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Physicochemical and germinative properties of biofortified pearl millet (*Pennisetum glaucum*) varieties

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Abstract

Four biofortified pearl millet varieties were compared with the local variety of Andhra Pradesh in terms of physicochemical and germinative properties. Significant varietal difference was found on studied properties. Significant ($p < 0.001$) high mean values of 1000 grain weight and bulk density were found in Dhanshakti and AHB 1200 respectively. High germinative energy was found in Dhanshakti. The extremely high and low mean values of protein found in Pittaganti and RHB 234, Fiber high in RHB234 and low in ABV 04, ash high in Dhanshakti, AHB 1200 and low in ABV 04, fat high in RHB 234 and low in Dhanshakti, moisture high in RHB 234 and low in Dahnshakti. Iron was found to be high ($p < 0.05$) in Dhanshakti whereas zinc was higher ($p < 0.001$) in ABV 04. Pittaganti has recorded the lowest mineral content. Biofortified varieties have shown significantly high values for physicochemical and germinative properties compared to local non-biofortified variety. Rootlets and coleoptile or acrospore were developed after 48 and 72-hour germination. Further germination can lead to the development of the plant itself, hence it was suggestive to germinate the grains only for 24 hours.

Keywords: Pearl millet, physical properties, proximate composition, mineral content

Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a nutri-cereal and is typically grown under hot, dry environments on infertile soils of low water-holding capacity, where other crops usually fail. Pearl millet is grown widely in the arid and semi-arid regions of Africa and Asia with 30 million hectares area under cultivation. In addition, pearl millet alone contributes to about 50% of the total world's millet production and ranks as the world's fourth most tropical food cereal (Kumari *et al.* 2022 and Sathyavathi *et al.* 2021) [19].

Physical properties are important in processing and value addition aspects such as thousand kernel weights, length, breadth and bulk density etc. Knowledge of the physical properties of grains and seeds is paramount in designing handling, transporting, storing processing equipment and nutritional security point of view (Mane *et al.* 2022, Badau *et al.* 2002) [21, 6]. The germinative properties are useful in selecting grains for malting. In brewing industries, it is

necessary to carry out a test on the viability of the grains by making germination counts. If germination falls below 65%, the grain is not viable enough to malt, because diastatic enzymes are activated only during germination (Badau *et al.* 2006) [7].

It is known that pearl millet has a better nutritional profile than sorghum and other major cereals, as reported by other authors such as Mawouma *et al.*, 2022 [23] and Iyabo *et al.* 2018 [17]. Pearl millet is a rich source of essential nutrients such as fiber and minerals—notably iron, zinc, and calcium, and thus, rightly said as “Nutri-cereal” (Thribhuvan *et al.*, 2023) [39].

Materials and Methods

Plant materials and preparation

The experiment material used for the study was four biofortified varieties and one nonbiofortified local variety (ABV-04, AHB-1200, RHB 234, Dhan Shakti and Pittaganti) which were collected from ICAR institutes,

ICRISAT and State Agricultural Universities. In the laboratory, the samples were carefully cleaned manually to remove broken grains, stones, chaff and dirt and were stored in fresh clean Ziplock bags.

Physical properties

Dimensional properties

A total of ten seeds for each replication were randomly selected from each variety. Three different dimensional properties (mm) were determined by measuring the length (L) and width (W) of the grains using a vernier digital calliper at an accuracy of 0.01 mm.

Bulk density

Bulk density (kg/m^3) is the ratio of the mass of the sample to its total volume. It was determined by filling a 500 mL cylinder with grains. Bulk density (kg/m^3) was calculated as a ratio between the sample weight and the volume of the cylinder using Equation.

$$\text{Bulk density} = \frac{\text{Sample weight}}{\text{Volume}}$$

Grain 1000 grain weight

The thousand-grain weight was determined by weighing 30 grains in three replications by manual counting. The counted grain samples were weighed using a digital electronic balance with 0.01 g accuracy.

Sprout length

Sprout length was measured by taking the average of length of 10 sprouts (Dahiya 2017)^[11]. The rootlets were separated from the germinated pearl millet kernels by rubbing the grains in a nylon bag of coarse mesh size, which allowed the rootlets to escape while retaining the kernels (Morrall *et al.*, 1986).

Germinative energy

One hundred kernels grains were placed on two filter papers (Whatman No. 1; Whatman plc., Maidstone, UK) wetted with 4 ml of distilled water placed at the bottom of a petri dish, taking care to ensure that all the kernels were in good contact with the moist filter papers. The petri dish was then covered and incubated at an average temperature of 30 °C for 48 h. The kernels that sprouted at the end of the incubation were counted and germinative energy (GE) was expressed as suggested by Agbo (1996).

$$\text{GE (\%)} = 100 - N$$

Where

N = number of ungerminated grains.

Proximate Composition

The proximate analysis is a quantitative method to determine different macronutrients present in pearl millet grain (Fig.3.3). It is the partition of seed compounds into various categories such as moisture (g/100 g), crude protein (g/100 g), fat (g/100 g), crude fibre and crude ash (g/100 g), carbohydrate (g/100 g) was estimated as per AOAC method (2006).

Minerals analysis

Raw, soaked and germinated grains were analysed

separately for minerals (iron, zinc and calcium) by using ICP (Inductively Coupled Plasma-Optical emission Spectrometry) (Murcia *et al.*, 1999).

Statistical analysis

The data was subjected to analysis of variance (ANOVA) for testing the significance of variation in millet varieties for physicochemical and germinative traits using the statistics software SPSS version 16.

Results and Discussion

Results of the physical and germinative properties of the grains are shown in Table 1.

Physical properties

Size

The size of the pearl millet grain was determined in terms of linear dimensions (L, B and T). The range of length, bread and thickness were 2.61-3.30, 1.41- 2.25 and 1.18-1.98 mm respectively. There is a significant variation ($p < 0.001$) among all varieties studied for length, breadth and thickness. Prakash *et al.* 2019^[31] have shown similar results with average values of length, width and thickness varying from 2.997-3.172, 2.433-2.609 and 2.036-2.20 mm respectively. Ramashia *et al.* (2017)^[33] reported a higher value of average length (3.85 mm), thickness (2.31 mm) and par value of average width (2.40 mm).

1000 grain weight

Thousand-grain weight ranged from 4.40 to 11.40 g with the significantly ($p < 0.001$) high value observed in Dhanshakti and lowest in control. 1000 grain weight of different pearl millet varieties viz., Phule Adishakti, Dhanshakti, Phule Mahashakti, Pioneer 86M32 and HC-20 studied by Pawase *et al.*, 2021^[28] ranged from 7.45 to 13.20 g which is slightly higher than the present study. The pearl millet varieties showed wide variation in thousand-kernel weight with a range of 6.75 g to 12.97 g, 9.114 to 10.123 g and 4.64 to 13.01g according to Kumar *et al.* 2018^[20], Prakash *et al.* 2019^[31] and Pallavi *et al.* 2020^[25] which were comparable to the present study.

Bulk density

Bulk density ranged from 681 to 800 kg/m^3 . Bulk Density has a significant variation among the varieties studied ($p < 0.001$). The highest bulk density was observed in AHB1200 followed by Dhanshakti (783 kg/m^3). The lowest was recorded in the control variety. The mean bulk density in the Pawar *et al.* 2020^[27] study was 830 kg/m^3 . The mean Bulk Density varied from 827.5-711.9 kg/m^3 and 737.42-765.83 kg/m^3 according to Prakash *et al.* 2019^[31] and Santakar *et al.* 2020 respectively concurrent to the present study.

Germinative properties

Sprout length

Sprout length was affected by germination time. Sprout length has increased with an increase in the germination period. Sprout length ranged from 0.12- 0.80, 0.60-1.36 and 0.57-1.85 cm at 24 hours, 48 hours and 72 hours germination time respectively. Significantly ($p < 0.001$) high sprout length was observed in RHB 234 and lowest in

control. There was an increase in sprout length after 48-hour germination. Rootlets and coleoptile or acrospore were also developed after 48 and 72-hour germination. Further germination can lead to the development of the plant itself. Rootlets and coleoptile or acrospire were produced at the expense of material from original seeds which can lead to

further loss in the yield of malt as reported by Agarwal *et al.* 2013. Similarly, Dahiya *et al.* 2017^[11] reported 0.31 and 1.95 cm of pearl millet sprout length at 24 Hr and 48 Hr germination time at 30 °C which is concurrent to the present study.

Table 1: Physical and germinative properties

Variety	Size			Bulk density (kg/m ³)	1000 grain wt (g)	Sprout length (cm)			Germinative energy (%)
	Length (mm)	Breadth (mm)	Thickness (mm)			24 Hr	48 Hr	72 Hr	
Pittaganti	2.61	1.41	1.18	681	4.40	0.12	0.60	0.57	24
ABV-04	2.88	2.14	1.85	761	9.96	0.66	1.36	1.42	92
AHB 1200	3.26	2.25	1.98	800	7.34	0.57	1.19	1.39	93
Dhanshakti	3.30	2.25	1.95	783	11.40	0.76	1.29	1.53	96
RHB 234	3.25	2.12	1.85	773	8.56	0.80	1.43	1.85	92
Mean	3.06	2.03	1.76	760	8.33	0.58	1.17	1.35	79
Range	2.61-3.30	1.41-2.25	1.18-1.98	681-800	4.40-11.40	0.12-0.80	0.60-1.36	0.57-1.39	24-96
SEM	0.08	0.01	0.02	0.00	0.26	0.05	0.08	0.08	0.04
SED	0.11	0.02	0.02	0.00	0.37	0.08	0.12	0.12	0.06
CD	0.39	0.08	0.09	0.01	1.23	0.26	0.40	0.40	0.19
CV	4.76	2.24	2.73	0.19	5.54	11.54	13.49	13.56	3.97

Germinative energy

Significant ($p < 0.001$) high germinative energy was observed in AHB 1200 (97%) and lowest in control (27%). Dahiya *et al.* 2017^[11] and Pelembe *et al.* 2002^[29] reported similar germinative energy of 96.8 and 97.9% respectively. The germinative energy of pearl millet studied by Badau *et al.* 2006^[7] ranged from 95.0 to 97.0% concurrent to the present study. Germination energy (GE) is the component of seed vigour that corresponds to the speed and uniformity of seedling emergence (Zhang *et al.* 2020)^[41].

Proximate composition of biofortified pearl millet varieties

Results of proximate composition of the grains was shown in Table 2

Moisture (g)

Moisture is an important determinant of food quality and

affects the physical and chemical aspects of food which relates to the freshness and stability for storage for a long time, preservation and resistance to deterioration. It is necessary to calculate the content of other food constituents (i.e., total solids) on a uniform basis (i.e., dry weight basis) (Iswarya and Narayanan 2016)^[16]. The mean moisture content was 9.26% and ranged between 8.69- 10.10% with significantly ($p < 0.05$) high moisture observed in RHB 234 and lowest in Dhanshakti. The moisture content of grains according to Sharma *et al.* 2023^[38] was $\leq 10\%$ recommended as a safe limit, for extended preservation of flours. The moisture content of two pearl millet varieties reported were 11.33% in Tohamy millet and 12.67% in Chinese millet from the study of Ali 2023^[4] which was higher than the present study. The moisture content of pearl millet studied by Owheruo *et al.* 2019^[24] was 4.50% which is lower than the results obtained in the present study.

Table 2: Proximate composition of biofortified pearl millet varieties per 100 g

Variety	Proximate composition (g %)						
	Moisture (g)	Protein (g)	Fat (g)	Fiber (g)	Ash (g)	CHO (g)	Energy (K.cal)
Pittaganti	9.02	10.05	5.02	2.28	1.87	75.67	390
ABV 04	8.75	8.62	5.02	1.50	1.60	71.07	361
AHB 1200	9.74	6.90	5.67	2.19	1.93	76.82	388
Dhanshakti	8.69	8.78	4.92	1.50	1.93	73.63	375
RHB 234	10.10	6.70	5.88	2.37	1.73	75.22	383
MEAN	9.26	8.21	5.30	1.97	1.81	74.48	379.40
Range	8.69- 10.10	6.70- 10.05	4.92-5.88	1.50-2.37	1.60-1.93	71.07-76.82	361-390
SEM	0.31	0.11	0.19	0.16	0.10	4.26	17.42
SED	0.44	0.15	0.28	0.23	0.15	6.02	24.63
CV	5.93	2.35	6.35	14.61	10.26	9.90	7.95
CD	1.47	0.51	0.92	0.77	0.50	19.82	81.08

Protein (g/100 g)

Protein content ranged from 6.70- 10.05 g/100g with the highest significant ($p < 0.001$) value found in control as it was protein-rich local variety and among biofortified varieties, Dhanshakti has shown high protein content with 8.78 g/100 g and RHB 234 has recorded the lowest protein

content of 6.70 g/100 g. Protein content in pearl millet as reported by Pandit *et al.*, 2021^[26], Pawar *et al.* 2020^[27] and Iswarya and Narayanan (2016)^[16] was 12.8%, 11.5% and 9.78 to 11.80% (Dhanshakti) protein which is higher than the present results. Owheruo *et al.*, 2019^[24] recorded a low protein content in raw pearl millet flour of 7.61%. The

protein content of pearl millet varied due to the varietal difference and the amount of nitrogen available in the soil (Iswarya and Narayanan 2016)^[16].

Fat (g/100 g)

Fat content ranged from 4.92-5.88 g/100g with a significant ($p < 0.01$) high value was observed in RHB 234 and lowest in Dhanshakti. Similar results were obtained by Pawase *et al.* 2021^[28] (4.85 to 5.50%), Satankar *et al.*, (2020)^[36] (5%), Pawar *et al.* 2020^[27] (4.9%), Hassan *et al.* 2021^[15] (5-7%) and Abdalla *et al.* 1998^[1] (2.7-7.1%). The fat content in the inbred lines of pearl millet ranged from 2.68 - 7.3% as reported by Pallavi *et al.*, 2023^[25], higher than the present study. The fat content of pearl millet was noted to be 2.2 per cent according to Pandit *et al.* 2021^[26] which was lower than the present study.

The crude fat content is one of the important components in course cereal grain, which acts as a medium to provide fat-soluble components to human health, however during storage of course cereal flour, the action of lipase enzyme on fat leads to the production of free fatty acids and which leads to rancidity to cereal flour during storage. Hence to study of crude fat content is very important for course cereals flour and course cereal-based food products to increase their storage life.

Carbohydrate

Carbohydrate content ranges from 61.07-66.82 g/100g with the lowest found in ABV 04 and the highest found in AHB 1200 with an average of 64.48 g/100g. There is no significant variation of carbohydrates among the varieties studied. Similar results were obtained by Owheruo *et al.*, 2019^[24] (74.41%) and 71.9 per cent in pearl millet (Pandit *et al.* 2021)^[26]. Lower carbohydrate content than the present study was reported by Pawar *et al.* 2020^[27] (67.0±0.50 %), Satankar *et al.*, (2020)^[36] (67.5 g/100 g), Abdalla *et al.* 1998^[1] (59-70 %).

The carbohydrates in pearl millet grains possess starch, dietary fiber, and soluble sugars. Starch is considered a predominant component of pearl millet endosperm, which comprises glucose in the form of amylase and amylopectin. Various pearl millet grain genotypes vary, in starch composition from 62.8 to 70.5% (Hassan *et al.* 2021)^[15]. The average content of carbohydrates reported in pearl millet grains was 72.2%, which is lower than rice 84.9%, maize 78.1% and higher than wheat 68.8% on dry wt. basis according to Dias-Martins *et al.* (2018)^[12].

Ash content (g/100g)

The mean ash content of the five varieties of pearl millet was 1.81 g/100 g with a range of 1.60-1.93 g/100 g. The highest ash was found in Dhanshakti and the lowest in ABV 04. There is no significant variation of ash among the varieties studied. Prajapati *et al.*, (2019)^[30], showed that the ash content of pearl millet was 2%. Martínez-Ballesta (2010)^[22] stated that environmental stressors such as high salt levels, low water accessibility, and excessive temperatures, are found to affect the mineral content of food. The ash content in the present study agrees with the findings of Florence *et al.*, (2014)^[13], and Ramashia (2018)^[33] where ash content is within the standard range of 1.6-3.6% in whole millet flour.

Crude fiber content

Crude fiber ranged from 1.50-2.37 mg/100 g with the significantly ($p < 0.01$) low content was found in Dhanshakti and the highest in RHB 234. Variations of these levels are possible due to genotype, climatic conditions and soil nutrient content (Dias-Martins *et al.*, 2018)^[12]. Similar results were observed by Mawouma *et al.* 2022^[23], Pandit *et al.* 2021^[26], Pawase *et al.* 2021^[28], Kulthe *et al.*, 2016^[18] and Sade 2009^[35].

Crude fibre in food is a sign of slowly digestible carbohydrates. Crude fiber content of 1.55 g/100 g in pearl millet lessens the assimilation of glucose, fat during metabolism and enhances digestibility (Rajalakshmi *et al.* 2021)^[32].

Energy

The calorific range of varieties studied was 361-390 k.cal/100g of pearl millet with no significant variation. Control has recorded significantly high kilocalories whereas lower kilocalories were observed in ABV 04. Similar results were observed by Choudhary *et al.* 2023^[10], Sachan and Shah 2023^[34] and Rajalakshmi *et al.* 2021^[32], whereas Sade *et al.* 2009^[35] recorded a higher energy range of 397-418 K.cal.

Mineral composition of biofortified pearl millet varieties **Iron**

The iron content of the raw grains ranged from 5.78-8.66 mg/100 g as shown in Table 3. The mean iron content across all varieties is 7.73 mg/100 g. A significant variation ($p < 0.05$) in the iron content among the varieties studied. Significantly high iron content was found in raw grains of the Dhanshakti variety (8.66). Control variety Pittaganti (5.78) has the lowest iron content. Anitha *et al.* 2024^[5] have reviewed that the iron content of pearl millet worldwide can range between 1.4-13.53 mg/100 g. Velu *et al.* 2008^[40] evaluated variability among 68 improved populations of pearl millet where the iron content of grains ranged from 42- 79.9 mg/kg which was slightly less when compared to the present findings. Grain iron content for hybrids ranged from 4.79 to 9.56 mg/kg over environments among all the 30 hybrids evaluated by Thribhuvan *et al.* 2023^[39] which is in line with the present study.

Zinc

The range of zinc was 2.21-6.12 mg/100 g as shown in Table 3. ABV 04 raw grains (6.12) had the significant ($p < 0.001$) highest zinc content among all the varieties. Significant ($p < 0.001$) low content was observed in control variety grains (2.21). The mean zinc content among the varieties was 4.09 mg/100 g. There is a significant variation ($p < 0.001$) in the zinc content among the varieties studied. Results are comparable with the earlier reports of Govindaraj *et al.* 2022^[14] with 928 entries of pearl millet in replicated trials during the 2012–2013 crop season in India the mean zinc content was 41 mg kg⁻¹. The mean zinc content of the genotypes studied by Berwal *et al.* 2017^[19] varied from 27 mg/kg to 51 mg/kg grains. The grain zinc content in the study of Thribhuvan *et al.*, 2023^[39] varied 4.47 and 5.73 mg/100g among *Cenchrus americanus* (L) lines and from 3.83 to 6.08 mg/100 g among testers (10 restorers). In the earlier study of Ishwarya *et al.* 2016 where

Dhanshakti has 3.59 mg/100 g of zinc and Sachan and Shah 2023 ^[34] recorded 1.84 mg/100 g in the available market sample which is lower when compared to the mean value obtained in the present study (4.09 mg/100 g).

Table 3: Mineral composition of biofortified pearl millet varieties per 100 g

Variety	Iron	Calcium	Zinc
	mg/100g		
Pittaganti	5.78	41.44	2.21
ABV 04	7.48	40.66	6.12
AHB 1200	8.42	42.60	3.23
Dhanshakti	8.66	43.64	4.77
RHB 234	8.30	43.22	4.10
MEAN	7.73	42.31	4.09
Range	5.78- 8.66	40.66-43.64	2.21-6.12
SEM	0.57	2.26	0.23
SED	0.81	3.19	0.33
CV	12.93	9.26	9.94
CD	2.68	10.53	1.09

Calcium

Calcium was observed to be in the range of 40.66-43.64 mg/100g as shown in Table 3. There is no significant variation in calcium among the varieties studied. Higher calcium content was found in Dhanshakti grains (43.64), whereas ABV 04 grains (40.66) had low calcium content. The mean calcium content was 42.31 mg/100 g. According to Ali, 2023 ^[4], the calcium content of two pearl millet varieties studied was 26-27 mg/100 g which is less when compared to the present study. Prajapati *et al.* 2019 ^[30] showed that pearl millet's calcium content was 42 mg/100g. A range of 4–40 mg 100 g was recorded in the 14-trial study of Govindaraj *et al.* 2022 ^[14] which are in line with the current study. The calcium content ranged from 52.99 to 61.89 mg/ 100 g in the report given by Abdelrahman *et al* 2007 ^[2].

Conclusion

The study has shown that biofortified pearl millet varieties have superior physicochemical and germinative properties compared to non-biofortified local variety. Among biofortified varieties, Dhanshakti has shown superior quality. As consumer attentiveness is increasing towards the higher quality and nutritive value of the foods biofortified pearl millet can be added to the daily diet to increase the nutritional and inclusiveness to a balanced diet. Biofortified pearl millets are a good source of iron and zinc and can be effectively put to use in the manufacture of nutrient-rich foods to combat micronutrient deficiencies.

Reference

1. Abdalla AA, El Tinay AH, Mohamed BE, Abdalla AH. Proximate composition, starch, phytate and mineral contents of 10 pearl millet genotypes. *Food Chem.* 1998;63(2):243-246.
2. Abdelrahman SM, Elmaki HB, Idris WH, Hassan AB, Babiker EE, El Tinay AH. Antinutritional factor content and hydrochloric acid extractability of minerals in pearl millet cultivars as affected by germination. *Int J Food Sci Nutr.* 2007;58(1):6-17.
3. Agrawal D, Upadhyay A, Nayak PS. Functional characteristics of malted flour of foxtail, barnyard and little millets. *Ann Food Sci Technol.* 2013;14(1):44-9.
4. Ali MG. Nutritional composition and technological studies on pearl millet grains (*Pennisetum glaucum* L.). *Alexandria Sci Exchange J.* 2023;44(2):147-159.
5. Anitha S, Rajendran A, Botha R, Baruah C, Mer P, Sebastian J, Upadhyay S, Kane-Potaka J. Variation in the nutrient content of different genotypes and varieties of millets, studied globally: A systematic review. *Front Sustain Food Syst.* 2024;8:1324046.
6. Badau MH, Nkama I, Ajalla CO. Physico-chemical characteristics of pearl millet cultivars grown in northern Nigeria. *Int J Food Prop.* 2002;5(1):37-47.
7. Badau MH, Nkama I, Jideani IA. Steep-out moisture, malting loss, and diastatic power of pearl millet and sorghum as affected by germination time and cultivar. *Int J Food Prop.* 2006;9(2):261-272.
8. Bean SR, Zhu L, Smith BM, Wilson JD, Ioerger BP, Tilley M. Starch and protein chemistry and functional properties. In: *Sorghum and millets.* 2019;131-170.
9. Berwal MK, Chugh LK, Goyal P, Kumar R, Vart D. 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 Appl Sci.* 2017;6(3):376-386.
10. Choudhary C, Vignesh S, Chidanand DV, Baskaran N. Effect of different processing methods on nutritional composition and microbial quality of pearl millet. [cited 2023 Oct 1]. Available from: <https://www.researchsquare.com/article/rs-3614114/v1>.
11. Dahiya R, Yadav RB, Yadav BS, Yadav R. Quality characteristics of pearl millet malt as affected by steeping temperature and germination period. *Qual Assur Saf Crops Foods.* 2018;10(1):41-50.
12. Dias-Martins AM, Pessanha KLF, Pacheco S, Rodrigues JAS, Carvalho CWP. Potential use of pearl millet (*Pennisetum glaucum* (L.) R. Br.) in Brazil: food security, processing, health benefits and nutritional products. *Food Res Int.* 2018;109:175-186.
13. Florence SP, Urooj A, Asha MR, Rajiv J. Sensory, physical and nutritional qualities of cookies prepared from pearl millet (*Pennisetum typhoideum*). *J Food Process Technol.* 2014;5:2-6.
14. Govindaraj M, Kanatti A, Rai KN, Pfeiffer WH, Shivade H. Association of grain iron and zinc content with other nutrients in pearl millet germplasm, breeding lines, and hybrids. *Front Nutr.* 2022;8:1357.
15. Hassan ZM, Sebola NA, Mabelebele M. The nutritional use of millet grain for food and feed: a review. *Agric Food Sec.* 2021;10:1-14.
16. Iswarya AL, Narayanan A. Effect of germination on biofortified pearl millet cultivars' nutrient content. [no further details provided].
17. Iyabo OO, Ibiyinka O, Abimbola Deola O. Comparative study of nutritional, functional and antinutritional properties of white *Sorghum bicolor* (Sorghum) and *Pennisetum glaucum* (Pearl millet). *Int J Eng Technol Manag Res.* 2018;5(3):151-158.
18. Kulthe AA, Thorat SS, Lande SB. Characterization of pearl millet cultivars for proximate composition, minerals and anti-nutritional contents. *Adv Life Sci.* 2016;5(11):4672-4675.

19. Kumari R, Bhatt S, Agrawal H, Dadwal V, Gupta M. Effect of fermentation conditions on nutritional and phytochemical constituents of pearl millet flour (*Pennisetum glaucum*) using response surface methodology. *Appl Food Res.* 2022;2(1):100055.
20. Kumari R, Singh K, Jha SK, Singh R, Sarkar SK, Bhatia N. Nutritional composition and popping characteristics of some selected varieties of pearl millet (*Pennisetum glaucum*). [no further details provided]; c2018.
21. Mane RP, Kshirsagar RB, Patil BM, Agarkar BS, Katke SD. Physicochemical, functional and nutritional properties of millet grains. *The Pharma Innovation J.* 2022;11(11):1596-600.
22. Martínez-Ballesta MC, Dominguez-Perles R, Moreno DA, Muries B, Alcaraz-López C, Bastías E. Minerals in plant food: effect of agricultural practices and role in human health. A review. *Agron Sustain Dev.* 2010;30:295-309.
23. Mawouma S, Condurache NN, Turturică M, Constantin OE, Croitoru C, Rapeanu G. Chemical composition and antioxidant profile of sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) grains cultivated in the far-North region of Cameroon. *Foods.* 2022;11(14):2026.
24. Owheru JO, Ifesan BO, Kolawole AO. Physicochemical properties of malted finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*). *Food Sci Nutr.* 2019;7(2):476-482.
25. Pallavi M, Reddy PS, Krishna KR, Ratnavathi CV, Sujatha P. Genetic variability, heritability and association of grain yield characters in pearl millet (*Pennisetum glaucum* L.). *J Pharmacogn Phytochem.* 2020;9(3):1666-1669.
26. Pandit MG, Gadhe KS, Alane ST. Studies on physicochemical and mineral evaluation of pearl millet, sorghum and soybean. *The Pharma Innovation J.* 2021;10(7):1650-1653.
27. Pawar PP, Sawate AR, Kshirsagar RB, Agarkar BS. Studies on physicochemical properties of finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*). *The Pharma Innovation J.* 2020;9(2):5-8.
28. Pawase PA, Chavan UD, Kotecha PM. Evaluation of functional properties of different pearl millet cultivars. *The Pharma Innovation J.* 2021;10(6):1234-1240.
29. Pelembe LAM, Dewar J, Taylor JRN. Effect of malting conditions on pearl millet malt quality. *J Inst Brew.* 2002;108(1):7-12.
30. Prajapati MR, Dave PH, Sable PA. Nutritional and functional benefits of finger millet (*Eleusine coracana*). *Int J Pure App Biosci.* 2019;7:342-5.
31. Prakash OM, Jha SK, Kar A, Sinha JP, Satyavathi CT, Iquebal MA. Physical properties of pearl millet grain. [no further details provided].
32. Rajalakshmi G, Gnanalakshmi K, Baskaran D, Reiyaz MA. Proximate composition of sorghum grain and pearl millet. *Int J Agric Sci Res.* 2023;11(1):97-102.
33. Ramashia SE, Gwata ET, Meddows-Taylor S, Anyasia TA, Jideani AIO. Some physical and functional properties of finger millet (*Eleusine coracana*) obtained in sub-Saharan Africa. *Food Res Int.* 2017;104:110-118.
34. Sachan N, Shah P. Analysis of the proximate composition, mineral content and antioxidant compound of pearl millet flour. *Int J Home Sci.* 2023;9(1):304-306.
35. Sade FO. Proximate, antinutritional factors and functional properties of processed pearl millet (*Pennisetum glaucum*). *J Food Technol.* 2009;7(3):92-97.
36. Satankar M, Sahoo PK, Mishra IM, TV AK. Varietal and moisture effect on physical properties of various pearl millet (*Pennisetum glaucum*) cultivars. *Environ Conserv J.* 2022;23(3):450-457.
37. Satyavathi CT, Ambawat S, Khandelwal V, Srivastava RK. Pearl millet: A climate-resilient nutriceal for mitigating hidden hunger and provide nutritional security. *Front Plant Sci.* 2021;12:659938.
38. Sharma S, Anurag, Amar PG. Effect of germination on the physicochemical and anti-nutritional properties of finger millet (*Eleusine coracana*), pearl millet (*Pennisetum glaucum*), and sorghum (*Sorghum bicolor*). *J Pharma Innov.* 2023;12(3):4763-4772.
39. Thribhuvan R, Singh SP, Sankar MS, Singh AM, Mallik M, Singhal T, et al. Combining ability and heterosis studies for grain iron and zinc concentrations in pearl millet [*Cenchrus americanus* (L.) Morrone]. *Front Plant Sci.* 2023;13:1029436.
40. Velu G, Rai KN, Sahrawat KL. Variability for grain iron and zinc content in a diverse range of pearl millet populations. *J Crop Improv.* 2008;35(2):186-91.
41. Zhang T, Fan S, Xiang Y, Zhang S, Wang J, Sun Q. Non-destructive analysis of germination percentage, germination energy and simple vigour index on wheat seeds during storage by Vis/NIR and SWIR hyperspectral imaging. *Spectrochim Acta A Mol Biomol Spectrosc.* 2020;239:118488.