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Research Article

Exploring the influence of water stress on iron and zinc accumulation in foxtail millet (*Setaria italica* L.) genotypes

Mukul Kumar Gandhi
Department of Agricultural Biotechnology and Molecular Biology, Dr. Rajendra Prasad Central Agricultural University, Pusa-848125 (Bihar), India
Kumari Anjani *
Department of Agricultural Biotechnology and Molecular Biology, Dr. Rajendra Prasad Central Agricultural University, Pusa-848125 (Bihar), India
Vinay Kumar Sharma
Department of Agricultural Biotechnology and Molecular Biology, Dr. Rajendra Prasad Central Agricultural University, Pusa-848125 (Bihar), India
Kaushal Kumar
Department of Agricultural Biotechnology and Molecular Biology, Dr. Rajendra Prasad Central Agricultural University, Pusa-848125 (Bihar), India
Satish Kumar Singh
Department of Genetics and Plant Breeding, Dr. Rajendra Prasad Central Agricultural University, Pusa-848125 (Bihar), India
Prasenjit Paul
Department of Genetics and Plant Breeding, Dr. Rajendra Prasad Central Agricultural University, Pusa-848125 (Bihar). India

*Corresponding author. E-mail: anjanikumari1234@gmail.com, anjani@rpcau.ac.in

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Abstract
Foxtail millet is a climate resilient crop rich in nutrients. However, the adverse conditions can affect the nutritional composition of the grains. The present study aimed to study the effect of drought on iron and zinc content of thirty foxtail millet [(*Setaria italica* (L.)] genotypes. The experiment was conducted in randomized block design under normal and drought conditions. The grain iron and zinc content were determined for both conditions. The result showed significant variation in iron concentration ranging from 21.32 to 61.19 ppm under normal condition, while zinc content ranged from 21.51 to 35.37 ppm. The highest iron and zinc content was found in the genotype IIMRFXM-11 (61.19 ppm) and STFO-7 (35.37 ppm), while the lowest was found in genotype GPUF-16 (21.32 ppm) and SiA3156 (21.51 ppm), respectively. Under drought condition iron content ranged from 19.62 ppm to 59.49 ppm, whereas zinc content ranged from 20.12 ppm to 33.97 ppm. The highest iron and zinc content was found in genotype IIMRFXM-11 (59.49 ppm) and STFO-6 (33.97 ppm), while the lowest was found in genotype GPUF-16 (19.62 ppm) and SiA3156 (20.11 ppm), respectively. The grain iron and zinc content variation may be due to genetic differences that influence plant nutrient uptake, transport, and storage mechanisms. An overall iron and zinc concentration decrease was observed under drought conditions for all the genotypes except IIMRFXM-11 and R. KAUNI-1. The experiments concluded a reduction in grain iron and zinc accumulation in foxtail millets subjected to water stress.

Keywords: Drought, Foxtail millet, Iron, Water stress, Zinc

INTRODUCTION

Foxtail millet (*Setaria italica* L.) stands out as a self-pollinating C_4 Panicoideae crop species, recognized by various names such as *kangni, navane, tenai, korra*, and *rala* across different regions of India. Its modest genome size and chromosome count of 2n=18, low levels of repetitive DNA, and tendency for inbreeding position it as an excellent model system for experimental research (Li and Brutnell, 2011; Doust *et al.*, 2009). Cultivated widely across Eurasia, America, Africa, and Australia, millets are esteemed for their rich protein and micronutrient content (Geervani and Eggum, 1989). Foxtail millet grains, in particular, offer notable nutritional benefits, providing 11.2 grams of protein, 28 mg of iron, 4 grams of fat, 4.1 mg of zinc, and beta-carotene, a precursor to vitamin A, per 100 grams (Murgun and Kumari, 2006). Acknowledging its nutritional significance, especially for individuals managing diabetes, the Joint Genome Institute (JGI) of the US Department of Energy initiated a project to generate a draft version of the foxtail millet genome (Doust *et al.*, 2009). This initiative reflects the growing recognition of foxtail millet as a valuable dietary resource. The crop is also particularly suitable for cultivating in harsh environmental conditions like drought since it can withstand extreme weather conditions. However, a significant decrease in the productivity and nutritional composition of the crop, particularly iron and zinc, is expected due to drought stress and changes in physiological and biochemical processes (Porwal *et al*.,2023).

Zinc, a micronutrient, is pivotal in crops by regulating various physiological and molecular mechanisms that aid in drought resistance. Key enzymes like carbonic anhydrase and aldolase, crucial for crop growth, rely on zinc (Umair *et al*.,2020). Moreover, zinc is essential in plant metabolism, including the synthesis of nucleic acids, as it is a vital component of numerous biomolecules, such as lipids, proteins, and auxins, all critical for plant function. Yet, an excessive zinc concentration can inhibit cell division and elongation, impacting biomass production and posing toxicity risks to plants. Iron (Fe) is another micronutrient of significant importance in global agriculture. Plants require iron in small quantities for proper growth and development. Its role in mitigating stress is indispensable, especially in conditions like salinity, drought, or heavy metal stress (Khan *et al.*, 2020; Nadeem *et al.*, 2020). These two micronutrients are also important for humans' proper growth and development. The deficiency of these can lead to several disorders. The millets are considered to be a good source of iron and zinc. However, water stress, particularly drought, can affect iron and zinc accumulation in grain owing to the role of these micronutrients in drought stress mitigation. Keeping this in mind, the present investigation was carried out to study the effect of drought stress on micronutrient accumulation in the grains of thirty foxtail millet [(*Setaria italica* (L.)] genotypes.

MATERIALS AND METHODS

Plant materials and experimental methods

Thirty foxtail millet genotypes, as indicated in Table 1, were used. These genotypes' grain iron and zinc content was estimated using atomic absorption spectroscopy (AAS) with the di-acid method (Gupta, 2020), with three biological and three technical replicates. To determine the values accurately, the samples were compared to a blank one. The concentration of micronutrients was then expressed in parts per million (ppm).

Extraction of micronutrients

The seeds were pulverized using a mortar and pestle to achieve a powdered consistency. Subsequently, 0.5g of the powdered seed was precisely measured and placed into a 100 ml conical flask. A meticulously measured 10 ml of di-acid mixture was added to the flask and allowed to undergo pre-digestion. Following this pre-digestion phase, the flask was positioned on a hot plate within a dedicated acid-proof digestion chamber featuring a fume exhaust system. Heating commenced at 100°C for one hour, after which the temperature was gradually elevated to approximately 200°C. Digestion proceeded until the solution achieved a colourless state, accompanied solely by the emergence of dense white fumes. The acid content was subsequently reduced to approximately 2-3 ml through continued heating. Following the digestion process, the flask was carefully removed from the hot plate and allowed to cool. Distilled water was then added to adjust the volume to 50 ml. The resulting solution was filtered into a volumetric flask through Whatman No. 42 filter paper. Using a Thermo Scientific Atomic Absorption Spectrophotometer, readings were taken against a blank solution containing only the di-acid mixture (prepared by combining 693 ml of concentrated nitric acid with 308 ml of concentrated perchloric acid and storing the solution in a bottle at room temperature).

Quantification of iron and zinc content (in ppm)

The analysis involved subtracting the reading of the blank sample obtained from the Atomic Absorption Spectrophotometer (AAS-200) from the sample reading. This difference was then multiplied by the dilution factor to determine the quantity of micronutrients present in the sample. The concentration in parts per million (ppm) was calculated using the formula:

Concentration (ppm) = (Sample reading – Blank reading) × Dilution factor, Eq. 1

Where the dilution factor equals the final volume prepared divided by the sample weight.

Data analysis

Iron and zinc content readings were taken in three replications for each sample. These readings were evaluated using a completely randomized design (CRD) at a 5% significance level to assess the results' significance. This rigorous approach ensured reliability and accuracy in determining micronutrient levels in the samples. The critical difference (C.D), Standard error upon mean (SEm) and Coefficient of variation (C.V) were calculated based on the ANOVA performed in CRD design with three technically replicated samples of Zinc and Iron of the thirty foxtail millet genotypes under both normal and drought condition.

Categorization of genotypes

The genotypes were classified into high, medium, and low categories based on their iron and zinc content and were conducted following the scoring methodology as outlined by Kumar *et al*. (2023). This systematic ap-

Table 1. List of foxtail millet genotypes and collection centre

S. No.	Genotype Name	Collection centre	Sl. No.	Genotype Name	Collection center
1	TNSi-380	Athiyandal	16	SiA-4201	Nandyal
2	TNSi-382		17	SiA-4213	
3	TNSi-385		18	SiA-3156	
4	IIMRFXM-6	Hyderabad	19	BUFTM-82	Buldana
5	IIMRFXM-7		20	BUFTM-98	
6	IIMRFXM-8		21	(R. KAUNI-1	
7	IIMRFXM-9		22	STFO-1	East Champaran
8	IIMRFXM-10		23	STFO-2	
9	IIMRFXM-11		24	STFO-3	
10	CRSFXM-3	CSR Solapur	25	STFO-4	
11	CRSFXM-4		26	STFO-5	West Champaran
12	GPUF-16	Bengaluru	27	STFO-6	
13	DHFt-20-3	Dharwad	28	STFO-7	
14	DHFt-20-153		29	STFO-8	Gopalganj
15	DHFt-109-3		30	STFO-9	

proach allowed for the relative categorization of the genotypes according to their respective levels of these essential micronutrients. Such classification facilitates a meticulous understanding of the nutritional profiles within the diverse genotypes under investigation. If the concentration (in ppm) was less than (Mean ± SD), then the genotype was categorised as 'Low', while greater than (Mean ± SD), dignified as 'High', and between (Mean - SD) and (Mean± SD), as 'Medium'.

RESULTS

Grain iron and zinc of foxtail millet genotypes under normal conditions

The micronutrient analysis of grain conducted across thirty foxtail millet genotypes revealed notable disparities in iron concentrations, spanning from 21.32 to 61.19 ppm under normal conditions. Similarly, the zinc content exhibited a range from 21.51 to 35.37ppm. These findings underscore the substantial variability in iron and zinc levels among the foxtail millet genotypes under study, highlighting the importance of comprehensively evaluating their nutritional compositions. Among the various genotypes of foxtail millet studied, genotype IIMR FXM-11 exhibited the highest grain iron content at 61.19 ppm, followed closely by STFO-7 at 59.52 ppm, IIMR FXM-8 at 56.24 ppm, and STFO-9 at 55.81 ppm. Conversely, the lowest iron content was observed in genotype GPUF-16 at 21.32 ppm, followed by IIMR FXM-7 at 23.52 ppm, and STFO-2 at 24.57 ppm (Table 2). These findings delineate the considerable variability in iron content among different foxtail millet genotypes, emphasizing the significance of genotype selection in breeding programs to enhance nutritional traits.

Similarly, significant variations were observed in the grain zinc content of foxtail millet genotypes. The zinc content ranged from 21.51 ppm to 35.37 ppm across different genotypes. Genotype STFO-7 exhibited the highest zinc content at 35.37 ppm, followed by STFO-9 at 32.54 ppm, IIMR FXM-11 at 32.69 ppm, and IIMR FXM-68 at 31.41 ppm. Conversely, the lowest zinc content was recorded in genotype SiA3156 at 21.32 ppm, followed by CRSFXM-3 at 22.27 ppm, and IIMR FXM-10 at 22.51 ppm (Table 2). The critical difference (CD) observed among the thirty genotypes of foxtail millet concerning zinc content was 1.02, while iron content was 1.34. The mean standard error was 0.196 and 0.143 for zinc and iron content, respectively, whereas the standard error of difference was 0.36 and 0.47, respectively. The coefficient of variation (CV) for zinc content was 2.26, and for iron content, it was 2.02 (Table 2). Notably, the genotypes exhibited more iron content variation than zinc content.

Relative distribution of the genotypes based on iron and zinc content in normal conditions

Based on the zinc and iron content of the thirty foxtail millet genotypes, they were categorized into three classes: low, medium, and high (Table 3). The low-grain iron content ranged from 21.32 ppm to 27.55 ppm, encompassing six foxtail millet genotypes. The medium grain iron content ranged from 32.26 ppm to 47.28 ppm, including seventeen genotypes, while the high iron content ranged from 53.32 ppm to 61.19 ppm, encompassing seven genotypes. Similarly, three categories based on zinc content were identified: low (21.51 to 23.36) ppm, including six genotypes; medium (24.24 to 30.84 ppm), including nineteen genotypes; and high (31.35 to 35.37 ppm), including five genotypes of foxtail millet. Notably, genotype STFO-7 emerged as the top performer in both iron and zinc content, and it was classified in the high category

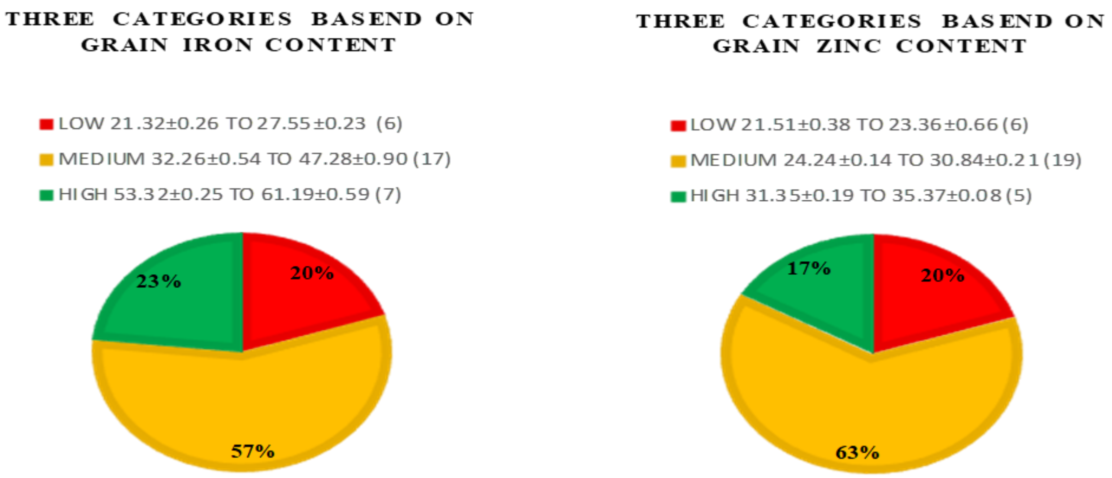

Fig. 1. *Percentage distribution of the genotypes in three categories depending on the amount of zinc and iron in the grain under normal condition*

for both micronutrients (Fig. 1).

Grain iron and zinc of foxtail millet genotypes under drought condition

Under drought conditions, iron concentrations varied from 19.62 ppm to 59.49 ppm, and zinc content ranged from 20.11 ppm to 33.97 ppm. Among the different genotypes of foxtail millet, genotype IIMR FXM-11 exhibited the highest grain iron content at 59.49 ppm, followed by STFO-7 at 57.82 ppm, IIMR FXM-8 at 54.54 ppm, and STFO-9 at 54.11 ppm. Conversely, the lowest iron content was observed in genotype GPUF-16 at 19.62 ppm, followed by IIMR FXM-7 at 21.82 ppm and STFO-2 at 22.87 ppm. Genotype STFO-6 exhibited the highest zinc content at 33.97 ppm, followed by STFO-7 at 32.30 ppm, R. KAUNI-1 at 32.46 ppm, and IIMR FXM-6 at 31.16 ppm. Conversely, the lowest zinc content was recorded in genotype SiA3156 at 20.11 ppm, followed by CRSFXM-3 at 20.87 ppm and IIMR FXM-10 at 21.11 ppm. The critical difference (CD) observed among the thirty foxtail millet genotypes concerning zinc content was 1.12, while iron content was 1.34. The mean standard error for zinc and iron content was 0.39 and 0.43, respectively, with the standard error of difference being 0.56 for zinc and 0.67 for iron. The coefficient of variation (CV) indicated a relative variability of 2.28 for zinc content and 2.06 for iron content. The results suggest that the zinc content shows more variation among the genotypes than iron content (Table 2).

Relative distribution of the genotypes based on iron and zinc content in drought conditions

The low grain content for iron ranged from 19.62 ppm to 25.85 ppm, with six genotypes falling into this category (Table 4). Medium grain iron content ranged from 30.56 ppm to 51.62 ppm, encompassing eighteen genotypes, while high iron content ranged from 54.11 ppm to 59.49 ppm, including six genotypes. Similarly, for zinc content, the low category ranged from 20.12 to 23.02 ppm, with ten genotypes included, while the medium category spanned from 24.30 to 30.27 ppm, comprising fifteen genotypes. The high category ranged from 31.14 to 33.97 ppm, including five genotypes. Among all foxtail millet genotypes, STFO-7 stood out as the top performer in terms of iron and zinc content, and it was classified in the high category for both micronutrients (Fig. 2). The genotypes showed more variation in their zinc content than iron content.

Effect of drought on iron and zinc content of foxtail millet

The comparison of grain iron and zinc content among thirty foxtail millet genotypes under both normal and drought conditions elucidates notable trends. A subtle decrease in the composition of zinc content was observed for all the genotypes except CRSFXM-3, IIMR FXM-10, IIMR FXM-11, TNSi-382 and SiA4201 showed a substantial decrease in the zinc content. However, genotypes IIMR FXM-6, TNSi-385, RKAUNI-1, STFO-2, STFO-5 and STFO-6 showed an increase in the zinc content under drought conditions. Concerning iron content, all the genotypes showed a decreased value.

In normal conditions, the analysis revealed that 20% of the foxtail millet genotypes exhibit low iron content, whereas 57% fall within the medium range, with the remaining 23% categorized as high. Similarly, in terms of zinc content, 25% of the genotypes manifested low levels, while 62% demonstrated medium levels, and 13% were characterized by high levels. Upon encountering drought conditions, there were discernible alterations in the distribution. Although 20% of the genotypes continued to display low iron content, the proportion of genotypes within the medium range increased to 60%, with 20% now designated as high. Similarly, the zinc content distribution maintains consistency, with 25% of genotypes retaining low levels, 62% remaining within the medium range, and 13% persisting as high (Fig. 2). With respect to zinc content, the distribution pattern showed a marked shift (Fig. 1,2). While the percentage

Table 2. Zinc and Iron content in different foxtail millet genotypes (in ppm) under normal and drought conditions

S. No.	Genotypes	Normal condition		Drought condition	
		Zn (ppm)	Fe (ppm)	Zn (ppm)	Fe (ppm)
1	TNSi-380	28.43± 0.22	36.34 ±0.74	27.03±0.39	34.64±0.68
2	IIMR FXM-6	30.56±0.43	32.26±0.54	31.16±0.36	30.56±0.54
3	IIMR FxM-7	22.38±0.38	23.52±0.16	24.98±0.22	21.82±0.14
4	CRSFXM-3	28.27±0.50	41.54±0.64	20.87±0.62	39.84±0.57
5	CRS FXM-4	26.85±0.38	33.42±0.34	25.46±0.55	31.72±0.31
6	IIMR FXM-8	31.41±0.65	56.25±0.20	30.01±0.45	54.55±0.29
7	IIMR FXM-9	24.24±0.14	37.81±1.01	22.85±0.31	36.11±1.13
8	IIMR FXM-10	27.51±0.24	41.50±0.54	21.11±0.32	39.80±0.43
9	IIMR FXM-11	32.69±0.14	61.19±0.59	24.30±0.30	59.49±0.62
10	GPUF-16	23.36±0.66	21.32±0.26	22.96±0.50	19.62±0.25
11	TNSi-382	30.02±0.52	45.24±0.35	26.35±0.52	43.54±0.32
12	TNSi-385	23.16±0.15	27.55±0.23	26.87±0.36	25.85±0.34
13	DHFt 20-3	24.72±0.07	43.08±0.20	22.33±0.22	41.38±0.31
14	DHFt 20-153	30.61±0.33	39.26±0.32	29.21±0.18	37.56±0.38
15	SiA 4201	31.35±0.19	55.33±0.35	22.96±0.36	53.63±0.41
16	SiA 4213	26.36±0.24	36.34±0.08	24.97±0.27	34.64±0.16
17	BUFTM 82	29.38±0.26	47.28±0.90	27.98±0.35	45.58±1.01
18	BUFTM 98	25.82±0.54	39.19±0.18	21.42±0.49	37.49±0.25
19	SiA 3156	21.51±0.38	26.33±0.27	20.12±0.35	24.63±0.30
20	DHFt 109-3	30.84±0.21	46.80±0.56	29.44±0.30	45.10±0.67
21	(RKAUNI-1)	29.46±0.13	35.45±0.10	32.06±0.18	33.75±0.05
22	STFO-1	26.60±0.86	57.49±0.40	25.21±1.01	55.79±0.45
23	STFO-2	22.45±0.17	24.58±0.08	26.06±0.04	22.88±0.04
24	STFO-3	25.62±0.17	32.92±0.30	22.22±0.33	31.22±0.19
25	STFO-4	28.74±0.12	53.32±0.50	28.34±0.33	51.62±0.40
26	STFO-5	22.67±0.21	24.26±0.16	30.27±0.30	22.56±0.14
27	STFO-6	30.37±0.36	46.93±0.84	33.97±0.19	45.23±0.88
28	STFO-7	35.37±0.08	59.52±0.30	32.30±0.26	57.82±0.25
29	STFO-8	24.41±0.22	39.14±0.32	23.02±0.43	37.44±0.30
30	STFO-9	32.54±0.15	55.81±0.73	31.14±0.24	54.11±0.65
	Mean	27.59±0.30	40.70±0.41	26.23±0.36	39.00±0.38
	C.D.	1.02	1.34	1.12	1.34
	SE(m)	0.36	0.47	0.39	0.43
	SE(d)	0.51	0.67	0.56	0.67
	C.V.	2.26	2.02	2.28	2.06

Table 3. Classification of thirty foxtail millet genotypes based on their grain iron and zinc content in normal condition

Category	Iron	Zinc
High	IIMR FXM-8, IIMR FXM-11, SiA 4201, STFO-1, STFO-4, STFO-7 and STFO-9	IIMR FXM-8, IIMR FXM-11, SiA 4201, STFO-7 and STFO9
Medium	TNSi-380, IIMR FXM-6, CRSFXM-3, CRS FXM-4, IIMR FXM-9, IIMR FXM-10, TNSi-382, DHFt 20-3, DHFt 20-153, SiA 4213, BUFTM 82, BUFTM 98, DHFt 109-3. R. KAUNI-1, STFO-3, STFO-6 and STFO-8	TNSi-380, IIMR FXM-6, CRSFXM-3, CRS FXM-4, IIMR FXM-9, IIMR FXM-10, TNSi-382, DHFt 20-3, SiA 4213, DHFt 20-153, BUFTM 82, BUFTM 98, DHFt 109-3, R. KAUNI-1, STFO-1, STFO-3, STFO-4, STFO-6 and STFO-8
Low	IIMR FXM-7, GPUF-16, TNSi-385, SiA 3156, STFO-2 and STFO-5	IIMR FxM-7, GPUF-16, TNSi-385, SiA 3156, STFO-2 and STFO-5

Table 4. Classification of thirty foxtail millet genotypes based on their grain iron and zinc content in drought condition

Category	Iron	Zinc
High	IIMR FXM-8, IIMR FXM-11, SiA 4201, STFO-1, STFO-7 and STFO-9	IIMR FXM-6, R. KAUNI-1, STFO-6, STFO-7 and STFO-9
Medium	TNSi-380, IIMR FXM-6, CRSFXM-3, CRS FXM-4, IIMR FXM-9, IIMR FXM-10 TNSi-382, TNSi-382, DHFt 20-3 DHFt 20-153, SiA 4213SiA-4201, BUFTM 82, BUFTM 98, DHFt 109-3 R. KAUNI-1, STFO-3, STFO-4, STFO-6, and STFO-8	TNSi-380, IIMR FxM-7, CRS FXM-4, IIMR FXM-8, IIMR FXM-11, TNSi-382, TNSi-385, DHFt 20-153, SiA 4213, BUFTM 82, DHFt 109 -3, STFO-1, STFO-2, STFO-4 and STFO-5
Low	IIMR FxM-7, GPUF-16, TNSi-385, SiA 3156 STFO-2, and STFO-5	CRSFXM-3, IIMR FXM-9, IIMR FXM-10, GPUF-16, DHFt 20-3, SiA 4201, BUFTM 98, SiA 3156, STFO-3 and STFO-8

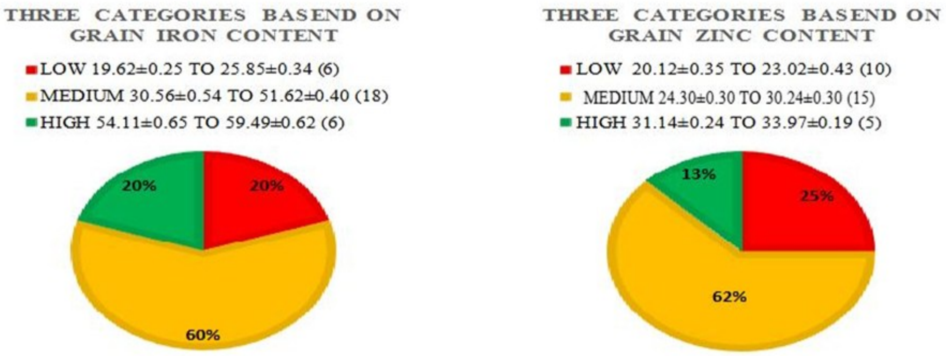

Fig. 2. *Percentage distribution of the genotypes in three categories depending on the amount of zinc and iron in the grain under drought condition*

of genotypes showing high zinc content was 17 % in normal conditions, it decreased to 13 % in drought conditions. Similarly, a decrease from 63 to 62 % was observed in the medium zinc content category, and an increase from 20 % to 25 % was observed in the low zinc content category.

DISCUSSION

Iron and zinc are very important micronutrient for human health. While iron is an essential component of haemoglobin and myoglobin, zinc is an essential cofactor for many enzymes and regulatory proteins, and it plays an important role in DNA and RNA synthesis and gene expression (Kumar, 2021). These two elements are also involved in the regulatory pathways and often help in stress mitigation in plants (Nadeem *et al*., 2020). Iron and zinc accumulation in grain involves a complex homeostatic pathway and are often correlated (Hanikenne and Bouché, 2023). The homeostasis of the plant is significantly affected by various stresses. Thus, abiotic stresses, particularly water stress like drought, can affect plant grain iron and zinc accumulation. Foxtail millet is believed to be a good source of iron and zinc, and it contains iron and zinc in amounts higher than rice and wheat (Borah, 2023). However, the grain iron and zinc content of foxtail millet can be severely affected by drought stress. Hence, the present study was carried out to determine the effect of drought on grain iron and zinc accumulation in foxtail millet.

Under normal conditions, micronutrient analysis of grain iron and zinc concentrations revealed significant variability. Iron concentrations ranged from 21.32 ppm to 61.19 ppm, while zinc content ranged from 21.51 ppm to 35.37 ppm (Table 2). Among the different genotypes of foxtail millet, genotype IIMR FXM-11 exhibited the highest grain iron content at 61.19 ppm, while genotype STFO-7 displayed the highest zinc content at 35.37 ppm. Conversely, the lowest iron content was observed in genotype GPUF-16 at 21.32 ppm, and the lowest zinc content was found in genotype SiA3156, also at 21.32 ppm. Similar results have been reported in other millet crops, such as Pearl millets (Singh and Srivastav., 2006; Velu *et al*., 2006; Kanatti *et al*., 2015; Anuradha *et al*., 2015; Anuradha *et al*., 2017), and little millets (Manimozhi *et al*., 2015 and Kaushal *et al*., 2023). These findings underscore the wide variability in micronutrient concentrations among different millet species and highlight the importance of such analyses for understanding their nutritional profiles. Under drought conditions, significant variations were observed in iron and zinc concentrations, with iron content ranging from 19.62 ppm to 59.49 ppm and zinc content ranging from 20.11 ppm to 33.97 ppm. Among the different genotypes of foxtail millet, genotype IIMR FXM-11 exhibited the highest grain iron content at 59.49 ppm, while genotype STFO-6 displayed the highest zinc content at 33.97 ppm. Conversely, the lowest iron content was observed in genotype GPUF-16 at 19.62 ppm, and the lowest zinc content was found in genotype SiA-3156 at

20.12 ppm. Similar results have been reported in other millets, such as foxtail millets (Impa *et al*., 2019; Narendra *et al*., 2021).

On comparison between the iron and zinc content of the genotypes under drought and normal conditions, an overall decrease in iron and zinc content was observed under drought conditions. The analysis showed a reduction in the iron and zinc content concentration of all the genotypes except a few (IIMR FXM-11 and R. KAUNI-1), which showed an increase in zinc content under drought condition. The change in the distribution pattern of the genotypes in high, low and medium categories was also observed. The change in zinc content was more pronounced than iron content. The findings can be attributed to the fact that zinc is an essential cofactor which is directly involved in maintaining physiological homeostasis of the plant and this homeostasis is affected by drought stress (Urwat *et al*., 2021). The observed changes in iron and zinc content distribution suggest nuanced responses to varying environmental conditions, highlighting the intricate mechanisms underlying foxtail millet's ability to cope with changing environmental dynamics.

Conclusion

The present study concluded that drought stress significantly reduces grain zinc content in foxtail millet, while iron content was affected somewhat. The relative categorization of the genotypes revealed that most of the genotypes fall under medium category for iron and zinc content in both conditions. The genotype IIMRFXM-11 was found to be the most stable genotype in terms of grain iron and zinc content under drought conditions since it remained in the high distribution class in both conditions. Conversely, GPUF-16 and SiA-3156 demonstrated the lowest iron and zinc content in both conditions. The identified genotypes with high grain iron and zinc content could be used in further breeding programs to enhance nutrient content under adverse conditions.

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Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Anuradha, K., Agarwal, S., Batchu, A. K., Babu, A. P., Swamy, B. M., Longvah, T., & Sarla, N. (2012). Evaluating rice germplasm for iron and zinc concentration in brown rice and seed dimensions. *J. Phytol*, 4 (1): 19-25.DOI: https://doi.org/10.5958/0975-6906.2012.00009.8
2. Anuradha, N., Tara Satyavathi, C., Meena, M. C., Sankar, M. S., Bharadwaj, C., Bhat, J., Singh, O & Singh, S. P. (2017). Evaluation of pearl millet [*Pennisetum glaucum* (L.) R. Br.] for grain iron and zinc content in agro climatic zones of India. *Indian Journal of Genetics*, 77 (1), 65-73. DOI: https://doi.org/10.5958/0975 6906.2017.00009.8
3. Borah, B. (2023). Morpho-physiological characterization and gene expression profiling of foxtail millet genotypes for waterlogging tolerance at seedling stage. M.Sc. Thesis submitted to Dr. Rajendra Prasad Central Agricultural University, Pusa.
4. Doust, A. N., Elizabeth, A. K., Katrien, M. D. and Jeffery, L. B. (2009). Foxtail Millet: A sequence-driven grass model system. *Plant Physiology*, 149 (1), 137-141. https://doi.org/10.1104/pp.108.129627
5. Geervani, P., and Eggum, B. O. (1989). Nutrient composition and protein quality of minor millets. Plant Foods for Human Nutrition, 39, 201-208. https://doi.org/10.1007/BF01091900
6. Gupta, D. S., Singh, U., Kumar, J., Shivay, Y. S., Dutta, A., Sharanagat, V. S., and Singh, N. P. (2020). Estimation and multi-variate analysis of iron and zinc concentration in adiverse panel of urdbean [*Vigna mungo* (L.) Hepper] genotypes grown under differing soil conditions. *Journal of Food Composition and Analysis*,93,103605. https://doi.org/10.1016/j.jfca.2020.103605
7. Hanikenne, M., & Bouché, F. (2023). Iron and zinc homeostasis in plants: a matter of trade-offs. *Journal of Experimental Botany*, 74(18), 5426-5430. https://doi.org/10.1093/jxb/erad304
8. Impa, S. M., Perumal, R., Bean, S. R., Sunoj, V. J. and Jagadish, S. K. (2019). Water deficit and heat stress induced alterations in grain physico-chemical characteristics and micronutrient composition in field grown grain sorghum. *Journal of Cereal Science*, 86, 124-131. https://doi.org/10.1016/j.jcs.2019.01.013
9. Kanatti, A., Rai, K.N., Radhika, K., Govindaraj, M., Sahrawat, K.L. and Rao, A.S. (2014). Grain iron and zinc density in pearl millet: combining ability, heterosis and association with grain yield and grain size. *Springer Plus*, 3: 1-12. https://doi.org/10.1186/2193-1801-3-763
10. Khan, I., Raza, M. A., Awan, S. A., Shah, G. A., Rizwan, M., Ali, B., and Huang, L. (2020). Amelioration of salt induced toxicity in pearl millet by seed priming with silver nano particles (AgNPs): The oxidative damage, antioxidant enzymes and ions uptake are major determinants of salt tolerant capacity. *Plant Physiology and Biochemistry*, 156, 221-232. https://doi:10.1016/j.plaphy.2020.09.018
11. Kumar, K. (2021). Molecular profiling of little millet genotypes using iron and zinc transporter based SSR markers of foxtail millet. M.Sc. Thesis submitted to Dr. Rajendra Prasad Central Agricultural University, Pusa.
12. Kumar, K., Thakur, L., Anjani, K., and Singh, S. K. (2023). Biochemical characterization of grain iron and zinc content in little millet genotypes. *The Pharma Innovation Journal*, 12(5), 4399-4402
13. Li, P., Brutnell, T. P. (2011). *Setaria viridis* and *Setaria italica,* model genetic systems for the panicoid grasses. *Journal of Experimental Botany*, 62(9), 3031–3037. https://doi.org/10.1093/jxb/err096
14. Manimozhi Selvi, V., Nirmala kumari, A., and Senthil, N. (2015). Genetic diversity for zinc, calcium and iron content

of selected little Millet Genotypes. *Journal of Nutrition and Food Science*, 5 (417): 2. http://dx.doi.org/10.4172/2155-9600.1000417

15. Murugan, R and Kumari, A N. (2006). Genetic divergence in foxtail millet [*Setaria italica* (L)]. *Indian Journal of Genetics*, 66 (4): 339-340. http://dx.doi.org/10.5958/0975-928X.2019.00003.6
16. Nadeem, F., Ahmad, Z., Ul Hassan, M., Wang, R., Diao, X., and Li, X. (2020). Adaptation of foxtail millet [*Setaria italica* (L.)] to abiotic stresses: a special perspective of responses to nitrogen and phosphate limitations. *Frontiers in Plant Science*, 11, 187. https://doi.org/10.3389/fpls.2020.00187
17. Narendra, M. C., Chandan, R., Sudhir, K., Parminder, V. and Nitish, D. (2021). Effect of terminal heat stress on physiological traits, grain zinc and iron content in wheat (Triticum aestivum L.). *Czech Journal of Genetics and Plant Breeding*, 57 (2), 43–50. http://dx.doi.org/10.17221/63/2020-CJGPB
18. Porwal, A., Bhagwat, G., Sawarkar, J., Kamble, P., & Rode, M. (2023). An overview of millets-the nutri-cereals: Its nutritional profile, potential health benefits and sustainable cultivation approach. *International Journal of Science and Research Archive*, 10(1), 841-859.https://doi.org/10.30574/ijsra.2023.10.1.0828
19. Singh, P. and Srivastava, S. (2006). Nutritional composition of sixteen new varieties of finger millet. *Journal of Community Mobilization Sustainable Development*, 1 (2), 81-84. http://dx.doi.org/10.5897/AJFSX10.010
20. Umair Hassan, M., Aamer, M., Umer Chattha, M., Haiying, T., Shahzad, B., Barbanti, L., ... & Guoqin, H. (2020). The critical role of zinc in plants facing the drought stress. *Agriculture*, 10(9), 396. https://doi.org/10.3390/agriculture10090396
21. Urwat, U., Ahmad, S. M., Masi, A., Ganai, N. A., Murtaza, I., Khan, I., & Zargar, S. M. (2021). Fe and Zn stress induced gene expression analysis unraveled mechanisms of mineral homeostasis in common bean [*Phaseolus vulgaris* (L.)]. Scientific Reports, 11(1), 24026. https://doi.org/10.3390%2Fmicroorganisms11112814
22. Velu, G., Rai, K. N., and Sahrawat, K. L. (2008). Variability for grain iron and zinc content in a diverse range of pearl millet populations. *Journal of Crop Improvement*, 35 (2), 186-191.