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Comparative study on nutritional and sensory quality of *Setaria italica*, *Echinochloa frumentacea*, *Eleusine coracana* and *Oryza sativa* based traditional food products

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This study investigates the potential of millets to bolster food and nutritional security by analyzing the physicochemical, functional, and nutritional properties of foxtail millet (*Setaria italica*), barnyard millet (*Echinochloa frumentacea*), finger millet (*Eleusine coracana*), and rice (*Oryza sativa*). It also evaluates the sensory and nutritional qualities of their derived products (laddu, halwa, pulaav). Physicochemical tests showed thousand kernel weights of 3.33 g (foxtail), 2.73 g (finger), 3.43 g (barnyard), and 19.0 g (rice), with thousand kernel volumes of 1.33 mL, 1.75 mL, 2.07 mL, and 8.13 mL, respectively. Nutritional analysis revealed moisture contents of 9.29% (foxtail), 12.85% (finger), 11.40% (barnyard), and 12.08% (rice). Foxtail millet had 10.34% protein, 3.13% fat, 4.32% fibre, and 69.89% carbohydrates; finger millet had 6.80% protein, 1.75% fat, 3.19% fibre, and 71.39% carbohydrates; barnyard millet had 6.89% protein, 3.6% fat, 2.96% fibre, and 71.86% carbohydrates; rice had 6.22% protein, 0.57% fat, 0.23 2.23% fibre, and 81.84% carbohydrates. Sensory evaluations indicated finger millet laddu (8.83±0.21) and halwa were most preferred, while foxtail pulaav outperformed others. The findings highlight foxtail and barnyard millets' superior nutritional profiles compared to rice, supporting their integration into traditional foods to enhance nutrition and food security.

Keywords: Food security, Millets, Nutritional quality, Sensory evaluation, Traditional food products

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Millets are popularly known as Shree Anna, which are nutrient-packed small-grained cereals from the Poaceae family, celebrated for their versatility and health benefits. Spearheaded by India, the UN declared 2023 the International Year of Millets, spotlighting their global potential[1]. Among the oldest crops cultivated in Asia and Africa, millets like foxtail, pearl, finger, and barnyard are now hailed as "Nutri cereals" for their rich protein, fibre, vitamins, and minerals[2]. These superfoods combat diabetes, heart disease, and celiac issues with low glycaemic indices and gluten-free profiles.

Recent agricultural data confirms that India remains the world's leading producer of millets, contributing approximately 38.4% to 41% of global production[3]. Foxtail millet, cultivated since 5000 BC, offers high protein, magnesium, and antioxidants, supporting heart health and diabetes management. Finger millet shines with 220-450 mg/100 g calcium and 3-20% iron, reducing plasma glucose effectively. Barnyard millet (*Echinochloa esculenta*) originated in Asia, with cultivation evidence in India and Japan dating back to 2500-1500 BC[4]. It is exceptionally rich in iron (up to 19.2 mg/100 g), dietary fiber (15.4%), and resistant starch (28.1%), effectively aiding diabetes and obesity management.

Despite their benefits, millet consumption has dropped over decades due to limited awareness, processing challenges, and policies favouring rice and wheat. Social perceptions tying millets to lower-income groups, urban dietary shifts, and labour-intensive dehulling further hinder adoption. Sensory acceptability was a critical factor for market adoption, as consumer's prioritized taste, texture, and appearance alongside nutritional benefits. Prior studies indicated that millet-based products could

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achieve sensory qualities comparable to rice-based counterparts, but comprehensive evaluations across multiple millet types and traditional recipes were limited to counter this, innovative millet-based products like laddu, halwa, and pulaav aim to align with modern tastes, emphasizing sensory appeal alongside nutrition. This study investigates the physicochemical, functional, and nutritional properties of foxtail, barnyard, and finger millets compared to rice, evaluating their sensory and nutritional performance in traditional recipes. By showcasing millets as superior alternatives, it aims to boost their inclusion in contemporary diets, advancing global nutritional security and UN SDG2 for zero hunger.

Materials and Methods

Source of raw material

The Sreelaxmi genotype of foxtail millet (*Setaria italica*) was procured from the Krishi Vigyan Kendra (KVK), Hamirpur District, Uttar Pradesh, India. The grain belonged to the 2023-24 harvest season and was supplied as a single lot maintained under ambient storage (approximately 25-30°C, low humidity) prior to experimentation. The Pratap Sanwa-1 variety of barnyard millet (*Echinochloa frumentacea*) and the VL Mandua 376 variety of finger millet (*Eleusin ecoracana*) were obtained from Jaspura Unnat Kisan Producer Company Limited, Jaspura Block, Banda District, Uttar Pradesh, from the 2023-24 harvest batch. Both millets were cleaned, graded, and stored in airtight polypropylene bags under dry storage conditions before procurement. Batch identification details were recorded at the time of purchase to ensure traceability. The Maha chinnawar rice variety was purchased from a certified grain retailer in the Banda District main market, Uttar Pradesh, India. The rice belonged to the 2023-24 harvest season and was sourced as a single lot with available varietal labeling provided by the vendor. All raw materials were transported to the laboratory under hygienic conditions and stored in airtight containers at room temperature until further processing.

Cleaning and milling of grains

All grains were manually cleaned to remove impurities and milled using an Atta Master Flour Mill (QROXA GOLD Automatic Flour Mill Machine). The flour was then sifted using a 40-mesh sieve, placed in airtight containers, and stored at room temperature until ready for analysis.

Physicochemical and functional characteristics

Physicochemical and functional characteristics were assessed in Post Graduate Laboratory and Post Harvest Management Facilities of Department of Post Harvest Technology, Banda University of Agriculture & Technology, Banda, U.P.

Thousand kernel weight

Thousand kernel weight was determined using three independent replicates (n = 3) for each grain type to ensure measurement reliability. For each replicate, 1000 sound and uniformly sized kernels were counted using a manual seed counting tray to minimize counting error (an automatic seed counter may alternatively be used for greater precision). The counted kernels were weighed on a calibrated digital electronic balance (Adam CPW Plus 150P, USA) with an accuracy of 0.01 g. Results were expressed as mean ± standard deviation (g)[5].

Thousand kernel volume

Thousand kernel volume was also measured in triplicate (n = 3) using a graduated cylinder withthe water displacement method described by Williams *et al*.[6]. For each replicate, 1000 healthy kernels were placed in a 50 mL graduated cylinder containing 25 mL of distilled water. The cylinder was gently tapped to remove entrapped air bubbles. Kernel volume was calculated by subtracting the initial water volume (25 mL) from the final observed volume. Values were reported as mean ± standard deviation (mL) to ensure statistical reliability and reproducibility.

Particle size distribution

Cleaned grains were milled using a laboratory hammer mill fitted with a 1.0 mm screen aperture, operated for 2-3 minutes per 500 g batch to ensure uniform grinding while minimizing heat generation. The milled flour was first passed through a 40-mesh (425 µm) sieve to remove coarse bran particles. All functional and compositional analyses were conducted exclusively on the <40-mesh fraction, and the retained coarse fraction was discarded. For particle size distribution analysis, 100 g of the <40-mesh flour was subjected to mechanical sieving using a standardized sieve stack of 25, 44, 60, 85, and 120 mesh (corresponding to 600, 355, 250, 180, and 125 µm, respectively). Sieving was performed for 15 min using a row-top electric sieve shaker. The weight of flour retained on each sieve and that collected in the pan (<120 mesh) was recorded, and particle size distribution was expressed as percentage retention on each sieve.

Water absorption capacity

We estimated the water absorption capacity of the flour following the method provided by Smith and Circle[7]. We mixed exactly 5 g of flour with 30 mL of distilled water in a centrifuge tube, using a glass rod for proper mixing. After 5 min, we centrifuged the mixture at 2000 rpm for another 5 min. We measured the supernatant using a graduated cylinder. The volume of water absorbed is calculated by subtracting the volume of the supernatant from 30 mL. We recorded the water absorption capacity as follows:

Water absorption capacity (mL/g) = Volume of water absorbed / Weight of sample

Water solubility index

It was figured out the water solubility index by following the AOAC method from 1990. First, we poured the supernatant liquid into a dish that we had weighed beforehand. Then, we dried it in an oven set to 100°C for 2 h and weighed it again. The weight of the solids we got after evaporating the supernatant gives us the water solubility index.

To calculate the water solubility index (%), following formula was used:

$$WSI = (Weight\ of\ dissolved\ solids\ in\ supernatant / Weight\ of\ the\ sample) \times 100$$

Viscosity

Viscosity (unit= cps) was measured with an Anton Paar Digital Viscometer DV-1P (KarntnerStrasse 322, A-8054 Graz, Austria) using spindle L-4 at 100 rpm and 40°C. A 15% (w/v) flour slurry was prepared by mixing 30 g of flour with 50 mL distilled water, adding 150 mL boiling distilled water, and stirring. The mixture was heated at 95°C in a boiling water bath, stirred every 5 min for 10 min.

Proximate composition

All chemical and functional analyses were performed in triplicate (n=3). The data obtained were expressed as the Mean ± Standard Deviation (SD).

Moisture determination

The AOAC: 925.10 21st Edition is the method we use to find out how much water is in the RagiLaddu. This procedure includes steps like preparing the sample, drying it, cooling it down, and then weighing it. To calculate the moisture content, you can use this formula: Moisture content (%) = [(W1 - W2) / W1] × 100.

Here, W1 is the initial weight of the sample before it's dried, and W2 is the weight after drying.The difference (W1 - W2) specifically quantifies the mass of water evaporated during the process.

Ash determination

The FSSAI (Food Safety and Standards Authority of India) Manual of Cereal & Cereal Products outlines the guidelines and standards for analyzing cereals and cereal products, including ash determination. This method consists of several steps: preparation, weighing, incineration, ashing, cooling, and final weighing. To find the ash content, use this formula:

Ash content (%) = (Weight of ash / Weight of the sample) x 100

Fat determination

The AOAC International (Association of Official Agricultural Chemists) method, AOAC 922.06, is used for measuring fat in food samples. This process involves weighing, extracting, and drying, followed by gravimetric determination. Following Formula was used to calculate fat content: Fat (%) = (Weight of extracted fat / Weight of sample) x 100

Protein determination

IS: 7219-1973 outlines the Indian Standard (IS) guidelines for measuring protein levels in food products. The Kjeldahl method is a well-known and respected approach for protein determination. This method includes several key steps: Digestion, Distillation, and Titration. By evaluating the volume of hydrochloric acid used during titration, we can determine the nitrogen content of the sample. Since proteins are roughly 16% nitrogen, we can figure out the protein content by multiplying the nitrogen quantity by a specific conversion factor.

Carbohydrates determination

This process involves measuring the total carbohydrates found in a food sample, which includes sugars, starches, and dietary fibers. To determine carbohydrates and fiber, we can subtract the total of moisture, ash, fat, and protein from the overall sample.

Fiber content

Crude fibre

Crude fibre content was determined according to IS: 10226 (Part 1):1982 using a gravimetric method. The sample was first defatted (if required) and subjected to sequential digestion with dilute acid followed by dilute alkali under controlled conditions.

The digested residue was filtered, thoroughly washed to remove soluble matter, dried to constant weight, and weighed. The residue was then incinerated to correct for ash content. Crude fibre percentage was calculated as the loss in weight on ignition of the dried residue, expressed as a percentage of the original sample weight.

Total dietary fibre (TDF)

It was determined using the enzymatic–gravimetric AOAC method**.** The sample was subjected to sequential enzymatic digestion with heat-stable α-amylase, protease, and amyloglucosidase to remove digestible starch and protein. The undigested residue was precipitated (for soluble fibre), filtered, washed with ethanol and acetone, dried to constant weight, and weighed. The residue was corrected for protein and ash content. Total dietary fibre was expressed as a percentage of the original sample weight and included both soluble and insoluble fibre fractions.

Calcium and Iron

The calcium content was determined using the titrimetric method (AOAC 927.02[8]), while the iron content was quantified colorimetrically using Wong's method[9], involving the formation of a red-colored ferric thiocyanate complex[10].

Preparation of food products

We prepared three delightful products: laddu, halwa, and pulaav, using ingredients such as foxtail millet, barnyard millet, finger millet, and rice (used as a control). For laddu and halwa, the flour particle size ranged between 125-355 µm. The recipes adhered to standard methods as outlined by Verma *et al.*[11].

Laddu

Laddu is a delicious treat made from a variety of ingredients, including cereals, millets, legumes, and oilseeds, combined with sugar and sometimes shortening. These sweet little balls are especially loved in North India.

Halwa

Halwa is a delightful dessert, a sweet Indian delicacy crafted from an assortment of fruits, vegetables, grains, and lentils, all simmered together with milk, almonds, sugar, butter, and a hint of cardamom. This tasty treat is enjoyed in the Middle East, Central Asia, and India.

Vegetable pulaav

Vegetable pulaav is an Indian dish made with highly seasoned rice and vegetables flavored with spices.

Sensory evaluation

Sensory evaluation was conducted by a semi-trained panel of 10 members from the Department of Post Harvest Technology, BUAT, Banda. "Semi-trained" indicates that panelists underwent two orientation and training sessions (2 h each) prior to evaluation. During training, panelists were familiarized with the sensory attributes (colour, texture, taste, flavour, appearance, and overall acceptability), scoring procedures, and attribute calibration using reference samples to improve consistency and reduce subjectivity.

All samples, including the rice-based control**,** were prepared under identical conditions and presented in a randomized, single-blind manner using three-digit coded containers to eliminate identification bias. The serving order was randomized across panellists to minimize positional bias. Water was provided for palate cleansing between samples. Sensory attributes were evaluated using a standardized scorecard method (9-point hedonic scale)[12] and mean scores were calculated for statistical analysis.

Nutrient composition

Nutrient profiles of laddu, halwa, and pulaav prepared from foxtail, finger, and barnyard millets, with rice as the control, were calculated per 100 g of cooked product[13]. The raw ingredients and final cooked products were accurately weighed using a digital balance to standardize portion size, determine yield, and compute nutrient composition per 100 g.

Statistical analysis

All experimental data were analyzed using one-way analysis of variance (ANOVA) to evaluate significant differences among foxtail, finger, barnyard millet, and rice-based products. Prior to analysis, the assumptions of normality and homogeneity of variance were verified. When significant differences were detected, Dunnett's post-hoc test was used to compare each millet-based product with the rice-based control. Results are presented as mean ± standard deviation (SD), with the number of independent replicates clearly indicated for each parameter (generally $n = 3$ for physico-chemical analyses and $n = 10$ for sensory evaluation). Statistical significance was established at $p < 0.05$. All statistical

Table 1 — Particle size distribution of foxtail millet, finger millet, barnyard millet and rice flour

Flour	Sieve No./Mesh Size (m)					
	25/600	44/355	60/250	85/180	120/125	Collection pan
Foxtail millet (%)	0	1.94±0.14	6.62±0.04	13.27±0.32	22.83±0.31	57.08±0.66
Finger millet (%)	0	1.79±0.03	5.97±0.17	11.93±0.04	22.30±0.33	58.57±0.56
Barnyard millet (%)	0	1.69±0.02	6.17±0.61	12.52±0.15	21.44±0.12	59.08±0.56
Rice (%)	0	1.23±0.03	4.39±0.12	11.79±0.07	20.35±0.60	62.67±0.45
CD	0	0.141	0.638	0.362	0.753	1.12
Sem	0	0.041	0.185	0.104	0.218	0.324
Sed	0	0.058	0.261	0.148	0.308	0.458

Note: Values are expressed as Mean ± SD (n=3); CD: Critical Difference at $p < 0.05$; SEM: Standard Error of Mean; SEd: Standard Error of Difference.

Table 2 — Functional characteristics of foxtail millet, finger millet, barnyard millet and rice flour*

Flour	Properties				
	Thousand kernel weight (g)	Thousand kernel volume (mL)	Water absorption capacity(mL/g)	Water solubility	Index (%) Viscosity (cps)
Foxtail millet	3.33±0.21	1.33±0.16	1.77±0.06	3.27±0.15	1672.20±0.79
Finger millet	2.73±0.05	1.75±0.03	2.03±0.10	1.72±0.04	1671.93±1.42
Barnyard millet	3.43±0.21	2.07±0.15	2.33±0.25	1.63±0.15	1577.17±1.61
Rice	19.00±0.11	8.13±0.21	2.36±0.15	1.57±0.15	1689.37±1.33
CD	0.315	1.184	0.313	0.264	2.642
Sem	0.091	0.342	0.091	0.076	0.764
Sed	0.129	0.484	0.128	0.108	1.080

Note: Values are expressed as Mean ± SD (n=3); CD: Critical Difference at $p < 0.05$; SEM: Standard Error of Mean; SEd: Standard Error of Difference.

analyses were performed using the Statistical Package for the Social Sciences (SPSS) software.

Results and Discussion

Physicochemical and functional characteristics

Table 1 reveals the particle size distribution of foxtail, finger, barnyard millet, and rice flours across various sieve sizes. All flours qualified as fine, with 98% passing the no. 44 sieve. Rice flour stood out, with 88.25% passing the 85-mesh sieve and the highest proportion of fine particles (<125 μm) in the collection pan. Significant differences emerged across 60, 85, and 120-mesh sizes for all flours, except at the 44-mesh, highlighting distinct granularity profiles.

The study revealed significant variations in thousand kernel weight and volume among foxtail millet (2.33 g, 1.33 ml), finger millet (2.73 g, 1.75 mL), barnyard millet (3.43 g, 2.07 mL), and rice (19 g, 8.13 mL), all statistically significant at $p<0.05$ (Table 2). Compared to prior research, foxtail and barnyard millet weights aligned closely with Sunil *et al.*[14] (2.45 g), while volumes were slightly lower than Verma *et al.*[11](1.6 mL, 2.0 mL) and Hadimani & Malleshi[15] (1.9 mL, 2.4 mL). Notably, Peplinski *et al.*[16] linked higher kernel weights to increased grain hardness and vitreousness, suggesting millets' robust physical traits enhance their processing potential.

Water absorption capacity, critical for water-scarce conditions, showed no significant differences among flours ($p<0.05$), with rice leading at 2.36 mL/g, followed by barnyard (2.33 mL/g), finger (2.03 mL/g), and foxtail millet (1.77 mL/g), likely due to rice's higher starch content[17]. Foxtail millet excelled in water solubility index (3.27%), significantly surpassing finger millet (1.72%), barnyard millet (1.63%), and rice (1.57%), indicating superior solubility (Table 2). Viscosity of 15% w/v gruels exceeded 1,500 cps, with rice gruel significantly thicker (1689.37 cps) than foxtail (1672.20 cps), finger (1671.93 cps), and barnyard millet (1577.17 cps), driven by enhanced starch gelatinization[18]. All viscosity differences were significant ($p<0.05$), highlighting rice's textural dominance and millets' unique functional profiles.

Foxtail millet flour exhibited the lowest moisture content at 9.29%, significantly below finger millet (12.86%), barnyard millet (11.40%), and rice (12.08%) flours (Table 3). Lower moisture enhances mixing, flow, and packaging efficiency[19]. Finger millet and rice flours showed near-identical moisture levels.

Table 3 — Proximate composition of foxtail millet, barnyard millet and rice on dry weight basis

Flour	Proximate composition								
	Moisture %	**Ash%**	**Crude protein %**	**Crude fat%**	**Crude Fibre%**	**Carbohydrate by difference%**	**Energy (Kcal)/ 100 g**	**Calcium (mg/100g)**	**Iron (mg/ 100g)**
Foxtail millet	9.29±0.05	3.25±0.13	10.34±0.05	3.13±0.09	4.32±0.06	69.89±0.06	349.00± 2.00	30.30± 0.20	3.69± 0.04
Finger millet	12.86±0.05	1.89±0.03	6.80±0.09	1.75±0.03	3.19±0.25	71.39±0.68	320.47± 0.87	92.80± 0.70	5.83± 0.31
Barnyard millet	11.40±0.01	4.30±0.05	6.89±0.07	3.6±0.02	2.96±0.04	71.86±0.02	334.67± 1.53	23.18± 0.02	7.10± 0.20
Rice	12.08±0.17	0.61±0.07	6.22±0.03	0.57±0.04	0.23±0.02	81.84±0.54	353.24± 1.06	11.89± 0.21	1.56± 0.13
CD	0.178	0.159	0.119	0.100	0.261	0.8632	2.860	0.753	0.489
Sem	0.052	0.045	0.035	0.029	0.075	0.250	0.826	0.218	0.141
Sed	0.073	0.065	0.049	0.041	0.107	0.353	1.169	0.308	0.200

Note: Values are expressed as Mean ± SD (n=3); CD: Critical Difference at $p < 0.05$; SEM: Standard Error of Mean; SEd: Standard Error of Difference.

Total ash, indicating mineral richness, was highest in barnyard millet (4.30%), followed by foxtail millet (3.25%), and finger millet (1.89%). Rice flour's ash content (0.61%) corroborated Gopalan *et al.*[13]. At 5% significance, foxtail and barnyard millets significantly outstripped rice in mineral density. Higher millet flour incorporation boosts ash but reduces protein, gluten, and loaf volume while increasing starch damage[20].

Foxtail millet flour led with 10.34% crude protein, followed by barnyard (6.89%), finger millet (6.80%), and rice (6.22%), with significant differences ($p<0.05$). Crude fat content was highest in barnyard millet (3.6%), followed by foxtail (3.13%), finger millet (1.75%), and rice (0.57%). Foxtail millet's fat content aligns with Zhang *et al.*[21], ranging from 3.38% – 6.49% (avg. 4.51%), Compared to rice, foxtail, finger, and barnyard millets had 5.49%, 1.31%, and 6.31% higher fat, respectively, with significant differences ($p<0.05$).

Foxtail millet flour exhibited the lowest moisture content (9.29%) compared to finger millet (12.86). The value of crude fibre of foxtail millet was 4.32% which was found close to Arya's[22] 4.8%. Finger millet had 3.19% crude fibre; Ramulu *et al*[23] reported 12% TDF, 11% IDF, and 2% SDF, while Kamath and Belavady[24] noted 18.6% dietary fibre and 3.6% crude fibre. Barnyard millet flour had 2.03% crude fibre, and rice flour had 0.23%, aligning with Gopalan *et al.*[13] at 0.20%. Millets have higher fibre than rice. Significant differences in crude fibre were found among the four grains at 5% significance.

Foxtail millet flour has 3.69 mg iron per 100 g, 0.89 mg more than Gopalan *et al.*[13] 2.80 mg. Finger millet is the richest in calcium and iron. Barnyard millet has 7.10 mg iron per 100 g, close to Mittal *et al*.[25] (7.31 mg). Rice has 1.56 mg iron per 100 g, matching Yadav *et al.*[26] 1.0 mg. Foxtail millet (3.73 mg/100 g) has 2.5 mg more iron than rice (6.91 mg/100 g), while barnyard millet has 5.68 mg more than rice. Iron content varies significantly among foxtail millet, barnyard millet, and rice at a 5% significance level (Table 3).

Fig. 1 — Samples of Laddu of Barnyard Millet, Finger Millet and Foxtail Millet

Representative photographs of the millet-based laddu products prepared from barnyard millet, finger millet, and foxtail millet are presented in (Fig. 1). These images illustrate the visual appearance and product characteristics prior to sensory evaluation. Halwa, laddu, and pulaav were prepared, and their sensory quality was evaluated using the scorecard method for foxtail millet, finger millet, barnyard millet, and rice (control). For laddu, no significant differences in colour, flavour, texture, appearance, or acceptability were found among the four grains, all rated positively (Table 4). For halwa, control halwa showed good sensory qualities, with no significant differences in colour, texture, taste, appearance, or acceptability among the grains (Table 5). Pulaav from foxtail millet was rated very good in colour, flavour, taste, and acceptability, while finger millet, barnyard millet, and rice were rated good. Pulaav exhibited notable differences in colour and flavour, with barnyard and foxtail millet Pulaav varying significantly across all sensory parameters (Table 6).

The nutritional value of formulated products was calculated per 100 g of cooked food. Nutrient

Table 4 — Sensory quality characteristics of laddu

Flour	**Sensory quality characteristics of laddu**					
	Colour	**Flavor**	**Texture**	**Taste**	**Appearance**	**Overall Acceptability**
Foxtailmillet	9.10±0.10	7.20±0.40	7.33±0.31	7.77±0.15	8.50±0.20	7.87±0.15
Finger millet	8.83±0.42	8.17±0.21	8.20±0.36	8.07±0.21	8.53±0.21	8.83±0.21
Barnyardmillet	8.67±0.21	8.30±0.36	8.57±0.35	7.80±0.20	8.73±0.21	8.43±0.25
Rice	8.20±0.36	7.73±0.15	7.37±0.15	7.47±0.23	8.13±0.06	7.60±0.30
CD	0.594	0.579	0.604	0.398	0.359	0.467
Sem	0.172	0.167	0.175	0.115	0.104	0.137
Sed	0.243	0.237	0.247	0.163	0.147	0.191

Note: Values are expressed as Mean ± SD (n=3); CD: Critical Difference at $p < 0.05$; SEM: Standard Error of Mean; SEd: Standard Error of Difference.

Table 5 — Sensory quality characteristics of Halwa

Flour	**Sensory quality characteristics of Halwa**					
	Colour	**Flavor**	**Texture**	**Taste**	**Appearance**	**Overall acceptability**
Foxtail millet	9.07±0.15	7.57±0.31	8.43±0.21	8.13±0.21	8.27±0.21	8.20±0.20
Finger millet	8.70±0.20	8.63±0.25	8.53±0.15	8.60±0.20	8.43±0.15	8.90±0.10
Barnyard millet	8.47±0.15	7.97±0.21	8.47±0.15	7.80±0.10	8.67±0.21	8.43±0.31
Rice	8.13±0.12	8.27±0.15	8.10±0.10	8.40±0.10	8.20±0.10	8.40±0.10
CD	0.313	0.469	0.315	0.318	0.345	0.389
Sem	0.091	0.136	0.091	0.092	0.099	0.112
Sed	0.128	0.192	0.129	0.130	0.141	0.159

Note: Values are expressed as Mean ± SD (n=3); CD: Critical Difference at $p < 0.05$; SEM: Standard Error of Mean; SEd: Standard Error of Difference.

Table 6 — Sensory quality characteristics of Pulaav

Flour	**Sensory quality characteristics of Pulaav**					
	Colour	**Flavour**	**Texture**	**Taste**	**Appearance**	**Overall acceptability**
Foxtail millet	9.10±0.26	9.30±0.20	9.07±0.21	9.10±0.20	8.47±0.40	8.63±0.32
Finger millet	8.47±0.50	9.03±0.25	8.27±0.35	8.53±0.40	8.37±0.25	8.60±0.26
Barnyard millet	7.57±0.25	7.80±0.20	8.00±0.26	7.87±0.42	7.33±0.35	7.93±0.21
Rice	8.33±0.25	8.30±0.26	7.47±0.25	8.67±0.31	8.50±0.26	8.52±0.25
CD	0.668	0.460	0.545	0.682	0.645	0.533
Sem	0.193	0.133	0.157	0.197	0.186	0.154
Sed	0.273	0.188	0.223	0.279	0.264	0.218

Note: Values are expressed as Mean ± SD (n=3); CD: Critical Difference at $p < 0.05$; SEM: Standard Error of Mean; SEd: Standard Error of Difference.

composition of laddu is shown in (Table 7). Finger millet laddu had the highest protein at 6.34%, compared to 5.23% for foxtail millet, 3.38% for barnyard millet, and the control rice laddu. Fat content was 25.48%, 24.82%, 25.09%, and 20.33% for foxtail, finger, barnyard, and rice laddus, with energy values of 506.2, 515, 497.9, and 476 kcal/100 g, respectively. Millet laddus had higher crude fibre than the control, with dietary fibre at 11.1%, 14.57%, 4.67%, and 1.48% for foxtail, finger, barnyard, and rice laddus. Calcium was highest in finger millet laddu at 172.3 mg/100 g, followed by foxtail (17.68 mg), barnyard (14.12 mg), and rice (8.4 mg). Iron content was 1.88, 5.3, 3.47, and 0.65 mg/100 g for foxtail, finger, barnyard, and rice laddus, respectively.

Table 8 details millet-based halwa formulations demonstrate a superior nutritional profile over rice-based controls, primarily through significant protein and micronutrient enrichment. Finger millet halwa emerged as the protein powerhouse (5.75%) and fiber leader (14.9%), offering nearly 26 times more fiber than the rice variant. This high fiber content is critical for slowing carbohydrate digestion and mitigating glucose spikes. Barnyard millet halwa provided the highest iron (1.42 mg/100 g), significantly outperforming the control. Overall, substituting rice with millets effectively reduces carbohydrate loads while substantially increasing bone-building minerals and satiety-inducing fiber, making these traditional sweets functionally healthier[26].

Table 7 — Nutrient composition of Laddu

Food Base	Foxtail millet	Finger millet	Barnyard millet	Rice
Protein (%)	5.23± 0.23	6.34±0.14	3.38±0.38	3.12±0.42
Fat (%)	25.48±1.04	24.82±0.54	25.09±0.19	20.33±0.69
Fibre (%)	2.67± 0.34	1.36±0.17	1.58±0.67	0.26±0.34
Carbohydrate (%)	63.6± 0.41	67.41±0.28	64.74±0.28	68.91±0.14
Dietary fibre (%)	11.1±0.26	14.57±0.71	4.67±0.34	1.48±0.65
Energy kcal/100 g	506.2±0.95	515±1.17	497.9±0.68	476±0.39
Calcium (mg/100 g)	17.68±0.48	172.3±0.36	14.12±0.51	8.4±0.38
Iron (mg/100 g)	1.88±0.39	5.3±0.69	3.47±0.29	0.65±0.30

Table 8 — Nutrient composition of Halwa

Food base	Foxtail millet	Finger millet	Barnyard millet	Rice
Protein (%)	1.99±0.12	5.75±0.60	1.23±0.16	0.96±1.12
Fat (%)	11.8±0.64	11.5±0.25	11.3±1.03	8.92±1.20
Fibre (%)	0.99±0.45	2.9±0.31	2.39±0.64	1.09±0.59
Carbohydrate (%)	32.1±0.22	35.8±0.42	31.19±0.51	38.7±0.36
Dietary fibre (%)	4.29±0.31	14.9±0.22	1.95±0.22	0.57±0.31
Energy kcal/100g	244±0.74	272±0.48	239±0.36	241±0.32
Calcium (mg/100g)	5.82±0.39	166.5±0.45	4.76±0.62	1.64±0.42
Iron (mg/100 g)	0.79±0.74	1.12±0.48	1.42±0.41	0.57±0.59

Table 9 — Nutrient composition of Pulaav

Food base	Foxtail millet	Finger millet	Barnyard millet	Rice
Protein (%)	4.71±0.41	6.93±0.62	3.24±0.54	2.87±1.31
Fat (%)	7.21±0.13	1.53±0.22	6.79±0.68	6.57±0.94
Fibre (%)	1.81±0.36	3.6±0.16	1.52±0.43	0.82±0.41
Carbohydrate (%)	21.68±0.62	41.9±0.36	21.69±0.31	23.09±0.13
Dietary fibre (%)	4.81±0.51	14.4±0.15	2.45±0.21	0.26±0.23
Energy kcal/100 g	171±0.51	208±0.26	168±0.63	165±0.38
Calcium (mg/100g)	18.79±0.14	174.2±0.64	15.8±0.11	12.13±0.36
Iron (mg/100 g)	1.14±0.38	4.1±0.24	1.24±0.31	0.09±0.62

This study found that foxtail millet, finger millet, barnyard millet, and rice pulaav have protein contents of 4.71%, 6.93%, 3.24%, and 2.87%, and fat contents of 7.21%, 1.53%, 6.79%, and 6.57%, respectively. The control pulaav had lower fibre (0.82%) than foxtail millet (1.81%), finger millet (3.6%), and barnyard millet (1.52%). Carbohydrate contents were 21.68%, 41.9%, 21.69%, and 23.09% for foxtail millet, finger millet, barnyard millet, and control pulaav, respectively (Table 9). Dietary fibre was highest in foxtail millet pulaav (4.81%) compared to finger millet (14.4%), barnyard millet (2.45%), and rice pulaav (0.26%). Calcium contents were 18.79 mg, 174.2 mg, 15.8 mg, and iron contents were 1.14 mg, 4.1 mg, 1.24 mg, and 0.09 mg per 100 grams for foxtail millet, finger millet, barnyard millet, and rice pulaav, respectively. Mittal[25] developed nutrient-rich convenience mixes using finger millet for products like mathri, sevain, kachari, kachauri, laddu, cheela, biscuits, and halwa.

Conclusion

Millet-based food products, including foxtail, barnyard, and finger millet laddu, halwa, and pulaav, exhibited sensory acceptability that equalled or surpassed traditional rice-based controls, with foxtail and finger millet pulaav earning the highest consumer preference ratings. Nutritionally, these millet-based foods significantly outperformed rice, offering elevated levels of protein, dietary fibre, calcium, and iron, with finger millet standing out for its exceptional fibre and calcium content. These compelling findings highlight the transformative potential of millets as nutrient-dense, sustainable alternatives to rice in traditional culinary applications. By integrating millets into modern diets, these versatile grains can play a pivotal role in enhancing nutritional security and promoting healthier eating habits across diverse populations.Aligned with the International Year of Millets 2023, the research underscores urgent policy needs–subsidies, market infrastructure, and extension services–to overcome barriers. Millets promise a resilient, nourished future, blending tradition with innovation.

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Author Contributions

PO: Conceptualization of research idea, performed the laboratory analysis and data collection, PKO: Writing, review and manuscript editing.VM: Lab Testing & AK: Data collection & literature search.

Conflict of Interest

The authors have declared no conflicts of interest.

Declaration of generative AI in scientific writing

The authors used ChatGPT (OpenAI) for language editing, grammar correction, and improvement of readability. The authors reviewed, edited, and verified all content and took full responsibility for the final manuscript.

Data Availability

The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

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