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Exploring the Correlation between Yield Components and Nutrient Content in Foxtail Millet [*Setaria italica* (L.) Beauv.] Genotypes Subjected to Drought Stress Condition

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study evaluated 30 genotypes of foxtail millet at 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

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traits and yield attributes in foxtail millet genotypes using a diverse range of genotypes. Correlation analysis under normal condition revealed positive relationships, particularly between panicle girth and number of productive tillers per plant, grain yield per plant and days to maturity, days to 50% flowering and iron content and days to 50% flowering and zinc content, 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 correlation only with days to 50% lowering and number of productive tillers per plant with panicle girth, with correlation coefficients of 0.315 and 0.314, respectively. Further, significantly negative correlation of days to maturity with number of productive tillers per plant, panicle girth and zinc content was observed. Similarly, days to 50% flowering was found negatively correlated with panicle girth. This suggests that under water stress, fewer traits positively 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 improve and speed up breeding programs aiming to enhance drought tolerance in crops, by prioritizing traits that significantly impact yield under adverse conditions.

Keywords: 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 [1]. 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% [2]. 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 [1]. This phenomenon is caused by uneven distribution of rainfall, resulting in a decrease in the number of rainy days during monsoon seasons. [3]. 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 [4], is recognized by Vavilov [5] as having its primary centre 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 [6]. Foxtail millet, among the earliest small millets cultivated, serves dual purposes as a food and fodder crop [7,8]. 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 [9].

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) [10,11]. 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 [12]. 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 [13]. 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. Standard practices such as weeding and required irrigation were applied at regular intervals. No external fertilizer was used in this experiment.

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 analysis of variance (ANOVA) according to Fisher and Yates [14 and 15]. Separate ANOVA for each treatment (normal and drought stress conditions) was conducted using OPSTAT. Correlation coefficients were calculated to assess the relationships between traits, following the methodology outlined by Fisher and Yates [16]. Correlation analysis was conducted using SPSS software.

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

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

3. RESULTS 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. [17] and Kumari et al. [18].

3.1 Correlation Analysis Under Normal and Drought Conditions

Under normal condition, grain yield per plant displayed significant positive correlation with days to maturity (0.320*). Panicle girth was found positively correlated with number of productive tillers per plant (0.307*). Similarly, days to 50% flowering exhibited significant positive correlation with iron (0.333*) and zinc (0.322*) contents. Days to 50% flowering showed positive correlation coefficient 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 negative coefficient with panicle girth (-0.295). Days to maturity correlation coefficient positively with test weight (0.025) and iron (0.162), but negative correlation coefficient 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 correlation coefficient with panicle length (0.287), grain yield per plant (0.069), iron (0.147), and zinc, but negative correlation coefficient with plant height (-0.252), test weight (-0.134), and fodder yield per plant (-0.052). Plant height correlated positive coefficient with panicle length (0.144), panicle girth (0.076), test weight (0.076), and fodder yield per plant (0.075), yet negative correlation coefficient with grain yield per plant (-0.172), iron (-0.007), zinc (-0.083. Panicle length correlated positive

Table 2. Analysis of variance for nine quantitative characters of foxtail millet genotypes under normal condition

Characters	Mean of sum square		
	Replication	Treatment	Error
Degree of freedom (df)	2	29	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 tillers 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. Analysis of variance for nine quantitative characters of foxtail millet genotypes under drought condition

Characters	Mean of sum square		
	Replication	Treatment	Error
Degree of freedom (df)	2	29	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 tillers 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*

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	0.130
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* coefficient with panicle girth (0.049), grain yield per plant (0.067), test weight (0.106), iron (0.212), and zinc (0.03), but negative corelation coefficient with fodder yield per plant (-0.290). Panicle girth demonstrated positive correlation coefficient with grain yield per plant (0.177), test weight (0.079), and iron (0.058), while negative correlation coefficient with fodder yield per plant (-0.302) and zinc (-0.042). Test weight, fodder yield per plant, iron, and zinc all exhibited strong correlation coefficient with grain yield per plant. Fodder yield per plant positive correlation coefficient with zinc (0.214) and negative correlation coefficient with iron (-0.219), whereas iron showed a positive correlation with zinc (0.243) (Table 4). Similar findings were observed in different millets [19,20,21].

Under drought conditions, significant positive correlations were observed between grain yield per plant and days to 50% flowering (0.315*), panicle girth and number of productive tillers per plant (0.314*), while significant negative correlations were found for the days to maturity with panicle girth (-0.385*) and zinc (-0.324*) content. Days to 50% flowering was found negatively correlated with panicle girth (-0.361*). Furthermore, days to 50% flowering displayed negative correlation coefficient 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 correlation coefficient with plant height (0.031), grain yield per plant (0.225), and fodder yield per plant (0.061), and negative correlation coefficient with panicle length (-0.230), test weight (-0.067), and iron (-0.034). The number of productive tillers per plant positive correlation coefficient with panicle length (0.050), grain yield per plant (0.084), fodder yield per plant (0.057) iron (0.131), and zinc (0.129), and negative correlation coefficient with plant height (-0.098) and test weight (-0.149). Plant height had positive correlation coefficient with panicle length (0.005), panicle girth (0.127), and fodder yield per plant (0.140), and negative correlation coefficient with grain yield per plant, test weight, iron, and zinc (-0.267), (-0.057), (-0.149), and (-0.028) respectively. Panicle length showed positive correlation coefficient with panicle girth (0.037), grain yield per plant (0.217), and iron (0.185), and negative correlation coefficient with test weight (-0.184), fodder yield per plant (-0.284) and zinc (-0.065). Panicle girth had positive correlation coefficient with grain yield per plant (0.176), test weight (0.098) and iron (0.060), and negative correlation coefficient with fodder yield per plant (-0.220) and zinc (-0.044). Test weight positive correlation coefficient with fodder yield per plant (0.272), iron (0.030), and zinc (0.277). Fodder yield per plant had a positive correlation coefficient with zinc (0.117) and a negative correlation coefficient with iron (-0.223). Iron showed a positive correlation coefficient with zinc (0.243) (Table 4). Similar findings are with [22,23,24,25 and 26] in different millets.

4. CONCLUSION

The study concluded that under normal conditions, there were significant positive correlations observed between yield per plant and days to maturity, number of productive tillers per plant and panicle girth, days to 50% flowering and iron content and days to 50% flowering and zinc content. These relationships suggest a coordinated enhancement of plant productivity in favourable environments. In contrast, under drought condition, yield per plant exhibited significant positive correlation solely with days to 50% flowering. Panicle girth exhibited significant positive correlation with number of productive tillers per plant. Significant negative correlations of days to maturity were obtained with number of productive tillers per plant, panicle girth and zinc content, 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, an understanding of these correlations' aids in targeted trait selection, ultimately contributing to better crop performance and food security.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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