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Research Article

Root characterization and Identification of drought tolerant dicoccum wheat germplasm lines using Stress tolerance Index (STI)

Sharada Halehundi Bellegowda[1]*, Uday Govidareddy[1], Priyanka Krishnareddy[2], Gopalareddy Krishnappa[3] and Shamarao Jagirdhar[2]

[1]AICRP on wheat, Department of Genetics and Plant Breeding, University of Agricultural Sciences Dharwad 580005, Karnataka
[2]Department of Plant Pathology, University of Agricultural Sciences Dharwad 580005, Karnataka
[3]Sugarcane Breeding Institute, Coimbatore 641007, Tamil Nadu

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****Corresponding author:***
E-mail: sharadabgowda234@gmail.com

ABSTRACT

Dicoccum wheat germplasm lines/local collections from different eco-geographical zones were evaluated for their response to terminal drought stress. Assessing the genetic diversity for dicoccum wheat germplasm lines under stress and non-stress conditions was prime objective of the study conducted in Rabi 2020-21. Results of multivariate analysis on root traits revealed that the root length and root volume were highly influencing grain yield under stress conditions. A clustering analysis based on agro-morphological and root 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 with increased root length and root volume under moisture stress than the top yielding standard check DDK 1025. These genotypes proven to be promising and carry genes for drought tolerance and can be further utilized in breeding program for drought tolerance.

Key words: *Triticum dicoccum*, Terminal Drought, Root Phenotyping, Drought Tolerance

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most widely grown cereal species and an essential component of the global food security, providing 20% of the total calories consumed by the world's growing population (Shahinnia *et al.,* 2016). Emmer wheat (*Triticum dicoccum* Schrank) is one among the oldest cultivated plant that has been a staple crop over centuries (Nesbitt and Samuel, 1996). It is now a minor crop, cultivated mainly in isolated, marginal areas where no other crop can be grown economically, where its typical characteristics, such as the ability to adopt to poor and stony soils, resistance to low temperatures, considerable ability to control weeds, and resistance to diseases common to other cereals can be used as advantage. Emmer wheat consequently represents a valuable genetic resource to improve resistance to biotic and abiotic stress in bread wheat and durum wheat

(Dorofeev *et al.,* 1979; Castagna *et al.,* 1996; Marconi and Cubadda, 2005; Zaharieva *et al.,* 2010; Singh *et al.,* 2018).

Climate change is expected to have large effects on global wheat production: for every 1°C increase in temperature, global wheat yields are predicted to decline by 4.1–6.4% (Budak *et al.*, 2013). Changing crop phenology is considered an important bio-indicator of climate change, with the recent warming trend causing advancement in crop phenology (Morgounov *et al.,* 2018). Rising temperatures are the main driver of projected negative climate change impacts on wheat yields (Porter *et al.,* 2014). However, with global climate change, the stability and productivity of wheat are affected by various abiotic stresses. Among the abiotic stresses, that limit crop productivity, drought is the most damaging factor and drought tolerance is one of the most difficult traits to improve by breeding (Tuberosa and Salvi, 2006). Therefore, increasing crop yield, under drought conditions is one of the most important challenges faced by the breeders (Tuberosa, 2012). Owing to the climate change, intensity and frequency of drought periods are expected to increase, and act as a difficulty for sustainable crop production (Wassmann *et al.,* 2009; Ray *et al.,* 2013; Mohammadi, 2016; Mwadzingeni *et al.,* 2016). 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 (Sharada *et al.,* 2021).

Domestication and selective breeding has limited the genetic diversity of wheat, leading to cultivars adapted to artificial environments which has resulted in reduced resistance to drought stress (Kumar *et al.,* 2008; Budak *et al.,* 2013). One opportunity is presented by the exploitation of local germplasm of emmer wheat. The present study focuses on characterizing and screening dicoccum wheat germplasm lines for root characters and to identify the drought tolerant wheat germplasam with relatively high stress tolerance index (STI).

2. Materials and methods

2.1 Plant materials

Study materials consisted of seventy-dicoccum wheat germplasm lines were used which were collected from different parts of Tamilnadu, Karnataka and Maharashtra. DDK 1025, DDK 1029, HW 1098 and NP 200 were used as cultivated check variety. The germplasm lines were evaluated in two different sets under stress (drought stress for 20 days during flowering stage), and non-stress (timely sown irrigated) conditions, during *Rabi* 2020 and 2021. Conducting the test for homogeneity-pooled data was used for statistical analysis. The germplasm lines were planted in an augmented design each entry spaced in 20 cm line spacing and plot size containing six rows of 3 m length. Standard agronomic practices were followed for raising the crop.

2.2 Root characterization

Root characterization was done under root phenotyping structures. Seeds were sown in the PVC pipes of 1.5 m height (Fig 1). A well-sieved soil mix along with the vermicompost was used to grow the plants in the PVC pipes. The non-stress and the stress conditions were artificially maintained in the pipes. The observations were recorded by maintaining the moisture through irrigating the pipes at a regular interval and moisture stress was imposed for drought set from 15-30 days at reproductive stage.

Observation on morphological and root characters was recorded following the standard procedures. Selection of genotypes based on their performance under drought stress and non-stress situations, was based on Fisher and Maurer (1978) stress susceptibility index (SSI) as a method of determining yield stability by accounting for variations in both prospective and actual yields in diverse environments. Stress Tolerance Index (STI) was developed as a tool for assessing genotype's potential for high yield and stress tolerance (Fernandez, 1992). These were used in order to classify genotypes into different drought tolerance categories as reported by Sang *et al.* (2014).

Fig 1: Different stages of dicoccum germplasm lines under PVC pipes for root characters

3. Results and discussion

3.1 Variability studies

Analysis of variance for the morpho-yield traits showed significant difference among the genotypes, which revealed that for most of germplasm diverse and collected from different ecological conditions (Table 1). Under drought stress condition, decreasing mean performance of the genotypes was recorded in morpho yield contributing characters like spikelets per spike, and 1000 grain weight in drought stress conditions compared to non-stress similar to the observations made by by Kilic and Yaggbasanlar (2010). Genotypes exhibited significant differences for the root related traits under both conditions (stress and non-stress), checks varieties showed no variations for their mean performance for root volume under both the conditions explaining their adaptability to irrigated conditions. Percent reduction in performance was computed for various traits to understand their sensitivity under moisture stress condition (Table 2). Most yield-attributing characters, such as spikelets per spike, and grain yield per plot, were seriously impacted by drought and showed a significant decrease in mean performance. Under drought stress, germplasm exhibited a significant reduction in grain yield production (41.76 %) compared to non-stress conditions. Under moisture stress, it was observed that there was an increase in performance of root related traits such as root length (by 46.44 %), root volume (by 34.24 %), dry root weight (by 43.43 %) and fresh root weight (by 42.24 %). Research findings explain that due to a lack of moisture during crop growth and development, the genotype with tolerance capacity elongates their roots towards the availability of water.

3.2 Phenotypic diversity

Correlation studies between root traits and yield revealed that with increase in root length, there was increase in the grain yield both under stress and non-stress condition. Interestingly it was observed that under drought condition there was decrease in the grain yield with the increase in shoot length. Phenotypic diversity analysis done using D^2-statistics revealed different number of clusters under stress and non-stress conditions. Nine clusters under non-stress and 3 clusters under stress condition was observed indicating ample amount of diversity. Root length followed by root volume was a major contributor to diversity under stress condition (Table 2a and 2b). Cluster I has the most lines, including the ones with the longest roots (DDK-50381, DDK-50378, DDK-50323, and DDK-50341). It's crucial to remember that when computing cluster mean, the superiority of one genotype over another for a specific feature might be diluted by other genotypes in the same cluster that is inferior or intermediate for the same trait. As a result, in addition to choosing genotypes for hybridization from clusters with a greater intercluster distance, one may also consider selecting parents depending on the amount of divergence for a trait of interest within a cluster (Sharada *et al.,* 2021).

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), Bhanupriya *et al.* (2014) and Kumar *et al.* (2019) 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.

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

	Source	Block (eliminating Treatments)	Treatment (ignoring Blocks)	Checks	Varieties	Checks vs Varieties	Error
	df	5	69	3	65	1	15
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
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
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
Root length	Non-stress	1.47	215.36**	685.38**	177.78**	1247.69**	0.51
	Stress	3.62	1186.14**	7939.7**	866.97**	1671.67**	4.79
Root volume	Non-stress	1.44	13.31**	0.63	11.15**	191.58**	2.1
	Stress	5.56	13.36**	2.65	13.83**	14.48**	2.42

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

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. 1	15.60	21.37	20.60	25.51	20.14	30.35	33.68	33.29	31.52
Cluster. 2		16.41	30.13	30.15	24.21	37.07	42.14	41.40	39.55
Cluster. 3			19.04	28.12	23.60	27.61	26.51	29.66	27.50
Cluster. 4				21.08	29.37	36.63	40.32	27.43	29.58
Cluster. 5					0.00	25.76	27.84	33.01	30.99
Cluster. 6						0.00	0.23	43.58	34.48
Cluster. 7							0.00	35.75	24.71
Cluster. 8								0.00	25.93
Cluster. 9									0.00

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

	Cluster. 1	Cluster. 2	Cluster. 3
Cluster. 1	21.63	32.47	46.38
Cluster. 2		0	43.47
Cluster. 3			0

Table 3: 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)		RV (cm³)	
							S	NS	S	NS
DDK-50341	3345.00	4025.00	0.95	Moderate	0.89	Moderate	87	35	14	12
DDK-50380	3240.00	3558.33	0.92	Moderate	0.84	Moderate	57	48	14	9
DDK-50381	3105.00	3416.67	0.63	Moderate	0.87	Moderate	150	28	14	13
DDK-50378	2591.67	2733.33	0.21	Tolerant	0.80	Moderate	125	48	19	13
DDK-50337	2233.33	2741.67	0.59	Moderate	0.81	Moderate	67	40	18	6
DDK-50323	2041.67	2458.33	0.58	Moderate	0.80	Moderate	138	52	15	11
DDK 1025	2751.44	3577.78	0.84	Moderate	0.55	Susceptible	60	45	14	12
DDK 1029	2474.17	2980.56	0.65	Moderate	0.65	Susceptible	55	35	13	12
NP 200	2211.39	2913.89	0.90	Moderate	0.67	Susceptible	70	60	15	12
HW 1098	2007.36	2741.67	0.92	Moderate	0.71	Susceptible	137	45	16	15

YS – Yield under stress; YP – Yield under non-stress; SSI – Stress susceptibility index STI – Stress tolerance index; RL – Root length; SL – Shoot length; RV – Root volume; S – Stress; NS – Non-stress

3.3 Identification of drought-tolerant germplasm lines

Measuring the root length revealed that the lines DDK-50381, DDK-50378, DDK-50323 and DDK-50341 exhibited better root length among all the lines. The absence of efficient, repeatable screening procedures and the inability to consistently establish defined and repeatable water stress circumstances where huge populations may be assessed efficiently make breeding for drought resistance difficult (Ramirez and Kelly, 1998). The relative yield performance of germplasm lines in stress and non-stress environments appears to be a typical starting point for finding stress-tolerant germplasm lines (Mohammadi *et al.,* 2012). Thus, drought indices have been used to screen drought-tolerant genotypes because they give a measure of drought based on the loss in yield under drought circumstances compared to normal environments (Mitra, 2001). Stress sensitivity and stress tolerance indices were investigated in the current study-utilizing yield under moisture stress and non-stress conditions to discover drought stress tolerance germplasm lines. Based on drought sensitivity, the 70 germplasm lines were categorized as tolerant, moderately tolerant, or sensitive. The yield ratio of each variety in stressed vs. non-stressed circumstances as compared to the proportions in total germplasm lines to determine the stress susceptibility index. So it was observed that one germplasm line (DDK-50378) was falling in the tolerant category. This line was having moderate production even under stressed condition. Three basic techniques for selecting tolerant genotypes were to select under favourable, stressed, and both circumstances simultaneously. Several indices have been developed to describe a genotype's behaviour in stress and non-stress conditions (Mohammadi *et al.,* 2012). Both the stress susceptibility index (SSI) and the stress tolerance index (STI) were utilised in our study to identify drought-tolerant germplasm lines without compromising yield under stress conditions. Thus, in our study, the selected tolerant line based on STI was found to be a promising drought tolerant line with modest production potential. Based on the stress tolerance index (STI), 20 germplasm lines were under the category of tolerance, 26 germplasm lines were moderately tolerant and 34 were susceptible lines. Germplasm lines viz., DDK-50378, DDK-50323 and DDK-50381 showed high STI values with more root length indicating they are suitable for terminal drought stress conditions. DDK 50341 showed high stress tolerance index with least difference in root length under stress and non-stress conditions, indicating the suitability of genotype to intermittent stress (restricted irrigation) with moderate tolerance to drought stress

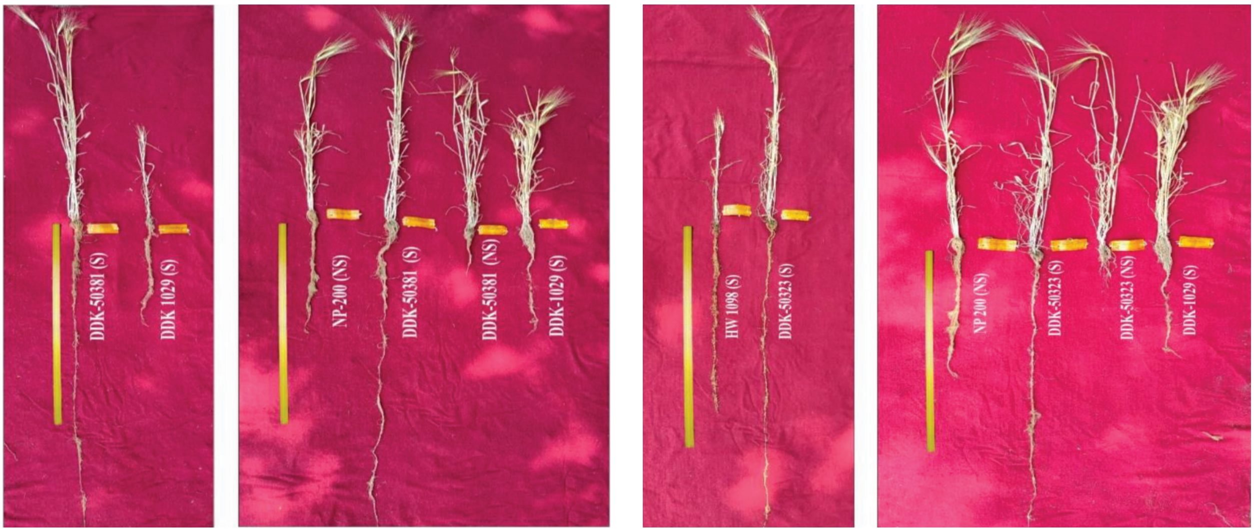

Figure 2: Differential root performance of dicoccum germplasm lines under stress and non-stress condition (S-stress and NS-non-stress conditions)

4. Conclusion

Our study revealed that the local germplasm collections act as reservoir of genes for abiotic stresses. This can be exploited in the breeding program for genetic improvement. 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 identified among the genotypes can be exploited in a breeding program aimed at developing drought-tolerant dicoccum wheat cultivars. DDK-50341 was found drought tolerant with minimal grain yield reduction. DDK-50378, DDK-50380, and DDK-50381 were moderately tolerant with higher yields based on SSI and STI.

Author contributions

All authors have contributed, read and agreed to the published version of the manuscript.

Compliance with ethical standards

No

Conflict of Interest

NA

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