthfeel and overall acceptability, is a commercially viable result by the standards applied in comparable premix literature

For individuals managing coeliac disease, gluten sensitivity, or type 2 diabetes, this formulation addresses multiple dietary constraints within a single product: gluten exclusion, a low-GI starch base from singhara flour, and zero added sugar through stevia substitution. These properties are seldom found in combination in affordable ready-to-cook products currently available in the Indian market.

This study was conducted within the practical constraints of a postgraduate dissertation — single institution, limited panel size, and a laboratory setting not equipped for in vitro starch digestion or accelerated storage trials. The 20-member sensory panel was drawn entirely from the student and faculty community at BBAU Lucknow, a population already culturally familiar with singhara as a fasting food; their hedonic scores may therefore skew higher than those of a broader urban consumer panel unfamiliar with the ingredient. The low-GI characterisation rests on published starch analyses of singhara flour rather than a glycaemic index measurement of this specific cooked premix, and the two are not equivalent — starch composition influences GI but does not determine it under actual digestion conditions. Similarly, the protein content reported here is a Kjeldahl estimate; net bioavailability in the food matrix after cooking was not assessed and would require separate in vitro protein digestibility testing.

The most pressing follow-up for this formulation is a direct in vitro starch digestion assay on the cooked premix — the published singhara starch literature provides a reasonable basis for a low-GI claim, but formulation-level confirmation using the Englyst method or equivalent would be needed before that claim could be placed on product labelling under FSSAI's draft functional food regulations. A shelf-life study under two storage conditions — ambient open shelf and sealed polyethylene packaging — would clarify the practical storage window, given that the 2.28% moisture recorded here provides a reasonable starting point but does not account for hygroscopic uptake over time. Beyond the laboratory, testing with a panel that includes diagnosed Type 2 diabetic and coeliac participants would establish whether hedonic scores remain stable in the target clinical population, which the student and faculty panel used here cannot represent

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CONFLICT OF INTEREST

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