Exploring the correlation between yield components and nutrient content in foxtail millet [*Setaria italica* (L.) Beauv.] genotypes subjected to drought stress conditions

Abstract

The study evaluated 30 genotypes of foxtail millet at the Field Experimentation Centre, Millets Research Station Dholi, RPCAU, Pusa, during Kharif 2021. A randomized block design with three replications was used. Before selecting genotypes based on micronutrient content (Fe and Zn) for nutritional quality traits, it's crucial to understand their potential impact on yield. The study examined the relationships between quality traits and yield attributes in foxtail millet genotypes using a diverse range of genotypes. Correlation analysis under normal conditions revealed positive relationships, particularly between panicle girth (mm), grain yield per plant (g), and iron and zinc levels, with correlation coefficients ranging from 0.307 to 0.333. This indicates that these traits collectively enhance plant productivity under favorable conditions. However, under drought conditions, the relationships shift. Grain yield per plant showed significant positive correlations only with itself and panicle girth, with correlation coefficients of 0.315 and 0.314, respectively. This suggests that under water stress, fewer traits influence yield, with panicle girth becoming a crucial factor in maintaining grain yield. This analysis highlights how environmental conditions affect the relationships between plant traits. Under normal conditions, a broader set of traits, including micronutrient levels, contribute to productivity. In contrast, under drought stress, the focus shifts to key traits like panicle girth, essential for resilience and yield stability. These insights can inform breeding programs aiming to enhance drought tolerance in crops by prioritizing traits that significantly impact yield under adverse conditions.

Keys: Foxtail millets [*Setaria italica* (L.) Beauv.]; Drought; Correlation analysis; Iron; zinc

1. Introduction

Drought, a temporary decrease in soil moisture, significantly impacts crop growth and yield, particularly under rainfed conditions (Jalihal *et al*., 2019). Even a modest 10% reduction in rainfall can lead to a substantial 4.2% decline in cereal crop yields (Webb and Braun, 1994). Global simulation models indicate that drought stress could reduce wheat and maize yields by 21 to 40% (Daryanto *et al*., 2016). Despite projections of increased Indian monsoon precipitation, due to factors like rising CO_2 levels, aerosols, and deforestation, the frequency of drought stress is expected to rise (Jalihal *et al*., 2019). This phenomenon is caused by uneven distribution of rainfall, resulting in a decrease in the number of rainy days during monsoon seasons. (Dash *et al*., 2009). In the unpredictable conditions of semi-arid regions, finding crops that can thrive is crucial for sustaining agricultural production. Foxtail millet stands out as a promising option due to its remarkable resilience to drought compared to other major cereal crops.

Foxtail millet (*Setaria italica* (L.) Beauv.), a staple cereal crop with a rich historical legacy in India and China spanning approximately 4000 years (Cao, 1986), is recognized by Vavilov (1926) as having its primary center of diversity in East Asia, including Japan and China. Classified as a self-pollinating crop with a chromosome count of 2n=18, foxtail millet belongs taxonomically to the family Poaceae and the subfamily Panicoidae (Fedorov, 1974). Foxtail millet, among the earliest small millets cultivated, serves dual purposes as a food and fodder crop[25-26]. It holds the second position in global millet production and continues to play a crucial role in agriculture, offering sustenance to millions in dry and semi-dry regions around the world. Native to China, it is highly regarded for its drought tolerance, thriving in regions with annual rainfall between 150-700 mm, such as India and Pakistan. In India, Karnataka, Andhra Pradesh and Tamil Nadu are the leading states for foxtail millet cultivation, contributing approximately 79% of the total area under its cultivation (Munirathnam *et al*., 2006).

Foxtail millet is distinguished as a prospective cereal, providing essential micronutrients and protein in greater quantities compared to other grains. According to the Millet Network of India (MINI), foxtail millet grain boasts significant nutritional content, with protein content at 12.30%, and notable amounts of iron (2.80 mg) and zinc (2.40 mg) and calcium (31.0 mg) per 100g, surpassing rice in these nutritional aspects (which contains 7.90 % protein and 1.80 mg iron) (Kumar *et al*., 2023; Shankar, C and Anjani, K. 2023). Additionally, it boasts a high content of beta-carotene. Moreover, foxtail millet contains a higher proportion of non-starchy dietary fiber and polysaccharides. These attributes contribute to a slow release of sugars, resulting in a low glycemic index (GI), making it potentially beneficial for therapeutic diets. Studies have demonstrated that adopting a low glycemic index (GI) diet can effectively lower blood glucose levels (Thathola *et al*., 2011). Thus, the crop has a high nutritional value as well as ability to withstand large number of stresses, which can be correlated. However, the relationship between these two aspects of foxtail millet remains largely untapped and underexplored.

The presence of correlations between nutritional component and yield traits may be due to genetic linkage, pleiotropic effects of genes, physiological and developmental relationships, environmental factors, or a combination of these. Before prioritizing breeding for nutritional quality traits, it is crucial to understand the relationship between yield and yield attributes, as well as the interconnections between yield and nutritional quality traits. Utilizing correlation analysis provides a deeper understanding of the cause-and-effect relationships between various characteristics (Wright, 1921). This analytical approach helps to measure the relationship between different pairs of traits, offering valuable insights into their interconnections. This knowledge will enable breeders to simultaneously enhance yield and nutritional characteristics. Correlation coefficients can help identify traits of minimal importance in the selection program. The correlation analysis can thus help to understand the relationship between the nutritional quality and yield traits of the crop particularly in the regime of drought stress and help to understand the effect of stress on the relationship of these characters. This study examined the relationships between two nutritional quality traits, grain yield, and yield attributes across a diverse range of genotypes.

2. Materials and Methods

The study took place at the Field Experimentation Centre, Millets Research Station Dholi, RPCAU, Pusa, in the Kharif season of 2021. It involved 30 different foxtail millet genotypes obtained from the same research station (Table 1). Employing a Randomized Block Design with three replications, each plot consisted of three rows spaced 30 cm apart, with individual plants spaced 10 cm apart. Line sowing was used to plant the genotypes within each plot, with randomization applied to each replication. We have used proper practices such as weeding and required irrigation. We have not applied any external fertilizer in given treatments.

Data was collected for various parameters including the days to 50% flowering, days to maturity, plant height (cm), number of productive tillers per plant, panicle length (cm), panicle girth (mm), grain yield per plant (gm), test weight (gm) and fodder yield per plant (gm).

The data underwent ANOVA (Analysis of variance) according to Fisher and Yates (1963), followed by biometrical procedures to determine phenotypic coefficients of variation as per Burton (1952). Correlation coefficients were then calculated to assess the relationships between plant characteristics, following the methodology outlined by Fisher and yates (1958). The comparison of correlation coefficients to the 't' value with (n-2) degrees of freedom at significance levels of 0.05 and 0.01 to establish their significance.

Table 1 Information on the 30 Foxtail millet genotypes [*Setaria italica*] used in this study.

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

3. Result and Discussion

The ANOVA (Analysis of variance) results for nine distinct quantitative traits are provided in table 2 and table 3.

The findings revealed notable distinctions in the mean sum of squares, significant at the 1% level, across all observed traits among the 30 foxtail millet genotypes, both in normal and drought conditions.

These results highlight substantial variability among the studied genotypes, indicating promising opportunities to improve diverse quantitative traits in foxtail millet. This observation aligns with previous studies by Yogeesh *et al*. (2015) and Kumari *et al*. (2010).

Table 2: ANOVA was conducted to assess nine distinct quantitative parameters within foxtail millet genotypes under normal conditions.

Characters	Mean of sum square		
	Replication df =2	**Treatment df=29**	**Error df=58**
Days to 50% flowering	28.46	875.83**	844.2
Days to maturity	120.8	3,425.16**	2,008.53
No. of productive tillets per plant	1.62	90.48**	28.37
Plant height	123.76	2,278.80*	6,641.85
Panicle length	32.77	466.12*	454.05
Panicle girth	9.28	282.19**	85.34
Grain yield per plant	144.24	6,181.57**	1,379.61
Test weight	0.03	1.74*	1.57
Fodder yield per plant	0.26	2.63*	2.43

** Significant with a 0.01 probability level, * significant at the 0.05 probability level.

Table 3. ANOVA was conducted to assess nine distinct quantitative parameters within foxtail millet genotypes under drought condition

Characters	Mean of sum square		
	Replication df =2	**Treatment df=29**	**Error df=58**
Days to 50% flowering	9.68	761.28**	532.31
Days to maturity	205.62	1,098.48*	1,501.04
No. of productive tillets per plant	1.48	94.45**	30.51
Plant height	44.95	4,615.65**	3,247.55
Panicle length	35.46	1,277.06**	329.86
Panicle girth	4.7	249.45**	89.39
Grain yield per plant	142.24	6,181.57**	1,379.61
Test weight	0.08	1.69*	1.54
Fodder yield per plant	0.31	2.59*	2.39

** Significant with a 0.01 probability level, * significant at the 0.05 probability level.

3.1 Correlation analysis conducted in both standard and drought conditions

Under normal conditions, grain yield per plant displayed significant positive correlations with panicle girth (0.307*), iron (0.333*), and zinc (0.322*). Days to 50% flowering showed positive correlations with days to maturity (0.153), number of productive tillers per plant (0.045), plant height (0.197), panicle length (0.139), grain yield per plant (0.269), test weight (0.024), and fodder yield per plant (0.032), while negatively correlating with panicle girth (-0.295). Days to maturity correlated positively with test weight (0.025) and iron (0.162), but negatively with the number of productive tillers per plant (-0.30), plant height (-0.129), panicle length (-0.213), panicle girth (-0.068), fodder yield per plant (-0.171), and zinc (-0.218). The number of productive tillers per plant showed positive correlations with panicle length (0.287), grain yield per plant (0.069), iron (0.147), and zinc, but negative correlations with plant height (-0.252), test weight (-0.134), and fodder yield (-0.052). Plant height correlated positively with panicle length (0.144), panicle girth (0.076), test weight (0.076), and fodder yield (0.075), yet negatively with grain yield per plant (-0.172) and iron (-0.007). Panicle length correlated positively with panicle girth (0.049), grain yield per plant (0.067), test weight (0.076), iron (0.212), and zinc

(0.03), but negatively with fodder yield. Panicle girth demonstrated positive correlations with grain yield per plant (0.177), test weight (0.079), and iron (0.058), while negatively correlating with fodder yield (-0.302) and zinc (-0.042). Test weight, fodder yield, iron, and zinc all exhibited strong correlations with grain yield per plant. Fodder yield positively correlated with zinc (0.214) and negatively with iron (-0.219), whereas iron showed a positive correlation with zinc (0.243) (Table 4). Similar findings are with (Chaudhry *et al*., 2003; Vinodhana *et al*., 2013; Kaushik *at al*., 2022) in different millets.

Under drought conditions, significant positive correlations were observed between grain yield per plant (0.315*) and panicle girth (0.314*), while significant negative correlations were found for the number of productive tillers per plant (-0.515**), panicle girth (-0.361*), and zinc (-0.324*). Days to 50% flowering displayed negative correlations with plant height (-0.019), panicle length (-0.070), and test weight (-0.094), but positive correlations with days to maturity (0.136), number of productive tillers per plant (0.056), fodder yield per plant (0.112), iron (0.250), and zinc (0.298). Days to maturity exhibited positive correlations with plant height (0.031), grain yield per plant (0.225), and fodder yield (0.061), and negative correlations with panicle length (-0.230), test weight (-0.067), and iron (-0.034). The number of productive tillers per plant positively correlated with panicle length (0.287), grain yield per plant (0.069), iron (0.147), and zinc, and negatively with plant height (-0.252), test weight (-0.134), and fodder yield (-0.052). Plant height had positive correlations with panicle length (0.005), panicle girth (0.127), and fodder yield (0.140), and negative correlations with grain yield per plant, test weight, iron, and zinc (-0.267), (-0.057), (-0.149), and (-0.028). Panicle length showed positive correlations with panicle girth (0.037), grain yield per plant (0.217), and iron (0.185), and negative correlations with test weight (-0.184), fodder yield (-0.284), and zinc (-0.065). Panicle girth had positive correlations with grain yield per plant (0.176), test weight (0.098), and iron (0.060), and negative correlations with fodder yield (-0.220) and zinc (-0.044). Test weight positively correlated with fodder yield (0.272), iron (0.030), and zinc (0.277). Fodder yield had a positive correlation with zinc (0.117) and a negative correlation with iron (-0.223). Iron showed a positive correlation with zinc (0.243) (Table 4). Similar findings are with (Bidinger *et al*.,1987; Sharma *et al*., 2003; Govindaraj *et al*.,2009; Dapke *et al*., 2014 and Krishna *et al*.,2021) in different millets.

Table 4. Correlation coefficient among different agronomical traits in foxtail millet under normal condition (above diagonal) and drought condition (below diagonal)

Character	DF	DM	NPT	PH	PNL	PNG	GYPP	TW	FY	Fe	Zn
DF	**-**	0.153	0.045	0.197	0.139	-0.295	0.269	0.024	0.032	**0.333***	**0.322***
DM	0.136	-	-0.300	-0.129	-0.213	-0.068	**0.320***	0.025	-0.171	0.162	-0.218
NPT	0.056	-0.515**	-	-0.252	0.287	**0.307***	0.069	-0.134	-0.052	0.147	0.13
PH	-0.019	0.031	-0.098	-	0.144	0.076	-0.172	0.076	0.075	-0.007	-0.083
PNL	-0.070	-0.230	0.050	0.005	-	0.049	0.067	0.106	-0.290	0.212	0.030
PNG	-0.361*	**-0.385***	0.**314***	0.127	0.037	-	0.177	0.079	-0.302	0.058	-0.042
GYPP	**0.315***	0.225	0.084	-0.267	0.217	0.176	-	0.020	0.112	0.022	0.269
TW	-0.094	-0.067	-0.149	-0.057	-0.184	0.098	0.01	-	-0.047	0.116	0.012
FY	0.112	0.061	0.057	0.140	-0.284	-0.220	0.272	0.085	-	-0.219	0.214
Fe	0.250	-0.034	0.131	-0.149	0.185	0.060	0.03	0.111	-0.223	-	0.243
Zn	0.298	**-0.324***	0.129	-0.028	-0.065	-0.044	0.277	0.014	0.117	0.243	-

DF: Days to 50% flowering, DM: Days to maturity, NPT: No. of productive tillers/plant, PH: Plant height, PNL: Panicle length, PNG: Panicle girth, GYPP; Grain yield/plant
TW: Test weight, FY: Fodder yield per plant, Fe-IRON AND Zn:ZINC
*. Correlation is significant at the 0.05 level. **. Correlation is significant at the 0.01 level

4. Conclusion

It is concluded that under normal conditions, there were significant positive correlations observed between yield per plant and traits such as panicle girth (0.307*), grain yield per plant (0.320*), iron (0.333*), and zinc (0.322*). These relationships suggest a coordinated enhancement of plant productivity in favourable environments. In contrast, under drought conditions, yield per plant exhibited significant positive correlations solely with grain yield per plant (0.315*) and panicle girth (0.314*), indicating a different pattern of trait interactions and productivity adaptations in response to water stress. Under normal conditions, traits such as panicle girth, grain yield per plant, and micronutrient levels (iron and zinc) positively correlate, collectively enhancing plant productivity. However, under drought conditions, the influence of these traits narrows, with panicle girth emerging as a key factor in maintaining grain yield. This shift highlights the need for breeding programs to prioritize traits like panicle girth that significantly impact yield stability under water stress. These insights are crucial for developing foxtail millet varieties that are both high-yielding and resilient to drought, ensuring food security and nutritional quality in adverse environmental conditions. This is true under both normal and drought conditions, emphasizing the need for breeding programs to focus on these key traits to develop crops that are resilient and high-yielding in diverse environmental scenarios. Thus, understanding these correlations aids in targeted trait selection, ultimately contributing to better crop performance and food security.

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Details of the AI usage are given below:

1.

2.

3.

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