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Development and nutritional profiling of Barnyard millet (*Echinochloa esculenta* (A. Broun) H. Schotz.) enriched ice-cream and wafer

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Abstract

The present study was conducted to develop Barnyard millet (*Echinochloa esculenta* (A. Broun) H. Schotz.) based ice-cream and wafers with optimum sensory attributes and to evaluate the nutritional content of the developed products by replacing staple cereals (wheat/rice). Two germplasm lines BM1 (IC-372797) and BM2 (IC-472348), one National check (MDU 1 IC-280656), wheat (PBW-826), and rice (PR-131) grains were nutritionally evaluated. Barnyard millet line BM1 had higher content of protein (10.12 g/100 g), calcium (25.7 mg/100 g), iron (19.2 mg/100 g), total dietary fiber (15.4 g/100 g) resistant starch (28.1 g/100 g), *in vitro* protein digestibility (85.7%) than BM2, National check, wheat, and rice. Two value-added products; namely, barnmill vanilla ice cream and barnyard wafer were developed by replacing traditional cereals ranging from 6 to 30%. The developed products showed higher overall acceptability (8.59 to 8.75) and better nutritional profiles than traditional cereal-based products. Barnmill vanilla ice cream showed a higher protein content (5.86 g/100 g) and *in vitro* protein digestibility (88.9%). Developed products had higher resistant starch (>10 g/100 g) with maximum content in barnyard wafer (13.3 g/100 g). Barnyard millet-based food products were found to have low to moderate predicted glycemic index ranging from 55.30 to 60.94 and had slower *in vitro* starch digestion rates ranging from 40.14 to 48.10%. Barnyard millet is effective replacement for wheat and rice to prepare food products with better nutritional profiles.

1. Introduction

Micronutrient deficiencies and lower crop yield have resulted from applying chemical fertilizers in the rice-wheat cropping system (RWCS) (Dhaliwal *et al.,* 2023). These deficiencies have a significant impact on social and economic development at the community, national, and individual levels (Rai *et al*., 2024). Reduction in food production and lack of access to enough nutrient-dense food is linked to a decline in food security (Miller, 2023). As a result, agricultural practices must be diverse to provide conventional grains that are both nutritionally adequate and environmentally sustainable. Therefore, the role of millets in the food sector holds much importance to create better nutritional profiles. Introduction of millets in the food plate is required not only to address issues with the wheat-rice farming system but also to address non-communicable diseases (NCDs). According to the Global Nutrition Report (2024), despite advancements, the rate of chronic malnutrition is still high, estimated at around 20% in 2024, and a substantial number of children under five are still stunted due to undernutrition. NCDs kill 41 million people each year, accounting for 74% of all deaths globally (WHO, 2024). According to the Global Hunger Index (2024), India ranks 105th out of 127 countries, falling into the "serious" category of hunger levels.

Diets based solely on wheat and rice consumed by most of the population of developing nations lack many vital nutrients (energy, essential amino acids, vitamins, minerals, dietary fiber, and antioxidants) that are essential for growth and maintenance. Millet based foods have been substituted by energy-dense, cheap, and easily accessible foods that are high in harmful fat, sugar, salt, and animal products (Krishnaswamy *et al.,* 2016). Diets deficient in nutrients harm children's short and long-term mental, physiological, and emotional growth. India ranks second in the world in terms of child malnutrition severity and it is home to more than one-third of the world's malnourished children (Nainwal and Verma, 2018). According to the National Family Health Survey (2019-21), in India, 35.5% of children below 5 years are stunted and 19.3% are wasted. The population also suffers from micronutrient deficiencies, including iron, zinc, calcium, vitamin A, folate, and riboflavin, which can result in anemia, keratomalacia, blindness, and infertility in severe cases (Nelson *et al.,* 2019). An efficient technique for dietary diversity and lowering the prevalence of NCDs and hidden hunger would be to supplement major cereals with millets having superior nutritional content and nutraceutical qualities (Kumar *et al.,* 2024). Being rich sources of protein, minerals, dietary fiber, phenols, and antioxidants, consumption of millets and whole grains are associated with a reduction in the incidence of non-communicable diseases (Joshi *et al*., 2024).

Minor millet like barnyard millet has a superior nutritional profile than wheat and rice. It is a significant crop in both Asia and Africa (Pathak and Singh, 2022). It can withstand the whims of climatic circumstances and can guarantee a secure agricultural future and global food security (Maithani *et al.,* 2022). Even though barnyard millet

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has more nutrients than traditional cereal grains and can supply food and nourishment, its use continues to be limited in our society because of a lack of knowledge (Verma and Kumar, 2023). Barnyard millet contains 8.7% moisture, 10.1% protein, 3.9% fat, 6.7% crude fiber, 68.8% carbohydrate and provides an energy density of 398 kcal/100 g of energy. It has a high total dietary fiber content (12.5%), which includes both soluble (4.2%) and insoluble (8.4%) fractions (Ugare *et al.,* 2014). As this millet is rich in dietary fiber, it acts as a binding agent to lengthen the small intestine's transit time and lower the risk of inflammatory bowel issues and it also has a higher amount of resistant starch due to the high degree of amylase retrogression. It also contains higher amounts of phenols (20.3-27.8 mg), iron (18.6 mg), and antioxidants (59.23%). Due to the presence of the phenolic compound, barnyard millet could combat and inhibit protein glycation as well as stop the production of advanced glycation end products (AGE) and this helps to prevent numerous biological impairments and diseases (Anis and Sreerama, 2020) while, consumption of iron-rich value-added millet-based products can be useful in meeting most of the dietary iron requirements and can curb the widespread problem of iron deficiency anaemia (Choudhury and Chaudhary, 2023). Further research analysis on the effects of these bioactive compounds on human health is in progress (Sharma and Sarwat, 2022). Evidence supported that Barnyard millet based quick dosa mix had 12.67% protein, 2.64 % fat, 1.81% crude fibre, 4.93 mg of iron, 2.21 mg of zinc and 23.94 mg of calcium (Karakannavar *et al*., 2021). Likewise, barnyard millet-based rusks had higher levels of protein (5.19 g) and dietary fibre (45.10 g) per 100 g (Karuna and Nazni, 2016). Therefore, barnyard millet has capacity to enhance nutritional value without compromising palatability which can be utilized as a functional ingredient in bakery products and as a partial ingredient for the substitution of wheat flour.

Since food is essential for the body's proper development and for preserving a person's health (Gupta and Sarwat, 2022), consumer demand for functional and healthy foods with higher amounts of nutrients has been driven by awareness of therapeutic nutrition. Currently, producers of various goods are focusing on underutilized, unknown crops like millets, which offer significant potential for the creation of such functional, demand-driven items. Due to their medicinal qualities and ability to withstand extreme weather, these underutilized crops can guarantee both health and food security challenges (Banerjee and Maitra, 2020). In addition, it blends well with other cereal grains without adding an unpleasant flavour or aftertaste (Goswami *et al.,* 2015). There are many ways to utilize barnyard millet in cooking as they can be used in everything from classic porridges and flatbreads to more contemporary recipes like millet-based gluten-free goods and nutritious snacks (Verma and Kumar, 2023).

Keeping in view, the nutritional properties and suitability of minor millets in contributing to sustainable agriculture and their beneficial role in the prevention of noncommunicable diseases, the present study has been planned to develop and nutritionally assess the Barnyard millet-based food products to provide healthier dietary options to the population.

2. Materials and Methods

2.1 Procurement of sample

Two germplasm lines of Barnyard millet (*Echinochloa esculenta* (A. Broun) H. Schotz.); namely, BM1 (IC- 372797), BM2 (IC-472348), which is under development and has not released yet by Punjab Agricultural University along with grains of National check (MDU 1 IC-280656), Rice (PR-131) which is a high-yielding, lodging-tolerant, and bacterial blight-resistant rice variety developed by the Punjab Agricultural University and Wheat (PBW-826) which is heat-tolerant wheat variety developed by the Punjab Agricultural University (PAU) recommended for cultivation under timely sown irrigated conditions, with an average grain yield of 24.0 quintals per acre and a maturity period of 148 days were procured from Director (Seeds), Punjab Agricultural University, Ludhiana immediately after harvesting.

2.2 Development of barnyard millet-based food products

Barnyard millet germplasm line BM1 was selected for developing ice-cream and wafers due to its better nutritional profile than BM2. For developing products, a traditional standard recipe was used to compare the products made from Barnyard millet with traditional cereals (wheat/rice) as control.

Table 1: Barnmill vanilla ice cream

Ingredients	Control	Experiment
Barnyard millet flour	-	6 g
Corn flour	6 g	-
Milk	35.5 ml	35.5 ml
Sugar powder	18 g	18 g
Butter	1.8 g	1.8 g
Cream	43 g	43 g
Cashews	7.5 g	7.5 g
Raisins	5 g	5 g
Dates	5 g	5 g
Vanilla essence	Few drops	Few drop

Table 2: Barnyard wafer

Ingredients	Control	Experiment
Refined wheat flour	45 g	15 g
Barnyard millet flour	-	30 g
Sugar powder	30 g	30 g
Melted butter	25 g	25 g
Milk	60 ml	60 ml
Vanilla essence	Few drops	Few drops

2.3 Organoleptic evaluation of the developed value-added products

Ten semi-trained individuals from the Department of Food and Nutrition, Punjab Agricultural University, in Ludhiana, assessed the sensory qualities of standardized products. The analysts used a nine-point Hedonic scale (Nicolas *et al.,* 2010), with 9 denoting "like extremely" and 1 denoting "dislike extremely," to rate several products made from barnyard millet according to their appearance, texture, colour, taste, flavour and general acceptability.

2.4 Nutritional evaluation of developed value-added products

The products prepared from Barnyard millet (BM1) along with their control counterpart (wheat and rice) were analyzed for various nutritional parameters as discussed below:

2.4.1 Proximate composition

Proximate parameters namely moisture, crude protein, crude fat, crude fiber, and ash were analyzed using three replications of each formulation using the standard method given by AOAC (2000). 5 g of the sample was weighed to determine its moisture content. It was then put in three pre-weighed china crucibles and dried for eight hours at 105°C in a hot air oven until its weight remained constant. The macro Kjeldahl method was employed to determine the amount of nitrogen. With a conversion factor of 6.25, nitrogen was transformed into crude protein. The crude fat content was determined using the Automatic Soxhlet apparatus (SOCSPLUS - SCS 06 AS DLS TS), by putting the moisture-free sample in a thimble where petroleum ether was used as a solvent. The extracted fat from the sample was weighed after evaporating the remaining solvent. 5 g of moisture-and fat-free sample was refluxed with 1.25% sulfuric acid and then 1.25% sodium hydroxide (NaOH) to estimate crude fiber content. The weight loss was estimated after it was further oven-dried, ignited in a muffle furnace, and cooled in a desiccator. The ash content was analyzed by igniting the weighed samples at 550°C in a muffle furnace for 4 h. After cooling, the crucible with residue was re-weighed. The total of all proximate indicators (moisture content, crude protein, crude fat, crude fiber, and total ash) was subtracted from 100 to determine the carbohydrate content.

2.4.2 *In vitro* protein digestibility

The methodology outlined by Akeson and Stachman (1964) was used to analyze it. Based on a 100 g sample, the digestibility coefficient was calculated by deducting the residual protein from the original protein amount.

2.4.3 Total starch and resistant starch

It was estimated according to AOAC (2002). Megazyme K-RSTAR assay kit was used to determine total starch and resistant starch content in samples by hydrolyzing and solubilizing non-resistant starch followed by measurement of resistant starch and non-resistant (solubilized) starch using the following calculations:

On dry weight basis, resistant starch, non-resistant starch and total starch content was determined as follows:

Resistant starch (sample containing >10% RS, g/ 100 g):

$= \Delta E \times F \times 100/0.1 \times 1/1000 \times 100/W \times 162/180$

$= \Delta E \times F/W \times 90$

Resistant starch (samples containing < 10% RS, g/ 100 g):

$= \Delta E \times F \times 10.3/0.1 \times 1/1000 \times 100/W \times 162/180$

$= \Delta E \times F/W \times 9.27$

Non-resistant (solubilised) starch (g/ 100 g sample):

$= \Delta E \times F \times 100/0.1 \times 1/ 1000 \times 100/W \times 162/180$

$= \Delta E \times F/W \times 90$

Total starch = resistant starch + non-resistant starch

where,

- ΔE = absorbance that was determined against the reagent blank.
- F = conversion from absorbance to micrograms by dividing by the GOPOD absorbance for this100 μg of D-glucose.
- 100/0.1 = corrected volume
- 1/1000 = micrograms was converted into milligrams.
- W = sample was analysed on dry weight basis
- 100/W = factor to present RS as % of sample weight.
- 162/ I 80 = factor to convert from free D-glucose, as calculated to anhydro-D-glucose as occurs in starch.
- 10.3/0.1 = corrected volume (0.1 ml taken from I 0.3 ml) for samples containing 0-10% RS where the incubation solution is not diluted and the final volume was 10.3 ml.

2.4.4 *In vitro* starch digestion rate

Estimation was done by a slightly modified version of Singh *et al.* (1982) approach by measuring the amount of maltose generated after 3,5 dinitrosalicyclic acid activity by using the following calculations:

1ml of extract = X mg maltose

20 ml of extract = 20 × X mg maltose

100 mg of substance released = 20 × X mg maltose

2.4.5 Dietary fibre

Analyzed by methodology stated by AOAC (2000) by adding MES-TRIS blend buffer solution (pH 8.2) and using heat-stable α-amylase followed by incubation and then treatment with a protease (100 μl) and incubation. Further, the addition of 0.561 N HCl (5 ml) and adjustment of pH between 4.1 and 4.8 followed by the addition of amyloglucosidase solution and placing in a shaker.

2.4.5.1 Insoluble dietary fibre

Treating the sample with enzyme mixture followed by washing with 10 ml of 95% acetone and ethanol and then drying of residue (103°C) and subsequently calculating residual weight by subtracting the tare weight from the weight of the dried crucible and celite and later, analysis of the protein and ash.

2.4.5.2 Soluble dietary fibre

Incubation of the sample with amyloglucosidase with the subsequent addition of four liters of hot ethanol (95% at 60°C). Later, rinsing of solution (78% & 95 % ethanol and acetone) followed by drying.

The dietary fiber was calculated using the formula below:

$$\text{Dietary fibre (\%)} = \frac{\frac{R_1 + R_2}{2} - p - A - B}{\frac{m_1 + m_2}{2}} \times 100$$

R1 = weight of residue 1 from m1, R2= weight of residue 2 from m2, m1= weight if 1st sample, m2 = weight of 2nd sample, A = weight of ash from R1, p = weight of protein from R2, B = blank

2.4.6 Predicted glycemic index (Goni *et al.,* 1997)

The predicted glycemic index was measured using an enhanced *in vitro* technique developed by Goni *et al.* (1997) by replicating the human small intestine using a dialysis tube (width 24.26 mm, diameter 14.3 mm). Following the addition of pepsin (250 mg/ ml), the reaction mixture was incubated for 60 min at 37°C in a water bath shaker at 110 rpm followed by the addition of AMG (amyloglucosidase, 3300 U/ ml) and allowed to react with GOPOD (glucose oxidase/peroxidase) reagent and calculated by estimating first Hydrolysis index:

$$HI = \frac{\text{Area under the hydrolysis curve of the test sample}}{\text{Area under control}}$$

Then GI was calculated using the formula:

$$GI = 39.71 + (0.549 \times HI)$$

Glycemic load was calculated using the formula:

$$GL = \frac{GI \times \text{Available carbohydrates}}{100}$$

2.5 Statistical analysis

The data was subjected to statistical analysis using SPSS software (version 26.0). Mean values, standard deviations, and t-test were employed.

3. Results

The raw grains were selected and nutritionally evaluated before the development of the food product. The barnyard millet BM_1 was found to have higher protein (10.12 g/100 g), total dietary fiber (15.47 g /100 g), *in vitro* protein digestibility (85.75%), resistant starch (28.19 g/100 g), predicted glycemic index (40.94) and *in vitro* starch digestion rate (53.15 mg maltose released/ 100 g)

3.1 Organoleptic evaluation of developed value-added products

The value-added food products were developed by substituting traditional cereals with barnyard millet keeping in view the preferences of people of different age groups. The organoleptic evaluation scores of the products prepared from barnyard millet and traditional cereals have been compared in Figure 1. From the results, it was found that both the developed products were highly acceptable than their control counterparts. The barnmill vanilla ice cream was developed using a complete substitution of traditional products and obtained an overall acceptability score of 8.75 while barnyard wafer was prepared by 30 per cent supplementation obtaining an overall acceptability score of 8.59.

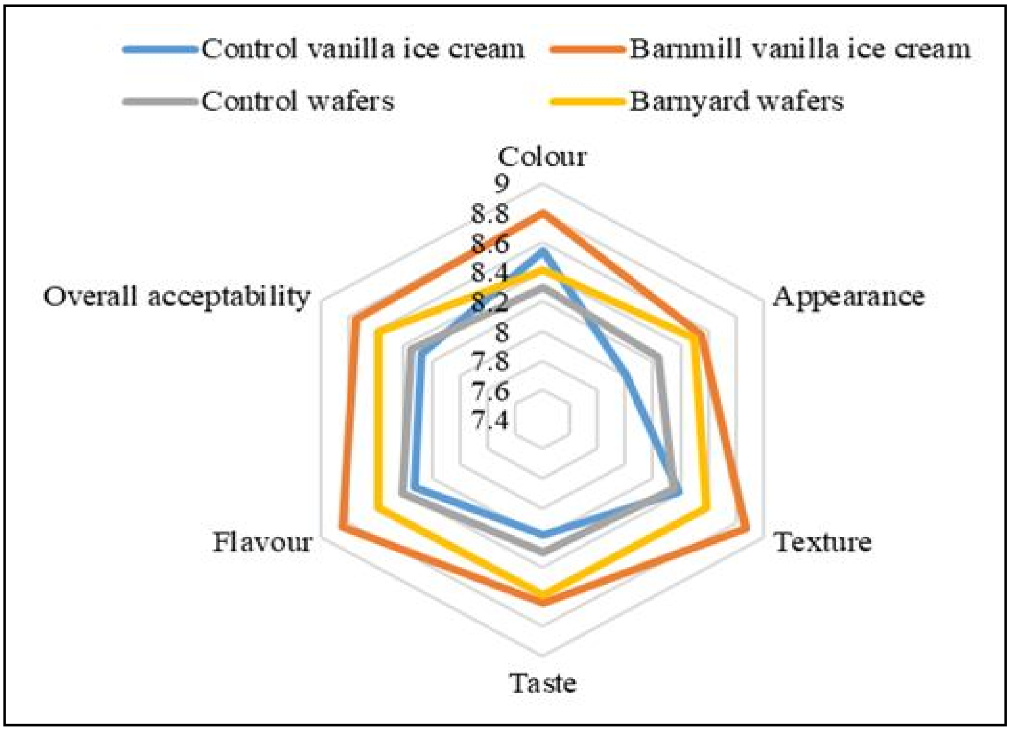

Figure 1: Organoleptic evaluation of developed value-added products.

Table 3: Nutritional composition of developed value-added products (g/100 g, dry weight basis)

Products		Moisture	Crude protein	Crude fat	Crude fibre	Ash	CHO
Barnmill vanilla ice cream	C	39.09 ± 1.38^{b}	4.11 ± 0.35^{b}	13.49 ± 0.47^{a}	1.07 ± 0.00^{b}	1.41 ± 0.02^{b}	40.83 ± 3.63^{b}
	E	30.24 ± 1.23^{a}	5.86 ± 0.39^{a}	13.86 ± 0.24^{ab}	2.51 ± 0.43^{a}	2.99 ± 0.15^{a}	44.54 ± 0.94^{a}
Barnyard wafer	C	02.70 ± 0.18^{a}	2.86 ± 0.36^{b}	10.13 ± 0.33^{ab}	2.05 ± 0.00^{b}	2.31 ± 0.06^{b}	79.95 ± 0.16^{a}
	E	01.44 ± 0.12^{b}	3.81 ± 0.21^{a}	10.28 ± 0.22^{a}	5.02 ± 0.20^{a}	3.08 ± 0.09^{a}	76.37 ± 0.44^{b}

C- Control, E-Experiment; Values are expressed as Mean ± SD of duplicates
Values in columns having different alphabetical superscripts represent significant difference ($p \leq 0.05$) among products in the control and experimental group.

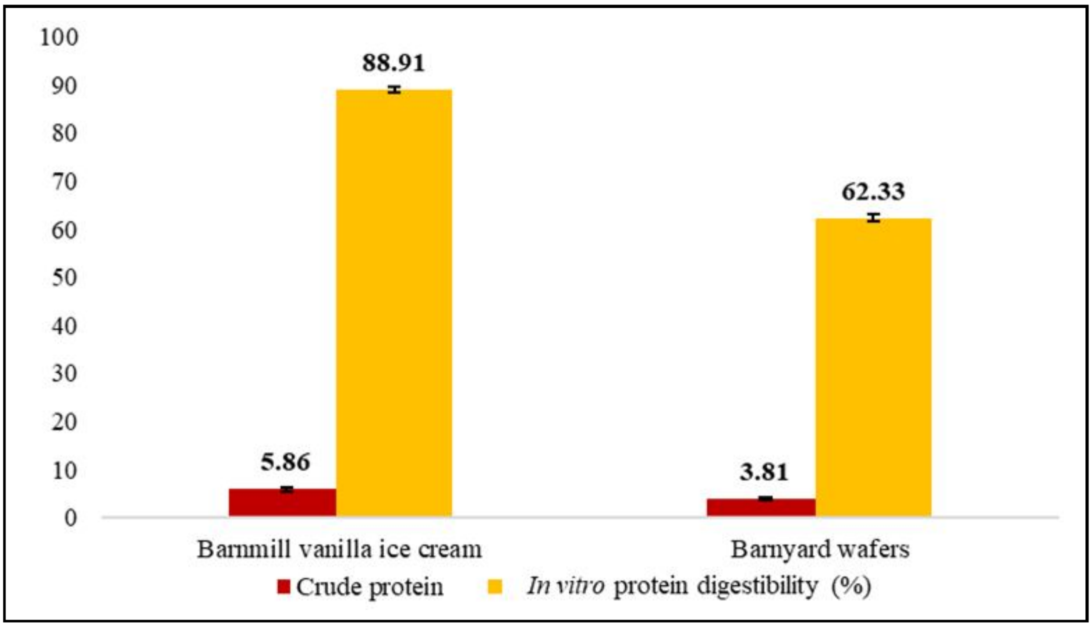

Figure 2: Crude protein and *in vitro* protein digestibility of developed value-added products.

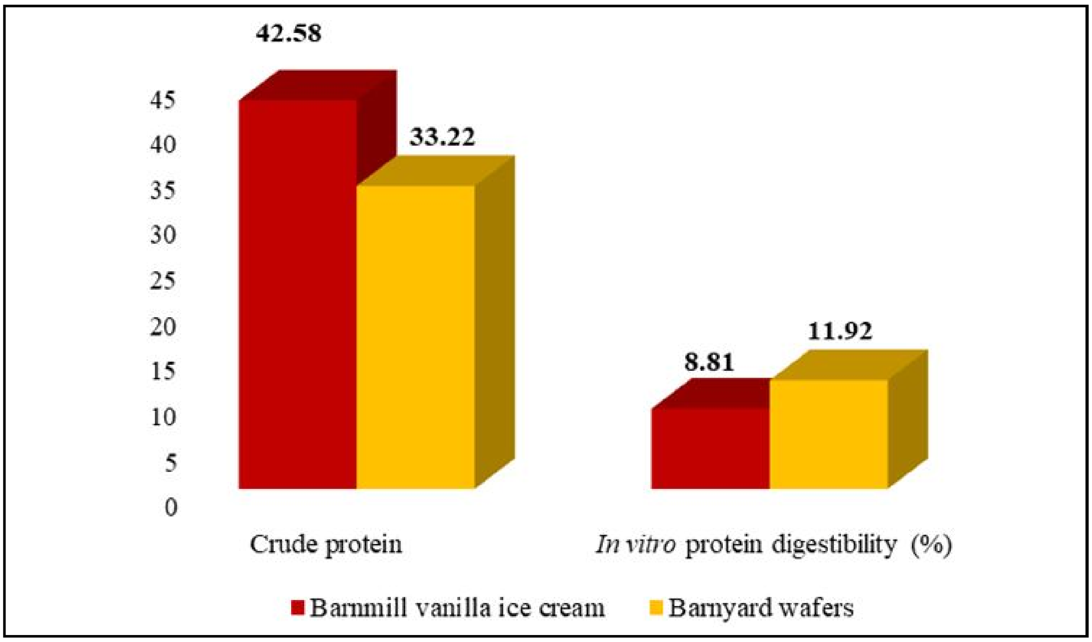

Figure 3: Per cent increase in the protein content and *in vitro* protein digestibility of developed value-added products with respect to the control group.

Figure 3 presents the per cent increase in the protein content and *in vitro* protein content of the food products prepared from barnyard millet. The protein content increased by a Maximum per cent increase in the protein content was seen in barnmill vanilla ice cream at 42.58 per cent whereas *in vitro* protein digestibility per cent increased in barnyard wafer at 11.92 per cent.

3.2 *In vitro* protein digestibility of developed value-added products

Protein digestibility, a measure of the bioavailability of dietary proteins revealed higher *in vitro* protein digestibility in barnmill vanilla ice cream (88.91 ± 0.56), followed by barnyard wafer (62.33 ± 0.81).

3.3 Total starch and starch nutritional fractions of developed value-added products

The experimental products showed reduced rapidly digestible starch, slowly digestible starch, and total starch levels compared to their control counterparts (Table 4). Barnyard wafer exhibited significantly ($p \leq 0.05$) lower level of rapidly digestible starch 7.37 ± 0.11 g. Maximum slowly digestible starch was seen in the barnyard wafer (30.78 ± 0.47 g). Conversely, resistant starch (RS) levels were significantly ($p \leq 0.05$) higher in experimental products compared to controls, indicating improved starch resistance. Resistant starch content in the experimental wafer was found to be the highest (13.30 ± 0.14 g) while total starch content ranged from 45.18 ± 0.16 g/100 g to 65.98 ± 0.67 g/100 g, with the highest in control vanilla ice cream while lowest in barnyard wafer. The barnyard millet-based products showed lower starch digestion rates compared to their control counterparts (Table 4), indicating a reduced rate of starch hydrolysis. Among the products, the barnyard wafer had the lowest starch digestion rate to the tune of 40.14 ± 0.37 mg/100 g.

Table 4: Total starch and starch nutritional fractions of the developed value-added products (g/100 g, dry weight basis)

Products		Rapidly digestible starch	Slowly digestible starch	Resistant starch	Total starch	*In vitro* starch digestion rate (mg maltose released/100 g, dry weight basis)
Barnmill vanilla ice cream	C	25.72 ± 0.17^b	30.72 ± 0.08^b	09.54 ± 0.42^a	52.75 ± 0.21^a	65.98 ± 0.67^b
	E	20.22 ± 0.23^a	23.77 ± 0.76^a	10.13 ± 0.11^b	48.10 ± 2.97^b	54.12 ± 0.42^a
Barnyard wafer	C	08.23 ± 0.28^b	30.78 ± 0.47^b	08.13 ± 0.14^a	49.34 ± 0.15^a	47.14 ± 0.61^b
	E	07.37 ± 0.11^a	24.51 ± 0.42^a	13.30 ± 0.14^b	40.14 ± 0.37^b	45.18 ± 0.16^a

C- Control, E-Experiment; Values are expressed as Mean ± SD of duplicates
Values in columns having different alphabetical superscripts represent significant difference ($p \leq 0.05$) among products in the control and experimental group

3.4 Soluble, insoluble, and total dietary fiber of developed value-added products

The experimental formulations demonstrated a significant ($p \leq 0.05$) improvement in dietary fiber content compared to their control counterparts (Table 5). The highest total dietary fiber was found in the barnyard wafer (4.61 ± 0.08 g/100 g) while the lowest in the control vanilla ice cream.

Table 5: Soluble, insoluble, and total dietary fiber of developed value-added products (g/100 g, dry weight basis)

Products		Soluble dietary fibre	Insoluble dietary fibre	Total dietary fibre
Barnmill vanilla ice cream	C	0.42 ± 0.08^b	1.38 ± 0.04^b	1.80 ± 0.13^b
	E	0.96 ± 0.00^a	1.52 ± 0.09^a	2.48 ± 0.09^a
Barnyard wafer	C	0.34 ± 0.31^b	2.16 ± 0.08^b	2.50 ± 0.39^b
	E	0.89 ± 0.29^a	3.72 ± 0.37^a	4.61 ± 0.08^a

C- Control, E-Experiment; Values are expressed as Mean ± SD of duplicates
Values in columns having different alphabetical superscripts represent significant difference ($p \leq 0.05$) among products in the control and experimental group

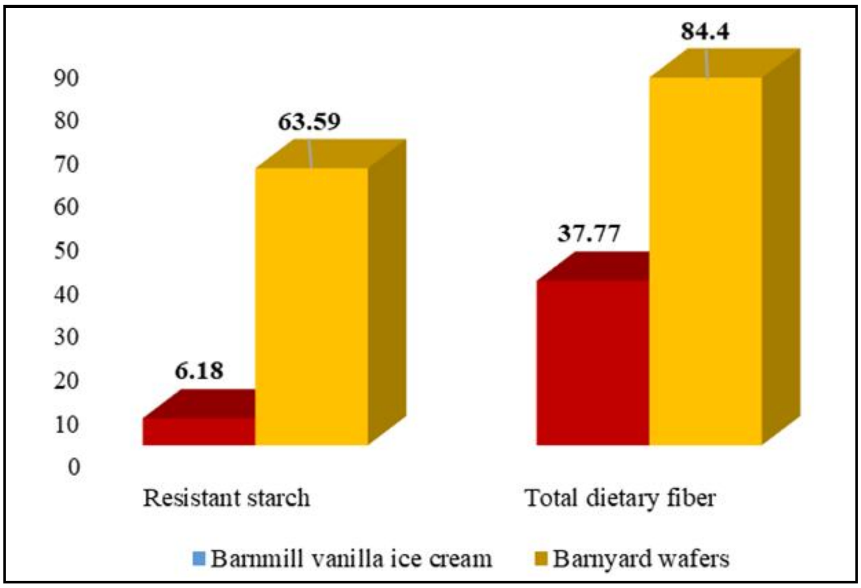

Figure 4: Per cent increase in resistant starch and total dietary fiber content of developed value-added products with respect to the control group.

The highest per cent increase in resistant starch and total dietary fiber was seen in barnyard wafer 63.59 and 84.4 per cent, respectively (Figure 4).

3.5 Predicted glycemic index and glycemic load of developed value-added products

The predicted glycemic index of the experimental products ranged from 55.30 ± 2.92 to 60.94 ± 1.82, respectively, with the lowest in barnyard wafer. Similarly, the glycemic load, which reflects both the quality and quantity of carbohydrates, exhibited significant reductions in the experimental products (Table 6).

The highest per cent decrease in predicted glycemic index was seen barnyard wafer (-13.51%) while per cent decrease in the *in vitro* starch digestibility of the products made from barnyard millet with respect to control group, ranged from -8.81 to -18.65% with maximum per cent decrease in barnyard wafer (Figure 5).

Table 6: Predicted glycemic index and glycemic load of developed value-added products (dry weight basis)

Products		Predicted glycemic index	Glycemic load
Barnmill vanilla ice cream	C	64.78 ± 1.45^{b}	26.44 ± 0.81^{b}
	E	60.94 ± 1.82^{a}	27.14 ± 0.59^{a}
Barnyard wafer	C	63.94 ± 1.64^{a}	51.12 ± 0.61^{a}
	E	55.30 ± 2.92^{b}	42.23 ± 0.82^{b}

C- Control, E-Experiment; Values are expressed as Mean ± SD of duplicates
Values in columns having different alphabetical superscripts represent significant difference ($p \leq 0.05$) among products in the control and experimental group

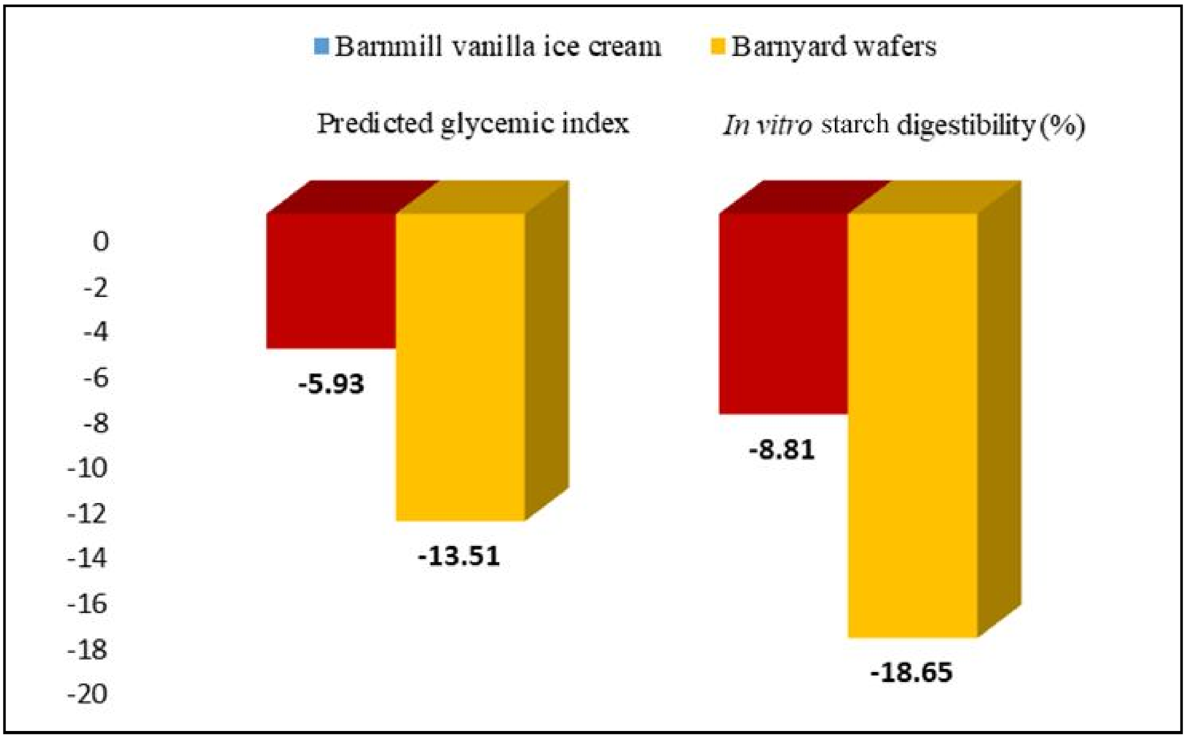

Figure 5: Per cent decrease in the predicted glycemic index and *in vitro* starch digestion rate of developed value-added products with respect to the control group.

4. Discussion

4.1 Organoleptic evaluation of developed value-added products

The two value-added products, *i.e.*, ice-cream and wafer are commonly consumed, therefore, an attempt was made to enhance its nutrition while retaining the taste. As the traditional ice-cream and wafers available in the market are high in sugar content and provide empty calories, an attempt was made to develop highly liked products with more nutritional benefits. Food products were prepared by using roasted barnyard millet flour to enhance the flavor and nutritional content of the developed products. The highest overall acceptability of 8.75 ± 0.61 was obtained by barnmill vanilla ice cream which could be attributed to the nutty and earthy flavour of the millet that added uniqueness to the ice-cream making it more appealing. Also, the pre-processing like roasting and germination of the flour during the preparation stage might have enhanced the texture, giving a creamy and smooth feel to the end products (Amirtha *et al.,* 2021). Barnyard wafer obtained the second-highest overall acceptability score of 8.59 ± 0.62. The barnyard wafer was developed considering its different uses as it can be used as such or as an ice cream cone. Mahulkar *et al.* (2024) used response surface methodology (RSM) to optimise a millet-based multigrain waffle ice cream cone formulation which received average sensory scores of 7.29, 6.86, 7.81, 6.90, and 7.86, respectively. Another study was conducted by Amirtha *et al.* (2021), in which, a healthy non-dairy ice cream of barnyard millet extract was created having higher sensory attributes (7.19±1.154 to 6.59±1.833) than control. Overall, in the current study, the experimental group outperformed the control group in most sensory parameters, demonstrating the potential of barnyard millet as a functional ingredient in food formulations, contributing to both sensory appeal and nutritional enhancement.

4.2 Nutritional composition of the value-added products

In the current study, barnmill vanilla ice cream had a significantly higher crude protein value (5.86 g/100 g) compared to the control (4.11 g/100 g) which may be due to the addition of cream, milk, and 6% barnyard millet flour. The addition of millet in the experimental products could have resulted in their higher protein content. Sruthi *et al.* (2018) developed a wafer by incorporating pearl millet, and barnyard millet flour with little amount of maida. Samples that contained 30, 50 and 70% barnyard millet along with maida had 5.9, 6.0, and 6.4 g crude protein content in the wafer, and samples that contained mixed amounts of pearl millet, barnyard millet, and maida had 9.3 g and 9.1 g of crude protein content. Another reason for the higher crude protein content in the developed products could be due to roasting of barnyard millet flour which enhanced protein availability by reducing anti-nutritional factors that interfere with protein absorption (Mohad *et al.,* 2023). In another study, Amirtha *et al.* (2021) developed ice cream from barnyard millet and soya bean extract. The crude protein content was found to be 21.04 ± 0.03 g/ 100 g and the high protein content was due to soya bean extract.

A significant improvement was also observed in the barnyard wafer where crude fibre increased from 2.05 g/100 g to 5.02 g/100 g. The increase in crude fiber across all experimental samples is attributed to the incorporation of barnyard millet flour, which is inherently rich in dietary fiber and is linked to better digestive health, increased satiety, and a lower. The crude fiber content in the wafer which was made using 20% barnyard millet flour, 30% pearl millet flour, and 50% refined flour, ranged from 1.9 g to 12.8 g/100 g, respectively (Sruthi *et al.,* 2018).

4.3 *In vitro* protein digestibility of developed value-added products

In the current study, experimental products showed higher protein digestibility due to the incorporation of barnyard millet flour ranging from 6 to 30%. Barnmill vanilla ice cream and barnyard wafer showed higher *in vitro* protein digestibility to the tune of 88.91 and 62.33 per cent due to the addition of milk, cream, and barnyard millet flour. The increased digestibility of the developed products could also be attributed to different cooking techniques used like baking, cooking, and roasting at high temperatures used in the current study for the development of the products. These techniques denature the protein structure, making it more accessible to enzymes and reducing the amount of anti-nutritional factors (Gong *et al.,* 2025). A pearl millet bar was developed and the *in vitro* protein digestibility of the bar was found to be 75.65% which was considered nutritionally rich and appealing (Samuel and Peerkhan, 2020).

4.4 Total starch and starch nutritional fractions of developed value-added products

Resistant starch (RS) is a form of starch that does not break down in the small intestine. Instead of being broken down into glucose like other starches, it goes through the digestive tract intact until it reaches the large intestine (Chen *et al.,* 2024). In this study, rapidly digestible starch and slowly digestible starch were lower in all experimental products as compared to their control counterparts. Barnmill vanilla ice cream showed a higher amount of rapidly digestible starch (20.22%). This can be due to its freezing rate as a higher freezing rate can slow the deterioration of frozen items by delaying starch retrogradation and limiting ice recrystallization (Qiao and Peng, 2024). Barnyard wafer had slowly digestible starch to the tune of 24.51% and this can be due to pan frying of wafer. Frying duration and elevated temperature can lead to an increase in the SDS in products and have a significant impact on the development of starch-lipid complexes (Li *et al.,* 2024). *In vitro* starch digestion rate is done in a laboratory in which enzymatic breakdown of starch is seen which occurs in human intestines (Wang *et al.,* 2022). In this study, experimental products exhibited lower starch digestion rates compared to their control counterparts, indicating a reduced rate of starch hydrolysis. This reduction may be attributed to the presence of higher levels of resistant starch and dietary fiber in the experimental products, which are known to slow down enzymatic starch breakdown. Among the developed products, barnyard wafer and barnmill vanilla ice cream had higher digestion rates. Barnyard wafer was pan fried and in foods that are pan-fried, a layer of fat is often formed on their surface and that fat can slow the digestion rate of carbohydrates and starch by reducing the enzymatic access (Li *et al.,* 2024) whereas in barnmill vanilla ice cream *in vitro* starch digested by 8.81% than control which could be due to freezing and presence of high fat and sugar. The freezing affects the digestion rate in which gelatinised starch retrogrades into resistant starch (RS) and is more difficult to digest because resistant starch is difficult for enzymes in the small intestine to break down, the digestion rate of foods after cooling may be reduced (Almeida *et al.,* 2024). Due to cooking at high heat flame and baking, barnyard wafer showed decreased per cent at -18.64 which made digestion easy (Gutiérrez *et al.,* 2024). The results of the current study are in line with the study conducted by Hu *et al.* (2025) who developed biscuits from millets and reported a slower *in vitro* starch digestion rate of 51.21%.

4.5 Soluble, insoluble, and total dietary fiber of developed value-added products

Dietary fiber supports several body processes and is an essential part of a balanced diet. It is derived from plants and is not completely broken down as it travels through the digestive tract. Dietary fiber can be water-soluble and water-insoluble (Anuratha *et al.,* 2024). In this study, across all products, the experimental versions showed significantly ($p \leq 0.05$) higher levels of both soluble (SDF) and insoluble (IDF) dietary fiber than their control counterparts. Soluble dietary fiber which aids in lowering cholesterol and regulating blood sugar levels was notably higher in the experimental formulations, especially in barnmill vanilla ice cream (0.96 g/100 g) and barnyard wafer (0.89 g/100 g). Insoluble dietary fiber which promotes digestive health by aiding bowel movements was also increased significantly ($p \leq 0.05$) in all experimental products, with the highest content in the barnyard wafer (3.72 g/100 g) and this could be due to the addition of barnyard millet flour. A millet-based snack bar was developed by Sandhya and Chinnathambi (2024) by using finger and pearl millet flour along with amla and Moringa powder contained 9.8 g of dietary fiber and was accepted by the population. Similarly, cookies prepared using germinated finger and pearl millet flour with a ratio of 50:50 had dietary fiber content of 17.22 g/100 g (Garg and Sharma, 2024), which is in line with the results of the present investigation.

4.6 Predicted glycemic index and glycemic load of developed value-added products

The glycemic index (GI) is a vital component in determining the postprandial glycemic response to carbohydrates in our daily diet (Li and Hu, 2022). In this study, experimental products showed lower glycemic index and glycemic load as barnyard millet is rich in dietary fiber, which slows down carbohydrate digestion and glucose absorption, leading to lower glycemic index values. And further more due to higher resistant starch content of all experimental products, supports better glycemic control (Volpe, 2024). Barnmill vanilla ice cream due to the addition of sugar and glucose powder showed higher carbohydrates, sugar, and rapidly digestible starch content, showed a glycemic index of 60.94 ± 1.82 and glycemic load was 27.14 ± 0.59. On the other hand, barnyard wafer contained refined flour and because of this glycemic index and glycemic load was found to be 55.30 ± 2.92 and 42.23 ± 0.82, respectively. Similarly, the multi-millet snack was developed by using sorghum, finger millet, and pearl millet, and the GI of the snack was found to be 45.71% which falls under the low glycemic index category (Ambulkar *et al.*, 2024).

5. Conclusion

The barnyard millet combination can be used for developing value-added cost-effective products with high organoleptic scores, nutritional profile, shelf-life, and consumer acceptability. The developed products offered higher amounts of protein with improved *in vitro* protein digestibility, dietary fiber, lower *in vitro* starch digestion rate, higher resistant starch, and lower predicted glycemic index in comparison to products prepared from traditional cereals. Therefore, barnyard millet can be effectively used as a replacement for wheat and rice for preparing various food products with better nutritional profiles. It is recommended that the production and consumption of barnyard millet should be expanded to address the concerns of rising malnutrition, non-communicable diseases, metabolic syndrome, and rising food prices. Also, the availability of millet-based food products can be improved by generating awareness and offering training to entrepreneurs, farmers, self-help groups, and the food industry.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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