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RESEARCH PAPER

Phenotypic diversity studies for terminal drought response in emmer wheat (*Triticum dicoccum* L.)

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Abstract: The present study was carried out to assess the phenotypic diversity in seventy dicoccum wheat germplasm lines under terminal drought stress and non-stress conditions atAll India Coordinated Research Project, University of Agricultural Sciences, Dharwad during *rabi* 2020-21 season. Results of multivariate analysis revealed that the number of tillers per meter and number of spikelets per spike were highly influencing grain yield under stress conditions.A clustering analysis based on agro-morphological traits indicated a good level of genetic diversity among germplasm. Most yield and yield-attributing characteristics showed a significant decrease in mean performance under stress conditions. Drought tolerant germplasm lines were classified based on Stress Susceptibility Index (SSI) and Stress Tolerance Index (STI). Among the seventy dicoccum germplasm lines DDK-50378 showed good SSI with 0.21. Twenty germplasm lines performed better with STI (>0.9). The germplasm lines DDK-50341, DDK-50380, and DDK-50381 produced better yield under moisture stress than the top yielding standard check DDK 1025. Under normal conditions these genotypes proven to be promising and carry genes for drought tolerance and further utilized for drought tolerance breeding.

Key words: Emmer wheat, Phenotypic diversity, Spikelet, Terminal drought

Introduction

Wheat (*Triticum aestivum* L.) is a crop of temperate region and the most important and second largest grown cereal crop in India after rice and plays a vital role in food and nutritional security. Currently it is grown on a large scale in the tropical and subtropical regions of the world (Onwuemeand Sinha, 1999). After rice, wheat is the major staple food in the world and considered as King of cereals. It provides food to 55% of the world population contributing 20% of the food calories and occupies a unique position as used for the preparation of wide range of food stuffs. Wheat has a global output of 765 million tonnes and is cultivated on 218 million hectares with a productivity of 3500 kg ha^{-1} (Anon., 2020). China, India, the United States, Russia, France, and Canada account for nearly half of the world's wheat production. On 30.5 million hectares of land, India produces 107.2 million metric tonnes of wheat with 3508 kg ha^{-1} productivity. Karnataka has about 1.66 lakh ha under wheat cultivation, with an annual output of 2.08 lakh tonnes and productivity of 1250 kg ha^{-1} (Anon., 2020). Dicoccum wheat varieties are generally high in protein and complex carbohydrates (dietary fibre). Dicoccum wheat has outstanding grain quality characteristics and is a good source of dietary fibres (over 16 %), protein (11.8 to 15.3 %) and total carbohydrates (78.7 to 83.2 %), (Singh *et al.,* 2015).

Drought is arising threat of world. It is the creeping disaster, slowly taking hold of an area and tightening its grip with time (Misra *et al.*, 2002). Yield losses due to drought depend on the growth stage and severity of stress (Daryanto *et al.*, 2016). Termina1 drought stress poses a big challenge to sustain wheat grain production in rainfed environments (Shokat *et a1.,* 2020). If terminal drought stress occurs, genotypes that reproduce and fill grain before the onset of stress will be selected (Blum, 2010).To maintain photoassimilate production during late season droughts, delayed senescence or stay green will be usually required (Thomas and Howarth, 2000; Gong *et al.,* 2005). Dicoccum wheat is cultivated majorly in areas under assured irrigation conditions. Farmers are nowadays willing to grow dicoccum wheat under limited water conditions. To extend the area under the cultivation of emmer wheat by making it possible to cultivate even under limited water conditions, to fulfil the value based market demand of dicoccum products and to preserve the conventional quality characters of dicoccum, the selection of lines that can perform better even under limited water condition is necessary.

The focus of this research was to assess the phenotypic diversity for drought tolerance of various locally cultivated dicoccum wheat germplasm lines and identify some of the drought tolerant lines.

Material and methods

In the present studyseventy dicoccum germplasm lines collected from different parts of Karnataka were studied. The emmer wheat germplasm lines were evaluated in the field in augmented design during *rabi* 2020-21 with two sets under stress (drought for 20 days during flowering stage), and non-stress (timely sown irrigated) conditions at All India Coordinated Research Project, University of Agricultural Sciences, Dharwad. The experiment was laid out in an augmented design each entry spaced in 20 × 5 cm and plot size containing six rows of 3m length. For about 15-30 days during reproductive stage the plots were exposed to drought stress by withholding irrigation, while the control plot received complete irrigation. Both controlled and water stress treated plots had the same environmental condition. Flag leaf length (cm), plant height (cm), number of productive tillers per meter, spike length (cm), number of spikelets per spike, thousand grain weight (g), and grain yield (kg/ha). The observations were recorded from five plants of each germplasm line and the mean value of five plants was calculated and used to analyse.

Clustering was done using D^2- statistic, which was introduced by Mahalanobis in 1928.This technique assesses the forces of differentiation at two levels: intra-cluster and intercluster, and hence assists in the selection of genetically diverse parents for a hybridization programme. Stress susceptibility index (SSI) and Stress tolerance index (STI) were used in order to classify genotypes into different drought tolerance categories. SSI was calculated as perFischer and Maurer (1978) and germplasm lines were grouped into three different tolerance category asreportedby Chopraand Vishwanathan(1999), STI was calculated according to Fernandez (1992) and germplasm lines were grouped into three different tolerance category asreportedby Sang *et al.*(2014).

Statistical analysis

The Analysis of variance (ANOVA) was carried out using R-statistical software (4.1.0). The diversity studies and clustering of seventy dicoccum germplasm lines was also done using the R-statistical software (4.1.0).

Results and discussion

The analysis of variance indicated that for all the characters evaluated there were statistically significant differences (p = 0.05) among the wheat genotypes studied and, for most of the characters evaluated. Under drought condition, decreasing pattern was experienced in morphologically yield contributing characters like plant height, spikelets per spike, and 1000 grain weight in drought conditions compared to non-stress (Table 1). Similar observations were reported by Kilic and Yaggbasanlar (2010).

By grouping seventy dicoccum lines, ten clusters were formed under non-stress conditions while nine clusters were formed under stressed conditions. The clustering pattern reflected that cluster II was the largest cluster with 32 germplasm lines, followed by cluster IV comprising of 13 germplasm lines under non-stress condition while under stress condition cluster II revealed the maximum number of 19 germplasm lines, followed by clusters IV and VII with 15 germplasm lines (Table 1a and 1b). The cluster pattern of the genotypes showed non-parallelism between geographic and genetic diversity. The discrimination of genotypes in to discrete clusters suggested presence of high degree of genetic diversity in the material evaluated.

The intra and inter-cluster distances were calculated and presented in Table 2a and 2b. Under non-stress condition maximum intra-cluster distance was shown by cluster X (D^2 = 98.77) followed by, cluster VII (D^2 = 94). The most divergent clusters indicated highest inter-cluster distance which was found between cluster IX and VII (132.85), followed by cluster IX and cluster VI (132.32), whereas the lowest inter-cluster distance was between cluster VIII and cluster III (D^2 = 0.29), (Table 2a). Maximum intra-cluster distance under stress condition was shown by cluster VII (D^2 = 100.19) followed by, cluster V (D^2 = 81.52). The inter cluster distance was maximum between clusters IX and VI (144.71), followed by cluster IX and cluster V with a distance of (144.69), while the lowest distance between clusters IV and cluster II (D^2 = 71.27) under stress condition suggested a closer relationship between these two clusters and low degree of diversity among the genotypes.

Because a high or optimal genetic divergence is desired between the parents of a hybridization plan in order to achieve a larger frequency of favourable recombinants, the chances of obtaining good segregants by crossing genotypes from the same cluster with little diversity are quite limited. It would be logical to seek crosses between diverse genotypes belonging to clusters separated by considerable inter-cluster distances in order to optimize the potential of isolating good segregants in the segregating generations.

Table 1. ANOVA for augmented design for different morpho-physiological traits under both stress and non-stress conditions

	Source	Block (Eliminating treatments)	Treatment (Ignoring blocks)	Checks	Varieties	Checks vs Varieties	Error
	df	5	69	3	65	1	15
Flag leaf length	Non-stress	1.07	3.12	2.75	3.10	5.69	2.36
	Stress	7.56	3.34	4.46	3.24	6.21	2.67
Spikelets per spike	Non-stress	0.84	5.02**	21.37**	3.70	41.42**	2.37
	Stress	0.16	3.13**	1.09	2.79	31.29**	0.02
Plant height	Non-stress	13.36	70.09**	262.11**	62.28	1.42	29.90
	Stress	35.17	61.71**	220.76**	44.59**	697.12**	6.16
Spike length	Non-stress	1.56	4.38**	6.38**	4.36**	0.01	0.73
	Stress	0.07	2.43**	4.16**	2.07**	20.87**	0.02
Tillers per meter	Non-stress	42.04	1883.60**	2598.15**	1702.64**	11502.27**	117.29
	Stress	125.14	1232.84**	2039.04**	996.12**	14200.76**	17.14
Thousand grain weight	Non-stress	1.09	27.07**	31.96**	24.55**	175.98**	1.86
	Stress	0.40	29.45**	39.22**	23.03**	417.56**	1.00
Grain yield	Non-stress	15983.80	557037.9**	793838.7**	506017.5**	3162964.7**	58079.5
	Stress	11624.34	411258.9**	625119.9**	334834.5**	4737257.3**	3486.69

* - P = < 0.05; ** P = < 0.01

Table 1a. Clustering of seventy dicoccum germplasm lines based on morpho-physiological, yield and yield attributing traits under non-stress condition

Cluster	No. of germplasm lines	Germplasm lines	Contributing traits
1	3	DDK 1025, DDK-50333, DDK-50355	SL, GY, NT, TGW
2	32	DDK-50361, DDK-50386, DDK-50372, DDK-50344, DDK-50352, DDK-50358, DDK-50392, DDK-50326, DDK-50359, DDK-50322, DDK-50341, DDK-50381, DDK-50351, DDK-50380, DDK-50338, DDK-50366, DDK-50397, DDK-50345, DDK-50370, DDK-50329, DDK-50369, DDK-50325, DDK-50347, DDK-50393, DDK-50400, DDK-50373, DDK-50321, DDK-50350, DDK-50353, NP 200, DDK 1029, DDK-50336	SL, GY, PH
3	7	DDK-50323, DDK-50346, DDK-50367, DDK-50391, GPM DIC_111, DDK-50419, DDK-50318	SL
4	13	DDK-50337, DDK-50357, HW 1098, DDK-50378, DDK-50356, DDK-50360, DDK-50412, DDK-50422, DDK-50399, GPM DIC_108, DDK-50403, DDK-50374, DDK-50384	SL, GY, NT
5	1	DDK-50324	FL, NS, SL, NT
6	1	DDK-50368	SL, TGW, NS, PH
7	4	DDK-50389, GPM DIC_110, DDK-50420, GPM DIC_18	SL, GY
8	1	DDK-50354	SL, GY, FL, TGW
9	1	DDK-50330	SL, GY, NS, NT, TGW
10	7	DDK-50320, DDK-50343, DDK-50377, DDK-50327, GPM DIC_109, DDK-50376, DDK-50411	SL, GY, PH, NT

Table 1b. Clustering of seventy dicoccum germplasm lines based on morpho-physiological, yield and yield attributing traits under stress condition

Cluster	No. of germplasm lines	Germplasm lines	Contributing traits
1	4	DDK-50358, DDK-50380, DDK-50338, DDK-50420	NT, GY
2	19	DDK-50336, DDK-50356, DDK-50377, DDK-50412, DDK-50369, DDK-50350, DDK-50352, DDK-50372, DDK-50391, DDK-50325, DDK-50327, DDK-50329, DDK-50344, DDK-50386, DDK-50361, DDK-50326, DDK-50321, DDK-50341, DDK-50351	NT, GY, SL
3	4	DDK-50337, DDK-50357, DDK-50378, HW 1098	NT, GY, NS
4	15	DDK-50345, DDK-50366, DDK-50322, DDK-50389, DDK-50399, DDK-50400, DDK-50353, DDK-50374, DDK-50373, DDK-50359, DDK-50367, DDK-50360, DDK-50318, DDK-50393, DDK-50384	NT, GY, PH
5	5	DDK-50330, DDK-50354, DDK-50320, DDK-50343, GPM DIC_108	NT, GY, TGW
6	5	DDK-50333, DDK-50355, DDK 1025, DDK-50376, DDK-50411	NT, GY, NS
7	15	DDK-50347, DDK-50368, DDK-50324, DDK-50392, GPM DIC_18, DDK-50370, DDK 1029, DDK-50397, NP 200, GPM DIC_110, DDK-50381, DDK-50403, GPM DIC_111, DDK-50419, GPM DIC_109	SL, PH
8	2	DDK-50323, DDK-50346	NT, GY, FL, PH, NS
9	1	DDK-50422	GY, PH

SL- Spike length; GY- Grain yield; NT- Number of tillers per meter; TGW- Thousand grain weight; PH- plant height; SL- Spike length; FL- Flag leaf length; NS- number of spikelets per spike

Contribution of traits to divergence

The per cent contribution of each trait towards phenotypic diversity under non-stress and stress conditions is presented in Table 3. It was observed that the spike length (14.41 %) was contributing highest to the total phenotypic divergence, followed by grain yield (9.80 %), under non-stress condition, whereas under stress condition the number of tillers per meter (13.25 %) was contributing highest to the total phenotypic divergence, followed by grain yield (10.90 %).

Per cent reduction in performance was computed for various traits to understand their sensitivity under moisture stress condition (Table 4). Most yield and yield-attributing characteristics, such as tillers per meter, spikelets per spike, and grain yield per plot, were seriously impacted by drought

Table 2a. Intra and inter-cluster D^2 values in dicoccum wheat germplasm lines under non-stress condition

	Cluster. 1	Cluster. 2	Cluster. 3	Cluster. 4	Cluster. 5	Cluster. 6	Cluster. 7	Cluster. 8	Cluster. 9	Cluster. 10
Cluster. 1	35.45	99.94	103.45	111.61	108.31	111.61	108.32	111.66	126.45	113.72
Cluster. 2		66.64	81.18	84.00	76.34	87.97	89.35	87.09	94.33	90.28
Cluster. 3			69.59	95.86	92.58	107.99	102.42	0.29	94.79	107.09
Cluster. 4				87.31	99.09	105.28	104.16	98.69	105.53	106.77
Cluster. 5					0.00	40.99	92.92	108.08	106.81	104.05
Cluster. 6						0.00	92.97	125.41	132.32	113.04
Cluster. 7							94.00	119.49	132.85	112.55
Cluster. 8								0.00	37.42	112.01
Cluster. 9									0.00	117.65
Cluster. 10										98.77

Table 2b. Intra and inter-cluster D^2 values in dicoccum wheat germplasm lines under stress condition

	Cluster. 1	Cluster. 2	Cluster. 3	Cluster. 4	Cluster. 5	Cluster. 6	Cluster. 7	Cluster. 8	Cluster. 9
Cluster. 1	39.59	71.56	93.37	78.18	96.57	100.10	92.79	110.69	121.63
Cluster. 2		61.60	90.21	71.27	90.09	95.90	86.87	111.89	120.39
Cluster. 3			52.67	89.90	116.35	111.38	104.98	131.05	124.24
Cluster. 4				71.69	96.02	96.42	92.25	113.34	118.65
Cluster. 5					81.52	108.62	117.55	113.80	144.69
Cluster. 6						61.76	115.38	129.92	144.71
Cluster. 7							100.19	124.90	120.24
Cluster. 8								39.24	l42.39
Cluster. 9									0.00

Table 3. Per cent contribution of morpho-physiological traits, yield and yield attributes to total phenotypic diversity under stress and non-stress condition

Source	Per cent contribution	
	Stress	Non stress
Flag leaf length (cm)	6.29	6.87
Spikelets per spike (cm)	8.82	6.05
Plant height (cm)	7.83	4.20
Spike length (cm)	9.44	14.41
Tillers per meter	13.25	5.67
Thousand grain weight (gm)	7.25	5.88
Grain yield (kg/ha)	10.90	9.80

and showed a significant decrease in mean performance. Under stress, germplasm accessions exhibited a significant reduction in grain production (41.76 %) compared to non-stress accessions. Days to maturity (8.67 % reduction) were shown to be sensitive when compared to days to 50 per cent flowering.

Identification of drought-tolerant germplasm lines

Stress susceptibility index (SSI) and the stress tolerance index (STI) were utilised in our study to identify drought-tolerant

Table 4. Per cent reduction in the performance of various traits under moisture stress condition

Characters	Per cent reduction
Flag leaf length (cm)	0.86
Spikelets per spike	8.06
Plant height (cm)	3.78
Spike length (cm)	3.21
Tillers per meter	14.63
Thousand grain weight (g)	7.54
Grain yield (kg/ha)	41.76

germplasm lines without compromising yield under stress conditions. Table 5 shows a list of drought-tolerant dicoccum lines with SSI values less than 0.5 and STI values greater than 0.9, as well as their yield. DDK-50341, DDK-50380, DDK-50381, DDK-50378 and DDK-50337 were the drought-tolerant lines with good grain yield potential, while the others were drought-tolerant with modest grain yield potential. The germplasm lines DDK-50341, DDK-50380, and DDK-50381 produced better yield under moisture stress than the top yielding standard check DDK 1025.

Table 5. Mean performance of drought tolerant germplasm lines based on SSI for root related traits and STI

Germplasm lines	Stress susceptibility indices						Root traits					
	YS (kg/ha)	YP (kg/ha)	SSI	Category	STI	Category	RL (cm)		SL (cm)		RV (cm^3)	
							S	NS	S	NS	S	NS
DDK-50341	3345.00	4025.00	0.95	Moderate	0.89	Moderate	87	35	94	110	14	12
DDK-50380	3240.00	3558.33	0.92	Moderate	0.84	Moderate	57	48	110	115	14	9
DDK-50381	3105.00	3416.67	0.63	Moderate	0.87	Moderate	150	28	109	118	14	13
DDK-50378	2591.67	2733.33	0.21	Tolerant	0.80	Moderate	125	48	100	126	19	13
DDK-50337	2233.33	2741.67	0.59	Moderate	0.81	Moderate	67	40	100	110	18	6
DDK-50323	2041.67	2458.33	0.58	Moderate	0.80	Moderate	138	52	100	109	15	11
DDK 1025	2751.44	3577.78	0.84	Moderate	0.55	Susceptible	60	45	100	125	14	12
DDK 1029	2474.17	2980.56	0.65	Moderate	0.65	Susceptible	55	35	105	115	13	12
NP 200	2211.39	2913.89	0.90	Moderate	0.67	Susceptible	70	60	88	126	15	12
HW 1098	2007.36	2741.67	0.92	Moderate	0.71	Susceptible	137	45	102	116	16	15

The clustering pattern shows that the distribution of different wheat genotypes into clusters happened at random, regardless of their geographical origin. Rahman *et al.* (2015), Mudra *et al.* (2015), and Bhanupriya *et al.* (2014) found that genetic drift and selection in diverse environments can produce more genotypic diversity than geographical distances. As a result, choosing parental material for hybridization solely on the basis of geographical diversity may not be productive.

Conclusion

From the present study it was concluded that the analysis of variance exhibited significant genetic variations among the genotypes for all quantitative characters studied under both the environmental conditions which help us for selection and utilize them for breeding programme. The genetic diversity that was identified among the genotypes can be exploited in a breeding program aimed at developing drought-tolerant dicoccum wheat cultivars. The crosses between the germplasm lines of clusters IX and VI having large inter cluster distances may be recommended for identifying desirable recombinants in the segregating generation. DDK-50341 was found drought tolerant with minimal grain yield reduction. While lines DDK-50378, DDK-50380, and DDK-50381 were moderately tolerant with higher yields based on SSI and STI.

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