African Journal of Agriculture and Food Science
ISSN: 2689-5331
Volume 8, Issue 2, 2025 (pp. 116-138)
www.abjournals.org

NUTRITIONAL PERSPECTIVE OF UNTAPPED INDIGENOUS FINGER MILLET [*ELEUSINE CORACANA* (L.) GAERTN.] ACCESSIONS IN MILLET HOTSPOT OF EASTERN GHATS, INDIA

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Cite this article:

Suchinnata S. Sardar, Sudha Suman, Soumya Barik, Swapan K. Tripathy (2025), Nutritional Perspective of Untapped Indigenous Finger Millet [Eleusine Coracana (L.) Gaertn.] Accessions in Millet Hotspot of Eastern Ghats, India. African Journal of Agriculture and Food Science 8(2), 116-138. DOI: 10.52589/AJAFS-EHGJGEI0

Manuscript History

Received: 25 Apr 2025

Accepted: 30 May 2025

Published: 24 Jun 2025

ABSTRACT: *Climate change and human influence aggravate threats to balanced ecosystem, declining performance of major food crops. Finger millet (Eleusine coracana), a vital millet crop stands as a climate resilient smart crop for future. The present investigation establishes towering nutrient assemblage in 10 under-identified indigenous accessions collected from blocks of Malkangiri district located in Eastern Ghats, Odisha, India and compared with 2 improved varieties KMR-204 and Arjuna for Ca,Fe,Zn,Mg,K,Mn,P & Cu by ICP-OES. Most of the accessions have multi-fold higher nutrient contents as compared to the best studied crops declared by Food Data Central, US Department of Agriculture. The nutrient diversity confirms two major clusters at 0% phenon-level and two subclusters at 90% phenon-level. Accessions in cluster-I (Acc-3,7 and KMR-204) signifies extremely high Zn content, whereas subcluster-IIB (Acc-1,2,8,9 and Arjuna) for dehydration tolerance. These indigenous accessions collected in two subsequent years are testimony of conserved nutritional package in undisturbed ecosystem of Eastern Ghats in Malkangiri district, Odisha, India and can be utilized for crop improvement and sustainable agriculture for future.*

KEYWORDS: Climate resilient cereal, Clusters, Eastern Ghats, Essential nutrients, Finger millet, Sustainable agriculture.

Article DOI: 10.52589/AJAFS-EHGJGEI0
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INTRODUCTION

Climate change parallel with global warming is the major issue of concern throughout the globe (Sara *et al*, 2021). Global climate change together with rapidly increasing population, urbanization and industrialization is mounting considerable pressure on agricultural sector to produce more food from less land (Beckers *et al*, 2020). The erratic climate change brings about anticipated increase in temperature, erratic rainfall and recurrent occurrence of drought and flood. The above conditions impose abiotic stresses on plants that show hampered plant growth and development and ultimately proceed towards poor agricultural productivity (Bashir *et al*, 2019). The reduced crop yield cannot meet the demand of the ever-increasing human population both in terms of quantity and quality and hence compromise food security, particularly in developing countries (Brás *et al*, 2021).

The major cereal crops like rice, maize, wheat have registered constrained productivity against the aforesaid abiotic stress. Hence it has become indispensable to explore crops with abiotic stress tolerance or adaptive mechanisms to counteract the detrimental effects of such stress and secure food at the same time. Crops with such abilities can be considered as the crop for future. The millets known as the minor cereal crops have been well recognized for its ability to withstand the adverse effect of abiotic and biotic stress without compromising its nutritional quality (Renganathan *et al*, 2020). These have now been identified as the climate resilient crops and also as the smart crops for future. The World Health Organization (WHO) is strongly advocating and promoting upon the use of such food crops as medicines enriched with high end nutritional values as described in ancient Indian siddha literature with a well-versioned dogma “food is medicine and medicine is food” (Elangovan *et al*, 2023). The recent G20 summit has also emphasized on the potential of these minor millet crops to meet the food demand of the globe along with providing a well-preserved nutrition in them (Nesari *et al*, 2023). The millets have the capability to feed the 9 billion populations round the globe. Once considered as the food for the poor, has now been established as the store-house of nutrition (Patil & D. A., 2020).

LITERATURE/THEORETICAL UNDERPINNING

Among the millets finger millet is best identified for its drought resilient nature and nutraceutical properties (Rani *et al*, 2024). It has been originated in the East African highlands and domesticated in India. The whole genome size is estimated to be 1453 Mb, but 1196 Mb has been yielded covering 82% of the total genome size. It is tetraploid having 36 number of chromosomes. Hence it is used as a staple food to feed the population of developing nations of Asia and Africa (Maharajan *et al*, 2021). Further the centre of diversity is the mining hub of exploring diverse food crop varieties that emphasizes more on the rich genetic diversity of that area. So, the present investigation relies more on exploring the finger millet crop diversity and their potential to mitigate the challenges of global climate change. In India, Himalayan regions and Eastern Ghats are best known for its millet diversity (Balkrishna *et al*, 2022). The Eastern Ghats extending from Odisha (18.5000° N, 83.0000° E) to Tamil Nadu (11030’ 220N, 76050’ 86030’E) is identified as the millet hotspot. A proportionate part of Eastern Ghats lies in the South-west region of Odisha. Malkangiri district present in the southernmost tip of Odisha has been declared as one of the millet hotspots in India by Indian Institute of Millet Research,

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Hyderabad, India. Finger millets are popularly cultivated by the tribal people inhabiting this region for their food demands. The finger millet cultivated in the tribal pockets of Eastern Ghats has conserved their indigenous nature owing to the negligence external influence and the remote location amidst dense forest coverage on hilly terrains being cut off from the main land. The indigenous finger millet genotypes are cultivated with almost nil agricultural practices to rain-fed conditions but sophisticated with nutritional sufficiency to fulfil the food demands of the hill-dwelling people (Dash *et al*, 2021). These indigenous finger millet genotypes are the store-house of gene pool that confers a variety of characters ranging from drought tolerance to nutritional mines (Choudhary *et al*, 2023). The variation of characters in these indigenous genotypes has been conserved because of the undisturbed ecosystem of this region so far (Manoj *et al*, 2024). Hence, mining these nutrition rich unidentified finger millets accessions and comparing its nutrition quality with the major group of food crops is the objective of this investigation which has not been explored till date.

Most of the literature has reported on the nutritional qualities of finger millet related to calcium because it has been well established as a calcium rich source. But maximum literatures have maintained silence on detecting the presence of other essential nutrients. So, this investigation aims at a thorough introspection for the presence of most essential nutrients like calcium, iron, zinc, potassium, phosphorus, magnesium, manganese and copper. The above nutrients support the overall metabolism in human beings.

Essential nutrients play vital role in metabolism and tissue function as cofactors, coenzymes, antioxidants and for genetic control (Ali *et al*, 2024; Shenkin 2006). These include calcium, iron, zinc, potassium, phosphorus, magnesium, manganese, and copper, etc. Calcium is essential for many metabolic processes including nerve functioning, muscle contraction and blood clotting (Yadav *et al* 2024). Iron containing proteins are required for vital cellular and organismal functions including oxygen transport, mitochondrial respiration, intermediary & xenobiotic metabolism, nucleic acid replication and repair, host defense and cell signaling (Hong *et al*, 2024). Zinc has vital role in immune system by regulating cytokine expression, suppressing inflammation and antioxidative properties (Olechnowicz *et al* 2017). It is ubiquitous within the cell and have various catalytic, structural and regulatory functions (Roth-Walter *et al*. 2024). Potassium helps maintain cellular osmolarity (normal levels of fluid inside the cell), nerve stimulation and regulate cardiac and muscle function (Yamada *et al*. 2021). Chronic phosphorus deficiency can lead to myopathy (Ravid *et al*. 1976) and bone resorption (Raisz *et al*. 1972), as it is one of the essential elements for ATP synthesis, signal transduction and bone mineralization, and a key component of phospholipids, nucleic acids, ATP, etc. (Serna *et al*,2020). It is a key element in organic molecules involved in various essential cellular functions, like biochemical energy function via ATP, maintenance of genetic information with nucleotides in DNA & RNA, intercellular signaling in cAMP and membrane structural integrity via glycerophospholipids (Peacock 2021). Magnesium plays vital role in maintaining myocardial mechanisms by influencing movement of other ions such as calcium, sodium and potassium. It is also involved in cellular metabolism, replication and protein synthesis (Wang *et al*. 2025). Mg deficiency can lead to hypocalcaemia, hypokalaemia, cardiac and neurological manifestations (Joshi *et al*, 2024). Manganese helps in synthesis and activation of enzymes, clotting factors, proteins, regulating endocrine system, fat and carbohydrate metabolism (Li *et al*.2018). Its deficiency can impair insulin activity and disrupt normal blood sugar regulation. Copper is essential for growth and energy metabolism, cardiovascular integrity, lung elasticity, ROS detoxification, neovascularization, endocrine

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functioning & iron metabolism. It also helps assemble cuproenzymes in mitochondria, ferroxidases (as Cu is a cofactor), and metabolic reprogramming through signals in bioenergetics and mitophagy (Lina *et al*. 2021). Cu deficiency or imbalance might cause Menkes disease, Wilson disease, anemia, and various neurodegenerative, metabolic and cardiovascular diseases and cancer (Chen *et al*. 2020).

METHODOLOGY

The study includes analysis of different nutrients in indigenous finger millet accessions collected from semi-arid rain-fed areas of tribal belts of Malkangiri district of Odisha declared as millet hotspot and their comparative analysis with that of the improved varieties cultivated in the plain lands of that area (Figure 1; Figure 2).

We have collected 10 indigenous accessions from Karanjaguda of Kalimela block (17.593^0, 81.4552^0), Balimela Rd of Korukonda block (18.31637^0, 81.9589^0), Jhikarkalani, Balimela of Korukonda block (18.29899^0, 81.96741^0), Koilipari of Malkangiri block (18.31635^0, 81.95891^0), Pujarimunda of Chitrakonda block (18.43843^0, 82.0128^0), Khairput block (18.48185^0, 82.21931^0), Tunnlecamp of Chitrakonda block (18.19569^0, 82.07619^0), Badapadar of Chitrakonda block (18.07865^0, 82.1627^0), Malkangiri block (18.19617^0, 82.07608^0), and Mathili block (18.55178^0, 82.22462^0)present at different altitudes of Malkangiri district and also 2 improved varieties, namely KMR-204 released by VC farm, UAS, Bengaluru of Karnataka and Arjuna released by OUAT, Bhubaneswar, Odisha, and collected from MSSRF, Jeypore, Odisha, which are generally being supplied by Govt. of Odisha for cultivation in the plain lands of Malkangiri district. This has been placed in record in Table no. 1.

Table 1: Indigenous finger millet accessions collected from different blocks of Malkangiri district, Odisha, India along with its location and common names

Sl. No	Name of accession	Type of Accession	Common Name	Landrace/ Variety	Geographical area from which collected	Global Positional Location of accessions	Altitude
1	Accession-1	Indigenous	Bada Mandia	Landrace	Karanjaguda of Kalimela block	17.593^0, 81.4552^0	75 m
2	Accession-2	Indigenous	Bada Mandia	Landrace	Balimela Rd of Korukonda block	18.31637^0, 81.9589^0	182 m
3	Accession-3	Indigenous	Garra	Landrace	Jhikarkalani, Balimela of Korukonda block	18.29899^0, 81.96741^0	107 m

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4	Accession-4	Indigenous	Bada Mandia	Landrace	Koilipari of Malkangiri block	18.31635^{0}, 81.95891^{0}	112 m
5	Accession-5	Indigenous	Sana Mandia	Landrace	Pujarimunda of Chitrakonda block	18.43843^{0}, 82.0128^{0}	271 m
6	Accession-6	Indigenous	Bada Mandia	Landrace	Khairput block	18.48185^{0}, 82.21931^{0}	282 m
7	Accession-7	Indigenous	Chili mandia	Landrace	Tunnelcamp of Chitrakonda block	18.19569^{0}, 82.07619^{0}	538 m
8	Accession-8	Indigenous	Chili mandia	Landrace	Badapadar of Chitrakonda block	18.07865^{0}, 82.1627^{0}	480 m
9	Accession-9	Indigenous	Chili mandia	Landrace	Malkangiri block	18.19617^{0}, 82.07608^{0}	471 m
10	Accession-10	Indigenous	Mathili Mandia	Landrace	Mathili block	18.55178^{0}, 82.22462^{0}	264 m
11	KMR-204	Improved variety		Variety	MSSRF, Jeypore, Odisha	-	-
12	Arjuna	Improved variety		Variety	MSSRF, Jeypore, Odisha	-	-

Accessions were collected from fields cultivated with indigenous finger millet landraces without proper agricultural practices from different blocks of Malkangiri district, Odisha, India

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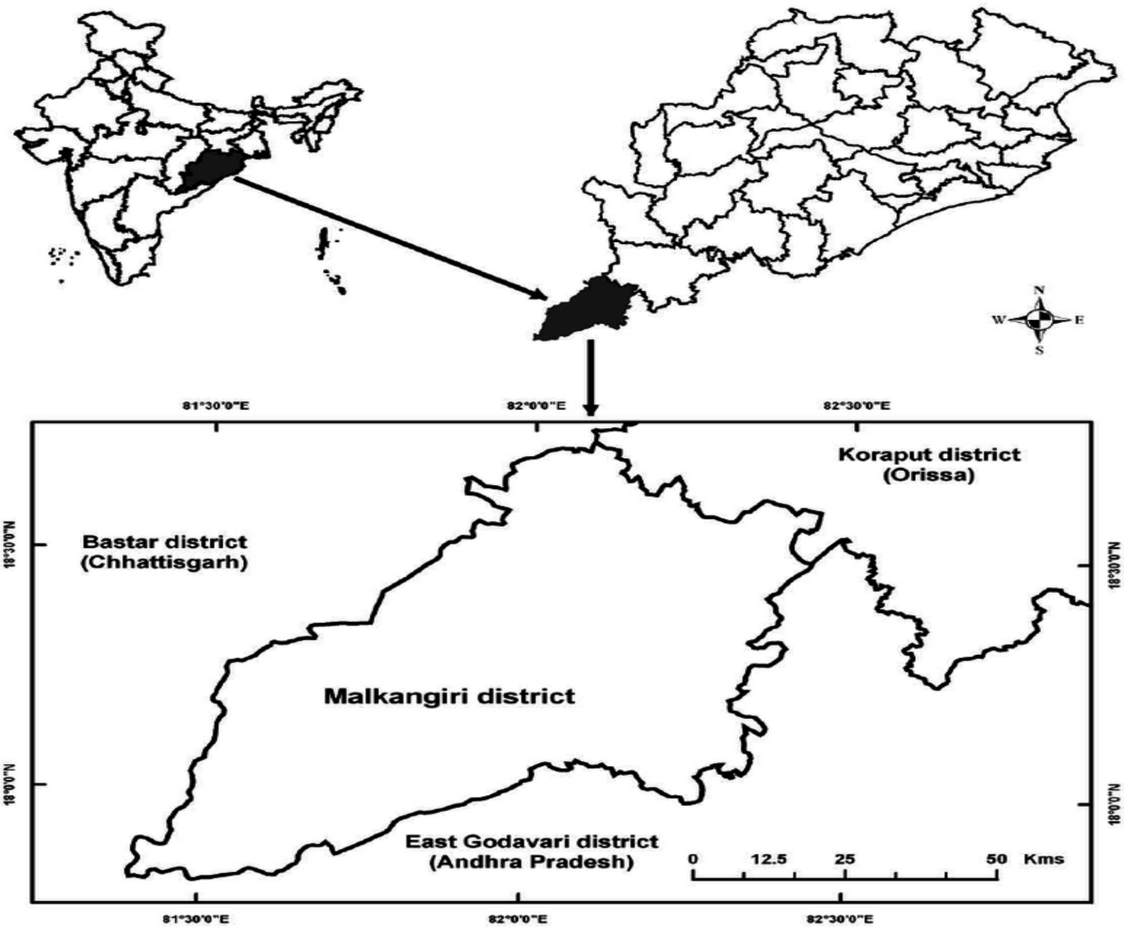

Figure 1: Map showing Malkangiri district of Odisha, India; the site for collection of unidentified indigenous finger millet accessions

Collection of whole plant during harvesting

The plants were collected during the harvesting month of December in 2022 and 2023.In each year, the whole plants were collected from the tribal-inhabited hilly terrains of different blocks of Malkangiri district as mentioned in Table no. 1. The plants were collected as a whole and were transported in non-airtight cloth bags and further processed in lab.

Retrieval of seeds from the collected accessions

The whole plants were sun-dried for 2 days for recovering the seeds. The panicles were separated from the parent plants and were subjected to threshing and cleaning. The acquired seeds from the panicles after threshing were further sun-dried to maintain a moisture content of 8-10% to ensure its eligibility for acid digestion.

Di-acid digestion of the resultant seeds

Di-acid digestion of the seeds is carried out for the resultant seeds to homogenize the sample by using a mixture of nitric acid and perchloric acid in very high temperature of 260^0 or more and mixed until the emission of red fumes come to an end. The complete digestion is indicated

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when the solution turns colorless. The solution is left to cool down, sub-sampled with addition of deionized water and aliquots are taken for determination of different elements like calcium, iron, zinc, magnesium, potassium, manganese, phosphorus and copper (Ca, Fe, Zn, Mg, K, Mn, P & Cu) as per Paul *et al*, 2017.

Elemental Analysis by ICP-OES

Quantification of nutrients has been done by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) in the Central Instrumentation Facility lab of OUAT, Bhubaneswar. In this technique of spectrometry, solid-state charge transfer devices are used to quantify the composition of elements in samples using plasma and a spectrometer.

Statistical Data Analysis

Two-way analysis of variance (ANOVA) was done by the Analysis Toolpak of Microsoft Office under Excel Add-ins. The different nutrients are studied in various accessions to establish correlation and significance was calculated at 99% with p-value as 0.01.

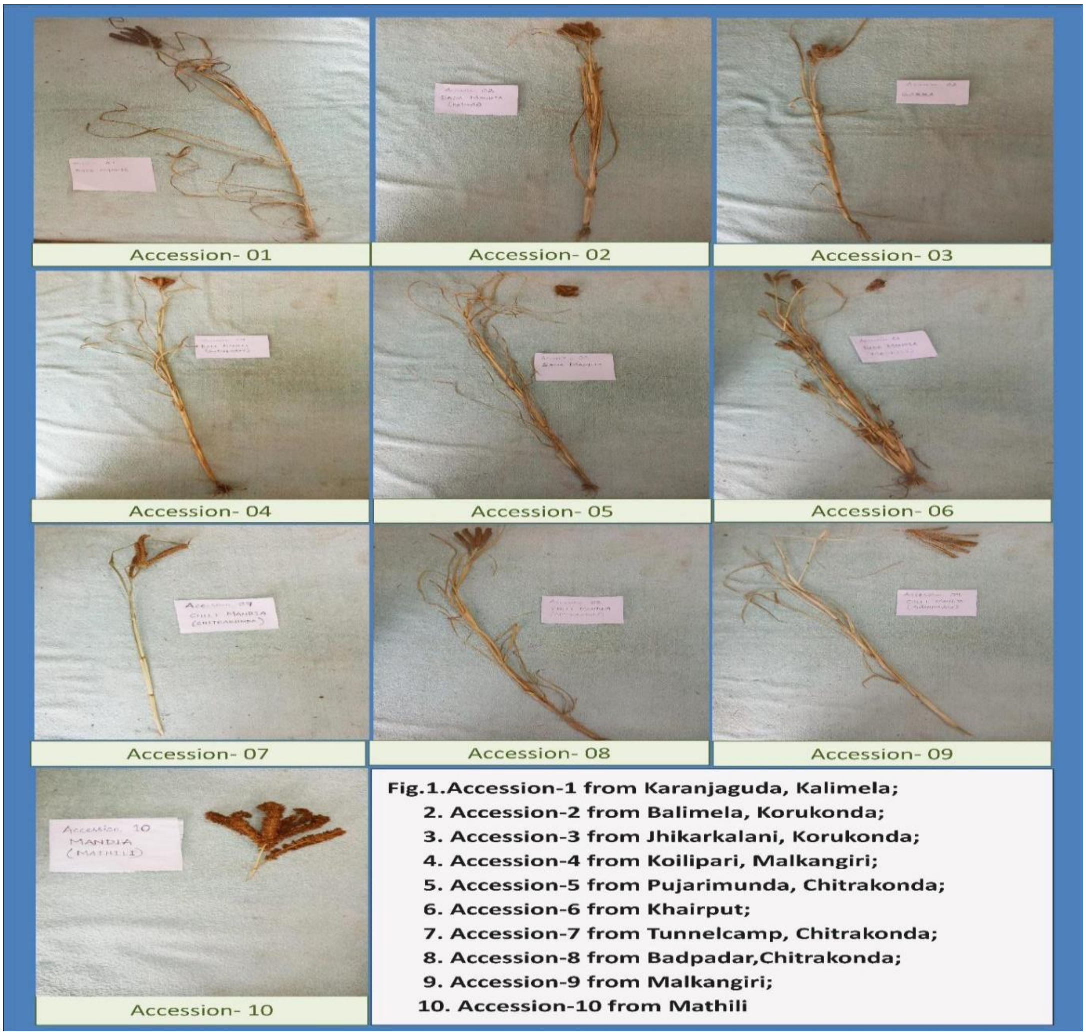

Figure 2: Collected indigenous finger millet accessions from different blocks of Malkangiri district, Odisha, India

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RESULTS/FINDINGS

Quantitative Analysis

The result found in this investigation is surprisingly high for most of the essential nutrients in the finger millet accessions collected from tribal pockets of Malkangiri district of Odisha (Table no. 2). Again, the quantity of each essential element is much higher when compared with the highest content of the same nutrients in different claimed major food crops as per the Food Data Central, Dept. of Agriculture, US (Table no. 3; Figure 3).

Finger millet is considered to have highest calcium content amongst all cereals (Reddy *et al*, 2009).The present report has recorded a range of calcium content in all the collected indigenous accessions and the 2 improved varieties from 174.5 mg/100g to 312.00 mg/100g. Eight (Accession- 1,3,4,5,6,7,9,10) out of the ten accessions have higher calcium content than the improved variety KMR-204, while all the 10 (Accession- 1 to 10)

accessions have higher calcium content than the improved variety Arjuna cultivated in that geographical area. Accession-1,3,4,5,6,10 are found to have higher calcium content than the mean value from the 10 collected finger millet genotypes from the Malkangiri district and 2 improved varieties grown in the district. Few of the accessions like acc-7, and the improved variety KMR-204 stands very near to the mean calcium content.

The iron content ranges from 21.78 mg/100g to 204.00 mg/100g in all the collected indigenous accessions and improved varieties. Six (Accession- 1,2,3,7,8,9) of the collected indigenous accessions have higher value of iron than both the improved varieties KMR-204 and Arjuna. Accession-1,2,3,7,8,9 and KMR-204 contains more iron content than the mean value from all the collected accessions, while Arjuna has considerable amount of iron when compared with the average value.

Table 2: Quantitative analysis of eight essential nutrients in collected indigenous finger millet accessions

Quantitative analysis of essential nutrients in different Indigenous accessions of Finger millet								
Accessions	**Ca (mg/100 g)**	**Fe (mg/100 g)**	**Zn (mg/100 g)**	**K (mg/100 g)**	**P (mg/100 g)**	**Mg (mg/100 g)**	**Mn (mg/100 g)**	**Cu (mg/100 g)**
1.	270 ± 0.95	204± 1.86	18.98± 0.51	290± 1.2	4.64± 0.28	155.94 ± 2	14.36± 0.8	0.5± 0.07
2.	227.2± 2	172.74 ± 1.3	25.32± 1	290.8± 1	33.88± 1.2	135.3± 1.03	11.74± 0.06	1.18± 0.06
3.	260.4± 1.34	168.82 ± 1	1734.13 ± 7.47	342.4± 0.86	96.5± 1.25	140.16 ± 1.48	11.46± 0.27	6.66± 0.25
4.	312± 1.74	102.96 ± 1.4	60.6± 0.98	358.8± 0.38	52.8± 0.7	156.9± 1	17.48± 0.56	2.3± 0.16

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5.	277.2± 0.9	21.78± 0.58	80.44± 0.46	373.4± 0.8	36.9± 0.69	95.42± 2.2	13.4± 0.33	20.02± 0.42
6.	306.8± 1.62	103.48 ± 0.66	59.12± 0.6	358.6± 0.5	88.86± 1.58	159.3± 1.355	17.24± 0.17	2.28± 0.13
7.	252± 0.75	157.8± 0.58	1646.6± 2.43	327.4± 2.26	37.7± 0.54	134.82 ± 1.63	11.14± 0.5	6.48± 0.33
8.	217.6± 1.7	166.98 ± 0	24.34± 0.46	280.4± 1.16	35.82± 0.53	126.06 ± 0.89	11.14± 0.34	1.14± 0.05
9.	248.4± 0.43	183.5± 0.65	15.4± 0.48	264.4± 0.84	0.74± 0.03	142.58 ± 1	13.1± 0.3	0.48± 0.02
10.	306.6± 2.44	100.52 ± 0.93	58.7± 0.6	358.4± 1.26	0± 0.00	152.82 ± 0.42	17.18± 0.64	2.26± 0.13
11.KMR	244± 1.2	155.14 ± 0.5	1596.4± 1.6	322± 2.26	34.08± 0.72	136.38 ± 0.41	10.98± 0.76	6.28± 0.55
12.Arjuna	174.5± 0.4	128.9± 0.3	20.16± 0.49	214.8± 1.52	68.12± 0.82	100.06 ± 0.11	9.1± 0.12	0.94± 0.03

Data are the mean of three replications ± SD.

Zinc content is found to be within the range of 15.4 mg/100g to 1734.13 mg/100gm in all the collected indigenous accessions and improved varieties. Accession- 3,7 and KMR-204 are recorded to have exceedingly extraordinary values of zinc content when compared with the mean value of all the accessions collected. Two (Accession- 3,7) amongst ten have been found to have more content of zinc than the improved variety KMR-204, while eight (Accession-2,3,4,5,6,7,8,10) are found to have more zinc content than Arjuna and other two (Accession-1,9) also have nearby values to it.

The present report shows a range of potassium content in all the collected indigenous accessions and the two improved varieties from 214.80 mg/100g to 373.4 mg/100g. Six (Accession- 3,4,5,6,7,10) out of the ten accessions have higher potassium content than the improved variety KMR-204, while all the 10 (Accession- 1 to 10) collected indigenous accessions have higher potassium content than the improved variety Arjuna cultivated in that geographical area. Accession-3,4,5,6,7,10 and KMR-204 are found to have higher potassium content than the average value from the 12 finger millet genotypes of the current study from the Malkangiri district.

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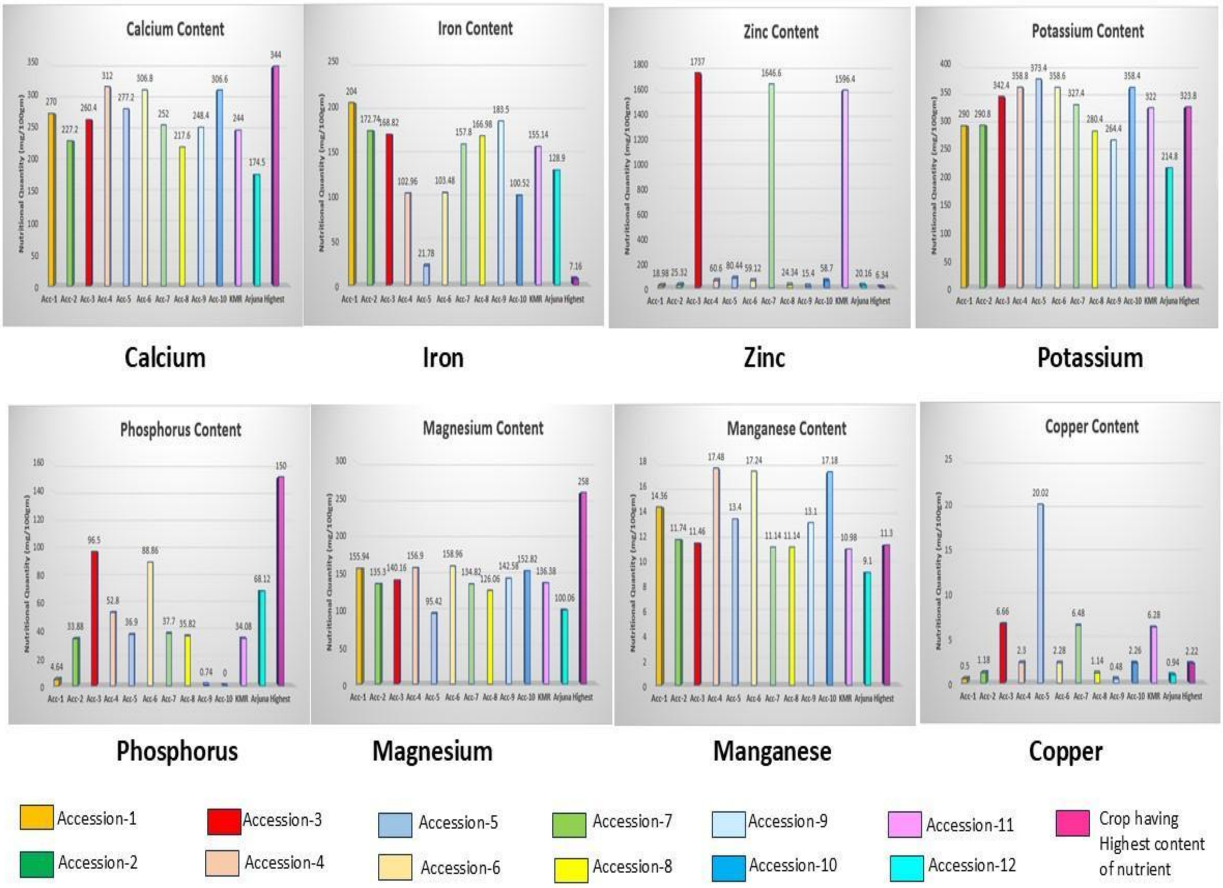

Figure 3: Comparative graph of nutrient contents present in the collected indigenous finger millet accessions with the declared crop having highest nutrient content by Food Data Central, U.S. Dept. of Agriculture

The phosphorus content ranges from 0 to 96.5 mg/100g in all the accessions and improved varieties. Six (Accession- 3,4,5,6,7,8) of the accessions have higher value of phosphorus than the improved variety KMR-204, while two (Accession- 3,6) accessions have higher content of phosphorus than Arjuna. Accession-3,4,6 and Arjuna contains more phosphorus content than the average value from all the collected accessions, while accession-2,5,7,8 and KMR-204 have substantial amount of phosphorus when compared with the average value.

Magnesium content is found to be within the range from 95.42 mg/100g to 159.30 mg/100gm in all the 10 collected indigenous accessions and 2 improved varieties. Accession-1,3,4,5,7,9,10 and improved variety KMR-204 are recorded to have higher values of magnesium content when compared with the mean value of all the accessions collected. Six (Accession- 1,3,4,6,9,10) amongst ten have been found to have more content of magnesium than the improved variety KMR-204, while nine (Accession- 1,2,3,4,6,7,8,9,10) are found to have more magnesium content than Arjuna and other one (Accession- 5) also has nearby value to it.

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Manganese content is found to be within the range of 9.1 mg/100g to 17.93 mg/100gm in all the collected indigenous accessions and improved varieties. Accession- 1,5,6,10 are recorded to have higher values of manganese content when compared with the mean value of all the accessions collected along with improved varieties. All the indigenous accessions have been found to have more content of manganese than the improved variety KMR-204 and Arjuna.

The copper content in all the accessions including the collected indigenous and the improved varieties ranges from 0.445 mg/100g to 20.02 mg/100g. Three (Accession- 3,5,7) among the ten collected indigenous accessions contain higher content of copper than the improved variety KMR-204, while eight (Accession- 2,3,4,5,6,7,8,10) among ten have higher values of copper than Arjuna. Accession-3,5,7 and improved variety KMR-204 has been seen to have higher values than the average copper content among all the twelve accessions under this study.

Table 3: Comparison of nutrients present in the collected indigenous Finger millet accessions from Malkangiri, Odisha with the declared crop having highest respective nutrient content by Food Data Central, U.S. Dept. of Agriculture

Sl. No.	Nutrient (in mg/100 g)	Data by US Dept of Agri. (containing highest conc. of the nutrient)		Data Obtained in the study for the collected indigenous accessions			
		Food crop	Highest Quantity of the nutrient (in mg/100 g)	Range of nutrient content in the accessions (in mg/100g)	Mean value (in mg/100 g)	Accession containing higher content than the average value of all accessions	Accession containing higher content of nutrients than the food crop having highest amount of the nutrient
1	Calcium (Ca)	Finger millet	344	174.5 - 312.00	258.07	Acc- 1,3,4,5,6, 10	-
2	Iron (Fe)	Lentils	7.16	21.78 - 204.00	138.85	Acc- 1,2,3,7,8, KMR	All the accessions
3	Zinc (Zn)	Pumpkin seeds	6.34	15.4 - 1734.13	445.00	Acc- 3,7, KMR	All the accessions
4	Potassium (K)	White beans	323.8	214.80 - 373.4	315.11	Acc- 3,4,5,6,7, 10, KMR	Acc- 3,4,5,6,7,10
5	Phosphorus (P)	Spelt	150	0 - 96.5	40.84	Acc- 3,4,6, Arjuna	-

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6	Magnesium (Mg)	Almonds	258	95.42 - 159.30	136.3	Acc- 1,3,4,6,9, 10, KMR	-
7	Manganese (Mn)	Macadamia Nuts	11.3	9.1 - 17.93	13.19	Acc- 1,4,5,6, 10	Acc- 1,2,3,4,5,6,9,10
8	Copper (Cu)	Cashew nuts	2.22	0.445 - 20.02	4.215	Acc- 3,5,7, KMR	Acc- 2,3,4,5,6,7,10 & KMR-204

Statistical Analysis

ANOVA Analysis

The ANOVA was highly significant (P<0.01) for calcium, iron, potassium, phosphorus, magnesium and manganese. Afterwards, the resultant data of ANOVA is not seen to be significant for zinc and copper. The values of most nutrients are found to be highly significant (P<0.01(Table no. 4)).

Table 4: Analysis of Variance (ANOVA) for different essential nutrients in collected indigenous finger millet accessions

	Calcium	**Iron**	**Zinc**	**Potassium**	**Phosphorus**	**Magnesium**	**Manganese**	**Copper**
F-value	432.23***	81.95***	4.29	475.59***	13.58**	411.23***	20.41***	1.33
Error	878.43	1283.01	268808.89	1201.57	520.69	245.75	13.16	23.55

***Significant at Prob<0.01; **Significant at Prob<0.01.

Coefficient of Correlation

The interactions between traits for nutrient contents were determined by correlation tests, thus the coefficients of correlation allow to quantify the magnitude and direction of the components that influence the expression of a certain trait (Figure 4). In the present investigation, calcium content shows significant positive correlation with potassium, magnesium, copper and manganese, while is negatively correlated with iron, zinc and phosphorus. Similarly, iron shows positive correlation with zinc and magnesium, while shows negative correlation with potassium, phosphorus, manganese and copper. Zinc shows positive correlation with potassium, phosphorus, copper and magnesium, while negative correlation with manganese. Potassium shows highly significant positive correlation with calcium, zinc, magnesium, manganese and copper, whereas negative correlation with iron. Phosphorus shows positive correlation with zinc, and much less positive relativity with potassium and copper, and negative relativity with iron, magnesium and manganese. Magnesium is observed to have highly positive significant association with calcium, potassium, and manganese, reciprocally related with copper. Manganese shows pragmatic correlation with calcium, potassium and magnesium,

Article DOI: 10.52589/AJAFS-EHGJGEI0
DOI URL: https://doi.org/10.52589/AJAFS-EHGJGEI0

and while negatively related with iron, zinc and phosphorus. Copper shows countering correlation with iron and magnesium, while showing positive correlation with calcium, zinc, potassium and phosphorus.

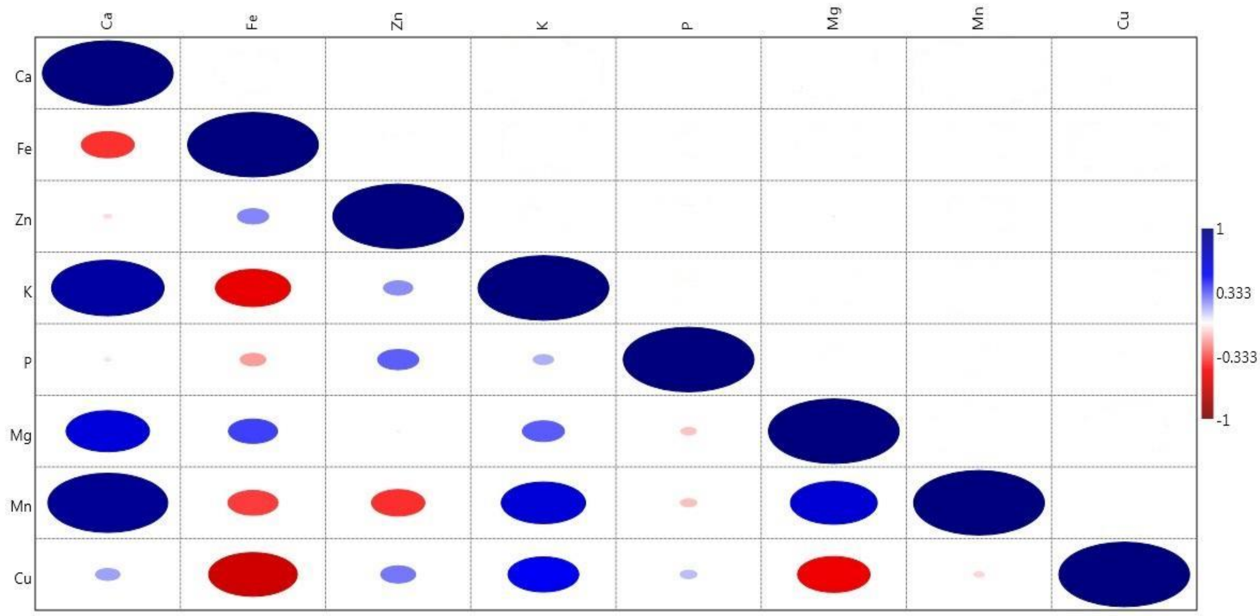

Figure 4: Relationship among essential nutrients present in the collected indigenous finger millet accessions from Malkangiri district of Odisha, India

Genetic variability Analysis

Phosphorus and zinc are the most variable elements present amongst the varieties, followed by copper and iron, while other elements have negligible variations in quantity present among the accessions of the study. With regard to average elemental status, zinc emerged as having the highest elemental status among all other estimated elements followed by potassium and calcium; vis a vis elements like zinc, potassium, copper and iron are found to be present in multi-folds in some accessions as compared to the whole collected population. Coefficient of variation value ranges from 0.75 in potassium (K) to 8.65 in copper (Cu), signifying statistical congruence of the observed data of elemental status in the present set of materials. In general, GCV is lower than PCV as expected. Among the varieties, Zinc content is shown to be highly genetically variable followed by copper and phosphorus, indicating ample scope for selection of zinc rich finger millet genotypes.

Heritable component can be calculated using heritability and genetic variants. The result from broad sense heritability ranges from 71.4 to 99.99 with maximum of 99.99% in case of zinc, indicating greater scope of transmission of the character to the follow-up generation. Also, all the other traits (nutrients) are exhibiting high heritability except manganese (Mn).

Article DOI: 10.52589/AJAFS-EHGJGEI0
DOI URL: https://doi.org/10.52589/AJAFS-EHGJGEI0

African Journal of Agriculture and Food Science
ISSN: 2689-5331
Volume 8, Issue 2, 2025 (pp. 116-138)

Table 5: Genetic variability parameters for different essential nutrients in collected indigenous finger millets accessions

Trait	Year	Mean± SE	Range	CD (1%)	σ^2 (Covariance)	CV (Coefficient of Variation)	GCV (%)	PCV (%)	H^2_{bs} (%)
Ca	2023 (Yr-1)	257.58± 11.6	174.9 - 310.26	3.11	1613.16	0.5	15.58	15.59	0.998
	2024 (Yr-2)	258.55± 11.81	174.1 - 313.74	7.82	1674.34	1.3	15.80	15.86	0.993
	Mean	258.07± 11.71	174.5 - 312.00	4.03	1643.75	0.90	15.68	15.73	0.993
Fe	2023 (Yr-1)	138.69± 14.53	21.2 - 205.87	2.32	2532.17	0.7	36.28	36.28	0.999
	2024 (Yr-2)	139 ± 14.33	22.36 - 202.14	5.64	2465.8	1.8	35.71	35.76	0.997
	Mean	138.85± 14.43	21.78 - 204.00	2.93	2498.99	1.25	35.99	36.03	0.997
Zn	2023 (Yr-1)	445.46± 211.7	15.88 – 1741.6	4.83	537824.5	0.5	164.63	164.63	0.999
	2024 (Yr-2)	444.53± 211.46	14.92 - 1726.66	22.31	536567.7	2.2	164.77	164.79	0.999
	Mean	445.00± 211.58	15.4 – 1734.13	10.00	537196.10	1.35	164.72	164.72	0.999
K	2023 (Yr-1)	314.85± 13.84	213.27 - 374.2	5.27	2298.62	0.7	15.22	15.24	0.997
	2024 (Yr-2)	315.37± 13.74	216.32 - 372.6	5.66	2263.95	0.8	15.07	15.09	0.997
	Mean	315.11± 13.79	214.80 - 373.4	4.025	2281.285	0.75	15.07	15.29	0.971
P	2023 (Yr-1)	40.4± 8.99	0 - 95.25	2.05	970.21	2.2	77.09	77.12	0.999
	2024 (Yr-2)	41.28± 9.29	0 - 97.75	5.00	1034.93	5.3	77.88	78.05	0.995
	Mean	40.84± 9.14	0 - 96.5	2.6	1002.57	3.75	77.29	77.95	0.983

Article DOI: 10.52589/AJAFS-EHGJGEI0
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Mg	2023 (Yr-1)	136.23± 6.07	93.22 - 157.95	2.75	441.64	0.9	15.42	15.44	0.996
	2024 (Yr-2)	136.37± 5.95	97.62 - 160.66	6.88	424.41	2.2	15.05	15.21	0.979
	Mean	136.3± 6.01	95.42 - 159.30	3.54	433.025	1.55	15.12	15.46	0.956
Mn	2023 (Yr-1)	13.32± 0.84	9.22 - 17.82	1.19	8.49	3.9	21.72	22.06	0.968
	2024 (Yr-2)	13.06± 0.81	8.98 - 18.04	1.62	7.82	5.4	21.17	21.84	0.939
	Mean	13.19± 0.825	9.1 - 17.93	1.035	8.155	4.65	20.03	23.70	0.714
Cu	2023 (Yr-1)	4.31± 1.64	0.46 - 20.44	0.70	32.18	7.1	131.68	131.87	0.997
	2024 (Yr-2)	4.12± 1.54	0.43 - 19.6	0.97	28.58	10.2	128.62	129.03	0.993
	Mean	4.215± 1.59	0.445 - 20.02	0.62	30.38	8.65	130.63	131.12	0.992

Genetic variability parameters include Range, Mean, Standard error (SE), Critical difference (CD), Covariance (σ^2), Coefficient of variation (CV), Genotypic Coefficient of Variation (GCV), Phenotypic Coefficient of Variation (PCV), Heritability in broad sense (H^2 bs)

Nutrient Cluster Analysis

Nutrient cluster analysis was done by UPGMA software, which constructed the rooted dendrogram as per the uniformity of different nutrients (elements) present in 10 collected indigenous and 2 improved accessions of the finger millet of the current study, and its further categorization as per sub-clusters formed (Figure 5). When provided 0% similarity (100% distance) at phenon-level, total genotypes are accumulated into two broad genetic clusters as Cluster- I (CI) and Cluster-II (CII), which are completely different based upon their nutrient status level, as they have 0% similarity found. The three genotypes of CI, namely acc-3,7 and KMR-204 altogether separated from rest of the genotypes which constituted another broad cluster CII including nine varieties, namely, accession- 4,6,10,5,9,1,2,8, Arjuna. Till 90% similarity, the above 9 genotypes maintained almost homology among them; beyond which, they get separated into 2 sub-clusters, CII-A & CII-B with 5 and 4 genotypes respectively. The 1st cluster C-I which included 3 accessions- 3,7 and KMR-204 seems to be quite divergent from rest of the test genotypes and this cluster of accessions is highly influenced by presence of much higher content of zinc as compared with other accessions.

C-IIA having 4 genotypes, namely accession- 4,5, 6 & 10 have been grouped altogether as they have promising quantities of many of the nutrients like Ca, Fe, Zn, K, Mn & Cu, when compared with other accessions collected for the study. Hereafter, acc-4 & 6 are exactly similar

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DOI URL: https://doi.org/10.52589/AJAFS-EHGJGEI0

with respect to nutrient accumulation, while acc-5 & 10 are a bit distant from them. C-IIB containing 5 genotypes includes improved variety Arjuna and collected accessions-1,2,8 and 9 seem to have intermediated nutrient quantities.

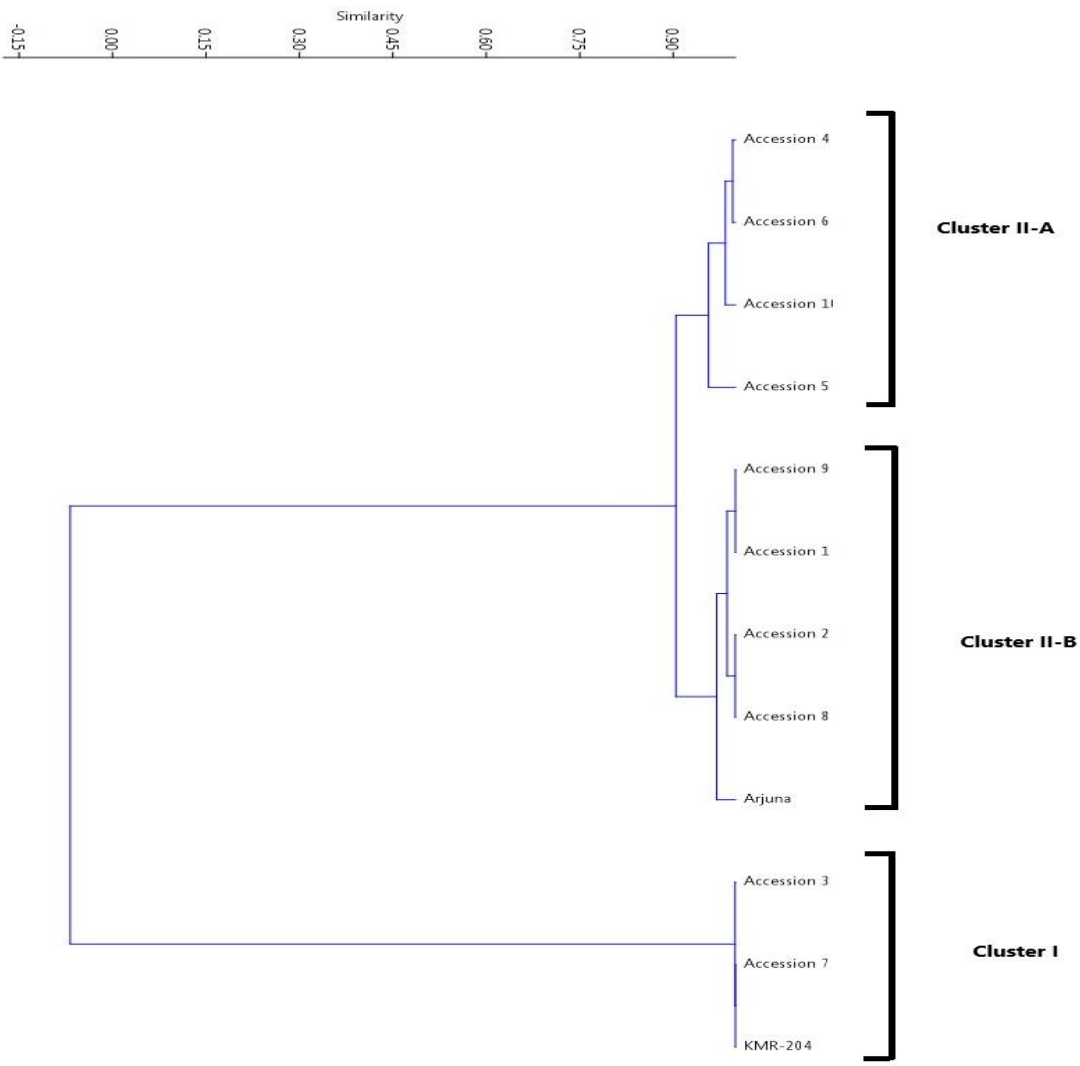

Figure 5: Dendrogram showing UPGMA similarity index of collected indigenous finger millet accessions based on essential nutrient contents

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DISCUSSION

Finger millet is considered to have highest calcium content amongst all cereals (Reddy *et al*, 2009) and the present report having a range of calcium content in all the 10 collected indigenous accessions and the 2 improved varieties from 174.5 mg/100g to 312.00 mg/100g is nearly comparable with the highest finger millet variant. As calcium is essential for many metabolic processes including nerve functioning, muscle contraction and blood clotting (Yadav *et al*, 2024), its consumption is highly prescribed by physicians. According to the Food Data Central by US Dept of Agriculture, lentils contain 7.16 mg/100g iron which is recorded to be the highest among food crops, fortunately all the collected accessions have much multi-folds of iron quantity than lentils and can be taken as an additive for iron which has multiple roles in oxygen transport, cell signaling and other xenobiotic metabolic processes (Hong *et al*, 2024). As standard data taken from Food Data Central, US Dept of agri., pumpkin seeds are found to have highest zinc content with 6.34 mg/100g, while all of our accessions have been quantified to have much higher content of this nutrient over 6.34 mg/100g, thus having potential towards strengthening immunity and better regulation of many processes where zinc has been found to be actively catalyzing as a co-factor (Roth-Walter *et al*, 2024). The Food Data Central by US Dept of Agriculture also suggests intake of white beans as it is been recorded to have highest potassium content with 323.8 mg/100g. As potassium finds its prime role in maintaining osmolarity during metabolic processes and neural, cardiac and muscular system, six (Accession- 3,4,5,6,7,10) of our collected indigenous accessions which are higher than above mentioned value and improved variety KMR-204 can be utilized as a wise alternative of white beans for its potassium abundance (Yamada *et al*, 2021). Additionally, as per the Food Data Central by US Dept of Agriculture, spelt (a species of wheat) contain 150 mg/100g phosphorus which is recorded to be highest among food crop, while our accessions-3, 6 and Arjuna have considerable quantity of the same, thus can be considered an option in case of ailments like weakness, spasms, respiratory impairments and skeletal abnormalities which is cured by phosphorus rich edibles. Also, phosphorus rich crops help in maintaining intercellular, membrane integrity and maintenance of genomic materials of which it is considered an important part (Peacock, 2020). Almonds are found to have highest magnesium content (as per the Food Data Central, US Dept of Agri.) with 258 mg/100g, while our accessions have been seen to have decent content of magnesium when compared to other food crops, and such magnesium rich food crops are appraised for their prominence in ionic channels along with Ca^{2+}, Na^{+} and K^{+}, present in myocardial mechanisms, replication, protein synthesis & other cellular metabolisms (Wang *et al*, 2025). Also, the standard data taken from Food Data Central, US Dept of agri. Suggests that macadamia nuts (or broadly nuts) having highest manganese content with 11.3 mg/100g, is advised by physicians for manganese deficiency diseases like hypocalcemia, hypokalemia, cardiac, neurological manifestations and impairment of insulin activity and normal blood sugar regulation. (Joshi *et al*, 2024). It is also readily seen to be functional in synthesis and activation of enzymes, clotting factors, proteins, regulating endocrine system, fat and carbohydrate metabolism, thus, to boost the much required manganese for the body, the eight of our accessions, i.e., acc- 1,2,3,4,5,6,9,10 where manganese content is seen to be higher than nuts and other two accessions, i.e., acc- 7,8 where nearby content of manganese is present, can be considered as better companion in basic dietary regime (Li *et al*, 2018).

Cashew nuts, being the crop having highest content of copper (Food Data Central, US Dept of Agri.) with 2.22 mg/100g, some of our accessions like accession-3,4,5,6,7,10 and improved

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African Journal of Agriculture and Food Science
ISSN: 2689-5331
Volume 8, Issue 2, 2025 (pp. 116-138)

variety KMR-204 have been tested with higher copper values than cashew nuts which can settle the obligatory need of copper which have salient roles in cuproenzymes (as Cu is a cofactor), metabolic reprogramming, bioenergetics and various neurodegenerative, metabolic and cardiovascular diseases (Lina *et al*, 2021; Chen *et al*, 2020).

The accessions containing higher content of specific essential nutrients have been mentioned above (Figure 3), while the other accessions also have generous contents of those nutrients and are found to be promising when compared with improved variety values. The lower amount of observed nutrients in few of the accessions as compared to better crops can be attributed because of lack of regular irrigation facilities (Table no. 3).

The ANOVA test was done to investigate the significant differences between the mean of the independent variables, considering high significance at $P_{0.01}$, and less differences at $P_{0.05}$. As the values of most nutrients are found here are seen to be highly significant ($P<0.01$), thus the indigenous accessions acquired have significant nutrient composition (Table no. 4). The insignificance seen in case of zinc and copper might be due to random chance alone, but also, the magnificently higher value of zinc seen in accession-3, 7 and KMR-204 may be used for further study and biofortification, with special consideration to zinc.

The interactions between traits were determined by correlation tests, thus the coefficients of correlation allow to quantify the magnitude and direction of the components that influence the expression of a certain trait (Figure 4). The coefficient of correlation confirms a strong linkage of calcium, potassium, magnesium and manganese in these indigenous FM, which may provide an insight for putative QTLs for identifying novel genes among these collected accessions from Eastern Ghats, Odisha (Basnet *et al*, 2022).

Phosphorus and zinc are the most variable elements present amongst the varieties, followed by copper and iron, while other elements varied in negligible amount among the varieties. With regard to average elemental status, zinc emerged as having the highest elemental status among all other estimated elements followed by potassium and calcium; but elements like zinc, potassium, copper and iron are found to be present in multi-folds in some accessions as compared to the whole collected population. Coefficient of variation value ranges from 0.75 (mean of K)-8.65 (mean of Cu), signifying statistical congruence of the observed data of elemental status in the present set of materials. In general, GCV is lower than PCV as expected. Among the varieties, Zinc content is shown to be highly genetically variable followed by copper and phosphorus, indicating ample scope for selection of zinc rich finger millet genotypes. Presence of minimal difference between PCV and GCV has been observed which clearly indicates negligible influence of environment on the expression of genes for different elemental status (Table no. 5).

The result from broad sense heritability ranges from 71.4 to 99.99 with maximum of 99.99% in case of zinc, indicating greater scope of transmission of the character to the follow-up generation. Also, all the other traits (nutrients) are exhibiting high heritability except manganese (Mn), which will evidently pave the way for reliable selection of genotype based on presence of almost all important nutrients, as high heritability indicates a high component of the heritable portion (Nithya *et al*, 2020).

With the presence of acc-3 & 7 with KMR-204 in cluster C-I, it shows that they have close associative properties and the collected indigenous accessions may help in developing

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improved varieties like the improved variety KMR-204, which have been recorded to have much higher yield than many other varieties of finger millet in the Eastern Ghats of Odisha (Panda *et al*, 2023) along with considerable presence of various essential nutrients. So, these may be further used for study and biofortification, with special consideration to zinc. The cluster C-IIA contains acc-4,5,6 & 10, where they have promising quantities of many of the nutrients like Ca, Fe, Zn, K, Mn & Cu, indicating greater scale for selection for biofortification breeding programs and enrichment of nutritional status in finger millet. Being at the same level in having same nutrient content cluster, acc-1 & 9 forms a set and acc-2 & 8 forms another set, standing a little distant from Arjuna in the cluster- C-IIB. In spite of being a bit distant, the accessions-1,2,8,9 & Arjuna are categorized as a same cluster, thus, they may show more inclination towards tolerance to dehydration, as Arjuna is a drought-tolerant variety of that geographical area (Panda *et al*, 2023). Thus, the genotypes of this cluster namely, accessions-1,2,8 and 9 may provide scope for crop improvement in rain-fed or areas facing dry spells (Tripathy *et al*, 2015).

Most of the collected indigenous accessions from the tribal pockets of Malkangiri district are observed to have much higher values of nutrients than the improved varieties (KMR-204, Arjuna) and also compete with the other food crops declared to have highest content of the respective essential nutrients by Food Data Central, US Department of Agriculture. Except few, most of the accessions are found to be best or promising above the best declared crops and contains more than maximum amounts of the different essential nutrients packed in studied accessions. These promising accessions are indigenous native to the rain-fed tribal belts in Malkangiri district of Odisha, India which represents one of the undisturbed ecosystems of Eastern Ghats of India with negligible urbanization influence. However, the irregular irrigation practices might also be the reason for decrease in nutritive values in few cases. The vast variability in micro-nutrients in the present study is possible as there are such data already reported in previous studies in Babu *et al*,1987; Vadivoo *et al*,1998; Sharma *et al*,2017; Admassu *et al, 2009*. Hence, regular intake of these finger millet accessions from this undisturbed ecosystem in diet will help stabilize basic metabolism of the body and help in alleviating health issues as ‘a food for medicine’ as it is anti-diabetic, antitumerogenic, anti-atherosclerogenic and antioxidative in nature. The wide range of essential nutrients in the indigenous genotypes might help in exploring many underutilized genotypes of finger millet and selective study of such accessions for further use in breeding programs, & can be utilized for nutrient biofortification, enhancing research in sustainable agriculture and accepting finger millet as an alternative and better staple food.

IMPLICATION TO RESEARCH AND PRACTICE

This investigation has come up with intriguing results showing towering quantity of essential nutrients among indigenous landraces found in the tribal pockets of Eastern Ghats of India which is declared as Millet hotspot in India by IIMR. The extra ordinary nutrient content discovered among the collected genotype can benefit the interest of nutritionist, scientist, plant breeders, policymakers towards ensuring the germplasm conservation and its proliferation as a climate resilient nutrient rich smart crop. Again, this could set a road map for enhancing the socio-economic status of the tribal people mostly relying upon this millet crop for food and fodder.

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The findings of our study in terms of essential nutrient could challenge the best declared food crops by US to have many of the essential nutrients in a single mining platform of finger millet genotypes of Eastern Ghats of India. This further knocks up the needs to explore the genes responsible for such high nutrient contents among the collected and tested genotypes. Such genes can be really helpful for gene pyramiding steps conforming biofortification. The accessions showing similarity index with the drought resistant improved variety “Arjuna” seeks attention for interactive studies of dehydration tolerance and its impact on nutrient assemblance (Panda *et al*, 2023). These nutritional and drought tolerance proprieties can further be exploited for breeding program towards sustainable agriculture to feed the global population even though in a changing climatic condition.

CONCLUSION

Most of the collected indigenous finger millet accessions from the tribal pockets of Malkanagiri district of Odisha present in the Eastern Ghats of India have been found to be the hub of essential nutrient mines especially for calcium, iron, zinc, potassium, manganese, copper, etc. which can be the best solution towards fulfilling the nutritional aspect of a healthy diet and also filling the gap of food insecurity (Jha *et al*, 2024).

The high nutritional quantity for many of the essential nutrients can be attributed to the reason of an undisturbed ecosystem present in the Eastern Ghats region situated in the Malkangiri district of Odisha, India (Manoj *et al*,2024).

The accessions showing nutritional and drought tolerance proprieties can be exploited for further breeding program towards sustainable agriculture to feed the global population even though in a changing climatic condition.

FUTURE RESEARCH

This investigation on properties in finger millet could can help explore the genes responsible for such high nutrient contents among the collected and tested genotypes. Such genes can be really helpful for gene pyramiding steps conforming biofortification. The accessions showing relativity with the drought resistant improved variety “Arjuna” can provide insight for studies of dehydration tolerance and its impact on nutrient assemblance. It can further be studied for breeding program towards sustainable agriculture critical climatic condition and various abiotic stresses.

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