frontiers | Frontiers in Sustainable Food Systems

TYPE Systematic Review
PUBLISHED 22 February 2024
DOI 10.3389/fsufs.2024.1324046

OPEN ACCESS

EDITED BY
Veda Krishnan,
Indian Agricultural Research Institute, India

REVIEWED BY
Mohammad Ehsan Dulloo,
Alliance Bioversity International and CIAT,
France
Debabrata Panda,
Central University of Orissa, Koraput, India

*CORRESPONDENCE
Seetha Anitha
✉ dr.anithaseetha@gmail.com
Ananthan Rajendran
✉ Ananthan.nin@gmail.com

RECEIVED 18 October 2023
ACCEPTED 07 February 2024
PUBLISHED 22 February 2024

CITATION
Anitha S, Rajendran A, Botha R, Baruah C, Mer P, Sebastian J, Upadhyay S and Kane-Potaka J (2024) Variation in the nutrient content of different genotypes and varieties of millets, studied globally: a systematic review.
Front. Sustain. Food Syst. 8:1324046.
doi: 10.3389/fsufs.2024.1324046

Variation in the nutrient content of different genotypes and varieties of millets, studied globally: a systematic review

Seetha Anitha[1]*, Ananthan Rajendran[2]*, Rosemary Botha[3], Chandrama Baruah[2], Pooja Mer[2], Julia Sebastian[2], Shweta Upadhyay[1] and Joanna Kane-Potaka[1,4]

[1]Asia-Pacific Association of Agricultural Research Institutions, Bangkok, Thailand, [2]National Institute of Nutrition, Hyderabad, India, [3]One Acre Fund, Kigali, Rwanda, [4]International Rice Research Institute, Los Banõs, Philippines

This study was conducted to understand the variation in the nutrient contents of different types of millets by collecting data from published scientific journals and collating it by variety. The data is analyzed as a whole and as a subset, where it is clearly categorized into a released variety or genotype/accession. Calcium level was consistently high in finger millet and teff regardless of varieties at 331.29 ± 10 mg/100 g and 183.41 ± 29 mg/100 g, respectively. Iron content was highest for finger millet at 12.21 ± 13.69 mg/100 g followed by teff at 11.09 ± 8.35 mg/100 g. Pearl millet contained the highest zinc content of 8.73 ± 11.55 mg/100 g. Protein content was highest in job's tears at 12.66 g/100 g followed by proso millet at 12.42 ± 1.99 g/100 g and barnyard millet with 12.05 ± 1.77 g/100 g. Some millets showed consistently low or consistently high levels of specific nutrients, while others had such wide variation that they could not be characterized as high or low for that particular nutrient. There is a huge variation in the nutrient content of each type of millet regardless of the released variety or genotype. In the interest of improving dietary nutrients, there is a need to have nutrition programs and product development based on selected high nutrient varieties of the millet, which requires attention from researchers and government and changes in research, policy, and awareness among the public and private sectors.

KEYWORDS

millet nutrient, millet variety, millet type, minor millet, major millet

1 Introduction

Packed with nutrients, millets (including sorghum) are traditional crops widely cultivated in Africa and Asia (Poole and Kane-Potaka, 2020). They are considered the most ancient-domesticated crop used for human food and animal feed (Basahy, 1996). Owing to climate change due to global warming, there is great demand for crops with high stress and drought tolerance while at the same time meeting the increasing demand for highly nutritious foods. With the global population ever-increasing, the threat of food and nutrition insecurity is growing alarmingly, especially in Africa and Asia. Potentially, the greatest challenge faced by the world today is attaining food sufficiency and accessibility through dietary diversification (Kennedy, 2002). Current global food systems are largely dependent on a few major cereal crops, namely rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.), which, however, have a considerably lower amount of important micro and macronutrients (Cakmak and Kutman, 2018; Willett et al., 2019) compared to millets and other indigenous crops. Millets are relatively more tolerant of climate change, pests, and diseases, and require low maintenance costs in terms of water, fertilizer, pesticides, etc., thus proving to be excellent crops for sustainable food and nutrition security (Otieno et al., 2020). Given their high levels of important nutrients, millets can be exploited to play a major role in solving world hunger and malnutrition (Barikmo et al., 2004).

Of the different types of millets grown globally (Vetriventhan et al., 2020), Job's tears, teff, fonio, little millet, kodo millet, pearl millet, barnyard millet, browntop millet, proso millet, finger millet, foxtail millet, and sorghum are the most commonly grown. According to FAOSTAT (2023), global production of millets (except teff) stood at 92.11 million tons in 2021, taking the sixth position in global cereal production. Africa is the largest producer of millets, accounting for 42.39% of global production, followed by Asia (27.88%), America (26%), and Europe (1.88%).

Millets are considered nutritionally superior or equal to major whole grains like rice and wheat (Kumari et al., 2016). They are commonly recognized as a good source of carbohydrates, protein, dietary fiber, vitamins, minerals, and essential fatty acids (Obilana, 2003; Ragaee et al., 2006; Longvah et al., 2017). They are known to contain a good amount of slowly digestible starch, which is resistant to enzymatic hydrolysis and prolongs the digestion and absorption period of carbohydrates in the small intestine. This helps in regulating the blood glucose level, which is beneficial to people with diabetes and hyperlipidemia (Anitha et al., 2022, 2024). Millets are also believed to contain a good amount of protein (7–12%) with a better amino acid profile that can complement legumes (Anitha et al., 2019).

According to the World Health Organization (WHO), micronutrient deficiencies (MNDs) due to low dietary consumption of essential minerals like calcium, iron, and zinc affect one-half of the global population, especially children and women in developing countries (FAO/WHO, 2021). Millets are reported to be good sources of minerals like calcium, zinc, iron, magnesium, and phosphorus, which can improve the micronutrient status of the general population.

However, as there are hundreds of publications on the macro and micronutrient levels of each type of millet, there is scope for confusion as publications present different values based on the type, variety, geographical region, and the method used to assess them. In addition, millets also contain antinutrients like phytic acid, tannins, and polyphenols that hinder the bioaccessibility of minerals (Cámara and Amaro, 2003). These antinutrients bind with dietary elements like zinc, calcium, and iron and make them unavailable for absorption in the body (García-Casal et al., 1998). However, various processing methods help to reduce the phytate content of millets (Anitha et al., 2021; Sheethal et al., 2022).

Over the past decade, emphasis has been placed on the biofortification of millets to increase bioavailable iron and zinc. This, however, requires millet varieties containing high mineral levels (Krishnan and Meera, 2017), which calls for breeding programs to enhance the mineral content while maintaining or enhancing yield and other qualities.

As this data collection and analysis shows, each type of millet has several varieties that vary in their micro- and macronutrient composition. Official national food composition tables contain data on the nutrition content of different types of millets commonly available in the market. This data is useful for knowing the typical average nutrient consumption from a specific food. However, information on the nutrient composition of all types of millet by its range of variety is not widely available or has not been collated so far. Indeed, a lot of scientific publications do contain information on the nutrient composition of millets, with or without variety-specific information, but it is spread over a wide range of journal articles published over several decades and has not been collated and therefore not easily accessible. More commonly available are a range of simple millet nutrient tables that are typically used by industry, consumers, government, and media for various purposes. They are easily accessible and easy to understand and use. However, this data may lack sufficient detail to be scientifically credible. To be able to include any type of millet in a nutrition intervention, it is essential to know nutrient content by variety. Keeping that context in mind, this systematic review was designed to collate existing information on the nutrient content of millets by variety and type.

1.1 Objective

The objective of this review is to determine the variation in the major nutritional composition of the different types of millets by its wide range of varieties.

2 Materials and methods

2.1 Information sources

The search selected all relevant research studies conducted from the year 1950 to the second quarter of the year 2023 using a set of criteria and keywords (Supplementary Table S1). Only studies published in the English language were considered. Scopus, Web of Science, Research Gate, Science Direct, PubMed, and Google Scholar were used to find studies relevant to the research questions. The downloaded papers were used only if they addressed the research questions. If the abstract was suitable, the open-access article was downloaded; otherwise, the full paper was requested by contacting the authors, the journal editors, or universities that have library facilities and subscriptions to the journal.

2.2 Inclusion criteria

The following criteria were used for inclusion of papers in the analysis: 1. Research papers that evaluated the nutrient content of one or more of the 12 main types of millets; 2. Research on a type of millet evaluated in one or several geographical locations; 3. Studies that had information on any one or all of the nutrient contents (moisture, ash, protein, fat, fiber, carbohydrate, iron, zinc, calcium, magnesium) of any type of millet. 4. Studies that had information on any one or all of the nutrient contents (moisture, ash, protein, fat, fiber, carbohydrate, iron, zinc, calcium, magnesium) of genotype or variety of any type of millet (released varieties including those available in the local market); 5. Nutritional information on millets available in food composition tables from different countries around the world; and 6. Peer-reviewed scientific journal articles and full Ph.D. or M.Sc. theses submitted to universities, if available online.

2.3 Exclusion criteria

Papers were excluded if they were review articles, full information could not be accessed, or if the methodology was identified as weak.

2.4 Data extraction and analysis

A total of 90 full-length research papers, book chapters, and food composition tables were selected for the study. Using the PRISMA checklist for systematic review data collection, extraction, and analysis were conducted. The data on the moisture, ash, protein, fat, fiber, carbohydrate, iron, zinc, calcium, and magnesium content of various types of millet was extracted. Nutrient information was recorded in an Excel spreadsheet, along with information on methods of determination (Supplementary Table S2), unit of measurement, variety, and country. All the collected data was converted to a uniform unit of measurement, i.e., g/100 g for macronutrients and mg/100 g for micronutrients. Simple descriptive statistics, i.e., mean, standard deviation, and range, were calculated for all varieties of different types of millets to gage the variation in nutrient content. Non-parametric one-way analysis of variance (ANOVA) was carried out with Duncan's *post hoc* test to define significant variance between the means of each nutrient for each millet using SPSS. Principal component analysis (PCA) was done to summarize the nutrient data for different varieties of millets.

2.5 Primary outcome(s)

Information regarding proximate composition, energy-contributing macronutrients and biologically important minerals, and variability of these nutrients in different varieties of millet around the globe were collected.

2.6 Secondary outcome(s)

The probable reasons for wide variation in nutrient content owing to different genetic as well as environmental and agronomic factors like rainfall, soil conditions, fertilizers, and access to water were summarized.

3 Results and discussion

Ninety studies relevant to the nutrient profiles of 12 types of millets, namely barnyard millet, brown top millet, finger millet, fonio, foxtail millet, Job's tears, kodo millet, little millet, pearl millet, proso millet, sorghum, and teff, were included in this review (Supplementary Figure S1). They reflected a wide range of analytical techniques (Supplementary Table S2).

In this section, the term 'genotypes' indicates research materials including accessions, genotypes, lines, hybrids, etc., whereas the term 'varieties' refers to materials released by researchers for consumption, landraces or those available in the market. Some studies did not provide enough information on the accessions if it is from heterogenous material therefore it is not elaborated. Some studies did not provide enough information on landraces, the variety of particular millet in the local market, and released varieties therefore, all these are categorized under the "varieties" group and there was not much difference in nutrients observed in the initial data curation stage. Tables 1, 2 describes the ash, total fat, total protein, carbohydrates, fiber, and minerals content (calcium, iron, magnesium, and zinc) in the various millets. The study characteristics extracted for the analysis are presented in Supplementary Tables S3, S4.

3.1 Macronutrient composition of millets

Out of the 90 studies (Figure 1) available on the proximate composition of millets, only 11 authors published the complete profile including the water/moisture, protein, fat, ash, fiber, and carbohydrate contents. Two of these studies reported the complete proximate profiles of finger and pearl millet genotypes and one reported the profile of foxtail millet genotypes (Shibairo et al., 2014; Kamatar et al., 2015; Elsadig et al., 2016; Shindume et al., 2019; Nakarani et al., 2021). Two authors reported the complete proximate profile of the sorghum variety (Mustafa and Magdi, 2003; Mugalavai and Onkware, 2018) and one study reported on fonio (Koreissi-Dembélé et al., 2013), teff (Derib et al., 2018) finger millet (Food Composition Table for Nepal, 2012), and pearl millet (Kulthe et al., 2016) varieties. For barnyard millet, only protein, fat, and fiber levels were reported. For foxtail millet, all authors except one (Kamatar et al., 2015) did not include the ash content in the proximate composition. In kodo and little millets, only protein levels were estimated while in proso millet, carbohydrate values were not reported by any of the authors. Most of the authors prioritized the investigation of protein variability among millet varieties/genotypes. Variation in the macronutrient contents of different millets is reported in Table 1.

Exceptionally high total dietary fiber content was reported in barnyard millet varieties (Panwar et al., 2016), ranging from 23.25 to 31.70 g/100 g, which can meet 100% of the fiber requirement of the body if 100 g of millet were consumed per day (ICMR, 2020). Only one variety of browntop millet was analyzed for proximate composition, and it showed 11.64 g/100 g of protein, 5.28 g/100 g of fat, and 16.08 g/100 g of fiber. Released varieties of finger millet showed a good proximate profile compared to genotypes. In fonio millet, a considerably high amount of total dietary fiber was reported in different varieties, with a range of 15.70 to 20.70 g/100 g.

Among foxtail millet genotypes, average fat and protein contents were 3.52 ± 0.29 g/100 g and 12.53 ± 2.19 g/100 g, respectively, while different varieties of foxtail millet contained 4.29 ± 0.33 g/100 g and 10.45 ± 1.05 g/100 g of fat and protein, respectively (Upadhyaya et al., 2011a,b). The proximate composition of Job's tears genotypes showed 13.00 ± 1.34 g/100 g of protein, 7.93 ± 0.56 g/100 g of fat, and 67.43 ± 1.27 g/100 g of carbohydrate. Only one report was available for a Job's tears variety; it reported 12.66 g/100 g of protein, 4.26 g/100 g of fat, and 3.80 g/100 g of fiber.

TABLE 1 Proximate composition and mineral concentrations of different millets genotypes reported across the globe.

		Browntop millet	Finger Millet	Fonio Millet	Foxtail Millet	Job's tears	Kodo Millet	Little Millet	Pearl Millet	Proso Millet	Sorghum	Tef
Ash	Mean ± SD	-	3.184 ± 0.337	-	-	1.41 ± 0.27	-	-	1.943 ± 0.589	-	-	-
	Number of Entries (N)	-	16	-	-	6	-	-	87	-	-	-
	Range	-	2.75–3.8	-	-	1.14–1.76	-	-	1.25–5.16	-	-	-
	Reference	-	Shibairo et al. (2014) and Nakarani et al. (2021)	-	-	Ramadhan et al. (2023)	-	-	Chen (1978), Singh et al. (1987), Mustafa et al. (2008), Elsadig et al. (2016), and Shindume et al. (2019)	-	-	-
Protein	Mean ± SD	10.71 ± 1.82	7.94 ± 1.75	6.17 ± 1.22	12.53 ± 2.19	13.00 ± 1.34	8 ± 0.57	11.12 ± 1.88	15.72 ± 2.2	13.17 ± 1.62	10.75 ± 1.38	9.89 ± 0.12
	Number of Entries (*N*)	30	252	13	185	6	30	65	87	26	90	9
	Range	8.93–19.33	2.6–14	3.75–7.75	6.2–18.5	10.53–13.82	7–9.3	7.2–14.6	9.45–20.8	10.8–16.9	7.2–15.26	9.66–10.1
	Reference	Niharika et al. (2020)	Sankara Vadivoo et al. (1998), Upadhyaya et al. (2011a,b), Nirgude et al. (2014), Shibairo et al. (2014), Patil et al. (2019), Udamala et al. (2020), and Nakarani et al. (2021)	Clottey et al. (2006)	Upadhyaya et al. (2011a,b), Sharma et al. (2014), Brunda et al. (2015), Kamatar et al. (2015), and Thippeswamy et al. (2017)	Ramadhan et al. (2023)	Vetriventhan and Upadhyaya (2019)	Vetriventhan et al. (2021)	Chen (1978), Singh et al. (1987), Mustafa et al. (2008), Elsadig et al. (2016), and Shindume et al. (2019)	Vetriventhan and Upadhyaya (2018)	Gerrano et al. (2006), Chavan et al. (2009), Shegro et al. (2012), Motlhaodi et al. (2018), and Mofokeng (2015)	Abewa et al. (2020)
Fat	Mean ± SD	-	1.59 ± 0.31	-	3.52 ± 0.29	7.93 ± 0.56	-	-	5.43 ± 0.99	-	-	2.77 ± 0.08
	Number of Entries (N)	-	16	-	78	6	-	-	82	-	-	9
	Range	-	1.2–2.23	-	2.79–4.16	6.83–8.44	-	-	4.1–7.4	-	-	2.65–2.86

(Continued)

TABLE 1 (Continued)

		Browntop millet	Finger Millet	Fonio Millet	Foxtail Millet	Job's tears	Kodo Millet	Little Millet	Pearl Millet	Proso Millet	Sorghum	Tef
	Reference	-	Shibairo et al. (2014) and Nakarani et al. (2021)	-	Kamatar et al. (2015)	Ramadhan et al. (2023)	-	-	Elsadig et al. (2016), Shindume et al. (2019), Singh et al. (1987), and Chen (1978)	-	-	Abewa et al. (2020)
Fiber	Mean ± SD	8.06 ± 0.82	4.18 ± 1.44	-	2.08 ± 0.13	-	-	-	9.6 ± 4.33	_	_	3.05 ± 0.17
	Number of Entries (N)	30	82	-	95	-	-	-	47	_	_	9
	Range	6.50–9.87	0.93–10.01	-	1.34–2.31	-	-	-	2.51–19.6	_	_	2.72–3.29
	Reference	Niharika et al. (2020)	Bachar et al. (2013), Shibairo et al. (2014), Patil et al. (2019), and Nakarani et al. (2021)	-	Brunda et al. (2015) and Kamatar et al. (2015)	-	-	-	Singh et al. (1987), Elsadig et al. (2016), and Shindume et al. (2019)	-	-	Abewa et al. (2020)
CHO	Mean ± SD	-	73.23 ± 2.27	-	72.89 ± 0.86	67.43 ± 1.27	-	-	69.05 ± 3.12	-	-	-
	Number of Entries (N)	-	52	-	78	6	-	-	44	-	-	-
	Range	-	68.23–78.46		70.9–74.63	66.30–69.85	-	-	62.53–75.6	-	-	-
	Reference	-	Shibairo et al. (2014), Patil et al. (2019), and Nakarani et al. (2021)	-	Kamatar et al. (2015)	Ramadhan et al. (2023)	-	-	Elsadig et al. (2016) and Shindume et al. (2019)	-	-	-
Fe	Mean ± SD	8.86 ± 3.30	5.13 ± 2.22	-	4.9 ± 2.63	-	11.85 ± 5.92	3.78 ± 3.36	6.74 ± 2.16	5.58 ± 0.7	4.38 ± 1.75	19.17 ± 2.37
	Number of Entries (N)	30	137	-	107	-	120	65	457	54	227	9
	Range	3.70–15.32	1.9–14.7	-	0.33–16.26	-	2.03–24.69	1.49–23.38	1.4–13.527	4.49–7.32	1.18–12.75	15.1–23.1

(Continued)

TABLE 1 (Continued)

		Browntop millet	Finger Millet	Fonio Millet	Foxtail Millet	Job’s tears	Kodo Millet	Little Millet	Pearl Millet	Proso Millet	Sorghum	Tef
	Reference	[94]	Shibairo et al. (2014), Sharma et al. (2018), Patil et al. (2019), Udamala et al. (2020), and Nakarani et al. (2021)	-	Upadhyaya et al. (2011a,b), Sharma et al. (2014), Brunda et al. (2015), and Thippeswamy et al. (2017)	-	Nirubana et al. (2017) and Vetriventhan and Upadhyaya (2019)	Manimozhi Selvi et al. (2015) and Vetriventhan et al. (2021)	Singh et al. (1987), Mustafa et al. (2008), Govindaraj et al. (2013), Elsadig et al. (2016), Anuradha et al. (2017), Manwaring (2018), Singhal et al. (2018), Shindume et al. (2019), Kumar et al. (2020), and Serba et al. (2020)	Vetriventhan and Upadhyaya (2018)	Gerrano et al. (2006), Kayodé et al. (2006), Ashok Kumar et al. (2011), Ng’uni et al. (2011), Shegro et al. (2012), Motlhaodi et al. (2018), Abdelhalim et al. (2019), Upadhyaya et al. (2019), and Ashok kumar (2012)	Abewa et al. (2020)
Zn	Mean ± SD	2.11 ± 0.50	3.25 ± 1.47	-	4.13 ± 1.83	-	3.35 ± 0.91	3.89 ± 1.61	4.76 ± 1.48	3.77 ± 0.52	2.6 ± 0.87	2.25 ± 0.08
	Number of Entries (N)	30	172	-	136	-	127	65	491	54	189	9
	Range	1.36–2.80	0.9–6.43	-	0.85–11.4	-	1.95–6.5	2.04–8	1.15–9.41	2.67–4.67	0.45–5.7	2.12–2.36
	Reference	Niharika et al. (2020)	Upadhyaya et al. (2011a,b), Sharma et al. (2018), Patil et al. (2019), Udamala et al. (2020), and Nakarani et al. (2021)	-	Upadhyaya et al. (2011a, b), Sharma et al. (2014), Brunda et al. (2015), and Thippeswamy et al. (2017)	-	Nirubana et al. (2017) and Vetriventhan and Upadhyaya (2019)	Manimozhi Selvi et al. (2015) and Vetriventhan et al. (2021)	Singh et al. (1987), Mustafa et al. (2008), Velu et al. (2008a,b), Panwar et al. (2010), Govindaraj et al. (2013), Elsadig et al. (2016), Anuradha et al. (2017), Manwaring (2018), Singhal et al. (2018), Shindume et al. (2019), and Serba et al. (2020)	Vetriventhan and Upadhyaya (2018)	Gerrano et al. (2006), Kayodé et al. (2006), Ashok Kumar et al. (2011), Shegro et al. (2012), Motlhaodi et al. (2018), Abdelhalim et al. (2019), and Upadhyaya et al. (2019)	Abewa et al. (2020)

(Continued)

TABLE 1 (Continued)

		Browntop millet	Finger Millet	Fonio Millet	Foxtail Millet	Job's tears	Kodo Millet	Little Millet	Pearl Millet	Proso Millet	Sorghum	Tef
Ca	Mean ± SD	13.97 ± 5.69	417 ± 298	-	13.49 ± 5.32	-	19.8 ± 2.08	10.91 ± 6.91	26.72 ± 11.52	107.7 ± 94.17	37.47 ± 48.32	122 ± 2.58
	Number of Entries (N)	30	342	-	84	-	30	65	275	54	88	9
	Range	8.00–33.00	117.5–1,400	-	1.99–28.87	-	15.84–23.5	1.14–23.35	6.07–73.71	9.11–235.4	9.2–270	118.7–125.7
	Reference	Niharika et al. (2020)	Sankara Vadivoo et al. (1998), Panwar et al. (2010), Upadhyaya et al. (2011a,b), Nirgude et al. (2014), Shibairo et al. (2014), Patil et al. (2019), Udamala et al. (2020), and Nakarani et al. (2021)	-	Upadhyaya et al. (2011a,b) and Thippeswamy et al. (2017)	-	Vetriventhan and Upadhyaya (2019)	Manimozhi Selvi et al. (2015) and Vetriventhan et al. (2021)	Singh et al. (1987), Mustafa et al. (2008), Elsadig et al. (2016), and Shindume et al. (2019)	Vetriventhan and Upadhyaya (2018)	Gerrano et al. (2006), Shegro et al. (2012), and Motlhaodi et al. (2018)	Abewa et al. (2020)
Mg	Mean ± SD	-	481 ± 285	-	-	-	-	-	130 ± 23.25	-	127 ± 21.39	146 ± 5.11
	Number of Entries (N)	-	67	-	-	-	-	-	275	-	76	9
	Range	-	84.7–900	-	-	-	-	-	54.2–240	-	75–173.4	140–153.5
	Reference	-	Bachar et al. (2013) and Patil et al. (2019)	-	-	-	-	-	Singh et al. (1987), Mustafa et al. (2008), Elsadig et al. (2016), Manwaring (2018), and Shindume et al. (2019)	-	Gerrano et al. (2006), Shegro et al. (2012), and Motlhaodi et al. (2018)	Abewa et al. (2020)

Different superscript alphabets in the same row indicate the statistically significant ($p < 0.05$) difference among millet samples.

Among kodo millet genotypes, the average protein content was 8.00 ± 0.57 g/100 g, while pooled varieties had 8.92 g/100 g. Among different genotypes of little millet, protein content averaged 11.12 ± 1.88 g/100 g, while varieties showed a similar level of 10.13 g/100 g.

In pearl millet, protein content ranged from 9.45-to 20.80-g/100 g for genotypes, and 4.5 to 17.10 g/100 for varieties, with the highest level being in the 700,112 genotype (Singh et al., 1987). The pearl millet genotype Sudan II was reported to have the highest crude fiber (15.37 g/100 g) content (Derib et al., 2018), while the variety of pearl millet Pioneer 86 M64 showed the highest level of crude fiber 17.60 g/100 g (Stadlmayr, 2012).

For two varieties of proso millet, ANUL, and HAML. Kumari et al. (2016) reported 2.26 and 2.17 g/100 g of ash, respectively, 3.32 and 3.09 g/100 g of fat, 10.70 and 9.37 g/100 g of protein, and 2.35 and 2.30 g/100 g of crude fiber. Many other authors reported only protein levels (Ershow and Wong-Chen, 1990; Bagdi et al., 2011; Food Composition Table for Nepal, 2012; Vetriventhan and Upadhyaya, 2018) which varied from 10.80 to 16.90 g/100 g for proso millet genotypes and from 9.37 to 15.20 g/100 g for released varieties. For sorghum, protein content was highest at 17 g/100 g in the variety Sandal Bar from Pakistan (Ahmad et al., 2018) and lowest at 4.28 g/100 g in N 68 from Western Kenya (Mugalavai and Onkware, 2018).

Among different types of millets, protein was high in nearly all the millets. Barnyard, foxtail, Job's tears, pearl, and proso millets exhibited the highest protein content with no significant difference among them, while finger, fonio, and kodo millets contained the lowest protein content. Fat content was significantly ($p < 0.05$) higher in Job's tears than in other millets. Barnyard millet exhibited a significantly ($p < 0.05$) high amount of fiber compared to other types of millet. The results showed a wide variation in nutrient content among the different types and varieties/genotypes of millets. This is mainly due to genetic, morphological, and agronomic differences, as reported by various authors. Additionally, the different analytical methods adopted by authors for the estimation of parameters could also be a reason for the variance.

3.2 Micronutrient profile of millets

Mineral content in barnyard millet varieties was reported in Korea (Kim et al., 2011) and India (Panwar et al., 2016) with variations between 2.28 and 22.98 mg/100 g for iron, 0.44 and 5.92 mg/100 g for zinc, and 5.81 and 36.13 mg/100 g for calcium. The wide range of nutrient values reported for barnyard millet varieties may be due to the particular variety itself or due to differences in soil nutrients and geographical variation.

Among browntop millet genotypes, iron, zinc, and calcium content was in the range of 3.70–15.32, 1.36–2.80, and 8.00–33.00 mg/100 g, respectively. In finger millet, the highest iron content was reported in improved finger millet varieties from Ethiopia (Admassu et al., 2009). The highest variation in zinc, calcium, and magnesium was found in finger millet genotypes (Patil et al., 2019), which the authors attributed to genotypic variability.

For fonio millet varieties, only iron and zinc were reported (Stadlmayr, 2012; Koreissi-Dembélé et al., 2013), with a range of 0.80 to 10.00 mg/100 g and 1.90 to 3.80 mg/100 g, respectively. High iron and zinc content were reported in several foxtail millet genotypes (Thippeswamy et al., 2017), whereas the highest calcium content was reported in the variety Tinmaase Kaaguno, which is a traditional mountain landrace from Nepal (Joshi et al., 2020). Kodo and little millet showed wide variation for all the nutrients, which was due to the selected genotype and precisely controlled homeostatic mechanisms that regulate the absorption of these nutrients from the soil, their translocation and redistribution, and accumulation in plant tissue (Manimozhi Selvi et al., 2015; Nirubana et al., 2017).

The nutrient profile of pearl millet genotypes showed that the highest ash content (5.16 g/100 g) was in the genotype L5P11Rep2 (Shindume et al., 2019) from Nigeria, which is a level almost four times higher than in the HSD10376 genotype (Food Composition Table for Nepal, 2012), indicating a good total mineral profile. Among different pearl millets, the huge variations in mineral content were primarily due to genotypic diversity, as reported by the authors. In proso millet, genotypes showed the highest content for all four minerals as compared to released varieties (Food Composition Table for Nepal, 2012; Mishra et al., 2015; Ng'uni et al., 2016).

Among sorghum exceptionally high levels of iron, zinc, and calcium were detected by Pontieri et al. (2017) in all varieties of sorghum from Italy as the authors had collected hybrid sorghum cultivars with improved nutritional characteristics for their study. High amounts of calcium were also reported in wild sorghum genotypes from Sudan, Ethiopia, and Eritrea (Abdelhalim et al., 2019) with the author attributing the variations to genetic variability between species and the effect of the environment at the collection site. Magnesium content also showed wide variability, which was attributed to genetic variation among cultivars and improved varieties (Chavan et al., 2009, 2015; Ng'uni et al., 2011). In teff, an exceptionally high amount of iron was reported in the Korma variety (Derib et al., 2018); the highest zinc content was reported in the white teff variety (406 W); and the highest calcium content was found in the brown teff variety (405 B), while magnesium was highest in the Bolo Giorgis variety from Ethiopia.

Among all the millets in this study, irrespective of variety and genotype, iron content was significantly higher ($p < 0.05$) in teff grains, followed by kodo millet, and barnyard millet. However, if we consider only the released varieties, finger millet had highest iron content followed by teff. Pearl millet contained significantly ($p < 0.05$) highest zinc content of 8.73 ± 11.55 mg/100 g compared to all other millets. Finger millet showed significantly high ($p < 0.05$) amounts of calcium and magnesium as compared to other millets (Table 2). Calcium level was consistently high in finger millet and teff regardless of the variety, at 331.29 ± 10 mg/100 g and 183.41 ± 29 mg/100 g, respectively. It is noteworthy that the calcium level in finger millets that are unreleased genotypes, also is a very high level being 417 ± 298 mg/100 g with a range of 117.5–1,400 mg/100 g. Therefore, bringing these varieties to market is very important to naturally increase the dietary calcium level. Interestingly, proso millet genotype 107.7 ± 94.17 had a high calcium level (ranging between 9.11–235.4) which is not available in the market so requires attention to leverage this opportunity. It was observed that iron and zinc were the most studied minerals in all the millet, whereas calcium was studied mainly in finger millet. It can be concluded that millet grain nutrient content varies widely among different types of millets as well as different varieties/genotypes.

TABLE 2 Proximate composition and mineral concentrations of different millets varieties reported across the globe.

		Barnyard Millet	Browntop millet	Finger Millet	Fonio	Foxtail Millet	Job's tears	Kodo Millet	Little Millet	Pearl Millet	Proso Millet	Sorghum	Tef
Ash	Mean ± SD	-	8.62	2.35 ± 0.78	3.07 ± 1.54	1.81 ± 0.27	1.38	-	-	1.90 ± 0.31	2.22 ± 0.06	2.09 ± 0.53	2.49 ± 0.32
	Number of Entries (N)	-	1	30	23	4	1	-	-	4	2	44	9
	Range	-	-	0.73–4.00	2.10–7.40	1.54–2.17	-	-	-	1.47–2.17	2.17–2.26	1.30–3.45	2.13–3.22
	Reference	-	Hemamalini et al. (2021)	Admassu et al. (2009), Kumari et al. (2016), and Otieno et al. (2020)	Koreissi-Dembélé et al. (2013)	Kumari et al. (2016)	Luithui and Meera (2019)	-	-	Singh et al. (1987) and Kulthe et al. (2016)	Kumari et al. (2016)	Mustafa et al. (2008), Chavan et al. (2015), Mabelebele et al. (2015), Pontieri et al. (2017), Ahmad et al. (2018), Mugalavai and Onkware (2018), and Otieno et al. (2020)	Derib et al. (2018)
Protein	Mean ± SD	12.05 ± 1.77	11.64	9.32 ± 2.60	8.52 ± 0.62	10.45 ± 1.05	12.66	8.92	10.13	9.02 ± 2.75	12.42 ± 1.99	10.74 ± 2.66	9.5 ± 1.82
	Number of Entries (N)	13	1	53	12	6	1	1	1	106	12	80	10
	Range	10.05–14.75	-	5.80–16.87	7.40–9.50	9.50–12.30	-	8.92–8.92	10.13–10.13	4.50–17.10	9.37–15.20	4.28–17.00	6.76–13.30
	Reference	[51]	Kayodé et al. (2006)	Ershow and Wong-Chen (1990), Barbeau and Hilu (1993), Admassu et al. (2009), Upadhyaya et al. (2011a,b), Food Composition Table for Nepal (2012), Kumari et al. (2016), Longvah et al. (2017), Otieno et al. (2020), and Van Graan et al. (2020)	Koreissi-Dembélé et al. (2013)	Ershow and Wong-Chen (1990), Food Composition Table for Nepal (2012), and Kumari et al. (2016)	Luithui and Meera (2019)	Longvah et al. (2017)	Longvah et al. (2017)	Singh et al. (1987), Cheik et al. (2006), Food Composition Table for Nepal (2012), Stadlmayr (2012), Kiprotich et al. (2015), Kulthe et al. (2016), Berwal et al. (2017), and Longvah et al. (2017)	Ershow and Wong-Chen (1990), Bagdi et al. (2011), Food Composition Table for Nepal (2012), and Kumari et al. (2016)	Manful et al. (2001), Mustafa et al. (2008), Chavan et al. (2009, 2015), Food Composition Table for Nepal (2012), Mabelebele et al. (2015), Ng'uni et al. (2016), Longvah et al. (2017), Pontieri et al. (2017), Ahmad et al. (2018), Mugalavai and Onkware (2018), Mwai et al. (2018), and Van Graan et al. (2020)	Derib et al. (2018) and Mwai et al. (2018)

(Continued)

TABLE 2 (Continued)

		Barnyard Millet	Browntop millet	Finger Millet	Fonio	Foxtail Millet	Job's tears	Kodo Millet	Little Millet	Pearl Millet	Proso Millet	Sorghum	Tef
Fat	Mean ± SD	5.65 ± 1.10	5.28	1.86 ± 1.56	4.16 ± 0.31	4.29 ± 0.33	4.26	-	-	7.52 ± 1.20	3.21 ± 0.16	3.13 ± 0.96	3.27 ± 0.16
	Number of Entries (N)	13	1	28	12	4	1	-	-	32	2	44	9
	Range	3.01–6.90	-	0.10–4.50	3.60–4.50	3.84–4.58	-	-	-	5.14–10.20	3.09–3.32	1.21–5.60	3.04–3.48
	Reference	[51]	Kayodé et al. (2006)	Barbeau and Hilu (1993), Kumari et al. (2016), and Otieno et al. (2020)	Koreissi-Dembélé et al. (2013)	Kumari et al. (2016)	Luithui and Meera (2019)	-	-	Singh et al. (1987), Cheik et al. (2006), Stadlmayr (2012), and Kulthe et al. (2016)	Kumari et al. (2016)	Mustafa et al. (2008), Chavan et al. (2015), Mabelebele et al. (2015), Pontieri et al. (2017), Ahmad et al. (2018), Mugalavai and Onkware (2018), and Otieno et al. (2020)	Derib et al. (2018)
Fiber	Mean ± SD	27.48 ± 3.59	16.08	8.19 ± 5.51	18.20 ± 1.56	2.01 ± 0.43	3.8	-	-	10.68 ± 3.18	2.33 ± 0.04	4.20 ± 2.12	1.75 ± 0.51
	Number of Entries (N)	5	1	25	12	4	1	-	-	31	2	44	9
	Range	23.25–31.70	-	2.22–18.06	15.70–20.70	1.52–2.38	-	-	-	2.07–17.60	2.30–2.35	1.64–9.12	0.79–2.25
	Reference	[34]	Kayodé et al. (2006)	Kumari et al. (2016), Panwar et al. (2016), and Otieno et al. (2020)	Koreissi-Dembélé et al. (2013)	Kumari et al. (2016)	Luithui and Meera (2019)	-	-	Singh et al. (1987), Stadlmayr (2012), Kulthe et al. (2016), and Krishnan and Meera (2017)	Kumari et al. (2016)	Mustafa et al. (2008), Chavan et al. (2015), Pontieri et al. (2017), Ahmad et al. (2018), Mugalavai and Onkware (2018), and Otieno et al. (2020)	Derib et al. (2018)
CHO	Mean ± SD	-	-	68.72 ± 5.23	65.99 ± 1.83	-	-	-	-	69.97 ± 8.36	-	67.01 ± 5.27	74.07 ± 1.43
	Number of Entries (N)	-	-	17	11	-	-	-	-	30	-	25	9
	Range	-	-	56.32–75.30	62.20–68.70	-	-	-	-	55.50–81.00	-	56.39–74.21	71.9676.48

(Continued)

TABLE 2 (Continued)

		Barnyard Millet	Browntop millet	Finger Millet	Fonio	Foxtail Millet	Job's tears	Kodo Millet	Little Millet	Pearl Millet	Proso Millet	Sorghum	Tef
	Reference	-	-	Barbeau and Hilu (1993) and Otieno et al. (2020)	Koreissi-Dembélé et al. (2013)	-	-	-	-	Cheik et al. (2006), Stadlmayr (2012), and Kulthe et al. (2016)	-	Mustafa et al. (2008), Pontieri et al. (2017), Mugalavai and Onkware (2018), and Otieno et al. (2020)	Derib et al. (2018)
Fe	Mean ± SD	10.06 ± 7	-	12.21 ± 13.69	2.42 ± 2.81	5.15 ± 4.06	-	2.34	1.26	6.14 ± 1.78	3.4 ± 0.56	6.60 ± 8.08	11.09 ± 8.35
	Number of Entries (N)	18	-	32	15	6	-	1	1	152	2	99	11
	Range	2.28–22.98	-	2.64–53.39	0.80–10.00	1.92–12.90	-	2.34–2.34	1.26–1.26	2.18–13.41	3–0.380	2.43–55.26	3.74–34.69
	Reference	[34, 51]	-	Lukmanji et al. (2008), Admassu et al. (2009), Food Composition Table for Nepal (2012), Panwar et al. (2016), Longvah et al. (2017), Mwai et al. (2018), Anitha et al. (2019), Joshi et al. (2020), Otieno et al. (2020), and Van Graan et al. (2020)	Stadlmayr (2012) and Koreissi-Dembélé et al. (2013)	Ershow and Wong-Chen (1990), Food Composition Table for Nepal (2012), and Joshi et al. (2020)	-	Longvah et al. (2017)	Longvah et al. (2017)	Singh et al. (1987), Hussain (2001), Lukmanji et al. (2008), Velu et al. (2008a,b), Food Composition Table for Nepal (2012), Stadlmayr (2012), Cercamondi et al. (2013), Rai et al. (2014, 2016), Finkelstein et al. (2015), Bachir et al. (2016), Bhati et al. (2016), Kulthe et al. (2016), Berwal et al. (2017), Krishnan and Meera (2017), Longvah et al. (2017), Mwai et al. (2018), Anitha et al. (2019), and Govindaraj et al. (2020a,b)	Ershow and Wong-Chen (1990) and Food Composition Table for Nepal (2012)	Ershow and Wong-Chen (1990), Hussain (2001), Lukmanji et al. (2008), Chavan et al. (2009, 2015), Ashok Kumar et al. (2011), Food Composition Table for Nepal (2012), Stadlmayr (2012), Mabelebele et al. (2015), Mishra et al. (2015), Ng'uni et al. (2016), Longvah et al. (2017), Pontieri et al. (2017), Mwai et al. (2018), Otieno et al. (2020), Van Graan et al. (2020)	Derib et al. (2018) and Tietel et al. (2020)

(Continued)

TABLE 2 (Continued)

		Barnyard Millet	Browntop millet	Finger Millet	Fonio	Foxtail Millet	Job's tears	Kodo Millet	Little Millet	Pearl Millet	Proso Millet	Sorghum	Tef
Zn	Mean ± SD	2.03 ± 1.85	-	2.49 ± 0.81	2.31 ± 0.52	-	-	1.65	1.82	8.73 ± 11.55	-	3.44 ± 4.45	2.91 ± 0.68
	Number of Entries (N)	18	-	28	13	-	-	1	1	200	-	114	11
	Range	0.44–5.92	-	0.97–3.93	1.9–3.8	-	-	1.65–1.65	1.82–1.82	1.70–134	-	0.8–26.99	2.36–4.43
	Reference	[34, 51]	-	Lukmanji et al. (2008), Admassu et al. (2009), Panwar et al. (2016), Longvah et al. (2017), Mwai et al. (2018), Otieno et al. (2020), and Van Graan et al. (2020)	Stadlmayr (2012) and Koreissi-Dembélé et al. (2013)	-	-	Longvah et al. (2017)	Longvah et al. (2017)	Singh et al. (1987), Hussain (2001), Lukmanji et al. (2008), Velu et al. (2008a,b), Stadlmayr (2012), Rai et al. (2014, 2016), Kiprotich et al. (2015), Berwal et al. (2017), Krishnan and Meera (2017), Longvah et al. (2017), Mwai et al. (2018), and Govindaraj et al. (2020a,b)	-	Hussain (2001), Lukmanji et al. (2008), Chavan et al. (2009, 2015), Ng'uni et al. (2011, 2016), Stadlmayr (2012), Mabelebele et al. (2015), Mishra et al. (2015), Longvah et al. (2017), Pontieri et al. (2017), Mwai et al. (2018), Otieno et al. (2020), Van Graan et al. (2020)	Derib et al. (2018) and Tietel et al. (2020)
Ca	Mean ± SD	23.83 ± 7.72	-	331.29 ± 103	-	70.07 ± 49.48	-	15.27	16.06	21.85 ± 14.18	15.50 ± 10.61	35.49 ± 40.95	183.41 ± 2,945
	Number of Entries (N)	18	-	36	-	5	-	1	1	83	2	112	11
	Range	5.81–36.13	-	29–523	-	31–155	-	15.27–15.27	16.06–16.06	3.17–72.87	8–23	5–241	148–232

(Continued)

TABLE 2 (Continued)

		Barnyard Millet	Browntop millet	Finger Millet	Fonio	Foxtail Millet	Job's tears	Kodo Millet	Little Millet	Pearl Millet	Proso Millet	Sorghum	Tef
	Reference	[34, 51]	-	Ershow and Wong-Chen (1990), Barbeau and Hilu (1993), Lukmanji et al. (2008), Admassu et al. (2009), Food Composition Table for Nepal (2012), Panwar et al. (2016), Longvah et al. (2017), Mwai et al. (2018), Anitha et al. (2019), Joshi et al. (2020), Otieno et al. (2020), and Van Graan et al. (2020)	-	Food Composition Table for Nepal (2012) and Joshi et al. (2020)	-	Longvah et al. (2017)	Longvah et al. (2017)	Singh et al. (1987), Hussain (2001), Lukmanji et al. (2008), Food Composition Table for Nepal (2012), Stadlmayr (2012), Kulthe et al. (2016), Adéoti et al. (2017), Longvah et al. (2017), Mwai et al. (2018), Anitha et al. (2019), and Govindaraj et al. (2020a,b)	Ershow and Wong-Chen (1990) and Food Composition Table for Nepal (2012)	Ershow and Wong-Chen (1990), Hussain (2001), Lukmanji et al. (2008), Chavan et al. (2009, 2015), Ng'uni et al. (2011, 2016), Food Composition Table for Nepal (2012), Stadlmayr (2012), Mabelebele et al. (2015), Longvah et al. (2017), Pontieri et al. (2017), Mwai et al. (2018), Otieno et al. (2020), and Van Graan et al. (2020)	Derib et al. (2018) and Tietel et al. (2020)
Mg	Mean ± SD	195.42 ± 16.33	-	168.67 ± 36.14	-	-	-	-	-	156.04 ± 70.54	-	157.48 ± 34.33	142.70 ± 16.29
	Number of Entries (N)	13	-	9	-	-	-	-	-	73	-	88	9
	Range	169–221	-	78–201	-	-	-	-	-	34.02–477	-	83.4–238	118–168
	Reference	[51]	-	Admassu et al. (2009)	-	-	-	-	-	Singh et al. (1987), Stadlmayr (2012), Adéoti et al. (2017), and Govindaraj et al. (2020a,b)	-	Chavan et al. (2009, 2015), Ng'uni et al. (2011, 2016), Mabelebele et al. (2015), and Pontieri et al. (2017))	Derib et al. (2018)

Different superscript alphabets in the same row indicate the statistically significant ($p < 0.05$) difference among millet samples.

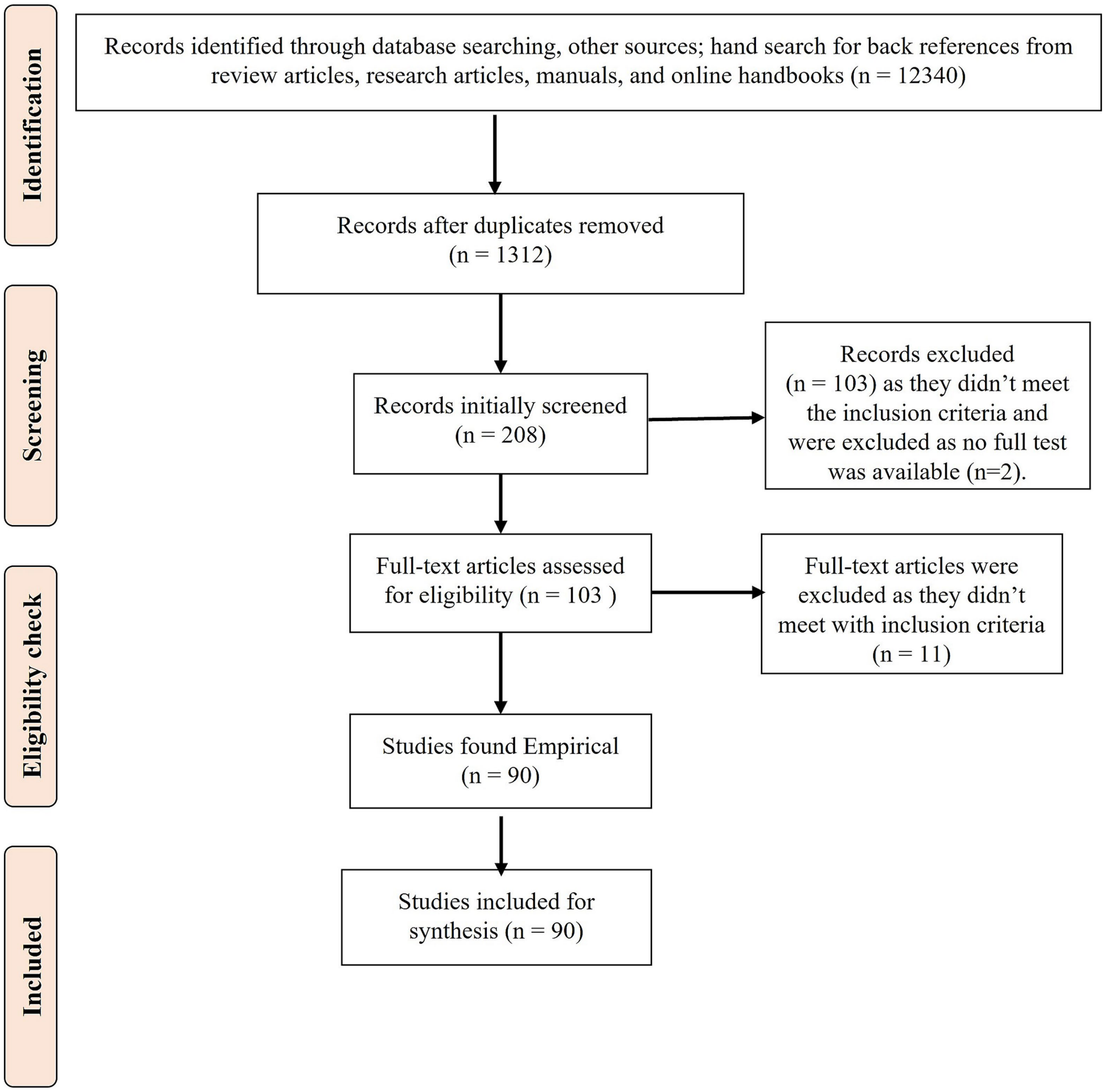


FIGURE 1
PRISMA flow diagram of the study.

3.3 Principal component analysis of different millets

Patterns of nutrient availability in the different types of millets considered in this study were identified through principal component analysis (Figure 2; Supplementary Figures S2, S3). PCA is a statistical method used to condense large data sets into smaller data sets without dropping much of the original sample data (Lever et al., 2017). Principal components (PC) are new variables (nutrient) that are constructed as linear combinations or combinations of the initial variables (nutrient). These combinations are constructed in such a way that the principal components are uncorrelated, and most of the information within the initial variables is covered in the first component. Variables are considered to have acceptable component loadings if the loading factors are greater than ±0.3 as they are regarded as highly correlated nutrients with a particular pattern (Mak et al., 2013). PCA calculates an eigenvalue and an eigenvector for each PC, which, respectively, represent the total amount of variance explained and its orientation. In this study, we used the Kaiser criterion to determine the number of PCs retained for interpretation or further analysis, which indicates that only PCs with eigenvalues greater than one should be retained. Thus, components with eigenvalues greater than 1 explain more variance than a single variable, given that a variable accounts for a unit of variance (Beavers et al., 2013). To simplify the interpretation of the PC results, a varimax rotation was used.

This process rotates the factors with an orthogonal rotation to improve interpretability and minimize the correlation between the factors. Among barnyard millet varieties, PC1 contributed 80.5%

and PC2 contributed 16.4% of the total variation. Among browntop millet genotypes, PC1 and PC2 together contributed 92.9% of the variation. PC1 of finger millet genotypes contributed 86% and PC2 14% to variation; on the other hand, between finger millet varieties, PC1 contributed 99.3% and PC2 0.4%.

In the case of fonio millet varieties, PC1 and PC2 contributed 64.8 and 23.7% variation, respectively. Among foxtail millet genotypes, PC1 (59.3%) and PC2 (22.5%) together accounted for 81.8% of the total variation whereas within varieties they contributed 100% of the variation (PC1 99.1%; PC2 0.9%). For Job's tears, kodo, little and proso millet genotypes, respectively, PC1 accounted for 89.3, 62.3, 80.3, and 94.1% of the variation, whereas PC2 contributed 7.9, 34.15, 15.2, and 4.7%, respectively. In pearl millet, PC1 contributed 90.1% of the variation among genotypes and 57.6% among varieties, while PC2 contributed 7.1% to genotypic variation and 36.1% among varieties. In sorghum genotypes, PC1 accounted for 87% variation and PC2 12.4%. But in the case of sorghum varieties, PC1 contributed only 2.4% and PC2 95.4%. PC1 and PC2, respectively, contributed 70.5 and 15.8% to variation in teff genotypes, while among teff varieties, PC1 and PC2 contributed 83.6 and 9.6% to variation, respectively (Figures 2, 3).

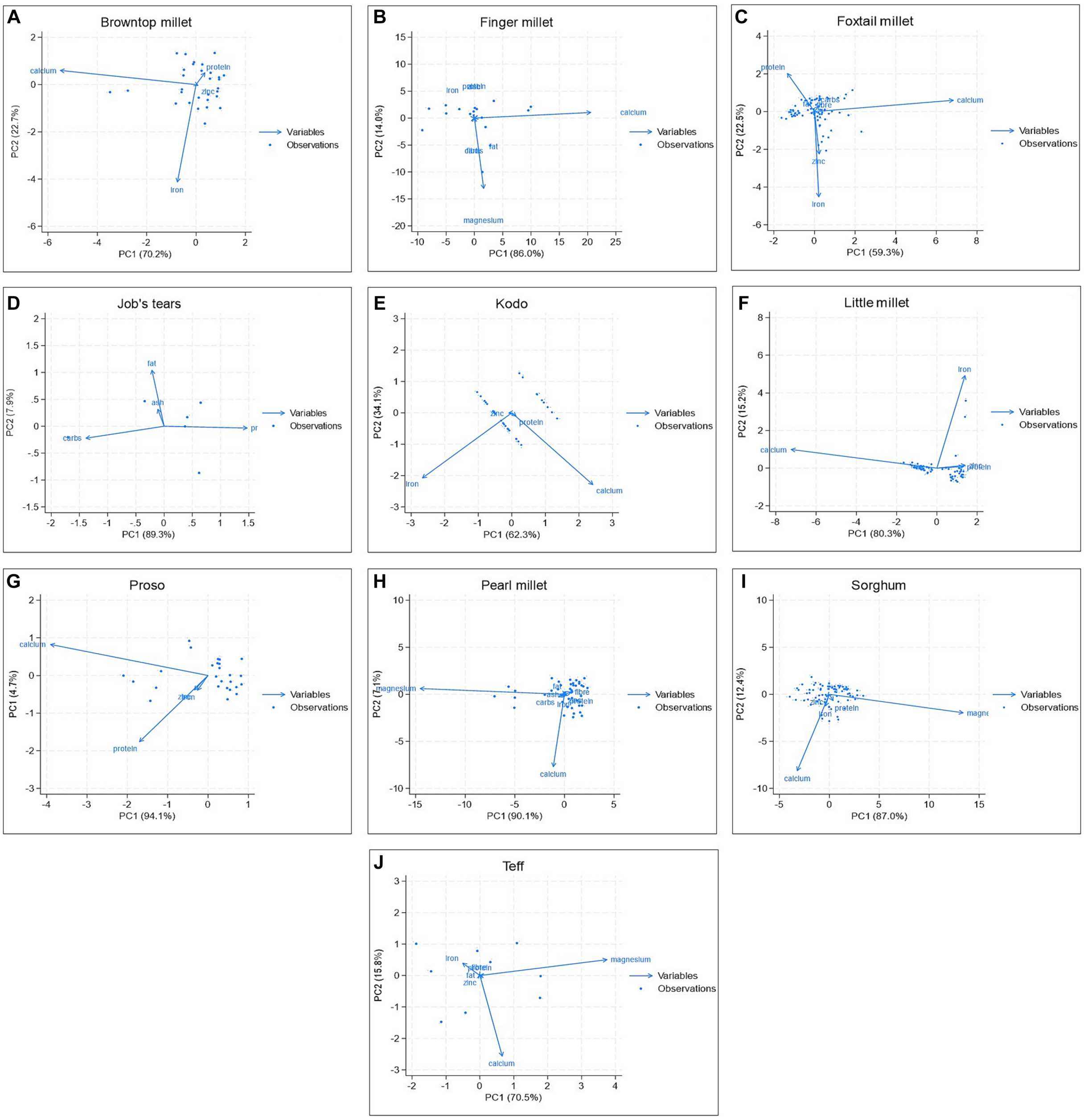


FIGURE 2
Biplot of different millet genotypes; **(A)** Browntop millet [*Brachiaria ramosa* (L.) Stapf]; **(B)** Finger millet (*Eleusine coracana*); **(C)** Foxtail millet (*Setaria italica*); **(D)** Job's tears (*Coix lacryma-jobi* L.); **(E)** Kodo millet (*Paspalum scrobiculatum*); **(F)** Little millet (*Panicum sumatrense*); **(G)** Pearl millet (*Pennisetum glaucum*); **(H)** Proso millet (*Panicum miliaceum* L.); **(I)** Sorghum (*Sorghum bicolor*); **(J)** Teff [*Eragrostis tef* (Zucc.) Trotter].

3.4 Correlation analysis

Correlation among micronutrients (iron, zinc, calcium, and magnesium) and macronutrients (ash, fat, protein, fiber, carbohydrates) in different millet genotypes and varieties was studied using heat maps (Figures 4, 5; Tables 1, 2).

It was observed that grain protein content in barnyard millet varieties was negatively correlated with zinc ($r = -0.268$) and calcium ($r = -0.197$). Among minerals, iron was positively correlated with protein ($r = 0.028$), zinc ($r = 0.178$), and magnesium ($r = 0.216$), whereas calcium was positively correlated with zinc ($r = 0.064$), magnesium ($r = 0.204$) and vice versa.

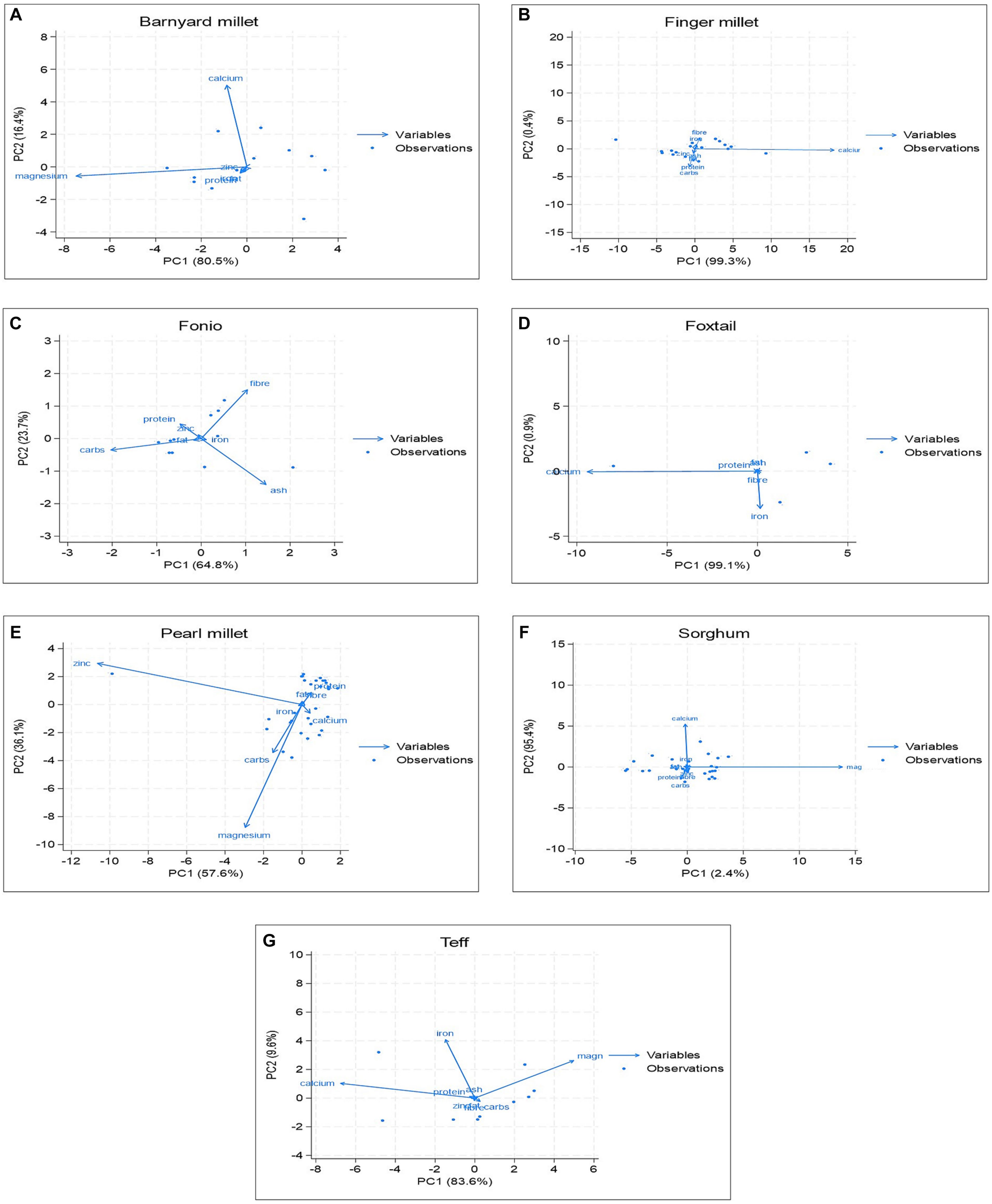
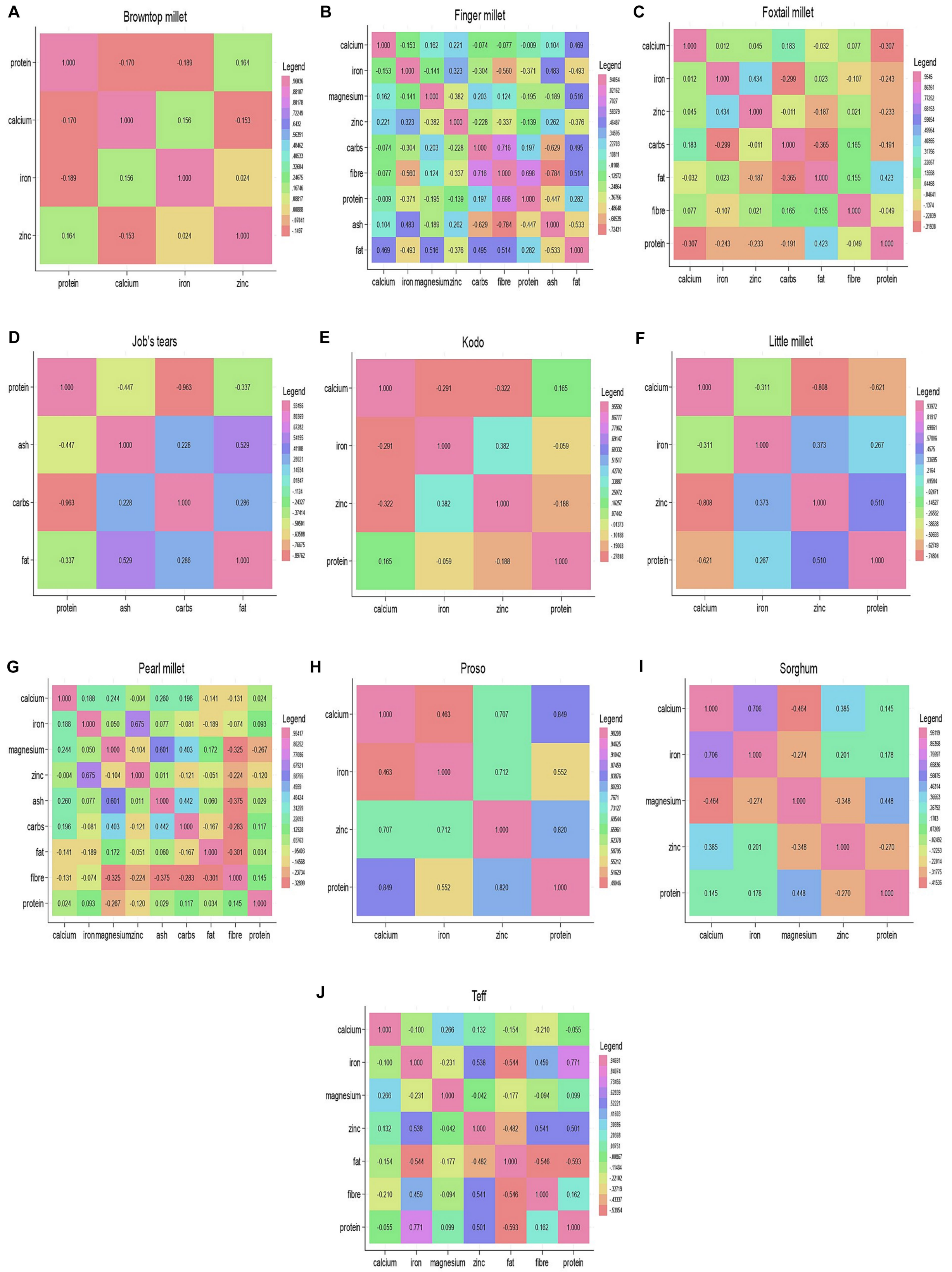


FIGURE 3
Biplot of different millet varieties; **(A)** Barnyard millet (*Echinochloa esculenta*); **(B)** Finger millet (*Eleusine coracana*); **(C)** Fonio (*Digitaria exilis* Stapf); **(D)** Foxtail millet (*Setaria italica*); **(E)** Pearl millet (*Pennisetum glaucum*); **(F)** Sorghum (*Sorghum bicolor*); **(G)** Teff [*Eragrostis tef* (Zucc.) Trotter].



A Browntop millet

	protein	calcium	iron	zinc
protein	1.000	-0.170	-0.189	0.164
calcium	-0.170	1.000	0.156	-0.153
iron	-0.189	0.156	1.000	0.024
zinc	0.164	-0.153	0.024	1.000

B Finger millet

	calcium	iron	magnesium	zinc	carbs	fibre	protein	ash	fat
calcium	1.000	-0.153	0.162	0.221	-0.074	-0.077	-0.009	0.104	0.469
iron	-0.153	1.000	-0.141	0.323	-0.304	-0.560	-0.371	0.483	-0.493
magnesium	0.162	-0.141	1.000	-0.382	0.203	0.124	-0.195	-0.189	0.516
zinc	0.221	0.323	-0.382	1.000	-0.228	-0.337	-0.139	0.262	-0.376
carbs	-0.074	-0.304	0.203	-0.228	1.000	0.716	0.197	-0.629	0.495
fibre	-0.077	-0.560	0.124	-0.337	0.716	1.000	0.698	-0.784	0.514
protein	-0.009	-0.371	-0.195	-0.139	0.197	0.698	1.000	-0.447	0.282
ash	0.104	0.483	-0.189	0.262	-0.629	-0.784	-0.447	1.000	-0.533
fat	0.469	-0.493	0.516	-0.376	0.495	0.514	0.282	-0.533	1.000

C Foxtail millet

	calcium	iron	zinc	carbs	fat	fibre	protein
calcium	1.000	0.012	0.045	0.183	-0.032	0.077	-0.307
iron	0.012	1.000	0.434	-0.299	0.023	-0.107	-0.243
zinc	0.045	0.434	1.000	-0.011	-0.187	0.021	-0.233
carbs	0.183	-0.299	-0.011	1.000	-0.365	0.165	-0.191
fat	-0.032	0.023	-0.187	-0.365	1.000	0.155	0.423
fibre	0.077	-0.107	0.021	0.165	0.155	1.000	-0.049
protein	-0.307	-0.243	-0.233	-0.191	0.423	-0.049	1.000

D Job's tears

	protein	ash	carbs	fat
protein	1.000	-0.447	-0.963	-0.337
ash	-0.447	1.000	0.228	0.529
carbs	-0.963	0.228	1.000	0.286
fat	-0.337	0.529	0.286	1.000

E Kodo

	calcium	iron	zinc	protein
calcium	1.000	-0.291	-0.322	0.165
iron	-0.291	1.000	0.382	-0.059
zinc	-0.322	0.382	1.000	-0.188
protein	0.165	-0.059	-0.188	1.000

F Little millet

	calcium	iron	zinc	protein
calcium	1.000	-0.311	-0.808	-0.621
iron	-0.311	1.000	0.373	0.267
zinc	-0.808	0.373	1.000	0.510
protein	-0.621	0.267	0.510	1.000

G Pearl millet

	calcium	iron	magnesium	zinc	ash	carbs	fat	fibre	protein
calcium	1.000	0.188	0.244	-0.004	0.260	0.196	-0.141	-0.131	0.024
iron	0.188	1.000	0.050	0.675	0.077	-0.081	-0.189	-0.074	0.093
magnesium	0.244	0.050	1.000	-0.104	0.601	0.403	0.172	-0.325	-0.267
zinc	-0.004	0.675	-0.104	1.000	0.011	-0.121	-0.051	-0.224	-0.120
ash	0.260	0.077	0.601	0.011	1.000	0.442	0.060	-0.375	0.029
carbs	0.196	-0.081	0.403	-0.121	0.442	1.000	-0.167	-0.283	0.117
fat	-0.141	-0.189	0.172	-0.051	0.060	-0.167	1.000	-0.301	0.034
fibre	-0.131	-0.074	-0.325	-0.224	-0.375	-0.283	-0.301	1.000	0.145
protein	0.024	0.093	-0.267	-0.120	0.029	0.117	0.034	0.145	1.000

H Proso

	calcium	iron	zinc	protein
calcium	1.000	0.463	0.707	0.849
iron	0.463	1.000	0.712	0.552
zinc	0.707	0.712	1.000	0.820
protein	0.849	0.552	0.820	1.000

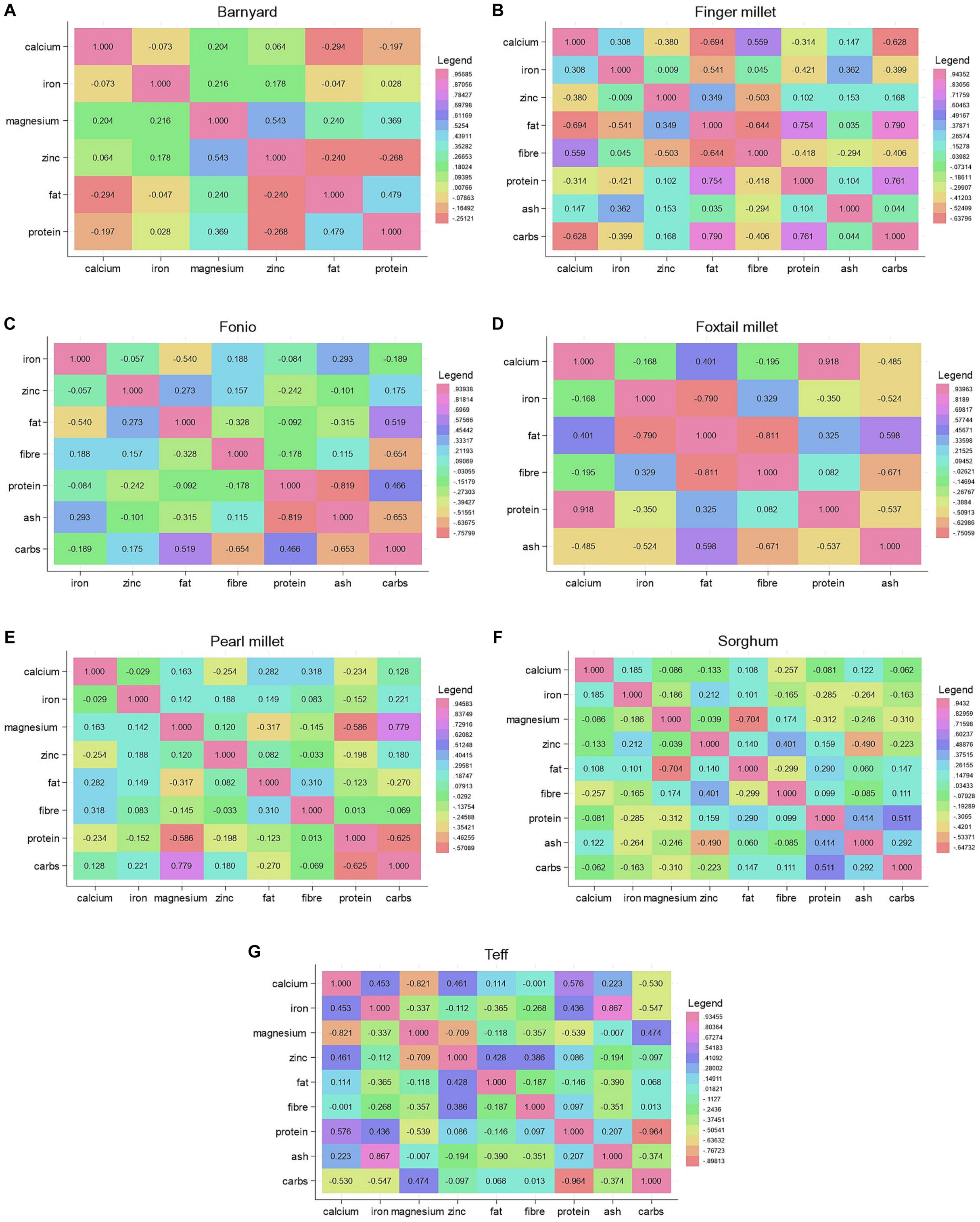
I Sorghum

	calcium	iron	magnesium	zinc	protein
calcium	1.000	0.706	-0.464	0.385	0.145
iron	0.706	1.000	-0.274	0.201	0.178
magnesium	-0.464	-0.274	1.000	-0.348	0.448
zinc	0.385	0.201	-0.348	1.000	-0.270
protein	0.145	0.178	0.448	-0.270	1.000

J Teff

	calcium	iron	magnesium	zinc	fat	fibre	protein
calcium	1.000	-0.100	0.266	0.132	-0.154	-0.210	-0.055
iron	-0.100	1.000	-0.231	0.538	-0.544	0.459	0.771
magnesium	0.266	-0.231	1.000	-0.042	-0.177	-0.094	0.099
zinc	0.132	0.538	-0.042	1.000	-0.482	0.541	0.501
fat	-0.154	-0.544	-0.177	-0.482	1.000	-0.546	-0.593
fibre	-0.210	0.459	-0.094	0.541	-0.546	1.000	0.162
protein	-0.055	0.771	0.099	0.501	-0.593	0.162	1.000

FIGURE 4
Heat plot of different millet genotypes; **(A)** Browntop millet [*Brachiaria ramosa* (L.) Stapf]; **(B)** Finger millet (*Eleusine coracana*); **(C)** Foxtail millet (*Setaria italica*); **(D)** Job's tears (*Coix lacryma-jobi L.*); **(E)** Kodo millet (*Paspalum scrobiculatum*); **(F)** Little millet (*Panicum sumatrense*); **(G)** Pearl millet (*Pennisetum glaucum*); **(H)** Proso millet (*Panicum miliaceum* L.); **(I)** Sorghum (*Sorghum bicolor*); **(J)** Teff [*Eragrostis tef* (Zucc.) Trotter].



A Barnyard

	calcium	iron	magnesium	zinc	fat	protein
calcium	1.000	-0.073	0.204	0.064	-0.294	-0.197
iron	-0.073	1.000	0.216	0.178	-0.047	0.028
magnesium	0.204	0.216	1.000	0.543	0.240	0.369
zinc	0.064	0.178	0.543	1.000	-0.240	-0.268
fat	-0.294	-0.047	0.240	-0.240	1.000	0.479
protein	-0.197	0.028	0.369	-0.268	0.479	1.000

B Finger millet

	calcium	iron	zinc	fat	fibre	protein	ash	carbs
calcium	1.000	0.308	-0.380	-0.694	0.559	-0.314	0.147	-0.628
iron	0.308	1.000	-0.009	-0.541	0.045	-0.421	0.362	-0.399
zinc	-0.380	-0.009	1.000	0.349	-0.503	0.102	0.153	0.168
fat	-0.694	-0.541	0.349	1.000	-0.644	0.754	0.035	0.790
fibre	0.559	0.045	-0.503	-0.644	1.000	-0.418	-0.294	-0.406
protein	-0.314	-0.421	0.102	0.754	-0.418	1.000	0.104	0.761
ash	0.147	0.362	0.153	0.035	-0.294	0.104	1.000	0.044
carbs	-0.628	-0.399	0.168	0.790	-0.406	0.761	0.044	1.000

C Fonio

	iron	zinc	fat	fibre	protein	ash	carbs
iron	1.000	-0.057	-0.540	0.188	-0.084	0.293	-0.189
zinc	-0.057	1.000	0.273	0.157	-0.242	-0.101	0.175
fat	-0.540	0.273	1.000	-0.328	-0.092	-0.315	0.519
fibre	0.188	0.157	-0.328	1.000	-0.178	0.115	-0.654
protein	-0.084	-0.242	-0.092	-0.178	1.000	-0.819	0.466
ash	0.293	-0.101	-0.315	0.115	-0.819	1.000	-0.653
carbs	-0.189	0.175	0.519	-0.654	0.466	-0.653	1.000

D Foxtail millet

	calcium	iron	fat	fibre	protein	ash
calcium	1.000	-0.168	0.401	-0.195	0.918	-0.485
iron	-0.168	1.000	-0.790	0.329	-0.350	-0.524
fat	0.401	-0.790	1.000	-0.811	0.325	0.598
fibre	-0.195	0.329	-0.811	1.000	0.082	-0.671
protein	0.918	-0.350	0.325	0.082	1.000	-0.537
ash	-0.485	-0.524	0.598	-0.671	-0.537	1.000

E Pearl millet

	calcium	iron	magnesium	zinc	fat	fibre	protein	carbs
calcium	1.000	-0.029	0.163	-0.254	0.282	0.318	-0.234	0.128
iron	-0.029	1.000	0.142	0.188	0.149	0.083	-0.152	0.221
magnesium	0.163	0.142	1.000	0.120	-0.317	-0.145	-0.586	0.779
zinc	-0.254	0.188	0.120	1.000	0.082	-0.033	-0.198	0.180
fat	0.282	0.149	-0.317	0.082	1.000	0.310	-0.123	-0.270
fibre	0.318	0.083	-0.145	-0.033	0.310	1.000	0.013	-0.069
protein	-0.234	-0.152	-0.586	-0.198	-0.123	0.013	1.000	-0.625
carbs	0.128	0.221	0.779	0.180	-0.270	-0.069	-0.625	1.000

F Sorghum

	calcium	iron	magnesium	zinc	fat	fibre	protein	ash	carbs
calcium	1.000	0.185	-0.086	-0.133	0.108	-0.257	-0.081	0.122	-0.062
iron	0.185	1.000	-0.186	0.212	0.101	-0.165	-0.285	-0.264	-0.163
magnesium	-0.086	-0.186	1.000	-0.039	-0.704	0.174	-0.312	-0.246	-0.310
zinc	-0.133	0.212	-0.039	1.000	0.140	0.401	0.159	-0.490	-0.223
fat	0.108	0.101	-0.704	0.140	1.000	-0.299	0.290	0.060	0.147
fibre	-0.257	-0.165	0.174	0.401	-0.299	1.000	0.099	-0.085	0.111
protein	-0.081	-0.285	-0.312	0.159	0.290	0.099	1.000	0.414	0.511
ash	0.122	-0.264	-0.246	-0.490	0.060	-0.085	0.414	1.000	0.292
carbs	-0.062	-0.163	-0.310	-0.223	0.147	0.111	0.511	0.292	1.000

G Teff

	calcium	iron	magnesium	zinc	fat	fibre	protein	ash	carbs
calcium	1.000	0.453	-0.821	0.461	0.114	-0.001	0.576	0.223	-0.530
iron	0.453	1.000	-0.337	-0.112	-0.365	-0.268	0.436	0.867	-0.547
magnesium	-0.821	-0.337	1.000	-0.709	-0.118	-0.357	-0.539	-0.007	0.474
zinc	0.461	-0.112	-0.709	1.000	0.428	0.386	0.086	-0.194	-0.097
fat	0.114	-0.365	-0.118	0.428	1.000	-0.187	-0.146	-0.390	0.068
fibre	-0.001	-0.268	-0.357	0.386	-0.187	1.000	0.097	-0.351	0.013
protein	0.576	0.436	-0.539	0.086	-0.146	0.097	1.000	0.207	-0.964
ash	0.223	0.867	-0.007	-0.194	-0.390	-0.351	0.207	1.000	-0.374
carbs	-0.530	-0.547	0.474	-0.097	0.068	0.013	-0.964	-0.374	1.000

FIGURE 5
Heat plot of different millets varieties; **(A)** Barnyard millet (*Echinochloa esculenta*); **(B)** Finger millet (*Eleusine coracana*); **(C)** Fonio (*Digitaria exilis* Stapf); **(D)** Foxtail millet (*Setaria italica*); **(E)** Pearl millet (*Pennisetum glaucum*); **(F)** Sorghum (*Sorghum bicolor*); **(G)** Teff [*Eragrostis* tef (Zucc.) Trotter].

Protein content in browntop millet accessions/genotypes was positively related to zinc ($r = 0.164$); among minerals, iron was positively correlated with both zinc and calcium. Iron and calcium showed positive correlation with zinc among browntop millet genotypes, but a negative correlation among varieties.

In fonio varieties, protein was negatively correlated with iron ($r = -0.084$) and zinc ($r = -0.242$); iron and zinc were also negatively correlated ($r = -0.057$) with each other. Among foxtail millet genotypes, protein content was negatively correlated with iron, zinc, and calcium but showed positive correlation with calcium among varieties. Calcium was positively correlated with iron in the foxtail millet genotypes whereas it was negatively correlated in varieties. Among Job's tears genotypes, protein was negatively correlated with macronutrients ash ($r = -0.447$), fat ($r = -0.337$) and carbohydrates ($r = -0.963$). Among kodo and little millet genotypes, positive correlation was observed between iron and zinc whereas calcium was negatively correlated with grain iron and zinc content in both millets. Pearl millet genotypes and varieties showed positive correlation between iron and zinc. Negative correlation was observed between iron and calcium ($r = -0.029$) in different pearl millet varieties. In proso millet, positive correlation was observed among the varieties.

Among sorghum genotypes/varieties, there was positive correlation between iron and zinc whereas magnesium was found to be negatively correlated with all minerals. Most of the genotypes and varieties of various types of millets showed positive correlation between grain iron and zinc content, as both minerals share the same physiological mechanism of absorption from soil and assimilation into grains. A positive correlation was observed between protein content and most of the minerals, which act as cofactors for most of the protein enzymes (Govindaraj et al., 2013; Tomar et al., 2021).

3.5 Recommendation

Nutrition tables displaying the nutrient content of various types of millets draw their data from different sources. This data can often be contradictory or confusing, and potentially misleading, because rarely is it mentioned which variety of millet the data pertains to. It is often not mentioned if the data represents a commonly grown variety. In the interests of clarity on the nutrient content of various millets, it is recommended that 'regional nutrient tables' are collated, including an even larger number of nutrients and antinutrients as well, and specifying the locally commonly grown millet varieties they pertain to. It is also important to use consistent methodologies and to specify the level of primary processing in relation to nutrient content. More accurate global nutrient tables can thus be collated for millets, showing the average and range of each nutrient. Importantly, it is recommended to base social programs and product development on varieties of millet that can better provide the required nutrients. Given the identified wide variation of nutrient levels in millet varieties and further variations found in the genotypes, it is recommended that breeding programs incorporate targeted nutrients in their selection process. Lastly, it is recommended that other factors like growing conditions and levels of primary and secondary processing are considered in the compilation of nutrient tables in order to show how big an influence they have on the nutrient levels of millets. Until these recommendations are followed, it is suggested that the millet nutrient data and summary table presented in this study are the most appropriate and accurate to use when referencing millet nutrition data globally.

3.6 Limitation of the publications included in this study

Some of the limitations observed in the studies included in this analysis were:

1. Some studies did not specify the name of the variety of millet that is available in the local market. Despite this lack of clarity, the study was included in the analysis.
2. Most of the studies did not provide detailed information on genotypes, and varieties. Therefore, the crops were categorized either under genotype (accessions, genotypes, lines, hybrids) or variety (materials released by researchers for consumption, landraces, or those available in the market) as indicated in the results section. Due to this, the multiple subgroup analysis could not be conducted.
3. The methodologies used to assess nutrient contents varied widely.
4. Some studies were conducted under glasshouse conditions and the studies did not provide any information on what is the future of the research.
5. Soil and other environmental conditions were not taken into account.
6. The level of processing of millet grain was not clearly indicated in many studies.

4 Conclusion

This systematic review showed that there is wide variation in the micro and macronutrient content of millet grains, based on the genotype or released variety (including landraces and those from the market). Finger millet and teff were consistently reported to have a very high calcium content of 331.29 ± 10 mg/100 g and 183.41 ± 29 mg/100 g, respectively in released varieties. Some released finger millet varieties were reported to have the lowest calcium content. This requires attention as finger millet is generally thought to be high in calcium. Low-calcium finger millet varieties should thus be replaced. Teff, regardless of variety or genotype, consistently reported calcium content >100 mg/100 g. Iron content was highest for finger millet at 12.21 ± 13.69 mg/100 g followed by teff at 11.09 ± 8.35 mg/100 g. Pearl millet contains the highest zinc content of 8.73 ± 11.55 mg/100 g. Protein content was highest in proso millet at 12.42 ± 1.99 g/100 g followed by job's tears at 12.66 g/100 g and barnyard millet with 12.05 ± 1.77 g/100 g. Most of the millets had high protein content. However, within finger millet, some varieties had protein content as low as 2.6 g/100 g. Based on this study, it is clear that nutrient content is not the same in all varieties or genotypes within each type of millet. This is likely due to various conditions such as genotypic and agronomic factors as well as geographical and environmental factors including rainfall, soil type, soil nutrient content, application of fertilizer, plant physiological mechanisms for transport and deposition of different minerals, and level of processing. Therefore, in dietary planning, it is essential to look at these aspects carefully.

This review consolidates data on the nutrient profiling of millets. It can help governments and development agencies in designing nutrition programs including millets; researchers in designing more accurate nutrition tables for millets and identifying nutrient-rich varieties for inclusion in intervention programs, or crop breeding programs to develop improved crop varieties, crop biofortification, etc.

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 authors.

Author contributions

SA: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Writing – original draft. AR: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. RB: Data curation, Formal analysis, Methodology, Writing – review & editing. CB: Data curation, Writing – review & editing. PM: Data curation, Writing – review & editing. JS: Data curation, Writing – review & editing. SU: Validation, Writing – review & editing. JK-P: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was funded by the Odisha millet mission as part of the International Year of Millet 2023.

Acknowledgments

The authors sincerely acknowledge Ram for language editing.

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.

The reviewer MD declared a shared research partnership group [CGIAR] with author SA and JK-P to the handling editor at the time of review.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1324046/full#supplementary-material

References

Abdelhalim, T. S., Kamal, N. M., and Hassan, A. B. (2019). Nutritional potential of wild sorghum: grain quality of Sudanese wild sorghum genotypes (*Sorghum bicolor* L. Moench). *Food Sci. Nutr.* 7, 1529–1539. doi: 10.1002/fsn3.1002

Abewa, A., Adgo, E., Alemayehu, G., Yitaferu, B., Solomon, J. K., Assefa, K., et al. (2020). Genotypes and their growing environments influence on physicochemical qualities of tef grain in the highlands of Ethiopia. *Ethiop. J. Agric. Sci.* 9, 1–27. doi: 10.3390/agronomy9060283

Adéoti, K., Kouhoundé, S. H., Noumavo, P. A., Baba-Moussa, F., and Toukourou, F. (2017). Nutritional value and physicochemical composition of pearl millet (*Pennisetum glaucum*) produced in Benin. *J. Microbiol. Biotechnol. Food Sci.* 7, 92–96. doi: 10.15414/jmbfs.2017.7.1.92-96

Admassu, S., Teamir, M., and Alemu, D. (2009). Chemical composition of local and improved finger millet [*Eleusine corocana* (L.) Gaetrtin] varieties grown in Ethiopia. *Ethiop. J. Health Sci.* 19:11.

Ahmad, F., Pasha, I., Saeed, M., and Asgher, M. (2018). Biochemical profiling of Pakistani sorghum and millet varieties with special reference to anthocyanins and condensed tannins. *Int. J. Food Prop.* 21, 1586–1597. doi: 10.1080/10942912.2018.1502198

Anitha, S., Govindaraj, M., and Kane-Potaka, J. (2019). Balanced amino acid and higher micronutrients in millets complements legumes for improved human dietary nutrition. *Cereal Chem.* 97, 74–84. doi: 10.1002/cche.10227

Anitha, S., Kane-Potaka, J., Botha, R., Givens, D. I., Sulaiman, N. L. B., Upadhyay, S., et al. (2021). Millets can have a major impact on improving Iron status, hemoglobin level, and in reducing Iron deficiency Anemia–a systematic review and Meta-analysis. *Front. Nutr.* 8:725529. doi: 10.3389/fnut.2021.725529

Anitha, S., Tsusaka, T. W., Botha, R., Givens, D. I., Rajendran, A., Parasannanavar, D. J., et al. (2024). Impact of regular consumption of millets on fasting and post-prandial blood glucose level: a systematic review and meta-analysis. *Front. Sustain. Food Syst.* 7:1226474. doi: 10.3389/fsufs.2023.1226474

Anitha, S., Tsusaka, T. W., Botha, R., Kane-Potaka, J., Givens, D. I., Rajendran, A., et al. (2022). Are millets more effective in managing Hyperlipidaemia and obesity than major cereal Staples? A systematic review and Meta-analysis. *Sustain. For.* 14:6659. doi: 10.3390/su14116659

Anuradha, N., Satyavathi, C. T., Meena, M. C., Sankar, S. M., Bharadwaj, C., Bhat, J., et al. (2017). Evaluation of pearl millet [*Pennisetum glaucum* (L.) R. Br.] for grain iron and zinc content in different agro climatic zones of India. *Indian J. Genet. Plant Breed.* 77, 65–73. doi: 10.5958/0975-6906.2017.00009.8

Ashok Kumar, A., Reddy, B. V., Ramaiah, B., Sahrawat, K. L., and Pfeiffer, W. H. (2012). Genetic variability and character association for grain iron and zinc contents in sorghum germplasm accessions and commercial cultivars. *Eur. J. Plant Sci. Biotechnol.* 6, 1–5.

Ashok Kumar, A., Reddy, B. V. S., Sharma, H. C., Hash, C. T., Srinivasa Rao, P., Ramaiah, B., et al. (2011). Recent advances in sorghum genetic enhancement research at ICRISAT. *Am. J. Plant Sci.* 2, 589–600. doi: 10.4236/ajps.2011.24070

Bachar, K., Mansour, E., Khaled, A. B., Abid, M., Haddad, M., Yahya, L. B., et al. (2013). Fiber content and mineral composition of the finger millet of the oasis of Gabes Tunisia. *J. Agric. Sci.* 5:219. doi: 10.5539/jas.v5n2p219

Bachir, G. D., Karimou, I., and Hash, C. T. (2016). Grain iron density variability among new farmer-preferred experimental millet varieties from Niger. *Int. J. Biol. Chem. Sci.* 10, 1865–1868. doi: 10.4314/ijbcs.v10i4.34

Bagdi, A., Balázs, G., Schmidt, J., Szatmári, M., Schoenlechner, R., Berghofer, E., et al. (2011). Protein characterization and nutrient composition of Hungarian proso millet varieties and the effect of decortication. *Acta Aliment.* 40, 128–141. doi: 10.1556/aalim.40.2011.1.15

Barbeau, W. E., and Hilu, K. W. (1993). Protein, calcium, iron, and amino acid content of selected wild and domesticated cultivars of finger millet. *Plant Foods Hum. Nutr.* 43, 97–104. doi: 10.1007/BF01087914

Barikmo, I., Ouattara, F., and Oshaug, A. (2004). Protein, carbohydrate and fiber in cereals from Mali–how to fit the results in a food composition table and database. *J. Food Comp. Anal.* 17, 291–300. doi: 10.1016/J.JFCA.2004.02.008

Basahy, A. Y. (1996). Nutritional and chemical evaluation of pearl millet grains (*Pennisetum typhoides* (Burm. F.) Stapf & Hubbard, Poaceae) grown in the Gizan area of Saudi Arabia. *Int. J. Food Sci. Nutr.* 47, 165–169. doi: 10.3109/09637489609012578

Beavers, A. S., Lounsbury, J. W., Richards, J. K., Huck, S. W., Skolits, G. J., and Esquivel, S. L. (2013). Practical considerations for using exploratory factor analysis in educational research. *Pract. Assess. Res. Eval.* 18:6. doi: 10.7275/qv2q-rk76

Berwal, M. K., Chugh, L. K., Goyal, P., Kumar, R., and Vart, D. (2017). Protein, micronutrient, antioxidant potential and phytate content of pearl millet hybrids and composites adopted for cultivation by farmers of Haryana, India. *Int. J. Curr. Microbiol. App. Sci.* 6, 376–386. doi: 10.20546/ijcmas.2017.603.043

Bhati, D., Bhatnagar, V., and Acharya, V. (2016). Effect of pre-milling processing techniques on pearl millet grains with special reference to in-vitro iron availability. *Asian J. Dairy Food Res.* 35, 76–80. doi: 10.18805/ajdfr.v35i1.9256

Brunda, S. M., Kamatar, M. Y., Naveenkumar, K. L., and Hundekar, R. (2015). Genetic variability in the foxtail millet (*Setaria italica*) germplasm as determined by nutritional traits. *Int. J. Pure App. Biosci.* 5:18. doi: 10.17660/ActaHortic.2019.1241.18

Cakmak, I., and Kutman, U. Á. (2018). Agronomic biofortification of cereals with zinc: a review. *Eur. J. Soil Sci.* 69, 172–180. doi: 10.1111/ejss.12437

Cámara, F., and Amaro, M. A. (2003). Nutritional aspect of zinc availability. *Int. J. Food Sci. Nutr.* 54, 143–151. doi: 10.1080/0963748031000084098

Cercamondi, C. I., Egli, I. M., Mitchikpe, E., Tossou, F., Zeder, C., Hounhouigan, J. D., et al. (2013). Total iron absorption by young women from iron-biofortified pearl millet composite meals is double that from regular millet meals but less than that from post-harvest iron-fortified millet meals. *J. Nutr.* 143, 1376–1382. doi: 10.3945/jn.113.176826

Chavan, U. D., Pansare, S. S., Patil, J. V., and Shinde, M. S. (2015). Preparation and nutritional quality of sorghum papads. *Int. J. Curr. Microbiol. App. Sci.* 4, 806–823.

Chavan, U. D., Patil, J. V., and Shinde, M. S. (2009). Nutritional and roti quality of sorghum genotypes, Indonesian. *J. Agric. Sci.* 10, 80–87. doi: 10.21082/ijas.v10n2.2009

Cheik, A. O., Aly, S., Yaya, B., and Alfred, T. S. (2006). Comparative study on nutritional and technological quality of fourteen (14) cultivars of pearl millets [*Pennisetum glaucum* (L) Leeke] in Burkina Faso. *Pak. J. Nutr.* 5, 512–521. doi: 10.3923/pjn.2006.512.521

Chen, C. H. (1978). *Chemical and physical variance in composition of thirty-five genotypes of pearl millet Pennisetum typhoides (Doctoral dissertation)*. Texas Tech University.

Clottey, V. A., Avornyo, F., Addo-Kwafo, A., and Agyare, W. A. (2006). The potential of fonio (*Digitaria exilis*, Stapf) as feed for monogastrics. *Livest. Res. Rural. Dev.* 18:7.

Derib, A., Wegayehu, F., Amhaeyesus, B., Mitiku, A., and Weldetsadik, K. (2018). Characterization of tef (*Eragrostis tef* zucc. Trotter [cv. Magna]) in minjar Shenkora district of Central Ethiopia. *Afr. J. Food Agric. Nutr. Dev.* 18, 13664–13676. doi: 10.18697/AJFAND.83.17365

Elsadig, L. M., Idris, A. E., Osman, A. A. M., and Abdel-Rahman, N. A. (2016). Investigation of quality traits in 30 Sudanese pearl millet (*Pennisetum glaucum* [L.] R. Br.) genotypes. *Int. J. Appl. Pure Sci. Agric.* 2, 62–71.

Ershow, A. G., and Wong-Chen, K. (1990). Chinese food composition tables: an annotated translation of the 1981 edition published by the Institute of Nutrition and Food Hygiene, Chinese academy of preventive medicine, Beijing. *J. Food Compos. Anal.* 3, 191–434. doi: 10.1016/0889-1575(90)90026-I

FAO/WHO. (2021). *Human vitamin and mineral requirements. Report of a joint FAO/WHO expert consultation Bangkok*. Thailand: FAO/WHO.

FAOSTAT. (2023). *Millet Production*. Available at: http://www.fao.org/faostat/en/#data/QC (Accessed August 25, 2023).

Finkelstein, J. L., Mehta, S., Udipi, S. A., Ghugre, P. S., Luna, S. V., Wenger, M. J., et al. (2015). A randomized trial of iron-biofortified pearl millet in school children in India. *J. Nutr.* 145, 1576–1581. doi: 10.3945/jn.114.208009

Food Composition Table for Nepal. (2012). *Nepal government, Ministry of Agriculture development, department of food technology and quality control*. Kathmandu, Nepal: National Nutrition Program.

García-Casal, M. N., Layrisse, M., Solano, L., Barón, M. A., Arguello, F., Llovera, D., et al. (1998). Vitamin a and β-carotene can improve nonheme iron absorption from rice, wheat and corn by humans. *J. Nutr.* 128, 646–650. doi: 10.1093/jn/128.3.646

Gerrano, A. S., Labuschagne, M. T., Van Biljon, A., and Shargie, N. G. (2006). Quantification of mineral composition and total protein content in sorghum [*Sorghum bicolor* (L.) Moench] genotypes. *Cereal Res. Commun.* 44, 272–285. doi: 10.1556/0806.43.2015.046

Govindaraj, M., Rai, K. N., Kanatti, A., Upadhyaya, H. D., Shivade, H., and Rao, A. S. (2020b). Exploring the genetic variability and diversity of pearl millet core collection germplasm for grain nutritional traits improvement. *Sci. Rep.* 10:21177. doi: 10.1038/s41598-020-77818-0

Govindaraj, M., Rai, K. N., Shanmugasundaram, P., Dwivedi, S. L., Sahrawat, K. L., Muthaiah, A. R., et al. (2013). Combining ability and heterosis for grain iron and zinc densities in pearl millet. *Crop Sci.* 53, 507–517. doi: 10.2135/cropsci2012.08.0477

Govindaraj, M., Yadav, O. P., Rajpurohit, B. S., Kanatti, A., Rai, K. N., and Dwivedi, S. L. (2020a). Genetic variability, diversity and interrelationship for twelve grain minerals in 122 commercial pearl millet cultivars in India. *Agric. Res.* 9, 516–525. doi: 10.1007/s40003-020-00470-7

Hemamalini, C., Sam, S., and Patro, T. S. S. (2021). Awareness and consumption of small millets. *Pharm. Innov. J.* 10, 34–37.

Hussain, T. (2001). *Food composition table for Pakistan*.

ICMR. (2020) *Recommended dietary allowances and estimated average requirements*. Hyderabad, India: National Institute of Nutrition, pp. 1–319.

Joshi, B. K., Vista, S. P., Gurung, S. B., Ghimire, K. H., Gurung, R., Pant, S., et al. (2020). *Cultivar mixture for minimizing risk in farming and conserving agrobiodiversity*. Traditional crop biodiversity for mountain food and nutrition security in Nepal. Tools and research results of the UNEP GEF local crop project, Nepal, pp. 14–24.

Kamatar, M. Y., Brunda, S. M., Rajaput, S., and Hundekar, R. (2015). Nutritional composition of seventy five, elite germplasm of foxtail millet (*Setaria italica*). *Int. J. Adv. Res. Technol.* 4, 1–6. doi: 10.17577/IJERTV4IS040075

Kayodé, A. P., Linnemann, A. R., Hounhouigan, J. D., Nout, M. J., and van Boekel, M. A. (2006). Genetic and environmental impact on iron, zinc, and phytate in food sorghum grown in Benin. *J. Agric. Food Chem.* 54, 256–262. doi: 10.1021/jf0521404

Kennedy, G. (2002). The scourge of" hidden hunger", global dimensions of micronutrient deficiencies. *Food Nutri. Agric*, 32, 8–14.

Kim, J. Y., Jang, K. C., Park, B. R., Han, S. I., Choi, K. J., Kim, S. Y., et al. (2011). Physicochemical and antioxidative properties of selected barnyard millet (*Echinochloa utilis*) species in Korea. *Food Sci. Biotechnol.* 20, 461–469. doi: 10.1007/s10068-011-0064-z

Kiprotich, F., Kimurto, P., Ombui, P., Towett, B., Jeptanui, L., Henry, O., et al. (2015). Multivariate analysis of nutritional diversity of selected macro and micro nutrients in pearl millet (*Pennisetum glaucum*) varieties. *Afr. J. Food Sci.* 9, 103–112. doi: 10.5897/AJFS2014.1236

Koreissi-Dembélé, Y., Fanou-Fogny, N., Hulshof, P. J., and Brouwer, I. D. (2013). Fonio (*Digitaria exilis*) landraces in Mali: nutrient and phytate content, genetic diversity and effect of processing. *J. Food Compos. Anal.* 29, 134–143. doi: 10.1016/J.JFCA.2012.07.010

Krishnan, R., and Meera, M. S. (2017). Assessment of inhibitory factors on bioaccessibility of iron and zinc in pearl millet (*Pennisetum glaucum* (L.) R. Br.) cultivars. *J. Food Sci. Technol.* 54, 4378–4386. doi: 10.1007/s13197-017-2911-2

Kulthe, A. A., Thorat, S. S., and Lande, S. B. (2016). Characterization of pearl millet cultivars for proximate composition, minerals and anti-nutritional contents. *Adv. Life Sci.* 5, 4672–4675.

Kumar, M., Rani, K., Ajay, B. C., Patel, M. S., Mungra, K. D., and Patel, M. P. (2020). Multivariate diversity analysis for grain micronutrients concentration, yield and agro-morphological traits in pearl millet (*Pennisetum glaucum* (L) R. Br.). *Int. J. Curr. Microbiol. Appl. Sci* 9, 2209–2226. doi: 10.20546/ijcmas.2020.903.253

Kumari, D., Madhujith, T., and Chandrasekara, A. (2016). Comparison of phenolic content and antioxidant activities of millet varieties grown in different locations in Sri Lanka. *Food Sci. nutr.* 5, 474–485. doi: 10.1002/fsn3.415

Lever, J., Krzywinski, M., and Altman, N. (2017). Points of significance: principal component analysis. *Nat. Methods* 14, 641–642. doi: 10.1038/nmeth.4346

Longvah, T., Ananthan, R., Bhaskarachary, K., and Venkaiah, K. (2017). *Indian food composition tables*. National Institute of Nutrition. Indian Council of Medical Research, Hyderabad, Telangana, India.

Luithui, Y., and Meera, M. S. (2019). Effect of heat processing on the physicochemical properties of Job's tears grain. *J. Food Meas. Charact.* 13, 874–882. doi: 10.1007/s11694-018-0001-4

Lukmanji, Z., Hertzmark, E., Mlingi, N., Assey, V., Ndossi, G., and Fawzi, W. (2008). *Tanzania food composition tables*. MUHAS-TFNC, HSPH, Dar Es Salaam Tanzania.

Mabelebele, M., Siwela, M., Gous, R. M., and Iji, P. A. (2015). Chemical composition and nutritive value of south African sorghum varieties as feed for broiler chickens. *S. Afr. J. Anim. Sci.* 45, 206–213. doi: 10.4314/sajas.v45i2.12

Mak, T. N., Prynne, C. J., Cole, D., Fitt, E., Bates, B., and Stephen, A. M. (2013). Patterns of sociodemographic and food practice characteristics in relation to fruit and vegetable consumption in children: results from the UK National Diet and nutrition survey rolling Programme (2008–2010). *Public Health Nutr.* 16, 1912–1923. doi: 10.1017/S1368980013001912

Manful, J. T., Atokple, I. D. K., and Gayin, J. (2001). *Evaluation of agronomic and nutritional characteristics of released/recommended sorghum varieties in Ghana*.

Manimozhi Selvi, V., Nirmalakumari, A., and Senthil, N. (2015). Genetic diversity for zinc, calcium and iron content of selected little millet genotypes. *J. Nutr. Food Sci.* 5:2. doi: 10.4172/2155-9600.1000417

Manwaring, H. R. (2018). *Accessing and dissecting useful genetic variations for Iron and zinc content in pearl millet (Pennisetum glaucum) using genome wide association studies, (Doctoral dissertation)*. Aberystwyth University.

Mishra, J. S., Hariprasanna, K., Rao, S. S., and Patil, J. V. (2015). Biofortification of post-rainy sorghum (*Sorghum bicolor*) with zinc and iron through fertilization strategy. *Indian J. Agric. Sci.* 85, 721–724. doi: 10.56093/ijas.v85i5.48515

Mofokeng, M. A. (2015). *Diversity analysis of south African sorghum genotypes using agronomic traits, SSR markers and protein content and amino acid composition (doctoral dissertation)*.

Motlhaodi, T., Bryngelsson, T., Chite, S., Fatih, M., Ortiz, R., and Geleta, M. (2018). Nutritional variation in sorghum [*Sorghum bicolor* (L.) Moench] accessions from southern Africa revealed by protein and mineral composition. *J. Cereal Sci.* 83, 123–129. doi: 10.1016/J.JCS.2018.08.010

Mugalavai, V. K., and Onkware, A. O. (2018). Exploiting the nutritional profile and consumer behavior on choice and utilization of selected sorghum varieties in Western Kenya. *Int. J. Sci. Res.* 8, 368–373. doi: 10.21275/ART20199415

Mustafa, A. A., and Magdi, A. (2003). Proximate composition and the content of sugars, amino acids and anti-nutritional factors of three sorghum varieties. *Res. Bult. Agric. Res. Center King Saud Univ.* 125, 5–19.

Mustafa, A. F., Seguin, P., Belair, G., and Kumar, A. (2008). Chemical composition and ruminal degradability of grain pearl millet grown in southwestern Quebec. *Can. J. Anim. Sci.* 88, 71–77. doi: 10.4141/CJAS07075

Mwai, J., Kimani, A., Mbelenga, E., Charrondiere, U. R., Grande, F., Rittenschober, D., et al. (2018). *Kenya food composition tables*. Nairobi: FAO and Kenya Go.

Nakarani, U. M., Singh, D., Suthar, K. P., Karmakar, N., Faldu, P., and Patil, H. E. (2021). Nutritional and phytochemical profiling of nutracereal finger millet (*Eleusine coracana* L.) genotypes. *Food Chem.* 341:128271. doi: 10.1016/j.foodchem.2020.128271

Ng'uni, D., Geleta, M., Johansson, E., Fatih, M., and Bryngelsson, T. (2011). Characterization of the southern African sorghum varieties for mineral contents: prospects for breeding for grain mineral dense lines. *Afr. J. Food Sci.* 5, 436–445. doi: 10.5897/AJFS.9000041

Ng'uni, D., Shargie, N. G., Andersson, S. C., van Biljon, A., and Labuschagne, M. T. (2016). Genetic variation and trait associations of yield, protein and grain micronutrients for identification of promising sorghum varieties. *Cereal Res. Commun.* 44, 681–693. doi: 10.1556/0806.44.2016.033

Niharika, V., Rao, B. G., Tushara, M., and Rao, V. S. (2020). Studies on performance of browntop millet indigenous collections for grain yield and nutritional traits. *J. Pharmacogn. Phytochem.* 9, 2636–2638.

Nirgude, M., Babu, B. K., Shambhavi, Y., Singh, U. M., Upadhyaya, H. D., and Kumar, A. (2014). Development and molecular characterization of genic molecular markers for grain protein and calcium content in finger millet (*Eleusine coracana* (L.) Gaertn.). *Mol. Biol. Rep.* 41, 1189–1200. doi: 10.1007/s11033-013-2825-7

Nirubana, V., Ganesamurthy, K., Ravikesavan, R., and Chitdeshwari, T. (2017). Genetic diversity studies in kodo millet (*Paspalum scrobiculatum* L.) germplasm accessions based on biometrical and nutritional quality traits. *Int. J. Curr. Microbiol. App. Sci.* 6, 832–839. doi: 10.20546/IJCMAS.2017.610.099

Obilana, A. B. (2003). Overview: importance of millets in Africa. In: *AFRIPRO Proceedings of workshop on the Proteins of Sorghum and Millets: Enhancing Nutritional and Functional Properties for Africa*. Pretoria, South Africa, pp. 26–43.

Otieno, G. A., Recha, T., Fadda, C., Nyamongo, D., Wahome, P., Okoth, E., et al. (2020). *Enhancing access to genetic resources for climate change adaptation in Kenya, Uganda and Tanzania: Seed catalogues of best perfoming varieties of finger millet and sorghum in Nyando, Kenya*.

Panwar, P., Dubey, A., and Verma, A. K. (2016). Evaluation of nutraceutical and antinutritional properties in barnyard and finger millet varieties grown in Himalayan region. *J. Food Sci. Technol.* 53, 2779–2787. doi: 10.1007/s13197-016-2250-8

Panwar, P., Nath, M., Yadav, V. K., and Kumar, A. (2010). Comparative evaluation of genetic diversity using RAPD, SSR and cytochrome P450 gene based markers with respect to calcium content in finger millet (*Eleusine coracana* L. Gaertn.). *J. Genet.* 89, 121–133. doi: 10.1007/s12041-010-0052-8

Patil, H. E., Patel, B. K., and Pali, V. (2019). Nutritive evaluation of finger millet [*Eleusine coracana* (L.) Gaertn.] genotypes for quality improvement. *Int. J. Chem. Stud.* 7, 642–646.

Pontieri, P., Troisi, J., Boffa, A., Giudice, F. D., Chessa, A. L., Pizzolante, G., et al. (2017). Nutrient, fatty acid and mineral composition of selected white food-grade sorghum hybrids grown in a Mediterranean area of southern Italy. *Maydica* 62, 1–13.

Poole, N., and Kane-Potaka, J. (2020). The smart food triple bottom line–starting with diversifying staples–including summary of latest smart food studies at ICRISAT. *Agric. Dev. J.* 41, 21–23.

Ragaee, S., Abdel-Aal, E. S. M., and Noaman, M. (2006). Antioxidant activity and nutrient composition of selected cereals for food use. *Food Chem.* 98, 32–38. doi: 10.1016/j.foodchem.2005.04.039

Rai, K. N., Patil, H. T., Yadav, O. P., Govindaraj, M., Khairwal, I. S., Cherian, B., et al. (2014). Dhanashakti: a high-iron pearl millet variety. *Indian Farm.* 64, 32–34.

Rai, K. N., Yadav, O. P., Govindaraj, M., Pfeiffer, W. H., Yadav, H. P., Rajpurohit, B. S., et al. (2016). Grain iron and zinc densities in released and commercial cultivars of pearl millet (*Pennisetum glaucum*). *Indian J. Agric. Sci.* 86, 11–16. doi: 10.56093/ijas.v86i3.56832

Ramadhan, N., Hervani, D., Martinsyah, R. H., and Mutia, Y. D. (2023). *Evaluation of nutrition content of six local job's tears (Coix lacryma jobi-L.) accessions in west Sumatera, Indonesia*. In: IOP Conference Series: Earth and Environmental Science, No. 1160.

Sankara Vadivoo, A., Joseph, R., and Meenakshi Ganesan, N. (1998). Genetic variability and diversity for protein and calcium contents in finger millet (*Eleusine coracana* (L.) Gaertn) in relation to grain color. *Plant Foods Hum. Nutr.* 52, 353–364. doi: 10.1023/A:1008074002390

Serba, D. D., Yadav, R. S., Varshney, R. K., Gupta, S. K., Mahalingam, G., Srivastava, R. K., et al. (2020). "Genomic designing of pearl millet: a resilient crop for arid and semi-arid environments" in *Genomic designing of climate-smart cereal crops*. ed. C. Kole (Berlin: Springer), 221–286.

Sharma, R., Girish, A. G., Upadhyaya, H. D., Humayun, P., Babu, T. K., Rao, V. P., et al. (2014). Identification of blast resistance in a core collection of foxtail millet germplasm. *Plant Dis.* 98, 519–524. doi: 10.1094/PDIS-06-13-0593-RE

Sharma, A., Kumar, R. A., Sood, S., Khulbe, R. K., Agrawal, P. K., and Bhatt, J. C. (2018). Evaluation of nutraceutical properties of finger millet genotypes from mid hills of northwestern Himalayan region of India. *Indian J. Exp. Biol.* 56, 39–47.

Sheethal, H. V., Baruah, C., Subhash, K., Ananthan, R., and Longvah, T. (2022). Insights of nutritional and anti-nutritional retention in traditionally processed millets. *Front. Sustain. Food Syst.* 5:735356. doi: 10.3389/fsufs.2021.735356

Shegro, A., Shargie, N. G., Biljon, A., and Labuschagne, M. T. (2012). Diversity in starch, protein and mineral composition of sorghum landrace accessions from Ethiopia. *J. Crop. Sci. Biotechnol.* 15, 275–280. doi: 10.1007/s12892-012-0008-z

Shibairo, S. I., Nyongesa, O., Onwonga, R., and Ambuko, J. (2014). Variation of nutritional and anti-nutritional contents in finger millet (*Eleusine coracana* (L.) Gaertn) genotypes. *J. Agric. Vet. Sci.* 7, 06–12. doi: 10.9790/2380-071110612

Shindume, F. N., Horn, L. N., and Kahaka, G. (2019). *Proximate content and functional properties of putative pearl millet (Pennisetum glaucum) mutants derived through gamma irradiation in Namibia*. In 3rd Multi/Interdisciplinary Research Conference.

Singh, P., Singh, U., Eggum, B. O., Kumar, K. A., and Andrews, D. J. (1987). Nutritional evaluation of high protein genotypes of pearl millet (*Pennisetum americanum* (L.) Leeke). *J. Sci. Food Agric.* 38, 41–48. doi: 10.1002/jsfa.2740380108

Singhal, T., Satyavathi, C. T., Kumar, A., Sankar, S. M., Singh, S. P., Bharadwaj, C., et al. (2018). Genotype× environment interaction and genetic association of grain iron and zinc content with other agronomic traits in RIL population of pearl millet. *Crop Pasture Sci.* 69, 1092–1102. doi: 10.1071/CP18306

Stadlmayr, B. (2012). *West African food composition table/table de composition des aliments d'Afrique de l'Ouest*.

Thippeswamy, V., Sajjanar, G. M., Nandini, C., Bhat, S., and Doddaraju, P. (2017). Characterization of genotypes for nutritional traits in foxtail millet [*Setaria italica* (L.) Beauv.]. *Int. J. Curr. Microbiol. App. Sci.* 6, 97–101. doi: 10.20546/ijcmas.2017.612.013

Tietel, Z., Simhon, E., Gashu, K., Ananth, D. A., Schwartz, B., Saranga, Y., et al. (2020). Nitrogen availability and genotype affect major nutritional quality parameters of tef grain grown under irrigation. *Sci. Rep.* 10:14339. doi: 10.1038/s41598-020-71299-x

Tomar, M., Bhardwaj, R., Kumar, M., Singh, S. P., Krishnan, V., Kansal, R., et al. (2021). Nutritional composition patterns and application of multivariate analysis to evaluate indigenous pearl millet [*Pennisetum glaucum* (L.) R Br] germplasm. *J. Food Compos. Anal.* 103:104086. doi: 10.1016/j.jfca.2021.104086

Udamala, A., Vijayalakshmi, B., Anuradha, N., Patro, T. S. S. K., and Sekhar, V. (2020, 2020). Studies on genetic variability for yield and quality traits in finger millet (*Eluesine coracana* (L.) Gaertn). *Int. J. Curr. Microbiol. App. Sci.* 9:81. doi: 10.20546/ijcmas.2020.909.081

Upadhyaya, H. D., Ramesh, S., Sharma, S., Singh, S. K., Varshney, S. K., Sarma, N. D. R. K., et al. (2011b). Genetic diversity for grain nutrients contents in a core collection of finger millet (*Eleusine coracana* (L.) Gaertn.) germplasm. *Field Crop Res.* 121, 42–52. doi: 10.1016/j.fcr.2010.11.017

Upadhyaya, H. D., Ravishankar, C. R., Narasimhudu, Y., Sarma, N. D. R. K., Singh, S. K., Varshney, S. K., et al. (2011a). Identification of trait-specific germplasm and developing a mini core collection for efficient use of foxtail millet genetic resources in crop improvement. *Field Crop Res.* 124, 459–467. doi: 10.1016/j.fcr.2011.08.004

Upadhyaya, H. D., Vetriventhan, M., Asiri, A. M., Azevedo, V. C. R., Sharma, H. C., Sharma, R., et al. (2019). Multi-trait diverse germplasm sources from mini core collection for sorghum improvement. *Agriculture* 9:121. doi: 10.3390/agriculture9060121

Van Graan, S. N. D., Masters, S. K. D., Phiri, K. S. D., and Mwangwela, A. M. (2020). *The Malawi food composition database (MAFOODS)*.

Velu, G., Bhattacharjee, R., Rai, K. N., Sahrawat, K. L., and Longvah, T. (2008a). A simple and rapid screening method for grain zinc content in pearl millet. *J. SAT Agric. Res.* 6, 1–4.

Velu, G., Rai, K. N., and Sahrawat, K. L. (2008b). Variability for grain iron and zinc content in a diverse range of pearl millet populations. *J. Crop Improv.* 35, 186–191.

Vetriventhan, M., Azevedo, V. C., Upadhyaya, H. D., Nirmalakumari, A., Kane-Potaka, J., Anitha, S., et al. (2020). Genetic and genomic resources, and breeding for accelerating improvement of small millets: current status and future interventions. *Nucleus* 63, 217–239. doi: 10.1007/s13237-020-00322-3

Vetriventhan, M., and Upadhyaya, H. D. (2018). Diversity and trait-specific sources for productivity and nutritional traits in the global proso millet (*Panicum miliaceum* L.) germplasm collection. *Crop J.* 6, 451–463. doi: 10.1016/j.cj.2018.04.002

Vetriventhan, M., and Upadhyaya, H. D. (2019). Variability for productivity and nutritional traits in germplasm of kodo millet, an underutilized nutrient rich climate smart crop. *Crop Sci.* 59, 1095–1106. doi: 10.2135/cropsci2018.07.0450

Vetriventhan, M., Upadhyaya, H. D., Azevedo, V. C., Allan, V., and Anitha, S. (2021). Variability and trait specific accessions for grain yield and nutritional traits in germplasm of little millet (*Panicum sumatrense* Roth. Ex. Roem. and Schult.). *Crop Sci.* 61, 2658–2679. doi: 10.1002/csc2.20527

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al. (2019). Food in the Anthropocene: the EAT-lancet commission on healthy diets from sustainable food systems. *Lancet* 393, 447–492. doi: 10.1016/S0140-6736(18)31788-4