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Sensory and nutritional evaluation of nine types of millet substituted for polished white rice in select Indian meal preparations

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This study was conducted to test the suitability of using nine types of millets namely finger millet, pearl millet, white and yellow sorghum, little millet, barnyard millet, proso millet, kodo millet, and browntop millet in seven popular Indian meal preparations based on sensory characteristics and nutrient value. The popular Indian meal preparations tested were boiled grain, dosa, idli, bisi belle bath, pulao, puttu, and pongal. In total, 53 variations in meal preparations were developed using the millets and seven polished white rice-based meal preparations were developed as control. The main findings indicated that meal preparation crafted from various millets garnered overall sensory scores closely resembling to those derived from polished white rice. Notably, little millet exhibited high scores in pongal and dosa, and achieved elevated overall sensory scores compared to meal preparation from polished white rice. Bisi belle bath made of barnyard millet scored higher in overall sensory score than polished white rice. Moreover, there was significant association between some types of millets' overall sensory characteristics ($p < 0.005$) with polished white rice-based meal preparations. In terms of nutrient value, all the millet-based meal preparations had significantly high nutritional value compared to those made with polished white rice ($p < 0.05$). Especially calcium content of the meal prepared with finger millet was significantly higher compared to polished white rice-based meals ($p < 0.05$). Puttu, idli, and dosa prepared with finger millet had calcium content of 59.4, 10.8, and 70.9 mg/100 g compared to those prepared with the polished white rice which had only 1.3, 6.3, and 9.2 mg/100 g. The magnesium content of all millet-based meal preparations was generally several-folds higher compared to the polished white rice-based meal preparations ($p < 0.05$). There is a significant difference in the fiber content of the meals prepared with millets compared to the meals prepared with polished white rice ($p < 0.05$). This study was conducted using millets that are locally available and does not represent all the millet varieties available globally, as each type of millet has a wide range of varieties. Therefore, it is important to understand and choose the type and variety of millet while enhancing the nutritional value of diets.

KEYWORDS

millets-based meal preparation, browntop millet, finger millet, proso millet, sensory evaluation, sorghum

1 Introduction

Millets are "Good for you," "Good for the farmers," and "Good for the planet" (Poole and Kane-Potaka, 2020). Although millets are traditional crops in many countries, including India, in the past few decades since 1961, the area under millets and their production in India declined to 50 and 18%, respectively; this was also reflected in a decline in *per capita* consumption brought on mainly by the increased consumption of polished white rice and wheat that dominated as staples while other indigenous crops are available (Willett et al., 2019; Vaidyanathan, 2021).

Considering the changing climatic conditions, global high levels of food insecurity and malnutrition, there is a need for diversification in staple production and consumption. It is therefore important to bring back traditional nutritious and climate-smart crops and expand the Big 3—rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.)—to the Big 5—by including millets and sorghum (often grouped as a millet). In recent years, there is a growing consumer awareness of the "Smart Choice" that millets and sorghum are mainly due to their perceived nutritional and health benefits (Kane-Potaka et al., 2021). This is driving consumption and the urge to incorporate millets into daily diets. Rice is normally consumed as polished white rice, which is generally lower in nutrient content compared to the millets which is typically not polished like rice.

Millets are cereal crops that belongs to the grass family *Poaceae*. They are an important crop of rainfed regions of semi-arid tropics, as they are drought tolerant (Vetriventhan et al., 2020). Millets are dry land crops especially cultivated in the semi-arid region, which usually receives low and erratic rainfall with periodic drought. Different types of millet have different mechanisms to cope with drought at various stages of plant growth (Tadele, 2016) based on agronomical traits such as flowering time, morphological traits such as shoot and root length, and physiological traits such as water extraction and chlorophyll content (Tadele, 2016).

There are nine types of millets commonly available in the Indian market, namely finger millet [*Eleusine coracana* (L.) Gaertn.], pearl millet (*Pennisetum glaucum*), white and yellow sorghum (*Sorghum bicolor*), little millet (*Panicum sumatrense* Roth. ex. Roem. & Schult.), barnyard millet [*Echinochloa crus-galli* (L.) P. Beauv. and *Echinochloa colona* (L.) Link], proso millet (*Panicum miliaceum* L.), kodo millet (*Paspalum scrobiculatum* L.), foxtail millet [*Setaria italica* (L.) P. Beauv.], and browntop millet (*Brachiaria ramosa* L.).

Millets have a high nutrient content compared to polished white rice. In particular, finger millet contains a high calcium content of 364 ± 58 mg/100 g compared to polished white rice and almost 23.4% of calcium from finger millet is retained in the body (Shobana et al., 2013; Longvah et al., 2017; Anitha et al., 2021) which is an important phenomena for calcium accretion in bone and bone growth. Depending on the variety and type of millet, it generally has high iron, and protein content. Millets have the potential to improve the blood hemoglobin concentration compared to polished white rice (Anitha et al., 2024b). Millets have potential to improve the growth of the children (Anitha et al., 2022a). Fiber content of finger millet (11.18 ± 1.14/100 g), and pearl millet (11.49 ± 0.62/100 g) are higher than polished white rice 2.81 ± 0.42/100 g (Longvah et al., 2017). Despite millets having high nutrition and health benefits, polished white rice and wheat are the dominant current staples, influenced by very limited consumer knowledge on how to substitute favorite rice and wheat-based meal preparations with healthier millets. This is compounded by the lack of evidence on which of the nine millets are suitable for substitution in specific meal preparations and the lack of consumer awareness on the proportions to be used in the preparation of millet-based meal preparations. This calls for a comprehensive interdisciplinary study on the optimization of the proportion in which each millet is to be used with other ingredients, standardization of cooking methods, and a comparison of the nutritional benefits and overall acceptability of the millet-based meal preparations using robust scientific methods.

Studies conducted on millets so far have been limited to assessing their sensory attributes. Also, limited types of millet have been figured in the studies which may not have information related to nutrition. For example, though the physical and sensory characteristics of various finger millet composite extruded products were studied earlier (Sawant et al., 2013) their nutritive value and the use of finger millet in any other recipe were out of the scope of the study. Similarly, studies on various types of millet-based products, and their effect on blood glucose levels and lipid profile have not included the nutritional value of the products (Sobhana et al., 2020; Joshi and Srivastava, 2021; Anitha et al., 2022b, 2023). There are several studies focused on the millet grain nutrient value whereas some studies focused on the nutritional value of millets in meal preparations with or without sensory evaluation. To our knowledge, there is no single study that tests the suitability of all the millets available in India as substitutes for popular polished white rice-based meal preparations in terms of sensory and nutritional characteristics. The current study was designed to cover multiple aspects including—nine different types of millet, common and popular meal preparations, their detailed sensory attributes, and nutrition value—to obtain in-depth knowledge on the suitability of each type of millet for various popular meal preparations and their nutritional value. This can aid consumers in choosing the right type of millet and meal preparations based on their suitability and nutritional quality.

The study was conducted based on the following hypotheses: (1) All nine types of millets may not be suitable in the preparation of common cereal-based meal preparations; (2) The nutritional content of cooked millet-based food may not necessarily match the sensory attributes of the recipes prepared using different types of millets; and (3) The nutritional content of millet-based food will be higher compared to that of commonly used polished white rice.

Therefore, the aim of the study is: (1) To identify the most suitable millets for seven types of meal preparations; and (2) To evaluate the organoleptic and nutritive properties of the standardized millet-based meal preparations and compare them with the same meal preparations made with commonly used polished white rice.

2 Materials and methods

2.1 Types of millet, including sorghum, used

Finger millet, pearl millet, sorghum (white and yellow), little millet, barnyard millet, proso millet, kodo millet, and browntop millet were used. Non-sticky polished white rice was used as a control.

2.2 Meal preparations selected

The following meal preparations were selected to substitute polished white rice with millets. They are popular and commonly cooked in India, specifically south India.

1 Boiled grain: Usually, polished white rice is boiled and consumed in this form all over India and globally.
2 Dosa, a thin crepe made of fermented rice and black gram (*Vigna Mungo*) batter, is a popular South Indian breakfast.
3 Idli (savory rice cake), made by steam cooking a fermented batter of polished white rice and de-husked black gram, is a typical breakfast menu popular in both south India and Sri Lanka.
4 Bisi belle bath is a spicy meal prepared with polished white rice, pigeonpea (*Cajanus Cajan*) and vegetables, popular in Karnataka state of south India.
5 Pulao is a single-pot meal made of polished white rice and vegetables that is very popular in India.
6 Puttu, made of coarse rice flour and grated coconut packed in alternate layers and steam-cooked in a special utensil, is a traditional breakfast popular in Kerala, Tamil Nadu and Sri Lanka.
7 Pongal, made of rice and split green gram (*Vigna Radiata*), is a south Indian breakfast. Though it can be cooked in both sweet and savory versions, in this study it was cooked as a savory meal.

2.3 Product or meal standardization

A total of seven meal preparations—boiled grain, dosa, idli, bisi belle bath, pulao, puttu, and pongal—were developed to replace regular polished white rice with the nine types of millet. The standardization and selection of recipes for sensory evaluation was conducted in two stages.

2.4 Stage 1: Screening of meal preparations

The suitability of the nine types of millets for the selected meal preparations was assessed by a chef based on a number of factors such as texture/consistency, taste, color/appearance, size, and cooking time. After the screening, the selected millet was used to prepare the selected meal preparations as described in Table 1, which was then used for sensory evaluation.

2.5 Stage 2

In stage 2, the selected millet was used to prepare all the seven meal preparations in combination with other ingredients, as described in Table 2. In each meal, rice (the main ingredient in the original meal) was fully replaced with the selected millet.

2.5.1 Panel recruitment for sensory evaluation

In the current study, 24 panel members were recruited following a selection process that included recognition tests, threshold tests, and triangle tests. The panel members were aged between 25 and 50 years (Lease et al., 2016). The major inclusion criteria for a panelist were: (1)

TABLE 1 The first-level screening of millets based on their suitability for the recipe in terms of cooking time, consistency, and final appearance.

Recipe	Millets that were selected in the screening	Millets that were rejected in the screening
Boiled grain	Little millet, barnyard millet, foxtail millet, proso millet, kodo millet, and browntop millet	Pearl millet, finger millet, and yellow and white sorghum
Dosa	Little millet, barnyard millet, foxtail millet, proso millet, kodo millet, browntop millet, pearl millet, finger millet, and yellow and white sorghum	-
Idli	Little millet, barnyard millet, foxtail millet, proso millet, kodo millet, browntop millet, pearl millet, finger millet, and yellow and white sorghum	-
Bisi belle bath	Little millet, barnyard millet, foxtail millet, proso millet, kodo millet, and browntop millet	Pearl millet, finger millet, and yellow and white sorghum
Pulao	Little millet, barnyard millet, foxtail millet, proso millet, kodo millet, and browntop millet	Pearl millet, finger millet, and yellow and white sorghum
Puttu	All millets were selected	
Pongal	Barnyard millet, browntop millet, foxtail millet, kodo millet, little millet, and proso millet rice	Pearl millet, finger millet, and yellow and white sorghum

TABLE 2 The quantity of millets used in each meal preparation and the final quantity of the meal.

Recipe	Quantity of millet used (g)	Other major ingredients used (g)	Quantity of the recipe (g)	Quantity of the control (polished white rice) (g)	Time taken to cook (minutes)
Boiled grain	100	-	276–314	288	10–12
Dosa	75	25 g of pulse	160–187	203 (each)	5
Idli	75	25 g of pulse	221–270	279	10–15
Bisi belle bath	50	50 g of vegetables	406–590	644	40–45
		30 g of pulse			
Pulao	50	25 g of vegetables	243–282	230	20
Puttu	100	50 g of coconut	198–228	236	8
Pongal	50	50 g of pulse	510–524	520	10

Age range between 18 and 50 years; (2) Inclusion of both males and females; and (3) Education level that enables an understanding of the questions in English or the vernacular language (Kannada). The major exclusion criteria were: (1) Those with known allergies or not interested in millet-based food; (2) Those with digestive disorders and under medication for digestive disorders; (3) Those with specific likes and dislikes of various foods; and (4) Those not qualifying in the taste recognition test.

Considering the number of recipes and combinations, two panels of 12 evaluators were recruited to conduct the sensory analysis of each meal by one panel. Each meal was tested for its sensory characteristics on a different day (Sharif et al., 2017). A consent form was obtained from each participant declaring that they did not have any identified food allergies, were not addicted to alcohol or cigarettes, had not come for sensory evaluation on an empty stomach, had not eaten anything an hour before starting the sensory evaluation, and that they were willing to participate in the sensory evaluation. The study was approved by the Institutional ethical committee (MSRMC/EC/AP-02/04-2019).

2.5.1.1 Blinding the study

The panelists for the sensory evaluation and laboratory assistants in the nutrient testing laboratory were blinded for the type of millets used in all the seven meal preparations. Non-sticky polished rice cannot be blinded as it is a common staple that can be recognized in any meal.

2.5.2 Sensory evaluation

The trained panel of judges evaluated all the seven meal preparations prepared using millets for their sensory properties. The meal preparations were scored on a nine-point hedonic scale for their appearance, taste, texture, aroma, and overall acceptability, where 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely (Lim, 2011).

2.5.3 Nutrient analysis of the raw grain and cooked meal preparations

A total of 10 raw grains (nine types of millets and rice) and 53 cooked recipes were analyzed for major nutrition parameters including carbohydrates, protein, fat, iron, zinc, selenium, magnesium, and calcium. The methods used for the analysis of the samples are listed below. Most of the methods are standard IS methods. All the non IS methods were internally standardized using protocol from NABL accredited drug and food testing laboratory (Fayaz et al., 2005).

2.5.3.1 Tested method used for each nutrient

Moisture%, total ash%, total fat%, and fiber% were tested using IS:7874 (Par-1)1975; protein% was tested using IS:7219:1973; carbohydrate was tested using IS 1656:2007; energy was tested using RATL/SOP/45; and iron, zinc, calcium, and magnesium were tested using RATL/SOP/404. Carbohydrates are determined using a formula: $100 - (M + A + C + P + F)$, where M is moisture content, A is Ash content, C is crude fiber content, P is Protein content, and F is fat content. For testing fiber, the crude fiber method was used. The quantity of protein is estimated by multiplying the nitrogen content with 6.25, nitrogen to protein conversion factor (Anitha et al., 2019a).

2.5.3.2 Quality control

The samples were analyzed in duplicate. The instruments used for the analysis are calibrated every 3 months and an intermediate check is also performed on the instruments. Data are also verified by Quality Assurance before the report is released. The analysis of metals in food was carried out by inductively coupled plasma optimal emission spectroscopy (ICP-OES). All reference standards were used for the metal analysis.

2.5.4 Data analysis

Hedonic scores of each recipe were documented and used to draw a radar plot, biplot, and ANOVA. A radar plot is a circular display of several different quantitative axes emerging like spokes on a wheel to create a unique shape of quantitative values. Each axis represents a quantity or value for a different categorical value for the variable. Values of different subcategories or variables are plotted along each axis and then connected up to form a shape depending on how the different variables/subcategories are related.

A biplot is a two-dimensional exploratory graph, used after conducting a Principal Component Analysis (PCA) to describe the relatedness of samples or data points in the first and second principal components (Ares et al., 2010; Xi et al., 2023). It overlays the different observations used in the analysis, with points that share the same attributes being positioned much closer to each other and vice versa. These biplots display vectors/arrows showing the variables that describe the patterns in the samples displayed.

3 Results

A total of 53 meal preparations were prepared using all the types of millets and seven meal preparations were made with polished white rice, which served as the control. Table 2 summarizes the quantity of raw ingredients used and the final quantity of the meal obtained. Table 3 summarizes the sensory evaluation and Table 4 summarizes the nutrient value of all the 60 meal preparations. Boiled grain, bisi belle bath, pulao, and pongal were each made from six types of millets and rice as the control. Ten variations of dosa, idli, and puttu were prepared each from nine types of millets and rice as the control.

3.1 Sensory evaluation of meal preparations

3.1.1 Boiled grain

Polished white rice scored the highest on all sensory attributes, with the exception of appearance, where barnyard millet scored relatively higher. Similarly, barnyard millet scored the most, similar or higher to polished white rice in appearance, taste, aroma and overall acceptance among all other millets. Proso millet scored relatively lower on all sensory attributes in comparison to all other millets (Supplementary Figure 1).

Supplementary Figure 2 shows that texture and aroma are strongly correlated attributes and polished white rice scored high on these sensory characteristics. Similarly, taste and appearance are strongly correlated attributes and barnyard millet scored high on them. The other millets are not explained by these attributes.

3.1.2 Dosa

Among all the millets, pearl millet scored relatively lower on all sensory attributes. Interestingly, yellow sorghum and foxtail millet scored relatively higher on all characteristics in comparison to other millet types and polished white rice (Supplementary Figure 3).

Appearance and texture are characteristics strongly correlated to each other. Yellow sorghum scored high on taste while little millet scored relatively lower on taste. Finger millet, kodo millet, white sorghum, and barnyard millet scored relatively lower on appearance and texture. Proso millet, browntop millet, and polished white rice cannot be explained by these attributes (Supplementary Figure 4).

3.1.3 Idli

The scoring for the millets considered for comparison here are very similar to that of polished white rice, all approaching a score of 8. Nevertheless, yellow sorghum scored relatively much lower among all the millets when compared to polished white rice (Supplementary Figure 5).

Barnyard millet and polished white rice both scored high on appearance and texture while little millet scored high on aroma and taste. Kodo and foxtail millets scored relatively low on aroma and taste while the rest of the millets were negatively correlated to all attributes considered (Supplementary Figure 6).

3.1.4 Bisi belle bath

Polished white rice as the control ingredient generally scored high on most characteristics, with an average score of 8 throughout. The other millet types scored similar to polished white rice. Foxtail millet scored slightly higher than all the other millets and polished white rice in terms of aroma. No great difference was observed in the scores of all the sensory characteristics for different types of millets used in bisi belle bath when compared to polished white rice, making these millet forms substitutable for rice (Supplementary Figure 7).

PC1 was mostly associated with a more desirable appearance, texture, and taste while PC2 was associated with greater aroma.

Generally, taste and texture were more associated with each other in the scoring of millets. Kodo millet was negatively associated with aroma while browntop millet was negatively associated with taste, texture and appearance. Barnyard millet, on the other hand, was positively associated with taste and texture (Supplementary Figure 8).

3.1.5 Pulao

The millets in this assessment generally scored similar to rice on all sensory attributes. Nevertheless, proso millet scored relatively much lower in comparison to all other millets. The score of barnyard millet was most similar to that of polished white rice (Supplementary Figure 9).

Taste, aroma, and texture were strongly correlated sensory attributes in this category. Polished white rice and little millet score high on appearance. Proso millet, browntop millet, kodo millet, and barnyard millet were not explained by these attributes (Supplementary Figure 10).

3.1.6 Puttu

The average values of scores for the different sensory characteristics were highly similar except for white sorghum. Barnyard millet puttu scored closer to rice puttu (control) in comparison to other millets. The scores of the other millets did not differ much compared to rice on almost all sensory characteristics, with the exception of texture, where polished white rice scored much higher and all the other millets were at least one score lower, with the exception of barnyard millet and finger millet (Supplementary Figure 11).

Finger millet and barnyard millet are highly associated with relatively higher scores of taste and appearance. Most other forms of millet tend to be negatively associated with all the characteristics assessed (Supplementary Figure 12).

3.1.7 Pongal

Most millets had scores for sensory characteristics that were much similar to polished white rice. However, little millet scored higher in appearance and taste in comparison to polished white rice. Compared to other millets, the scores for proso millet were farthest away from those of polished white rice (Supplementary Figure 13).

Appearance and aroma seem to be highly correlated among the millets while taste and texture are also highly correlated. Generally, foxtail millet and rice scored high on appearance and aroma while little millet scored high on taste and texture (Supplementary Figure 14).

There was no significant difference between polished white rice and barnyard millet in terms of overall sensory characteristics in boiled grain (Table 3). Other millets differed in overall sensory characteristics from rice significantly ($p < 0.005$). In dosa, no

TABLE 3 Sensory characteristics of millets compared to polished white rice in all the seven meal preparations.

Meal	Millet type	Appearance	Taste	Texture	Aroma	Overall
Boiled grain	Barnyard millet	7.55 ± 0.67^{c}	7.36 ± 0.74^{b}	6.94 ± 0.61^{bc}	7 ± 0.66^{bc}	7.24 ± 0.71^{bc}
	Browntop millet	6.94 ± 0.75^{ab}	6.82 ± 0.58^{ab}	6.48 ± 0.67^{b}	6.58 ± 0.9^{ab}	6.79 ± 0.6^{ab}
	Foxtail millet	6.88 ± 0.65^{ab}	6.55 ± 0.51^{a}	6.39 ± 0.86^{ab}	6.58 ± 0.87^{ab}	6.55 ± 0.67^{a}
	Kodo millet	6.82 ± 0.85^{a}	6.7 ± 0.81^{a}	$6.7 \pm 0.81b^{c}$	6.61 ± 0.79^{ab}	6.79 ± 0.74^{ab}
	Little millet	7.06 ± 0.66^{ab}	6.61 ± 0.83^{a}	6.58 ± 0.83^{b}	6.67 ± 0.85^{ab}	6.85 ± 0.71^{ab}
	Proso millet	6.64 ± 0.74^{a}	6.42 ± 0.94^{a}	5.85 ± 0.83^{a}	6.3 ± 0.95^{a}	6.39 ± 0.79^{a}
	Polished white rice	7.42 ± 1.03^{bc}	7.33 ± 0.78^{b}	7.18 ± 0.81^{c}	7.27 ± 0.63^{c}	7.42 ± 0.71^{c}
	p value	<0.005	<0.005	<0.005	<0.005	<0.005
Dosa	Barnyard millet	7.70 ± 0.73^{b}	7.67 ± 0.89^{b}	7.67 ± 0.89	7.70 ± 0.98^{b}	7.73 ± 0.88^{b}
	Browntop millet	7.42 ± 0.61^{ab}	7.52 ± 0.91^{ab}	7.52 ± 0.76	7.48 ± 0.87^{ab}	7.55 ± 0.79^{ab}
	Finger millet	7.58 ± 0.87^{ab}	7.61 ± 0.75^{ab}	7.58 ± 0.75	7.48 ± 0.8^{ab}	7.58 ± 0.75^{ab}
	Foxtail millet	7.82 ± 0.58^{b}	7.82 ± 0.73^{b}	7.64 ± 0.6	7.76 ± 0.83^{b}	7.82 ± 0.64^{b}
	Kodo millet	7.70 ± 0.85^{b}	7.73 ± 0.67^{b}	7.48 ± 0.67	7.55 ± 0.79^{ab}	7.64 ± 0.7^{b}
	Little millet	7.52 ± 0.87^{ab}	7.70 ± 0.88^{b}	7.48 ± 0.87	7.45 ± 0.9^{ab}	7.67 ± 0.78^{b}
	Pearl millet	7.06 ± 0.79^{a}	7.00 ± 0.79^{a}	7.21 ± 0.7	6.97 ± 0.85^{a}	7.00 ± 0.71^{a}
	Proso millet	7.64 ± 0.93^{ab}	7.39 ± 0.9^{ab}	7.39 ± 0.93	7.27 ± 1.01^{ab}	7.42 ± 0.87^{ab}
	Polished white rice	7.30 ± 0.73^{ab}	7.52 ± 0.76^{ab}	7.24 ± 0.75	7.33 ± 0.96^{ab}	7.45 ± 0.75^{ab}
	White sorghum	7.67 ± 0.74^{ab}	7.70 ± 0.77^{b}	7.64 ± 0.86	7.55 ± 0.79^{ab}	7.79 ± 0.74^{b}
	Yellow sorghum	7.67 ± 0.82^{ab}	7.91 ± 0.58^{b}	7.7 ± 0.64	7.82 ± 0.58^{b}	7.88 ± 0.48^{b}
	p value	<0.005	<0.005	0.065	<0.005	<0.005
Idli	Barnyard millet	7.94 ± 0.67^{c}	7.75 ± 0.67^{bc}	7.72 ± 0.77^{c}	7.66 ± 0.87^{c}	7.81 ± 0.64^{cd}
	Browntop millet	7.13 ± 0.61^{a}	7.22 ± 0.79^{ab}	7.09 ± 0.69^{ab}	6.84 ± 0.57^{ab}	7.13 ± 0.61^{ab}
	Finger millet	7.19 ± 0.93^{ab}	7.47 ± 0.8^{abc}	7.13 ± 0.66^{ab}	7.28 ± 0.73^{abc}	7.28 ± 0.73^{abc}
	Foxtail millet	7.53 ± 0.8^{abc}	7.59 ± 0.67^{abc}	7.47 ± 0.57^{bc}	7.44 ± 0.84^{bc}	7.56 ± 0.72^{bcd}
	Kodo millet	7.38 ± 0.79^{abc}	7.53 ± 0.67^{abc}	7.41 ± 0.71^{abc}	7.31 ± 0.82^{abc}	7.47 ± 0.67^{bcd}
	Little millet	7.78 ± 0.75^{bc}	7.88 ± 0.75^{c}	7.81 ± 0.78^{c}	7.69 ± 0.86^{c}	7.91 ± 0.82^{d}
	Pearl millet	7.06 ± 0.88^{a}	7.09 ± 0.96^{a}	7.09 ± 0.93^{ab}	6.75 ± 0.8^{a}	7.06 ± 0.8^{ab}
	Proso millet	7.25 ± 0.76^{ab}	7.06 ± 0.72^{a}	6.97 ± 0.59^{ab}	6.91 ± 0.73^{ab}	7.16 ± 0.63^{ab}
	Polished white rice	8 ± 0.88^{c}	8.03 ± 0.86^{c}	8 ± 0.8^{c}	7.75 ± 0.95^{c}	8.06 ± 0.8^{d}
	White sorghum	7.25 ± 0.84^{ab}	7.13 ± 0.83^{a}	7.03 ± 0.78^{ab}	6.97 ± 0.82^{ab}	7.19 ± 0.74^{ab}
	Yellow sorghum	7 ± 0.76^{a}	7 ± 0.72^{a}	6.84 ± 0.77^{a}	6.84 ± 0.72^{ab}	6.88 ± 0.71^{a}
	p value	<0.005	<0.005	<0.005	<0.005	<0.005
Bisi belle bath	Barnyard millet	8.03 ± 0.64	8.09 ± 0.52^{b}	7.73 ± 0.84^{ab}	7.94 ± 0.79	8 ± 0.61
	Browntop millet	7.76 ± 0.94	7.7 ± 0.53^{ab}	7.27 ± 0.91^{a}	7.82 ± 0.64	7.58 ± 0.5
	Foxtail millet	7.85 ± 0.67	7.61 ± 0.56^{a}	7.39 ± 0.66^{ab}	8.03 ± 0.64	7.64 ± 0.7
	Kodo millet	8.06 ± 0.79	7.7 ± 0.47^{ab}	7.48 ± 0.8^{ab}	7.7 ± 0.53	7.7 ± 0.53
	Little millet	7.88 ± 0.93	7.79 ± 0.99^{ab}	7.73 ± 1.21^{ab}	7.85 ± 0.8	7.76 ± 0.87
	Proso millet	8.15 ± 0.76	7.94 ± 0.56^{ab}	7.52 ± 0.62^{ab}	7.88 ± 0.55	7.67 ± 0.6
	Polished white rice	8.12 ± 0.86	8.03 ± 0.77^{ab}	8 ± 0.83^{b}	7.82 ± 0.77	7.94 ± 0.75
	p value	0.127	0.022	0.015	0.423	0.065
Pulao	Barnyard millet	7.33 ± 0.74^{ab}	7.42 ± 0.75^{abc}	7.21 ± 0.86^{bc}	7.52 ± 0.87^{bc}	7.42 ± 0.75^{b}
	Browntop millet	7.30 ± 0.47^{ab}	7.33 ± 0.65^{ab}	7.09 ± 0.52^{ab}	7.33 ± 0.65^{ab}	7.39 ± 0.5^{ab}
	Foxtail millet	7.73 ± 0.63^{bc}	7.82 ± 0.58^{bcd}	7.61 ± 0.56^{bcd}	7.88 ± 0.74^{c}	7.94 ± 0.56^{c}
	Kodo millet	7.24 ± 0.5^{a}	7.48 ± 0.67^{bc}	7.18 ± 0.64^{bc}	7.39 ± 0.61^{abc}	7.33 ± 0.6^{ab}
	Little millet	7.94 ± 0.7^{c}	7.91 ± 0.63^{cd}	7.70 ± 0.85^{cd}	7.91 ± 0.72^{c}	7.97 ± 0.64^{c}
	Proso millet	7.15 ± 0.62^{a}	6.97 ± 0.77^{a}	6.61 ± 0.7^{a}	6.91 ± 0.68^{a}	6.94 ± 0.66^{a}
	Polished white rice	7.97 ± 0.73^{c}	8.00 ± 0.75^{d}	7.88 ± 0.74^{d}	7.91 ± 0.8^{c}	8.00 ± 0.75^{c}
	p value	<0.005	<0.005	<0.005	<0.005	<0.005

(Continued)

TABLE 3 (Continued)

Meal	Millet type	Appearance	Taste	Texture	Aroma	Overall
Puttu	Barnyard millet	7.88 ± 0.65^{de}	7.85 ± 0.62^{cd}	7.36 ± 0.78^{bc}	7.55 ± 0.75^{bc}	7.82 ± 0.64^{d}
	Browntop millet	7.33 ± 0.6^{bc}	7.36 ± 0.6^{bc}	6.82 ± 0.68^{ab}	7.06 ± 0.83^{ab}	7.15 ± 0.71^{ab}
	Finger millet	8.03 ± 0.68^{e}	7.73 ± 0.67^{cd}	7.36 ± 0.7^{bc}	7.55 ± 0.79^{bc}	7.73 ± 0.63^{cd}
	Foxtail millet	7.55 ± 0.79^{bcde}	7.55 ± 0.51^{bc}	6.97 ± 0.53^{ab}	7.3 ± 0.64^{abc}	7.42 ± 0.56^{bcd}
	Kodo millet	7.15 ± 0.57^{ab}	7.12 ± 0.48^{ab}	7.09 ± 0.58^{b}	7 ± 0.43^{ab}	7 ± 0.43^{ab}
	Little millet	7.39 ± 0.7^{bcd}	7.36 ± 0.65^{bc}	6.97 ± 0.64^{ab}	7.09 ± 0.63^{ab}	7.39 ± 0.61^{bcd}
	Pearl millet	7.18 ± 0.64^{ab}	7.45 ± 0.71^{bc}	6.91 ± 0.84^{ab}	7.09 ± 0.88^{ab}	7.24 ± 0.87^{abc}
	Proso millet	7.18 ± 0.68^{ab}	7.12 ± 0.65^{ab}	6.82 ± 0.64^{ab}	7.09 ± 0.68^{ab}	7.15 ± 0.57^{ab}
	Polished white rice	7.82 ± 0.68^{cde}	8.06 ± 0.66^{d}	7.88 ± 0.74^{c}	7.76 ± 0.66^{c}	7.82 ± 0.68^{d}
	White sorghum	6.79 ± 0.86^{a}	6.85 ± 0.8^{a}	6.45 ± 0.87^{a}	6.76 ± 0.9^{a}	6.85 ± 0.83^{a}
	p value	<0.005	<0.005	<0.005	<0.005	<0.005
Pongal	Barnyard millet	7.7 ± 0.81^{abc}	7.7 ± 0.85^{abc}	7.67 ± 0.74^{bc}	7.61 ± 0.86^{ab}	7.7 ± 0.85^{ab}
	Browntop millet	7.18 ± 0.68^{a}	7.3 ± 0.81^{ab}	7.18 ± 0.88^{ab}	7.12 ± 0.65^{a}	7.36 ± 0.74^{a}
	Foxtail millet	7.79 ± 0.6^{bc}	7.79 ± 0.78^{bc}	7.67 ± 0.74^{bc}	7.79 ± 0.65^{b}	7.94 ± 0.61^{b}
	Kodo millet	7.3 ± 0.81^{ab}	7.58 ± 0.75^{abc}	7.21 ± 0.7^{ab}	7.24 ± 0.83^{a}	7.36 ± 0.82^{a}
	Little millet	8.12 ± 0.55^{c}	8.03 ± 0.53^{c}	7.88 ± 0.65^{c}	7.91 ± 0.58^{b}	8.06 ± 0.5^{b}
	Proso millet	7.24 ± 0.9^{a}	7.21 ± 0.89^{a}	6.94 ± 1^{a}	7.15 ± 0.83^{a}	7.18 ± 0.88^{a}
	Polished white rice	7.97 ± 0.68^{c}	7.91 ± 0.68^{c}	7.88 ± 0.6^{c}	7.94 ± 0.66^{b}	7.97 ± 0.64^{b}
	p value	<0.005	<0.005	<0.005	<0.005	<0.005

Different superscripts in the same column represent statistically significant differences at $p < 0.05$.

significant difference was observed in overall sensory characteristics between any of the millets and rice, except for pearl millet ($p < 0.005$). There was no significant difference between barnyard millet, kodo millet, and foxtail millet in overall sensory characteristics in idli ($p < 0.005$). There was a significant difference in appearance ($p = 0.127$) and aroma ($p = 0.423$) of bisi belle bath between millets and polished white rice, but no significant difference in terms of texture ($p = 0.015$) and taste ($p = 0.022$). At 10% confidence level, there was no significant difference in overall acceptance between millets and polished white rice in bisi belle bath (Table 3). There was no significant difference in the overall sensory characteristics of foxtail millet, and little millet, and polished white rice while all other millets are significantly different from polished white rice sensory characteristics in pulao ($p < 0.005$). No significant difference was observed between barnyard millet, finger millet, foxtail millet, little millet, and polished white rice in terms of overall sensory characteristics, and the sensory characteristics of all the other millets were significantly different from that of polished white rice in puttu ($p < 0.005$). While no significant difference was observed in the overall sensory characteristics of barnyard millet, foxtail millet, and little millet in pongal ($p < 0.005$), a significant difference was observed between browntop millet, proso millet, and kodo millet ($p < 0.005$).

3.2 Nutrient content in the meal preparations

Table 4 shows the nutrient value of all the meal preparations made from nine types of millets and polished white rice. Only select nutrients are discussed below. The nutrient value is for 100 grams of cooked meal. However, depending on one's consumption, this value can increase. For example, if the consumption is 300 then the value can be multiplied by 3 (Anitha et al., 2019b).

3.2.1 Boiled grain

A 100 g of boiled grain contains approximately 32 g of raw grain. Therefore, based on the amount consumed, the content of raw grain will either increase or decrease as will the nutrient value. Protein content was double in proso millet followed by browntop millet which has 1.8 times higher protein compared to polished white rice and foxtail millet which has 1.3 times higher protein compared to polished white rice (Figure 1). Other millets had equal or less protein content compared to polished white rice. Fiber content was 2–3.6 times higher in little millet compared to polished white rice. Magnesium content was 2.8 times more in foxtail millet and 9 times more in browntop millet compared to polished white rice.

3.2.2 Dosa

A 100 g of dosa contains 40 g of raw grain. One dosa weighed around 180 g. Considering that a normal person can eat a minimum of two dosas, the values provided in the tables can be multiplied around 3.5–4 times.

Browntop millet and proso millet dosa had 32 and 24% more protein, respectively compared to polished white rice dosa. Except for white sorghum and little millet, all the other millets had less iron content compared to polished white rice dosa. Foxtail millet, proso millet, and little millet dosa had more zinc (1.8–2.1 times) compared to polished white rice dosa. Calcium content in finger millet dosa was around 7.7 times higher than in the polished white rice dosa (Figure 2).

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TABLE 4 Nutrient content of millets in seven meal preparations compared to that in rice.

	Little millet	Barnyard millet	Foxtail millet	Proso millet	Kodo millet	Browntop millet	Pearl millet	White sorghum	Yellow sorghum	Finger millet	Polished white rice
Parameters	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Boiled grain											
Moisture (%)	73.5±0.43^{e}	74.0±0.18^{e}	72.3±0.21^{d}	65.5±0.05^{a}	73.8±0.11^{e}	68.2±0.26^{b}	n.a	n.a	n.a	n.a	70.7±0.34^{c}
Total ash (%)	0.1±0.01^{a}	0.5±0.01^{b}	0.5±0.01^{b}	0.7±0.01^{d}	0.6±0.01^{c}	1.1±0.02^{e}	n.a	n.a	n.a	n.a	0.5±0.02^{c}
Protein (%)	3.2±0.04^{b}	3.7±0.09^{c}	4.2±0.04^{d}	6.1±0.06^{f}	2.8±0.05^{a}	5.7±0.12^{e}	n.a	n.a	n.a	n.a	3.2±0.06^{b}
Total fat (%)	7.6±0.13^{c}	8.4±0.11^{d}	7.2±0.04^{b}	7.3±0.12^{b}	15.4±0.12^{e}	16.1±0.06^{f}	n.a	n.a	n.a	n.a	5.3±0.24^{a}
Fibre (%)	3.1±0.01^{e}	1.7±0.10^{c}	2.0±0.08^{d}	1.0±0.05^{b}	2.1±0.09^{d}	1.8±0.06^{c}	n.a	n.a	n.a	n.a	0.8±0.04^{a}
Carbohydrates (%)	12.5±0.53^{c}	11.7±0.45^{c}	13.9±0.22^{d}	19.5±0.06^{e}	5.4±0.06^{a}	7.1±0.48^{b}	n.a	n.a	n.a	n.a	19.5±0.58^{e}
Energy (Kcal/100 g)	119.6±0.86^{a}	125.2±0.28^{b}	124.3±1.20^{b}	150.9±0.36^{c}	157.9±1.50^{d}	181.9±0.78^{e}	n.a	n.a	n.a	n.a	124.0±0.18^{b}
Iron (mg/100 g)	0.3±0.02^{c}	0.3±0.01^{c}	0.5±0.01^{d}	0.1±0.00^{a}	0.6±0.03^{e}	0.1±0.00^{a}	n.a	n.a	n.a	n.a	0.2±0.01^{b}
Zinc (mg/100 g)	0.7±0.04^{d}	0.8±0.02^{e}	0.9±0.01^{e}	0.1±0.00^{a}	0.6±0.03^{c}	0.1±0.00^{a}	n.a	n.a	n.a	n.a	0.3±0.01^{b}
Calcium (mg/100 g)	2.8±0.02^{d}	1.7±0.03^{b}	1.3±0.02^{a}	2.5±0.05^{c}	5.3±0.10^{e}	2.3±0.06^{c}	n.a	n.a	n.a	n.a	2.3±0.04^{c}
Magnesium (mg/100 g)	14.2±0.12^{abc}	12.5±0.12^{ab}	8.8±0.08^{ab}	11.7±1.60^{ab}	23.4±0.22^{bc}	28.3±0.13^{c}	n.a	n.a	n.a	n.a	3.1±0.03^{a}
Dosa											
Moisture (%)	64.2±0.03^{f}	55.6±0.23^{a}	61.6±0.37^{c}	62.2±0.04^{de}	61.8±0.15^{cd}	62.1±0.04^{cde}	64.2±0.11^{f}	62.5±0.52^{e}	62.4±0.12^{e}	59.4±0.06^{b}	62.2±0.04^{de}
Total ash (%)	1.2±0.06^{bc}	1.3±0.06^{bc}	1.6±0.09^{c}	1.3±0.01^{bc}	0.5±0.06^{a}	1.1±0.02bc	1.1±0.08^{b}	1.1±0.01^{b}	1.3±0.11^{bc}	0.6±0.65^{a}	1.1±0.13^{bc}
Protein (%)	5.4±0.06^{fe}	4.8±0.11^{c}	6.1±0.11^{g}	6.4±0.35^{g}	4.9±0.06^{cd}	6.8±0.13^{h}	5.7±0.11^{f}	4.4±0.04^{b}	5.1±0.13^{cd}	4.1±0.04^{a}	5.1±0.08^{de}
Total fat (%)	1.6±0.06^{b}	2.8±0.05^{d}	2.8±0.05^{d}	1.3±0.01^{a}	1.6±0.08^{b}	2.0±0.04^{c}	1.8±0.06^{b}	2.2±0.07^{c}	2.2±0.06^{c}	4.2±0.25^{f}	3.7±0.12^{e}
Fibre (%)	1.3±0.04^{cd}	1.6±0.04^{ef}	1.9±0.04^{gh}	1.5±0.05^{de}	8.4±0.35^{i}	1.2±0.04^{c}	2.1±0.01^{h}	1.2±0.02^{c}	0.6±0.04^{b}	0.3±0.04^{a}	1.8±0.03^{fg}
Carbohydrates (%)	26.3±0.12^{c}	34.0±0.40^{g}	26.1±0.66^{bc}	27.4±0.23^{d}	22.9±0.42^{a}	26.8±0.11^{cd}	25.3±0.25^{b}	28.7±0.45^{e}	28.5±0.37^{e}	31.4±0.84^{f}	26.0±0.14^{bc}
Energy (Kcal/100 g)	125.1±0.76^{b}	159.6±0.62^{f}	136.1±1.50^{d}	129.2±0.30^{c}	110.9±1.96^{a}	134.8±0.29^{d}	123.5±1.00^{b}	134.1±2.05^{d}	136.3±0.42^{d}	160.2±0.93^{f}	140.3±0.82^{e}
Iron (mg/100 g)	0.9±0.01^{c}	0.1±0.00^{a}	0.1±0.01^{a}	0.1±0.00^{a}	0.5±0.62^{abc}	0.2±0.00$_{ab}$	0.2±0.00^{a}	0.9±0.00^{c}	0.1±0.00^{a}	0.1±0.00^{a}	0.6±0.01^{bc}
Zinc (mg/100 g)	0.9±0.01^{e}	0.1±0.00^{a}	0.9±0.05^{f}	0.9±0.01^{f}	0.8±0.01^{e}	0.1±0.00^{a}	0.9±0.01^{f}	0.6±0.00^{c}	0.7±0.00^{d}	0.7±0.01^{d}	0.4±0.00^{b}
Calcium (mg/100 g)	12.5±0.08^{d}	12.7±0.14^{d}	12.2±0.62^{cd}	10.6±0.01^{b}	13.6±0.25^{e}	10.7±0.06^{b}	13.0±0.36^{de}	11.6±0.00^{c}	12.7±0.31^{d}	70.9±0.83^{f}	9.2±0.17^{a}
Magnesium (mg/100 g)	0.9±0.01^{a}	20.1±0.28^{d}	18.9±0.24^{c}	20.3±0.64^{d}	21.4±0.30^{e}	21.5±0.35^{e}	19.5±0.66^{cd}	18.9±0.22^{c}	19.8±0.49^{cd}	20.2±0.31^{d}	14.1±0.05^{b}
Idli											
Moisture (%)	68.3±0.37^{a}	71.5±0.52^{bc}	72.5±0.46^{cd}	71.4±0.71^{bc}	72.4±0.44^{cd}	70.5±0.50^{b}	73.2±0.26^{d}	73.4±0.62^{d}	71.3±0.46^{bc}	71.6±0.52^{bc}	67.7±0.64^{a}

(Continued)

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TABLE 4 (Continued)

Parameters	Little millet Mean ± SD	Barnyard millet Mean ± SD	Foxtail millet Mean ± SD	Proso millet Mean ± SD	Kodo millet Mean ± SD	Browntop millet Mean ± SD	Pearl millet Mean ± SD	White sorghum Mean ± SD	Yellow sorghum Mean ± SD	Finger millet Mean ± SD	Polished white rice Mean ± SD
Total ash (%)	1.4±0.03^{ef}	1.3±0.04^{cd}	1.3±0.05^{c}	1.1±0.01^{a}	1.2±0.03^{ab}	1.2±0.02^{bc}	1.1±0.03^{a}	1.3±0.04^{de}	1.5±0.05^{f}	1.4±0.03^{e}	1.2±0.04^{ab}
Protein (%)	4.9±0.10^{bc}	4.5±0.10^{a}	4.5±0.02^{a}	5.2±0.04^{d}	4.4±0.07^{a}	5.1±0.04^{cd}	4.5±0.02^{a}	4.3±0.06^{a}	4.5±0.15^{a}	4.5±0.10^{a}	4.8±0.14^{b}
Total fat (%)	0.6±0.03^{c}	0.4±0.02^{b}	0.6±0.03^{c}	0.4±0.02^{b}	0.5±0.02^{b}	2.9±0.06^{e}	0.7±0.04^{c}	0.4±0.03^{b}	0.3±0.02^{a}	0.4±0.02^{b}	2.9±0.09^{d}
Fibre (%)	0.3±0.01^{a}	0.7±0.01^{c}	0.7±0.02^{c}	0.9±0.01^{e}	0.7±0.02^{c}	0.7±0.02^{c}	0.9±0.06^{d}	0.6±0.02^{b}	0.6±0.01^{b}	1.9±0.04^{f}	0.3±0.01^{a}
Carbohydrates (%)	24.5±0.32^{g}	21.6±0.47^{de}	20.4±0.44^{abcd}	21.1±0.53^{cde}	20.9±0.49^{bcde}	19.6±0.49^{a}	19.7±0.40^{ab}	19.9±0.66^{ab}	21.9±0.55^{e}	20.2±0.41^{abc}	23.2±0.64^{f}
Energy (Kcal/100 g)	108.1±1.22^{d}	94.9±1.63^{c}	92.5±1.22^{abc}	95.5±2.18^{c}	92.4±1.66^{abc}	111.6±1.29^{d}	90.4±1.04^{ab}	88.4±2.34^{a}	94.4±1.59^{bc}	90.0±1.96^{a}	122.3±2.51^{e}
Iron (mg/100 g)	0.9±0.01^{f}	0.7±0.01^{c}	0.6±0.00^{b}	0.7±0.02^{d}	0.8±0.01^{f}	0.7±0.01^{cd}	0.6±0.03^{b}	0.7±0.04^{cd}	0.8±0.02^{e}	1.4±0.02^{g}	0.3±0.01^{a}
Zinc (mg/100 g)	0.5±0.02^{d}	0.5±0.00^{c}	0.5±0.00^{e}	0.6±0.01^{f}	0.5±0.01^{c}	0.4±0.02^{b}	0.4±0.01^{b}	0.5±0.01^{d}	0.5±0.01^{c}	1.0±0.01^{g}	0.3±0.01^{a}
Calcium (mg/100 g)	7.5±0.31^{bc}	7.9±0.19^{bc}	8.2±0.05^{c}	8.6±0.46^{c}	39.9±0.93^{e}	8.4±0.48^{c}	8.3±0.34^{c}	6.7±0.30^{ab}	39.9±0.93^{e}	10.8±0.20^{d}	6.3±0.34^{a}
Magnesium (mg/100 g)	15.8±0.36^{bc}	16.4±0.57^{cd}	16.2±0.43^{bcd}	17.6±0.24^{e}	16.5±0.53^{cd}	16.8±0.36^{de}	16.3±0.49^{cd}	15.3±0.17^{b}	16.4±0.58^{cd}	21.3±0.04^{f}	9.6±0.22^{a}
Bisi belle bath											
Moisture (%)	73.2±1.07^{d}	71.1±0.72^{c}	70.6±0.44^{c}	64.8±0.45^{a}	70.8±0.63^{c}	67.9±0.45^{b}	n.a	n.a	n.a	n.a	73.2±0.97^{d}
Total ash (%)	1.3±0.04^{d}	1.1±0.06^{b}	1.3±0.04^{d}	1.3±0.04^{d}	1.2±0.05^{bc}	1.2±0.04^{cd}	n.a	n.a	n.a	n.a	0.9±0.02^{a}
Protein (%)	3.6±0.06^{d}	2.4±0.01^{a}	3.5±0.07^{d}	6.3±0.04^{f}	3.3±0.05^{c}	4.4±0.06^{e}	n.a	n.a	n.a	n.a	2.5±0.01^{b}
Total fat (%)	2.7±0.04^{b}	2.9±0.06^{c}	3.3±0.05^{e}	3.5±0.06^{f}	2.8±0.04^{bc}	3.1±0.05^{d}	n.a	n.a	n.a	n.a	2.2±0.04^{a}
Fibre (%)	6.4±0.20^{d}	3.1±0.04^{b}	1.8±0.04^{a}	7.8±0.38^{e}	4.3±0.13^{c}	11.1±0.11^{g}	n.a	n.a	n.a	n.a	8.7±0.21^{f}
Carbohydrates (%)	12.8±0.81^{a}	19.5±0.57^{c}	19.5±0.42^{c}	16.3±0.77^{b}	17.5±0.64^{b}	12.2±0.24^{a}	n.a	n.a	n.a	n.a	12.4±0.71^{a}
Energy (Kcal/100 g)	80.6±2.67^{b}	101.4±2.25^{c}	108.9±1.29^{d}	108.9±3.33^{d}	97.0±1.75^{c}	84.2±1.26^{b}	n.a	n.a	n.a	n.a	70.8±2.83^{a}
Iron (mg/100 g)	0.3±0.01^{a}	0.4±0.00^{b}	0.6±0.02^{c}	0.9±0.01^{e}	0.8±0.01^{d}	0.5±0.03^{b}	n.a	n.a	n.a	n.a	0.5±0.00^{c}
Zinc (mg/100 g)	0.3±0.00^{b}	0.5±0.00^{c}	0.5±0.00^{c}	0.8±0.03^{e}	0.4±0.00^{b}	0.6±0.03^{d}	n.a	n.a	n.a	n.a	0.3±0.00^{a}
Calcium (mg/100 g)	4.4±0.21^{a}	5.7±0.28^{c}	5.1±0.32^{bc}	8.9±0.42^{e}	7.1±0.23^{d}	4.7±0.20^{ab}	n.a	n.a	n.a	n.a	5.2±0.16^{bc}
Magnesium (mg/100 g)	8.5±0.18^{b}	12.7±0.40^{c}	9.3±0.44^{b}	22.3±1.98^{e}	16.0±0.59^{d}	9.8±0.82^{b}	n.a	n.a	n.a	n.a	5.5±0.09^{a}
Pulao											
Moisture (%)	74.9±0.15^{e}	73.9±0.21^{d}	70.6±0.53^{b}	73.4±0.42^{d}	72.0±0.08^{c}	73.9±0.29^{d}	n.a	n.a	n.a	n.a	65.0±0.16^{a}
Total ash (%)	1.3±0.13^{c}	1.2±0.04^{c}	1.2±0.04^{c}	1.3±0.09^{c}	0.8±0.06^{a}	1.2±0.04^{c}	n.a	n.a	n.a	n.a	1.0±0.01^{b}
Protein (%)	3.5±0.08^{b}	2.5±0.19^{a}	3.8±0.17^{b}	2.4±0.23^{a}	5.2±0.30^{d}	4.6±0.10^{c}	n.a	n.a	n.a	n.a	8.1±0.18^{e}

(Continued)

TABLE 4 (Continued)

	Little millet	Barnyard millet	Foxtail millet	Proso millet	Kodo millet	Browntop millet	Pearl millet	White sorghum	Yellow sorghum	Finger millet	Polished white rice
Parameters	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Total fat (%)	3.9±0.06[c]	4.6±0.14[d]	5.9±0.05[e]	3.5±0.06[b]	4.3±0.30[d]	2.6±0.10[a]	n.a	n.a	n.a	n.a	4.5±0.14[d]
Fibre (%)	0.4±0.01[d]	0.3±0.01[c]	0.6±0.03[e]	0.2±0.01[b]	0.3±0.01[c]	0.1±0.02[a]	n.a	n.a	n.a	n.a	0.4±0.03[d]
Carbohydrates (%)	15.9±0.41[a]	17.5±0.06[b]	17.9±0.35[b]	19.3±0.69[c]	17.3±0.59[b]	17.6±0.03[b]	n.a	n.a	n.a	n.a	21.0±0.18[d]
Energy (Kcal/100 g)	101.6±0.66[a]	109.1±1.52[c]	127.0±1.58[e]	105.3±2.15[b]	115.7±1.57[d]	99.6±1.28[a]	n.a	n.a	n.a	n.a	140.2±1.20[f]
Iron (mg/100 g)	0.5±0.01[f]	0.5±0.01[f]	0.4±0.00[d]	0.4±0.00[c]	0.3±0.00[b]	0.2±0.00[a]	n.a	n.a	n.a	n.a	0.4±0.03[e]
Zinc (mg/100 g)	0.4±0.00[f]	0.7±0.00[g]	0.3±0.00[e]	0.2±0.00[c]	0.1±0.00[b]	0.1±0.00[a]	n.a	n.a	n.a	n.a	0.3±0.00[d]
Calcium (mg/100 g)	17.7±0.12[d]	17.3±0.05[d]	16.5±0.09[d]	5.5±0.01[b]	8.2±0.24[c]	3.1±0.16[a]	n.a	n.a	n.a	n.a	28.7±1.65[e]
Magnesium (mg/100 g)	17.8±0.19[d]	19.6±0.62[e]	13.4±0.00[c]	5.6±0.12[b]	6.0±0.04[b]	4.7±0.11[a]	n.a	n.a	n.a	n.a	13.2±0.35[c]
Puttu											
Moisture (%)	42.2±0.28[b]	40.9±0.21[a]	43.5±0.57[c]	40.9±0.39[a]	40.4±0.64[a]	40.8±0.42[a]	45.0±0.30[d]	41.9±0.14[b]	n.a	47.0±0.54[e]	47.6±0.38[e]
Total ash (%)	1.6±0.21[cd]	1.3±0.14[bc]	0.26±0.06[a]	1.6±0.14[de]	1.2±0.06[b]	1.9±0.17[f]	1.7±0.10[fde]	1.9±0.05[f]	n.a	1.9±0.11[ef]	1.2±0.14[b]
Protein (%)	5.5±0.30[bc]	6.1±0.23[c]	7.3±0.46[d]	9.1±0.25[e]	5.4±0.31b	9.3±0.25[e]	7.0±0.10[d]	5.6±0.28[bc]	n.a	4.4±0.06[a]	4.4±0.15[a]
Total fat (%)	12.4±0.59[e]	9.3±0.25[bc]	10.3±0.49[cd]	11.1±0.18[d]	6.6±0.38a	19.4±0.57[g]	14.8±0.23[f]	33.8±0.40[h]	n.a	37.4±0.81[i]	9.2±0.34[b]
Fibre (%)	1.6±0.17[ab]	5.7±0.42[f]	1.4±0.43[a]	4.1±0.22[cde]	2.0±0.08[b]	3.5±0.25[c]	3.7±0.21[cd]	4.6±0.30[e]	n.a	5.7±0.21[f]	4.3±0.28[de]
Carbohydrates (%)	36.7±0.22[f]	36.7±0.13[f]	37.3±2.01[f]	33.2±0.13[e]	44.4±1.19[g]	25.0±0.01[c]	27.8±0.54[d]	12.1±0.57[b]	n.a	3.6±1.61[a]	33.1±0.90[e]
Energy (Kcal/100 g)	253.3±5.28[d]	229.2±2.47[b]	243.3±1.22[c]	242.6±2.02[c]	230.0±0.18[b]	284.8±5.76[e]	247.7±0.42[cd]	349.5±2.41[g]	n.a	339.3±7.[f]	209.1±5.51[a]
Iron (mg/100 g)	0.8±0.04[b]	1±0.03[c]	1.6±0.03[f]	1.5±0.02[e]	1.1±0.01[c]	1.7±0.02[g]	1.2±0.01[d]	0.9±0.04[b]	n.a	1.5±0.03[e]	0.4±0.01[a]
Zinc (mg/100 g)	1.1±0.02[de]	1.4±0.01[f]	1.6±0.04[gh]	1.5±0.06[g]	1.0±0.04[d]	1.6±0.03[h]	1.1±0.03[e]	0.7±0.03[b]	n.a	0.8±0.05[c]	0.5±0.02[a]
Calcium (mg/100 g)	4.6±0.06[f]	4.1±0.02[e]	4.9±0.04[g]	1.7±0.04[b]	4.3±0.05[e]	3.8±0.04[d]	2.4±0.03[c]	2.4±0.04[c]	n.a	59.4±0.15[h]	1.3±0.03[a]
Magnesium (mg/100 g)	24.4±0.18[d]	34.2±0.18[g]	28.6±0.07[f]	28.1±0.07[e]	28.4±0.15[f]	45.7±0.15[i]	19.3±0.18[b]	20.0±0.12[c]	n.a	36.7±0.14[h]	3.5±0.03[a]
Pongal											
Moisture (%)	70.6±0.49[a]	70.4±0.25[a]	70.7±0.49[a]	70.7±0.13[a]	70.2±0.18[a]	70.6±0.06[a]	n.a	n.a	n.a	n.a	71.7±0.18[b]
Total ash (%)	0.5±0.01[b]	1.3±0.14[e]	0.8±0.07[c]	0.1±0.02[a]	0.5±0.02[b]	2.0±0.04[f]	n.a	n.a	n.a	n.a	0.9±0.02[d]
Protein (%)	3.2±0.16[a]	3.4±0.18[a]	3.9±0.11[b]	4.9±0.18[c]	3.2±0.17[a]	5.1±0.18[c]	n.a	n.a	n.a	n.a	3.8±0.03[b]
Total fat (%)	13.0±0.03[c]	16.0±0.04[e]	15.2±0.13[d]	10.6±0.27[a]	12.3±0.22[b]	15.2±0.26[d]	n.a	n.a	n.a	n.a	18.1±0.22[f]
Fibre (%)	0.2±0.03[a]	1.2±0.06[d]	1.1±0.04[d]	0.2±0.05[a]	0.1±0.03[a]	0.7±0.06[c]	n.a	n.a	n.a	n.a	0.6±0.03[b]

(Continued)

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TABLE 4 (Continued)

	Little millet	Barnyard millet	Foxtail millet	Proso millet	Kodo millet	Browntop millet	Pearl millet	White sorghum	Yellow sorghum	Finger millet	Polished white rice
Parameters	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Carbohydrates (%)	12.6±0.25^{d}	7.7±0.40^{c}	8.6±0.02^{c}	13.5±0.39^{de}	13.7±0.52^{e}	6.4±0.60^{b}	n.a	n.a	n.a	n.a	4.9±0.33^{a}
Energy (Kcal/100 g)	165.5±2.15^{b}	175.0±0.40^{d}	173.3±0.79^{d}	154.6±1.55^{a}	163.4±0.62^{b}	169.2±0.74^{c}	n.a	n.a	n.a	n.a	184.6±0.63^{e}
Iron (mg/100 g)	0.3±0.01^{c}	0.3±0.01^{c}	0.5±0.01^{f}	0.3±0.00^{d}	0.2±0.00^{b}	0.4±0.00^{e}	n.a	n.a	n.a	n.a	0.2±0.00^{a}
Zinc (mg/100 g)	0.2±0.00^{b}	0.2±0.00^{c}	2.8±0.01^{f}	0.3±0.00^{d}	0.2±0.00^{b}	0.3±0.00^{e}	n.a	n.a	n.a	n.a	0.2±0.00^{a}
Calcium (mg/100 g)	12.2±0.02^{c}	5.6±0.02^{ab}	54.8±1.80^{d}	4.4±0.15^{a}	6.4±0.19^{b}	6.1±0.10^{ab}	n.a	n.a	n.a	n.a	6.4±0.25^{b}
Magnesium (mg/100 g)	12.8±0.28^{cd}	13.9±0.05^{d}	112.0±2.98^{f}	10.9±0.28^{bc}	8.7±0.22^{ab}	17.0±0.64^{e}	n.a	n.a	n.a	n.a	7.7±0.24^{a}

Different superscripts in the same row indicate the statistically significant ($p < 0.05$) difference among samples. n.a, not analyzed.

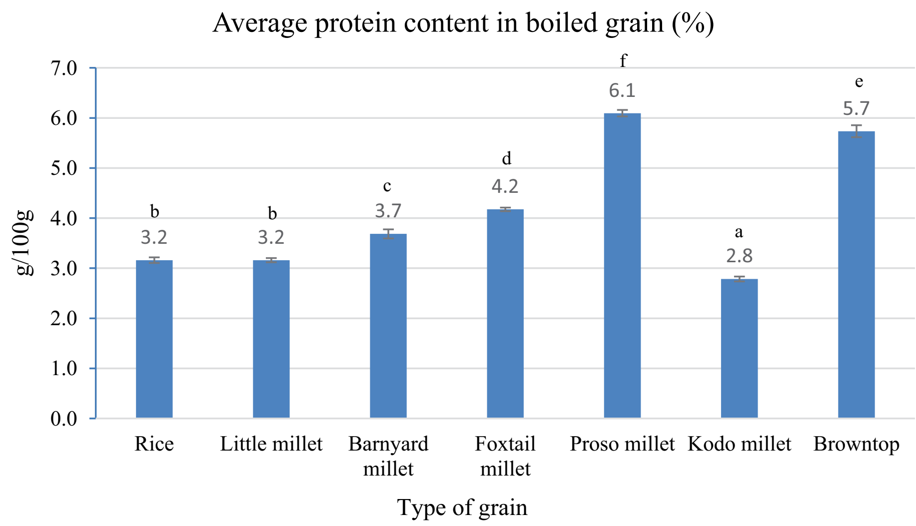

FIGURE 1
Average protein content in boiled grains. Different alphabets on top of each bar indicate the statistically significant ($p < 0.05$) difference among samples.

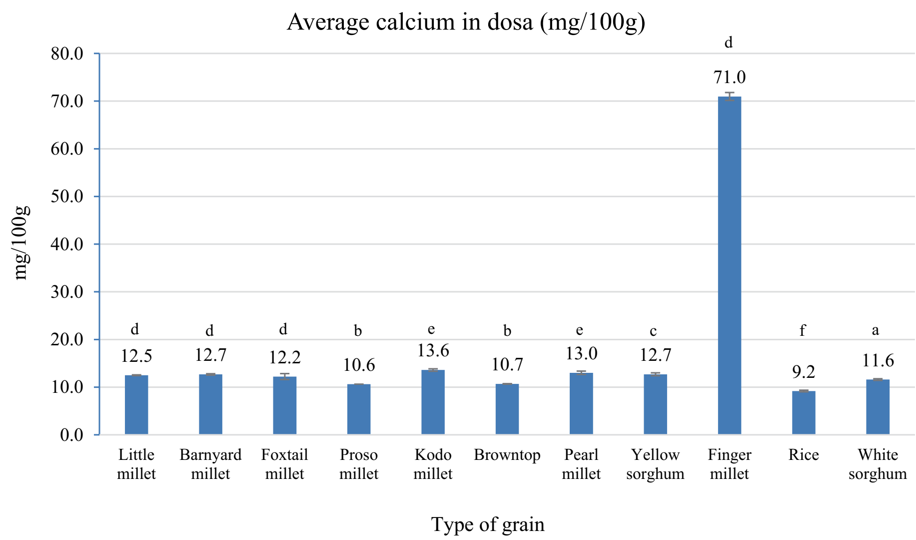

FIGURE 2
Average calcium content in dosa prepared with various millets. Different alphabet letters in the bar indicate the statistically significant ($p < 0.05$) difference among samples.

3.2.3 Idli

Each idli weighed 40 g. Therefore, 100 g comprised 2.5 idlis. The normal intake of idlis at the household level varies between 4 and 6. Therefore, the nutrient content will vary with consumption.

The fiber content in finger millet idli was 6.5 times higher (1.89 ± 0.04/100 g of idli) compared to polished white rice idli (0.29 ± 0.01/100 g of idli). The iron content in finger millet idli was 4.5 times higher (1.36 ± 0.02 mg/100 g of idli) compared to that in polished white rice idli (0.29 ± 0.01 mg/100 g of idli). Calcium content was also high in finger millet idli compared to polished white rice idli.

3.2.4 Bisi belle bath

A 100 g of cooked bisi belle bath had 10 g of millet or polished white rice. Proso millet bisi belle bath had nutrient levels higher than rice bisi belle bath and bisi belle bath made of other millets. Protein content was high in the proso millet meal (6.28 ± 0.04/100 g of bisi belle bath) which was 2.4 times higher than in polished white rice bisi belle bath. Browntop millet had 1.7 times higher protein compared to polished white rice bisi belle bath. Iron content was 1.8 times higher in proso millet bisi belle bath compared to the polished white rice counterpart. The zinc content in proso millet bisi belle bath was 2.6 times higher compared to that in polished white rice bisi belle bath. The magnesium content in proso millet bisi belle bath was 4 times higher than that in polished white rice bisi belle bath.

Fiber content was 2.7% higher in browntop millet bisi belle bath compared to that in polished white rice bisi belle bath. Zinc content was double in browntop millet bisi belle bath compared to that in polished white rice bisi belle bath. Magnesium content in the browntop millet bisi belle bath was 1.7 times higher compared to that in polished white rice bisi belle bath.

3.2.5 Pulao

In pulao, nutrient value comes from millet and vegetables. 100 g of cooked pulao contains approximately 21.7 g of raw millet and 10 g of vegetables. In pulao, rice (control meal) had higher fiber content compared to any millet. Vegetables added to pulao and bisi belle bath contributed to the fiber content compared to other meal preparations. In terms of other nutrients, there was no significant difference between pulao made from millets and that made from polished white rice.

3.2.6 Puttu

It is important to note the nutrient value comes not only from millet but also from other ingredients. For example, 100 g of cooked puttu contains approximately 44 g of raw millet and 22 g of uncooked coconut.

Iron, magnesium, and zinc content were high in all the millet puttu meal preparations compared to the polished white rice meal. Magnesium content was at least 5 times higher in pearl millet puttu, 13 times more in browntop millet puttu, and 10.5 times higher in finger millet puttu, than that in polished white rice puttu. Calcium content was highest in finger millet (59.35 ± 0.15 mg/100 g of puttu). This can be further increased depending on how much is consumed. Protein content was equal to or higher in all type of millet puttu. Browntop millet and proso millet had double the amount of protein compared to the polished white rice-based meal (Figure 3).

3.2.7 Pongal

Pongal contained 50% millet and 50% pulses. A 100 g of cooked pongal has 10 g of millet and 10 g of pulses. Therefore, increasing the content of grain-based on consumption size will further increase the nutrient content of the meal. For example, if the amount consumed is 300 g, then the nutrient content is 3 times more than what is presented in the table. Magnesium, iron, and zinc content were higher in millets pongal than in the polished white rice pongal. Protein content was 1.3 times higher in browntop millet pongal and 1.2 times more in proso millet pongal than in the polished white rice pongal. Protein content in the other millets was either less or equal to that in polished white rice.

3.3 Limitations of the study

Following were the limitations of the study: (1) The millet used in the meal preparations were not selected based on their variety or high nutritional value; so the nutrition levels in the final meal could vary and may be higher. (2) Only seven meal preparations were selected for testing due to funding constraints. (3) Major staples like wheat and maize as well as wholegrain wheat and wholegrain rice were not used to compare the nutritional value.

4 Discussion and conclusion

The selected meals are popular in India and Sri Lanka and are typically consumed as breakfast (dosa, idli, puttu, and pongal) or as lunch/dinner (boiled grain, bisi belle bath, and pulao). In the current study, the final quantity of the cooked meal is not equal for each millet even within the same type of meal (Table 2). This could be due to the difference in physicochemical properties of each millet, especially as the hydration capacity and swelling capacity of the millet normally vary depending on the type of millet (Reddy et al., 2019).

The sensory quality of all the millets selected for the meal preparation was almost similar to that of polished white rice. However, their nutrient values differed.

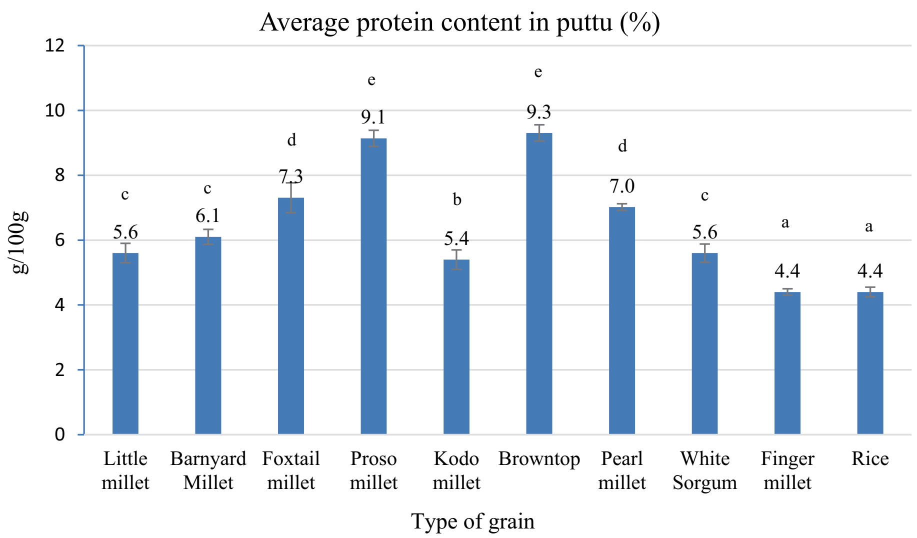

FIGURE 3
Average protein content in puttu made with various millets. Different alphabet letters in the bar indicate the statistically significant ($p < 0.05$) difference among samples.

All nine types of millets were suitable for puttu, dosa, and idli, mainly so because these meal preparations are based on a coarse powder form (puttu) or batter form (idli and dosa) and not the full grain. When finger millet was used in idli, dosa, and puttu, the calcium content in puttu was greater compared to that in polished white rice or other millets ($p < 0.005$). This is in line with the other studies, especially finger millet dosa which had 70.9 mg/100 g calcium and is similar to a previous study reported, where dosa had 83.8 mg/100 g calcium (Kazi and Auti, 2017). However, the calcium content of finger millet idli is less in the current study compared to the previous study (Kazi and Auti, 2017). This could be due to the amount of raw material used in the previous study (Kazi and Auti, 2017) not being the same as the current study. Proso millet and browntop millet puttu had more protein compared to other millet puttu. Although, there is a slight difference in sensory score, all the millets except white sorghum, scored between 7 and 8 points which indicates that all the millets and polished white rice-based puttu were scored similarly (7 = liked moderately). This result led to the assumption that puttu with either millet or polished white rice is accepted but scored 7, as puttu is not a staple food of the region where the sensory evaluation is conducted. Therefore, in this case, it could be wise to choose finger millet for preparing puttu as it provides more calcium, than other millets and polished white rice.

The fiber content of the millet-based meals was high compared to the polished white rice-based meals ($p < 0.005$). However, the fiber content of the millet-based meals varied in levels. Little millet in boiled grain form had the highest fiber content of 3.1/100 g compared to 0.8/100 g in polished white rice-based boiled grain. Finger millet and barnyard millet-based puttu had the highest fiber content of 5.7/100 g compared to 4.3/100 g in polished white rice-based puttu. The difference in the levels of fiber content in a meal, made with different millets, could be due to the other ingredients in the meal impacting the overall fiber content of the meal. In addition, the hydration capacity of each type of millet is generally different (Reddy et al., 2019), which could affect the amount of fiber and other nutrients per 100 g of a cooked meal. Having high fiber in the meal is advantageous to health. Consuming refined food will lead to less fiber intake. Millets have a high satiety value compared to polished white rice and other major staples mainly due to the high fiber content (Cisse et al., 2018). This same property helps in reducing the blood glucose response as it delays gastric emptying time and therefore, glucose is released slowly into the blood (Hayes et al., 2020).

Among all the meals, puttu prepared with millets provided more energy ranging from 229.2 to 349.5 Kcal, and more than polished white rice which provided 209.1 Kcal (Table 4). Bisi belle bath is the meal that provided the least amount of energy ranging from 80.6 to 108.9 Kcal for different types of millet compared to 70.8 Kcal for polished white rice-based bisi belle bath. This could be due to the reason that bisi belle bath mainly contains vegetables and pulses apart from millet and the amount of millet or polished white rice used for 100 g of bisi belle bath was only 10 g. Whereas in puttu, there was 44 g of raw millet and 22 g of coconut therefore possibly increasing the amount of energy in puttu.

Finger millet's overall sensory score was close to that of polished white rice, and in most of the meal preparations tested it was also nutritionally superior due to its high calcium content. The Indian Food Composition table also shows confirms that finger millet has high calcium content compared to polished white rice and other millet (Longvah et al., 2017). Hence it is a good substitute for rice in puttu, idli, and dosa. It is to be noted if high calcium finger millet variety is used then the dietary calcium can be further improved.

Since proso millet had high nutrient value and the same sensory score as polished white rice in bisi belle bath, the millet is a suitable for preparing bisi belle bath.

While most of the selected millets were suited to various meal that are traditionally prepared with rice, it is clear that pearl millet, finger millet, and sorghum can be used only in some recipes where it is used in powder (flour) or batter form due to a number of factors, including the texture/consistency, taste, color/appearance, size and cooking time. It is noted that traditionally, pearl millet and finger millet are used in porridge, malted beverages, or flat bread in the powder form (Tripathi et al., 2023) hence powder form could be a highly convenient form of usage of these millets.

It is interesting to note that most of the proso millet and browntop millet-based meal preparations had high protein content compared to the polished white rice-based meals. Considering that the sensory quality of meals prepared with most millets is very similar to meals prepared with the polished white rice-based meals, it is an opportunity to select a meal based on nutrient value. This study was conducted using locally available varieties of millets. It is recognized that millets' nutritional value varies significantly based on the type and variety of the millet (Longvah et al., 2017; Anitha et al., 2024a), therefore, it is important to select by the specific type and variety when the focus is on enhancing dietary nutritional quality.

In conclusion, it is clear that the sensory characteristics of the millets selected as appropriate for all the seven meal preparations are close to polished white rice; however, nutritional values varied based on the type of millet and type of meal. For example, finger millet-based preparations had high calcium content. In general, millet-based meals had higher fiber, protein, energy, and magnesium content compared to the same meals prepared with polished white rice. These nutrients are important in all stages of the human life cycle. Also considering the high levels of malnutrition and need for food system transformation to cope with climate change and other challenges, efforts to drive consumer demand and productivity of millets to diversify the staples will help improve the dietary nutrient intake and planetary health.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by M. S. Ramaiah University of Applied Sciences, Institutional ethical committee (MSRMC/EC/AP-02/04-2019). The studies were conducted in accordance with the local legislation and institutional requirements.

Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

SA: Conceptualization, Data curation, Methodology, Supervision, Validation, Writing – original draft. PA: Investigation, Supervision, Writing – review & editing. NCP: Investigation, Methodology, Writing – review & editing. NS: Investigation, Methodology, Validation, Writing – review & editing. MDSA: Data curation, Formal Analysis, Validation, Writing – review & editing. SA: Validation, Writing – review & editing. SK: Investigation, Methodology, Validation, Writing – review & editing. SP: Investigation, Methodology, Validation, Writing – review & editing. SS: Investigation, Methodology, Validation, Writing – review & editing. KNCM: Methodology, Writing – review & editing. RB: Data curation, Formal Analysis, Writing – review & editing. SU: Validation, Writing – original draft. JK-P: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1331260/full#supplementary-material

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