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Research Article

Evaluation of wheat genotypes for yield potential under combined drought and heat stress conditions

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Abstract

The combined effects of drought and heat stress severely impact the potential of crop yield. The present study was conducted to determine the tolerant genotypes among 80 wheat genotypes for combined drought and heat stress based on several stress indices. Results showed that grain yield under normal and combined stressed environments was significantly and positively correlated with stress tolerance index (STI) whereas indices like stress susceptibility index (SSI), tolerance (TOL) and reduction (RED) had negative and significant association with grain yield under stressed conditions and significant positive correlation with grain yield under normal conditions. Based on the stress tolerance index, genotypes RW5, WH1142, PBW773, GW463, HD3086 and UP2981 were identified as high yielding as well as stress tolerant, while C306, HD2888, GW477, HD3043, DBW173, JWS825 and MP3288 are promising genotypes to be cultivated under combined drought and heat stress conditions based on stress susceptibility index, tolerance and reduction. The selected genotypes can be further utilized in wheat breeding programmes to develop tolerant cultivars for combined drought and heath stress.

Keywords: Wheat, SSI, STI, TOL, RED, Combined drought and heat stress

Abbreviations: SSI: Stress susceptibility index; **TOL:** Tolerance; **RED:** Reductionl **STI:** Stress tolerance index; **GYN:** Grain yield under normal conditions; **GYC:** Grain yield under combined (drought + heat) stress conditions

1. Introduction

Wheat (*Triticum aestivum* L.) is a self-pollinated and one of the most important cereal crops in the world. It occupies second ranks in terms of production and area after rice in India. Currently, the production of wheat in India is 109.52 million tonnes and an area is 30.55 million hectare with an average productivity of 3464 kg/ha. Among the wheat producing states, Uttar Pradesh (33%) accounted for the highest share of crop production followed by Punjab (16%), Madhya Pradesh (16%), Haryana (11%), Rajasthan (10%) and Bihar (6%). These six states contributed around 92% of the total wheat production. While Haryana, produced 12.15 million tonnes of wheat from 25.21 lakh hectare with an average productivity of 4822 q/ha (Anonymous, 2021). Wheat is cultivated under a wide range of environment and most of the growing areas are facing different biotic and abiotic stresses. Abiotic stresses such as drought and heat which often occur simultaneously reduces crop productivity. It has been estimated that, crops attain only about 25% of their potential yield because of the detrimental effects of environmental stress. Wheat yield will decline by 4.1% to 6.4% for each global increase of 1°C temperature due to climate change (Liu *et al.*, 2016*)* while wheat consumption is expected to increase by over 30% in the next 40 years. Major effects of heat stress include the reduction in the crop cycle, pollen abortion, grain shrinkage, reduction in seed reserves, anther indehiscence and reduced development of the pollen tube, all these events resulted in reduced yield potential. Moreover, high temperature also affects some physiological processes like, photosynthesis and respiration, disintegration of chlorophyll, damage to photosystem II of the photosynthetic apparatus. Likewise, drought stress also has detrimental effects on grain yield including reduction in leaf area, stomata closure, reduced water potential, kernel abortion and reduced mobilization of stem reserves. Simultaneous occurrence of heat and drought stress initiate various processes like a decreased rate of photosynthesis coupled with abnormal respiration, closed stomata and high leaf temperature. Under such situation where on one side demand of wheat production is increasing to feed the large population of the world and on the other side combined heat and drought stresses are creating problems in sustaining wheat productivity, there is an immediate need to identify genotypes which can perform well under drought as well as temperature stress conditions. Stress indices provides a measure of stress tolerance based on minimization of yield loss under stress compared to optimum conditions, rather than on grain yield level, which has been used to characterize relative stress tolerance of wheat genotypes (Clarke *et al*., 1984).Therefore, the present study was conducted to identify stress tolerant and sensitive wheat genotypes based on stress susceptibility index (SSI), tolerance (TOL), stress tolerance index (STI) and reduction (RED) under combined drought and heat stress conditions.

2. Materials and methods

The present investigation was conducted at the research farm area of Wheat & Barley Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, during the *Rabi* season of 2019-2020 and 2020-2021. The research material was sown in randomized block design under two different environments *viz.,* timely sown irrigated conditions and late sown rainfed conditions. The genetic material was consisted of 80 diverse wheat genotypes. The experimental material was sown in three rows of 2 m length, with row to row spacing 20 cm and plant to plant spacing 10 cm. All the recommended cultural practices were adopted to raise the crop. The pooled data was subjected to analysis using OPSTAT Software (Sheoran *et al*., 1998). SSI was calculated for grain yield by using the formula as suggested by Fischer and Maurer (1978). SSI = [1-YD/YP]/D Where, YP = Mean of genotypes under normal sown conditions, YD = Mean of genotypes under stress conditions and D = 1- Mean YD of all genotypes/Mean YP of all genotypes. Stress tolerance (TOL) was calculated with the formula suggested by Rosielle and Hamblin (1981). TOL = Yp – Ys Where, Yp = grain yield of genotype under normal conditions and Ys = grain yield of genotype under stress conditions. Stress tolerance index was calculated with the help of formula suggested by Fernandez (1992). STI = (Yp x Ys) / Xp^2 Where, Yp = grain yield of genotype under normal conditions, Ys = grain yield of genotype under stress conditions and Xp^2 = mean yield of all genotypes under normal conditions. Reduction was calculated with the help of formula given by Farshadfar and Javadinia (2011). RED = (Yp – Ys) / Yp x 100, where, Yp = grain yield of genotype under normal conditions and Ys = grain yield of genotype under stress conditions

3. Results and Discussion

The analysis of variance (Table 1) revealed that variances due to genotypes were highly significant ($p < 0.01$), whereas, variance due to replication was non-significant for all the stress indices. The performance of wheat genotypes under stress conditions was assessed in terms of SSI, TOL, STI and RED which have been presented in Table 3. The genotypes having high positive SSI values are susceptible to combined drought and heat stress and vice versa (Fischer and Maurer, 1978). Assessments of stress susceptibility index (SSI) revealed that 37 genotypes showed significantly lower estimates (<1.00), thereby, signifying these are promising stress tolerant genotypes. Genotypes C-306 (0.13) followed by HD2888 (0.24), GW477 (0.30), HD3043 (0.52), HD3043 (0.52) and JWS825 (0.61) noted significantly lowest SSI value. Therefore, these genotypes possessed low stress susceptibility and high yield stability under combined stress conditions. In contrast, WB2 (1.46) followed by ESWYT18-121 (1.41), WH1124 (1.29) and WH1062 (1.28) recorded with high stress susceptibility index and were identified as highly susceptible to combined drought and heat stress. The mean values of tolerance and reduction for grain yield revealed that the genotypes like C306 (26.25, 4.48, respectively), HD2888 (50.00, 8.18, respectively), GW477 (77.00, 10.30, respectively), HD3043 (138.25, 17.85, respectively), HD3043 (144.00, 19.66, respectively) and JWS825 (126.00, 20.87, respectively) exhibited minimum values for tolerance and reduction. Rosielle and Hamblin (1981) suggested that a high value of tolerance is associated with high sensitivity to stress. Therefore, sensitive genotypes for tolerance were ESWYT18-121 (423.25), WH1151 (406.50), WH1105 (402.00), WH1184 (399.50) and HD2967 (399.25). Reduction (RED) was found to be highest for WB2 (50.32) followed by ESWYT18-121 (48.58), WH1151 (46.94), WH1124 (44.35) and WH1062 (44.02). Stress tolerance index (STI) is a useful tool for determining high yield and stress tolerance potential of genotypes revealed that 58 genotypes recorded significantly higher values of STI ($\geq$0.60), thereby promising for drought tolerance. HD3086 (1.21) followed by WH1184 (1.21), UP2981 (1.19), RW5 (1.13), PBW773 (1.13) and WH1105 (1.11) recorded significantly highest STI magnitudes, whereas, the low value for STI was found for FLW16 (0.27), FLW22 (0.31), WB2 (0.44), JWS825 (0.46) and WH1131 (0.49). Similar findings were reported by Hossain *et al.* (2012), Dorostkar *et al.* (2015) and Suresh *et al.* (2018). Selection solely based on single index potentially leads to inappropriate predictions about genotypes. When dealing with a large number of genotypes, it is always better to screen them in two phases. First, genotypes with high values of STI should be selected. Second, genotypes should be screened for SSI, TOL and RED and genotypes with low values should be selected (Aghaei-Sarbarze *et al.* 2009). This process leads to high yielding genotypes in both stress and non-stress conditions (Ramirez & Kelly 1998). Other researchers have also used different indices for selecting tolerant genotypes. Khakwani *et al.* (2011) screened drought-tolerant wheat varieties having high values of STI and low values of SSI under both 100% and 25% FC conditions and found that the cultivar Hashim-8 was drought-tolerant.

Table 1. Analysis of variance for different stress indices in 80 wheat genotypes under combined (drought + heat) stress conditions

Traits	DF	SSI	TOL	STI	RED	GYC	GYN
Replication	1	0.001	8,910.23	0.007	85.337	6,727.54	153.077
Genotypes	79	0.126**	14,783.20**	0.030**	147.97**	16,997.45**	6,806.82**
Error	79	0.027	2,778.47	0.002	31.314	1,323.65	854.58

Table 2. Mean performance of wheat genotypes for various stress indices under combined (drought + heat) stress conditions

Genotypes	GYC (2020)	GYC (2021)	GYN (2020)	GYN (2021)	Genotypes	GYC (2020)	GYC (2021)	GYN (2020)	GYN (2021)
C306	611.5	507.5	615.0	556.5	PBW773	546.5	610.0	991.0	917.5
DBW136	480.5	497.0	731.5	707.0	RAJ3765	514.0	504.0	806.5	784.5
DBW14	447.0	547.5	789.0	682.0	RAJ4480	533.5	475.0	650.0	786.0
DBW150	493.5	504.0	797.5	776.0	RW5	678.5	661.5	876.0	923.0
DBW173	655.0	522.0	700.0	765.0	RWP2017-21	549.5	515.5	790.0	790.5
DBW221	559.0	503.5	839.0	823.5	UP2981	557.5	574.5	1015.0	909.5
DBW233	532.5	555.5	752.0	822.0	WB2	357.5	384.0	752.0	740.5
DBW71	496.0	564.0	722.0	787.0	WH1021	508.5	507.5	775.0	749.5
ESWYT18-115	497.5	505.5	854.0	869.0	WH1062	444.0	466.5	800.0	826.5
ESWYT18-116	516.5	495.0	773.0	830.0	WH1063	489.0	449.0	775.0	778.5
ESWYT18-121	436.0	460.0	860.0	882.5	WH1100	555.5	553.5	919.5	941.5
ESWYT18-122	492.5	561.0	794.0	803.0	WH1105	507.5	538.0	1005.0	986.0
ESWYT18-147	482.5	480.5	749.5	747.5	WH1123	574.0	536.5	788.0	720.0
FLW10	443.5	492.5	722.0	725.5	WH1124	460.5	455.0	801.0	844.0

FLW16	371.5	334.5	497.5	479.5	WH1129	555.0	581.0	812.5	846.0
FLW22	347.0	394.5	511.5	535.5	WH1131	480.0	456.0	605.0	724.0
GW463	619.0	606.5	889.0	887.5	WH1132	543.5	507.0	807.0	766.5
GW477	687.0	654.0	767.5	727.5	WH1138	510.0	549.5	793.5	845.0
HD2888	546.0	576.0	611.0	611.0	WH1142	679.0	647.0	911.0	863.5
HD2932	571.0	550.5	812.0	826.0	WH1151	438.5	480.5	890.0	842.0
HD2967	534.0	529.5	955.0	979.0	WH1152	500.5	505.0	840.0	886.0
HD3043	678.0	593.0	721.0	826.5	WH1153	469.5	520.0	876.0	790.5
HD3086	576.5	560.5	1030.	1013.0	WH1158	492.5	495.0	818.0	892.0
HD3219	480.0	510.5	789.0	757.5	WH1160	470.0	488.5	766.5	874.5
HI1621	572.5	553.5	762.0	770.5	WH1164	557.0	523.0	720.5	758.0
HI1625	509.5	499.5	733.0	802.5	WH1175	490.5	449.0	744.0	755.5
HI1628	529.0	504.0	759.5	755.5	WH1179	545.5	546.5	765.0	764.0
JWS825	484.0	471.5	612.5	595.0	WH1182	457.5	471.0	670.0	660.0
KBRL79-2	507.5	462.5	760.0	767.0	WH1184	550.5	546.5	1020.0	982.0
LOK54	480.0	602.0	750.0	797.5	WH1186	484.0	453.5	710.0	805.5
MP3288	554.5	587.0	747.5	706.5	WH1188	492.5	496.0	852.5	794.5
NI5439	550.5	534.0	700.0	762.5	WH1192	452.0	480.0	818.0	820.5
PBW681	453.0	450.5	757.5	795.5	WH1202	563.0	545.0	889.0	921.0
PBW719	504.0	503.5	673.0	740.0	WH1235	547.5	496.5	833.0	871.5
PBW752	536.0	509.5	830.5	875.5	WH147	518.0	604.0	924.0	822.0
PBW762	518.5	518.5	852.5	914.0	WH157	505.0	449.0	697.5	776.0
PBW763	625.0	583.0	755.0	809.0	WH542	539.5	551.5	892.5	916.5
PBW766	526.0	509.5	842.0	911.0	WH711	603.0	597.0	898.5	893.0
PBW769	538.0	541.0	776.5	833.5	WH730	576.0	564.0	735.0	739.0
PBW771	471.5	483.5	729.0	803.5	WH789	557.0	559.0	869.0	890.0

Table 3. Pooled mean, range of different combined stress indices in the 80 wheat genotypes

Genotypes	SSI	TOL	STI	RED	Genotypes	SSI	TOL	STI	RED
C306	0.13	26.25	0.52	4.48	PBW773	1.15	376.00	0.88	39.40
DBW136	0.93	230.50	0.56	32.05	RAJ3765	1.05	286.50	0.64	36.02
DBW14	0.94	238.25	0.58	32.39	RAJ4480	0.87	213.75	0.57	29.77
DBW150	1.07	288.00	0.62	36.61	RW5	0.74	229.50	0.96	25.51
DBW173	0.57	144.00	0.68	19.66	RWP2017-21	0.95	257.75	0.67	32.62
DBW221	1.05	300.00	0.70	36.09	UP2981	1.20	396.25	0.86	41.18
DBW233	0.90	243.00	0.68	30.88	WB2	1.46	375.50	0.44	50.32
DBW71	0.87	224.50	0.63	29.75	WH1021	0.97	254.25	0.61	33.36
ESWYT18-115	1.22	360.00	0.69	41.79	WH1062	1.28	358.00	0.59	44.02
ESWYT18-116	1.07	295.75	0.64	36.90	WH1063	1.15	307.75	0.58	39.62
ESWYT18-121	1.41	423.25	0.62	48.58	WH1100	1.18	376.00	0.82	40.41

ESWYT18-122	0.99	271.75	0.67	34.03	WH1105	1.27	402.00	0.77	43.47
ESWYT18-147	1.04	267.00	0.57	35.67	WH1123	0.77	198.75	0.66	26.36
FLW10	1.03	255.75	0.54	35.34	WH1124	1.29	364.75	0.60	44.35
FLW16	0.81	135.50	0.27	27.74	WH1129	0.92	261.25	0.75	31.50
FLW22	0.85	152.75	0.31	29.18	WH1131	0.86	196.50	0.49	29.57
GW463	0.90	275.50	0.86	31.02	WH1132	0.97	261.50	0.66	33.24
GW477	0.30	77.00	0.80	10.30	WH1138	1.03	289.50	0.69	35.34
HD2888	0.24	50.00	0.54	8.18	WH1142	0.74	224.25	0.93	25.27
HD2932	0.92	258.25	0.73	31.53	WH1151	1.37	406.50	0.63	46.94
HD2967	1.25	399.25	0.79	42.88	WH1152	1.22	360.25	0.69	41.74
HD3043	0.52	138.25	0.78	17.87	WH1153	1.18	338.50	0.65	40.62
HD3086	1.16	379.25	0.86	40.02	WH1158	1.23	361.25	0.67	42.25
HD3219	1.05	278.00	0.61	35.95	WH1160	1.21	341.25	0.62	41.59
HI1621	0.77	203.25	0.68	26.53	WH1164	0.78	199.25	0.63	26.95
HI1625	1.00	263.25	0.61	34.29	WH1175	1.09	280.00	0.56	37.35
HI1628	0.93	241.00	0.62	31.82	WH1179	0.83	218.50	0.66	28.58
JWS825	0.61	126.00	0.46	20.87	WH1182	0.88	200.75	0.49	30.19
KBRL79-2	1.06	278.50	0.59	36.48	WH1184	1.23	399.50	0.83	42.14
LOK54	0.88	232.75	0.66	30.08	WH1186	1.11	289.00	0.56	38.14
MP3288	0.63	156.25	0.66	21.49	WH1188	1.16	329.25	0.65	39.98
NI5439	0.75	189.00	0.63	25.85	WH1192	1.26	353.25	0.61	43.12
PBW681	1.22	324.75	0.56	41.82	WH1202	1.13	351.00	0.80	38.78
PBW719	0.84	202.75	0.56	28.70	WH1235	1.13	330.25	0.71	38.75
PBW752	1.13	330.25	0.71	38.72	WH147	1.04	312.00	0.78	35.74
PBW762	1.20	364.75	0.73	41.30	WH157	1.03	259.75	0.56	35.26
PBW763	0.66	178.00	0.75	22.76	WH542	1.16	359.00	0.78	39.69
PBW766	1.19	358.75	0.72	40.93	WH711	0.96	295.75	0.85	33.02
PBW769	0.96	265.50	0.69	32.98	WH730	0.66	167.00	0.67	22.66
PBW771	1.10	288.75	0.58	37.68	WH789	1.06	321.50	0.78	36.55
Mean ±SE	0.98 ±0.25	272.73 ±5.21	0.66 ±0.15	33.78 ±1.48	Mean ±SE	0.98 ±0.25	272.73 ±5.21	0.66 ±0.15	33.78 ±1.48
Range	0.13–1.46	26.25–423.25	0.27–0.96	4.48–50.32	Range	0.13–1.46	26.25–423.25	0.27–0.96	4.48–50.32

Correlation analysis

Correlation coefficients between grain yield (under normal and stress conditions) and different stress indices are presented in Tables 4. There was a positive significant correlation between GYN and GYC (r=0.419**). This indicates that high yield performance under normal condition resulted in relatively high yield under combined stress conditions. The results were in accordance with B. Ali and El-Sadek (2016). Grain yield under normal conditions was significantly and positively correlated with indices like stress susceptibility index (0.584**), tolerance (0.788**) and reduction (0.584**), whereas grain yield under combined stressed conditions had significant negative correlation with stress susceptibility index

(-0.483**), tolerance (-0.229*) and reduction (-0.482**). Stress tolerance index had positive and significant association with grain yield under normal (0.849**) as well as combined drought and heat stress (0.827**) conditions. Indices which are highly correlated with the grain yield under stressed conditions are most suitable for identifying stress tolerant genotypes (Farshadfar *et al.,* 2011). Jatav and Kandalkar (2014) also found negative associations of stress susceptibility index and tolerance with the grain yield under drought stress conditions.

Table 4. Correlation coefficients among GYN, GYC and different stress indices of 80 wheat genotypes evaluated under normal and combined stress conditions

	SSI	TOL	STI	RED	GYN
SSI					
TOL	0.953**				
STI	0.081	0.349**			
RED	1.000**	0.953**	0.081		
GYN	0.584**	0.788**	0.849**	0.584**	
GYC	-0.483**	-0.229*	0.827**	-0.482**	0.419**

4. Conclusions

Stable genotypes under non-stressed and stressed environments are vital for plant breeding programs. The genotype that shows low fluctuations of yield under stress conditions can be considered stress tolerant. Further, stress indices could be good indicators of genotypes stability. In the present study, a high positive correlation was recorded between grain yield under normal conditions and all the stress indices studied, whereas, under stress conditions, indices, like stress susceptibility index, tolerance and reduction were significantly and negatively correlated with grain yield. In addition, it was concluded that reduction, and stress susceptibility index are the best indices for selecting stress tolerant genotypes. Therefore, based on the mean values of different stress indices like stress susceptibility index, tolerance and reduction C306, HD2888, GW477, HD3043, DBW173, JWS825 and MP3288 are promising to be cultivated in combined drought and heat stress conditions, whereas, if we consider stress tolerance index, genotypes *viz*, RW5, WH1142, PBW773, GW463, HD3086 and UP2981 were better performing under stressed environments based on their grain yield potential.

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Compliance with ethical standards

NA

Conflict of Interest

Authors declare that they have no conflict of interest

Author contributions

Concept of research and designing of experiments (SD, VS), Conduction of experiment (SD, N), Preparation of manuscript (SD, VS), Quality assessment (SD, VS, N).

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