International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(6): 1946-1952

Received: 16-09-2019
Accepted: 18-10-2019

Vijay Kamal Meena
Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi, India

RK Sharma
Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi, India

PK Singh
Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi, India

Naresh Kumar
Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi, India

Neelu Jain
Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi, India

Anuj Kumar
Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi, India

Ankita
Department of Plant Pathology, Dr. Y. S. Parmar University of Horticulture & Forestry, Nauni, Solan, Himachal Pradesh, India

Corresponding Author:
Vijay Kamal Meena
Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi, India

Identification of terminal heat tolerance spring wheat genotypes using different selection indices for yield

Vijay Kamal Meena, RK Sharma, PK Singh, Naresh Kumar, Neelu Jain, Anuj Kumar and Ankita

Abstract
Present investigation was carried out to identify the terminal heat tolerant genotypes using different tolerance indices. Study was planned with 36 spring wheat genotypes, grown in two viz., timely (E1) and late (E2) sowings in years viz., 2016-17 and 2017-18. The analysis of variance revealed the presence of sufficient variability among the genotypes for all the traits under two sowings in both crop seasons. Considering the prevailed high temperature during the crop season E2 environment was considered as heat stress environment. Six genotypes viz., DW1630, DW1636, HD3266, HD3090, DW1635 and DW1638 emerged as terminal heat tolerant genotypes based on their consistence performance in seven different selection indices in both years viz., susceptibility index, mean productivity index, geometric mean productivity index, tolerance index, stress tolerance index, yield index and yield stability index.

Keywords: Terminal heat stress, stress tolerance indices, yield, spring wheat genotyes

Introduction

Wheat (*Triticum aestivum* L.), is the leading cereal grown and consumed globally. This golden grain winter cereal is being cultivated under varied agro-climatic conditions of the India covering 30.72 million ha of area with a record production of 97.44 million tons and productivity level of 3.17 ton per hectare during 2016-17. Temperature is considered as one of the main natural factors which decide the rate of crop development. The significance of heat stress in diminishing yield was first announced by Howard (1924) [1] who expressed that "wheat production in India is a gamble with temperature". This statement is valid till today.

Higher temperature during the grain filling is one of the significant constraints in decreasing productivity of wheat in tropical countries and India (Rane and Nagarajan, 2000) [2]. Wardlaw (1994) [3] revealed that mean temperature more prominent than 15 – 18^0 C during anthesis will bring about decline in grain weight at maturity in wheat. Selection of diverse genotypes under stress environments is one of the prior works of plant breeders for exploiting genetic variations to improve stress tolerant genotypes (Clarke *et al*., 1984) [4]. So, a key task in traditional breeding for heat tolerance is the identification of consistent screening approaches and effective selection criteria to ease finding of heat tolerant genotypes.

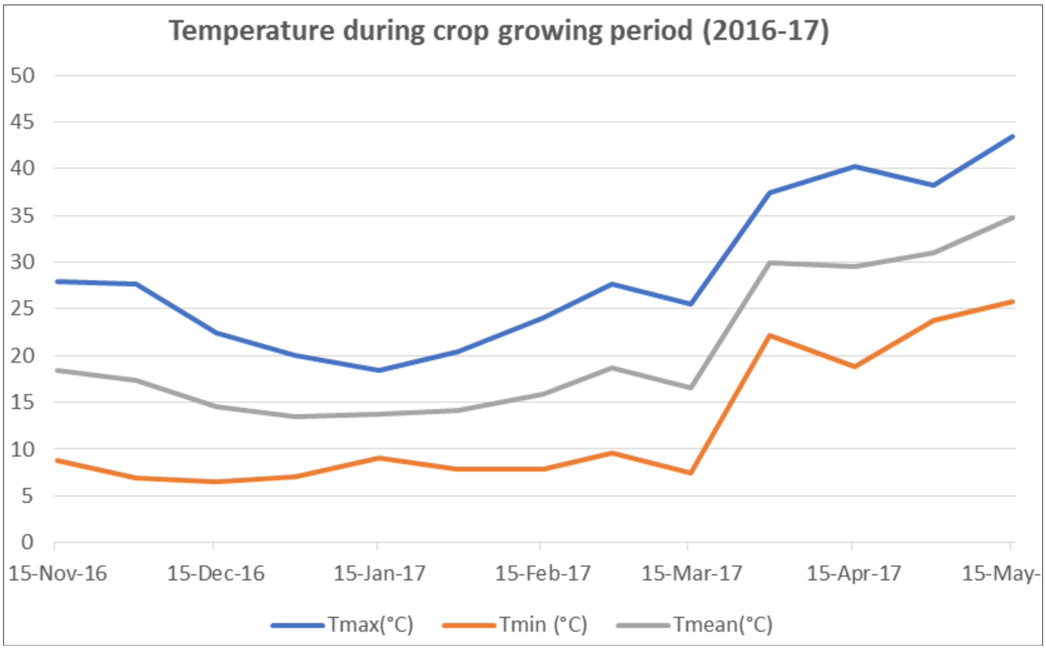
Numerous screening methods and selection criteria have been anticipated by various researchers, but very few were reported for screening heat tolerant genotypes in wheat. Rosielle and Hamblin (1981) [5] defined stress tolerance (TOL) as the differences in yield between the non-stress and stress environments and mean productivity (MP) as the average yield of these two environments. They reported a positive correlation between mean productivity (MP) and yield under stress environment (Ys), therefore selection based on MP could improve average yield under both stress and non-stress environments. Several studies also showed a high and positive correlation between MP and Ys (Sanjeri, 1998; Ghagar Sepanlo *et al*., 2000; Nouri *et al*., 2011) [6, 7, 8]. Fischer and Maurer (1978) [9] proposed genotype stress susceptibility index (SSI) as a ratio of genotypic performance under stress and non-stress conditions. They suggested the SSI for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Bansal and Sinha (1991) [14] proposed to use SSI and grain yield as stability parameters to identify drought resistant genotypes of wheat.

Several authors (Clarke *et al*., 1992; Guttieri *et al*., 2001) [4, 10] also used SSI to evaluate drought tolerance in wheat genotypes and suggested that an SSI > 1 indicated above average susceptibility to drought stress. Fernandez (1992) [11] proposed that stress tolerance index (STI) can be used to identify mungbean genotypes that produce high yield under both stressed and non-stressed conditions. Geometric mean productivity (GMP) is another index which is often used by breeders interested in relative performance (Ramirez and Kelly, 1998) [12]. GMP under both stressed and non-stressed conditions could be used to determine the extent or degree of susceptibility to avoid the effects of stress variation in different years (Fernandez, 1992; Kristin *et al*., 1997; Mitra, 2001) [11, 15]. Other yield-based resistances estimates are yield index (YI) and yield stability index (YSI) were used by different authors (Bouslama and Schapaugh, 1984; Lin *et al*., 1986; Gavuzzi *et al*., 1997) [17, 18].

Many authors (Golabadi *et al*., 2006; Sio-Se Mardeh *et al*., 2006; Talebi *et al*., 2009; Nouri *et al*., 2011) [20, 21, 8] suggested that breeders can choose better stress resistant durum wheat genotypes based on MP, GMP and STI under drought stressed and non-stressed environments. Combination of different stress indices was examined in different crops. For instance, SSI, STI and GMP were proved to be the most effective criteria for selecting heat tolerant and high yielding genotypes of maize (Khodarahmpour *et al*., 2011) [22]. They found positive and significant correlation of GMP and grain yield under both stressed and non-stressed conditions and suggested that this index is more applicable and efficient for selection of parent material in producing maize hybrids tolerant to high temperatures and high yielding under both conditions. GMP in combination with SSI was found a desirable criterion for selecting improved drought resistant common bean genotype (Ramirez and Kelly, 1998) [12]. In another study, Moghaddam and Hadizadeh (2000) [23] found STI more applicable than SSI for selection of maize genotypes tolerant to stress. Therefore, the present study was conducted to evaluate the accuracy of different stress tolerance indices for identifying heat tolerance in spring wheat genotypes.

Material and Methods

The present investigation was carried out at the Experimental Farm, Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi during Rabi season 2016-17 and 17-18 using two dates in each crop year [i.e., 22th Nov, 2016 timely (E1) and 9th Jan 2017 late (E2) during 2016-17] and [22th Nov, 2017 timely (E1) and 9th Jan 2018 late (E2) during 2017-18] of sowings. The experimental material is consisted of 36 genotypes including released wheat varieties recommended for various production situations of different zones of the country and pre-released advance lines of bread wheat developed at Indian Agricultural Research Institute, New Delhi. The experiment was laid out in Randomized Block Design (RBD) replicated thrice for all the sowings. Each genotype was sown in a six-row plot having a gross area of 5 m x 1.20 m with a row spacing of 20 cm using self-propelled Norwegian Seed Drill in a well-prepared field. Observations in field were recorded from each experimental plot either on ten randomly selected plants or on plot basis in the two sowings. The average values of ten randomly selected plants or value observed on plot basis were used for the statistical analysis. Observations has recorded for the following traits, Days to 50% heading (HDNG), Number of spike per square meter (SPMS), Number of grains per spike (GNPS), Grain weight per spike in grams (GWPS), Spike length (cm) (SL), Days to maturity (DTM), Grain filling period (GFD), Grain yield per square meter (g) (YPMS), Biological yield per square meter (g) (BYPMS), Harvest Index (HI), 1000- kernel weight (TGW), and Canopy temperature depression (CTD). Tolerance indices were calculated using the following relationships: 1.Stress susceptibility index (SSI) = $1-(Y_s / Y_p)/ 1- (Y_{sm}/ Y_{pm})$ (Fischer and Maurer, 1978) [9], 2. Stress tolerance (TOL) = Yp – Ys **(**Hossain *et al*., 1990), 3. Mean productivity (MP) = (Yp+ Ys) / 2 (Rosielle and Hamblin, 1981) [5], 4. Stress tolerance index (STI) = $(Y_P \times Y_s) / Y^2_p$ **(**Fernandez, 1992) [11], 5. Geometric mean productivity (GMP) **=** $\sqrt{Y_p \times Y_s}$ (Fernandez, 1992) [11]**,** 6. Yield index (YI) = Y_S / Y_{sm} (Lin *et al*., 1998), 7. Yield stability index (YSI) = Ys / Yp (Bouslama and Schapaugh, 1984) [17]. Where: Y_s = yield of genotypes under heat stress or late sown condition, Y_p = yield of genotypes under non-heat stress or timely sown condition, Y_{sm}= mean yields of all genotypes under heat stress condition, Y_{pm}= mean yields of all genotypes under non-heat stress condition, 1- (Y_{sm}/ Y_{pm}) =Stress intensity. Temperature during growing seasons shown in Figure1.



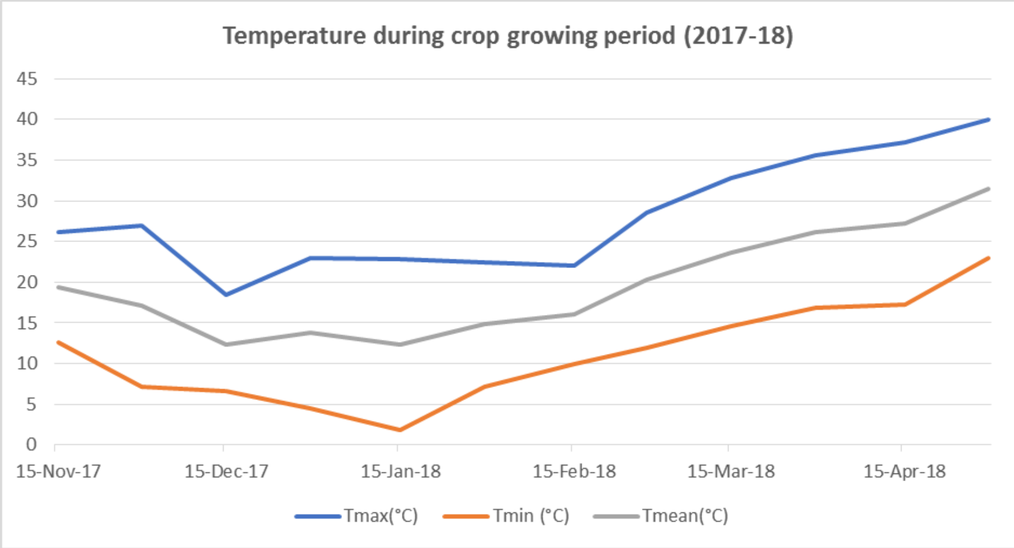


Fig 1: Evaluation in temperature during crop growing period

Results and Discussion

The analysis of variance for all the traits during both the crop seasons revealed highly significant difference among the genotypes suggested the wide range of variability present in the set of genotypes (Table 1). The grain yield performance of different genotypes under study was calculated for different selection indices for the crop year 2016-17 and 2017-18 presented in Table 2 and Table 3 respectively.

Nine genotypes showing promising SSI index value in 2016-17 were DW1638 (0.272), DW 1636 (0.359). DW1634 (0.365), HD 3090 (0.448), HD 3255 (0.629), HD 3266(0.678), DW 1635(0.690), DW1635 (0.692) and DW 1644 (0.701). Based on mean productivity, the better performing genotypes were HD 3262 (1133.8), HD 3266 (1058.2), HD 1631 (64), DW1615 (910.8), HD 3265 (895.7), DW 1635 (881.5), DW1636 (855.7), HD 3118 (855.2) and HD 3059 (843.2). The genotypes adjudged as terminal heat tolerant through this tolerance index were DW1638 (98), HD3090 (137), DW1634 (177), DW1636 (210), HD 3086 (315), DW1644 (327), DW 1633(334), DW 1643 (379), HD 3255(387), DW1616 (448) and DW 1635 (468). The 10 genotypes viz., DW1638 (0.835), DW1636 (0.781), DW1634 (0.778) HD3090 (0.728), HD 3255 (0.593), HD3266 (0.588), DW1635 (0.580), DW1633 (0.579) DW1644 (0.574) and DW1615 (0.561) emerged out as terminal heat tolerant genotypes based on STI. The value of this index varied from 0.835 (DW1638) to 0.139 (DW1631) with a general mean value 0.392. With an average value of 639, the GMP index value ranged from 106.07 (HD 3262) to 357.8 (HD 3086). The promising genotypes emerged in this index were HD 3262(1060.7), HD 3266 (1021.9), DW1615 (874.2) DW 1635(874.2), DW 1636(849.2), HD 3265 (806.5), HDCSW18 (719.2), HD 3059 (777.1), DW 1642 (759.5) and HD 3255 (731.5). Using yield index, the promising genotypes emerged are HD3266 (1.958), HD 1636(1.877), HD 3262(1.833), HD1615 (1.638), DW1635 (1.618), DW 1634 (1.556), HDCSW (1.475), HD 3255 (1.408), DW1642 (1.383) and HD 3059 (1.29). In general, the yield index value varied from 1.958 (HD 3266) to 0.375 (DW1629) with a mean value of 1.018. The value of YSI Index ranged from 0.392 (DW1638) to 0.139 (DW1631) with a general mean value of 0.392. The genotypes DW1638 (0.835), DW 1636 (0.781), DW 1634 (0.778), HD 3090 (0.728), HD 3255 (0.593), HD 3266(0.588), DW1635 (0.580), DW1633 (0.579) DW1644 (0.574) and DW1615 (0.561) emerged out as terminal heat tolerant genotypes based on YSI.

During the crop year 2017-18, The SSI value ranged from 0.084 (HD3090) to DW 1631(1.926) with a general mean value 0.972 while mean productivity index value varied from 1245.2 (HD 3318) to 745.5 (HD 3086) with an average value of 1047. The estimated index value for tolerance index ranged from 31 (HD 3090) to DW 1631 (1024) with a mean value of 437. Minimum estimated value of STI 0.347 exhibited by DW 1631 and maximum value of 0.972 exhibited by HD 3090 with a general mean value of 0.671. Geometric mean productivity index values ranged from 744.4 (HD3086) to HD 3118 (1214.9) with mean value of 1016. The yield index value found to vary from 0.551 to 1.329 in genotype DW 1627 and DW1630, respectively with general mean value of 0.965. The minimum yield susceptibility index value of 0.349 recorded by genotype DW 1631 and maximum value of 0.972 recorded by genotype HD 3086 with a general mean value 0.7671. The genotypes viz., HD3090 (0.084), DW1630 (0.11), HD 3265 (0.112), HD 3086 (0.115), WR544 (0.327), HD3059 (0.353), DW1636 (0.473), DW1638 (0.551) and HD3266 (0.598) emerged as terminal heat tolerant genotypes based on SSI values. Considering mean productivity index, the promising genotypes emerged were HD3118 (1245.2), DW1645 (1225.4), HDCSW18 (1206.6), HD 3266 (1201.1), DW1642 (1201.1), DW1635 (1165.4), DW1630 (1162.7), HD3262 (1150.5) and HD3171 (1149.9). Genotypes viz., HD3090 (31), HD3265 (42), DW1630 (44), HD 3086(82), HD3059 (100), WR544 (104), DW1638 (172), DW1636 (199) and DW 1632(264) adjudged terminal heat tolerant genotypes based on tolerance index. The genotypes showed tolerant reaction to terminal heat stress based on STI index were HD3090 (0.972), DW1630 (0.963), HD3265 (0.962), HD3086 (0.895), WR544 (0.889), DW1636 (0.84), DW1638 (0.813) and HD3266 (0.797). Similarly, the promising genotyped identified based on geometric mean productivity index were HD3118 (1214.9), DW1645 (1196.1), HD3266 (1193.5), DW1642 (1189.4), HDCSW18 (1179.6), DW1630 (1162.5), DW1636 (1135.3), DW1635 (1126.2) and HD 3194 (118.7). Based on yield index, the promising genotypes emerged were DW1630 (1.329), HD3265 (1.248), HD3266 (1.242), HD3090 (1.241), DW1636 (1.213), DW1642 (1.211), HD3118 (1.133) DW1645 (1.118), HDCSW18 (1.11). Based on the estimate of yield susceptibility index, the promising genotypes found were HD3090 (0.972), DW1630 (0.963), HD3265 (0.962), HD3086 (0.895), WR544 (0.889), HD3059 (0.88), DW1636 (0.84), DW1638 (0.813) and HD3266 (0.797).

The genotypes showed wide ranges of variations for the estimated indices. A close look on the performance of different selection indices in both the year revealed that number of genotypes emerged as tolerant varied from 8 to 11 during crop season 2016-17 and 9 to 10 in crop season 2017-18 Of these indices, two tolerance and geometric mean productivity indices were identified maximum number of total tolerant (20 each genotypes) in both the years while minimum number of 17 genotypes were identified by stress susceptibility index. The remaining five indices identified equal number of 19 genotypes each. This indicated there is not much difference in identification of tolerant genotypes by these indices. However, there is change in list of genotypes adjudged as tolerant genotypes as far as the years are concerned. Similarly, there is change in genotypes as far as different selection indices are concerned.

The comparative performance of different tolerant genotypes in crop year 2016-17 and 2017-18 revealed that the six genotypes viz., DW1630, DW1636, HD3266, HD3090, DW1635 and DW 1638 emerged as terminal heat tolerant genotypes based on their consistence performance in both the years and in different selection indices. The comparative performance of genotypes also revealed that 16 genotypes out of 36 genotypes emerged as susceptible genotypes for terminal heat stress. These 16 genotypes could not emerge as tolerant genotypes in any of seven tolerance indices used. Of these 12 genotypes exhibited consistent performance during both the years while remaining four genotypes were not consistent and showing susceptible behavior in one year only (Table 5.5). These 12 genotypes were HD2864, HD3249, DW1627, DW1628, DW1629, HD3184, HD3252, HD2932, DW1632, WR544, DW1639, DW1640 and DW1645. The four genotypes which did not gave consist performance were HD 3171, HD 3184, DW 1631 and DW 1613. The performance of other genotypes understudy is varied with selection indices and years and hence not considered as terminal heat tolerant genotypes.

The results of our finding are in same line with the finding of other researchers of the past. These researchers have also used various tolerance indices to identify the terminal heat tolerant genotypes, but could find variable result different tolerance indices. Mohammad *et al*. (2011) [24] calculated eight stress tolerance indices in wheat based on grain yield under normal and heat-stressed conditions and reported the variable result with different tolerance indices. Puri *et al*. (2014) performed a study to comparative performance of ten diverse wheat lines under various stress tolerance indices. They concluded that grain yield under both environments had significant and positive correlation with mean productivity (MP), geometric mean productivity (GMP) and heat tolerance index (HTI) whereas non-significant correlation with stress susceptibility index (SSI) and tolerance index (TOL). Khan *et al*. (2015) [25] reported significant variations due to genotypes for all characters in two sowing conditions. The indices SSI, YSI and TOL could be useful parameters in discriminating the tolerant genotypes that might be recommended for heat stressed conditions. Hassan *et al*. (2016) [26] observed based on tolerance indices that grain yield/plant was strongly positively correlated with stress tolerance index (STI), yield index (YI), mean productivity (MP), geometric mean productivity (GMP) and harmonic mean (HM) under heat stress and with root length under drought condition, suggesting that STI, YI, MP, GMP and HM are powerful indices for heat tolerance. Kamrani and co-workers (2017) [27] concluded that the stress tolerance index (STI), geometric mean productivity and mean productivity (MP) indices were the most profitable criteria for selection of heat tolerant and high yielding genotypes. Mohammadi *et al* (2017) [28] based on tolerance indices concluded that Grain yield/plant was strongly positively correlated with stress tolerance index (STI), yield index (YI), mean productivity (MP), geometric mean productivity (GMP) and harmonic mean (HM) under heat stress. Recently, Ghajghate (2017) evaluated the set of 35 genotypes using seven different tolerance indices to find out the terminal heat tolerant genotypes. They also find variable results with different selection indices.

Table 1: Analysis of Variance for 13 characters

	Timely Sown (E1) -2016-17				**Late Sown (E2)-2016-17**		
SN	**SV**	**REP**	**GEN**	**ERR**	**REP**	**GEN**	**ERR**
	D.F.	**2**	**35**	**70**	**2**	**35**	**70**
1	HDNG	1.361	61.219**	0.133	0.8405	117.659**	0.383
2	DTM	8.028	39.79**	3.499	6.25	68.233**	0.836
3	GFD	16	26.850**	3.300	2.507	54.435**	0.493
4	PH	0.903	78.858**	0.701	4.037	140.835**	0.237
5	SL	0.1225	2.734**	0.0009	0.07	2.100**	0.029
6	GWPS	0.0055	0.331**	0.004	0.001	0.316**	0.001
7	GNPS	2.528	83.550**	0.956	4.8425	58.558**	0.700
8	SPMS	278.528	21982.962**	39.013	100.75	17,952.590**	37.464
9	YPMS	4935.121	216628.418**	1301.778	0.1205	96,195.006**	211.749
10	BYPMS	182.4815	179246.897**	544.739	1144.7315	153,277.783**	389.789
11	HI	17.3165	546.374**	4.400	8.6945	1,207.752**	5.171
12	TGW	7.105	41.391**	2.642	7.1545	167.702**	1.508
13	CTD	0.01	6.819**	0.018	0.261	2.743**	0.010
	Timely Sown (E1) - 2017-18				**Late Sown (E2) - 2017-18**		
SN	**SV**	**REP**	**GEN**	**ERR**	**REP**	**GEN**	**ERR**
	D.F.	**2**	**35**	**70**	**2**	**35**	**70**
1	HDNG	0.111	43.950**	0.454	3.528	336.312**	0.299
2	DTM	1	113.571**	1.714	3.028	320.105**	0.428
3	GFD	0.4445	62.464**	1.244	2.287	56.047**	0.258
4	PH	0.3405	91.974**	0.088	2.4815	171.745**	1.053
5	SL	0.3495	5.002**	0.048	0.01	2.910**	0.043

6	GWPS	0.0515	0.440**	0.007	0.002	0.197**	0.009
7	GNPS	21.6225	207.973**	1.063	1.9535	202.662**	1.078
8	SPMS	128.4445	13,041.726**	75.973	40.2595	15,829.666**	93.954
9	YPMS	23784.293	125,691.674**	2,912.641	75.3425	81,075.507**	2,150.533
10	BYPMS	4032.25	514,687.648**	663.393	1973.028	280,902.598**	617.142
11	HI	23.535	155.116**	3.861	0.2055	144.025**	7.749
12	TGW	0.4565	60.408**	2.207	5.003	262.160**	6.493
13	CTD	0.047	6.609**	0.003	0.0135	2.755**	0.010

*, ** Significant at 5% and Significant at 1% levels, respectively

Table 2: Tolerance indices for YPMS of 36 wheat genotypes under timely sowing and late sowing conditions during 2016-2017

Genotypes	Yield(E1)	Yield(E2)	SSI	MP	TOL	STI	GMP	YI	YSI
HD3171	1311	295	1.275	803.0	1017	0.225	621.6	0.737	0.225
DW1616	791	343	0.931	567.0	448	0.434	520.9	0.858	0.434
HD2864	964	205	1.295	584.3	759	0.212	444.2	0.512	0.212
HD3086	549	233	0.945	391.0	315	0.425	357.8	0.583	0.425
HD3249	893	290	1.110	591.3	603	0.325	508.8	0.725	0.325
DW1627	751	199	1.209	474.8	552	0.265	386.3	0.497	0.265
DW1628	1064	212	1.316	638.0	851	0.200	475.2	0.531	0.200
DW1629	1076	150	1.415	613.0	926	0.139	401.7	0.375	0.139
HD3184	1280	236	1.341	758.0	1044	0.184	549.6	0.590	0.184
HD3252	1168	253	1.288	710.3	915	0.217	543.5	0.633	0.217
DW1630	1070	290	1.199	680.0	780	0.271	557.0	0.725	0.271
HD2932	796	237	1.155	516.5	559	0.298	434.3	0.593	0.298
DW1631	1692	236	1.415	964.0	1456	0.139	631.9	0.590	0.139
DW1632	1197	332	1.188	764.3	865	0.277	630.3	0.830	0.277
WR544	854	220	1.220	537.2	634	0.258	433.8	0.551	0.258
HD3255	950	563	0.669	756.3	387	0.593	731.2	1.408	0.593
DW1633	794	460	0.692	626.8	334	0.579	604.1	1.149	0.579
DW1634	800	622	0.365	711.0	177	0.778	705.4	1.556	0.778
DW1635	1116	647	0.690	881.5	468	0.580	849.8	1.618	0.580
HD3090	502	365	0.448	433.7	137	0.728	428.2	0.913	0.728
HD3262	1534	733	0.858	1133.8	801	0.478	1060.7	1.833	0.478
DW1636	961	751	0.359	855.7	210	0.781	849.2	1.877	0.781
DW1637	1016	434	0.942	725.0	582	0.427	664.0	1.085	0.427
DW1638	593	495	0.272	543.7	98	0.835	541.5	1.237	0.835
DW1639	794	243	1.140	518.5	550	0.307	439.5	0.608	0.307
DW1640	1109	257	1.263	683.3	852	0.232	534.3	0.643	0.232
HD3318	1411	299	1.295	855.2	1112	0.212	649.9	0.748	0.212
HD3265	1285	506	0.997	895.7	779	0.394	806.5	1.265	0.394
DW1642	1043	553	0.772	798.0	490	0.530	759.5	1.383	0.530
DW1643	738	359	0.844	548.3	379	0.487	514.6	0.898	0.487
DW1644	768	441	0.701	604.3	327	0.574	581.7	1.102	0.574
DW1645	1146	399	1.071	772.8	747	0.348	676.6	0.998	0.348
HD3059	1170	516	0.919	843.2	654	0.441	777.1	1.290	0.441
HD3266	1333	783	0.678	1058.2	550	0.588	1021.9	1.958	0.588
DW1615	1167	655	0.721	910.8	512	0.561	874.2	1.638	0.561
HDCSW18	1061	590	0.730	825.5	471	0.556	791.2	1.475	0.556
Mean	1021	400	0.965	710.4	621	0.392	639.0	1.018	0.392

Table 2: Tolerance indices for YPMS of 36 wheat genotypes under timely sowing and late sowing conditions during 2016-2017

Genotypes	Yield(E1)	Yield(E2)	SSI	MP	TOL	STI	GMP	YI	YSI
HD3171	1566	733	1.569	1149.9	833	0.468	1071.8	0.855	0.468
DW1616	1355	867	1.062	1111.0	487	0.640	1084.0	1.011	0.640
HD2864	1416	864	1.150	1139.9	552	0.610	1106.0	1.007	0.610
HD3086	787	704	0.309	745.5	82	0.895	744.4	0.821	0.895
HD3249	1324	780	1.214	1052.0	545	0.589	1016.1	0.909	0.589
DW1627	1196	472	1.785	834.1	723	0.395	751.5	0.551	0.395
DW1628	1351	875	1.040	1112.8	476	0.647	1087.0	1.019	0.647
DW1629	1075	711	0.999	893.0	364	0.661	874.3	0.829	0.661
HD3184	1394	898	1.049	1145.8	496	0.644	1118.7	1.047	0.644
HD3252	1343	856	1.070	1099.1	487	0.637	1071.8	0.997	0.637
DW1630	1185	1141	0.110	1162.7	44	0.963	1162.5	1.329	0.963
HD2932	1185	799	0.962	991.9	386	0.674	972.9	0.931	0.674
DW1631	1569	545	1.926	1056.7	1024	0.347	924.4	0.635	0.347
DW1632	955	691	0.817	822.8	264	0.723	812.1	0.805	0.723
WR544	939	835	0.327	887.0	104	0.889	885.5	0.973	0.889
HD3255	1255	735	1.222	994.8	520	0.586	960.3	0.857	0.586

DW1633	1437	679	1.556	1058.3	758	0.473	988.1	0.792	0.473
DW1634	1225	649	1.387	936.9	576	0.530	891.5	0.756	0.530
DW1635	1465	866	1.206	1165.4	599	0.591	1126.2	1.009	0.591
HD3090	1096	1065	0.084	1080.5	31	0.972	1080.4	1.241	0.972
HD3262	1445	856	1.202	1150.5	588	0.593	1112.3	0.998	0.593
DW1636	1239	1040	0.473	1139.7	199	0.840	1135.3	1.213	0.840
DW1637	1396	627	1.626	1011.6	769	0.449	935.6	0.731	0.449
DW1638	922	750	0.551	836.1	172	0.813	831.7	0.874	0.813
DW1639	1226	943	0.682	1084.2	283	0.769	1074.9	1.099	0.769
DW1640	1331	503	1.835	917.0	827	0.378	818.4	0.587	0.378
HD3318	1518	972	1.061	1245.2	546	0.640	1214.9	1.133	0.640
HD3265	1113	1071	0.112	1092.2	42	0.962	1092.0	1.248	0.962
DW1642	1362	1039	0.699	1200.3	323	0.763	1189.4	1.211	0.763
DW1643	1212	779	1.054	995.1	433	0.643	971.3	0.908	0.643
DW1644	1326	828	1.108	1077.1	498	0.624	1047.9	0.965	0.624
DW1645	1492	959	1.054	1225.4	533	0.643	1196.1	1.118	0.643
HD3059	837	737	0.353	787.1	100	0.880	785.5	0.859	0.880
HD3266	1337	1066	0.598	1201.1	271	0.797	1193.5	1.242	0.797
DW1615	1226	935	0.700	1080.4	291	0.763	1070.6	1.090	0.763
HDCSW18	1461	953	1.026	1206.6	508	0.652	1179.6	1.110	0.652
Mean	1265	828	0.972	1047	437	0.671	1016	0.965	0.671

Conclusion

Using seven tolerance indices viz., susceptibility index (SSI), mean productivity index (MP), geometric mean productivity index (GMP), tolerance (TOL) index, stress tolerance index (STI), yield index (YI) and yield stability index (YSI) terminal heat tolerant genotypes were identified in both years. Six genotypes viz., DW 1630, DW 1636, HD 3266, HD 3090, DW1635 and DW 1638 emerged as terminal heat tolerant genotypes based on their consistence performance in seven different selection indices in both years. Twelve genotypes viz., HD2864, HD3249, DW1627, DW1628, DW1629, HD3184, HD3252, HD2932, DW1632, WR544, DW1639, DW1640 and DW1645 emerged as terminal heat susceptible genotypes based on their performance in all tolerance indices under study in both years.

Acknowledgement

The first author is grateful to Indian Council of Agricultural Research (ICAR), New Delhi, for providing Junior Research Fellowship for Master's Degree programme.

References

1. Howard A. Crop-production in India: A critical survey of its problem. Oxford University Press, Humphrey Milford, London, 1924, 156.
2. Rane J, Shoran J, Nagarajan S. Heat stress environments and impact on wheat productivity in India: Guestimate of losses. Indian Wheat Newsletter. 2000; 6(1):5-6.
3. Wardlaw IF. The effect of high temperature on kernel development in wheat: variability related to pre-heading and post-anthesis conditions. Functional Plant Biology. 1994; 21(6):731-9.
4. Clarke M, De Pauw M, Townley Smith M. Evaluation of methods for quantification of drought tolerance in wheat. Crop Sciences. 1998; 3(2):728-732.
5. Rosielle AA, Hamblin J. Theoretical aspects of selection for yield in stress and non-stress environment 1. Crop science. 1981; 21(6):943-6.
6. Sanjeri AG. Evaluation Drought Stress Tolerance Resources and Wheat (*Triticum aestivum* L.) Lines and Varieties Yield Stability in Semi Drought Region of Country. InThe 5th Crop Production and Breeding Congress, 1998, 244-243.
7. Ghagar Sepanlo M, Siyadat H, Mirlatifi M, Mirnia SK. Effect of cutting of irrigation in different growth sages on yield and water use efficiency and comparison some drought tolerance indices in four wheat (*Triticum aestivum* L.) varieties. Soil Water J. 2000; 12(10):64-75.
8. Nouri A, Etminan A, Teixeira da Silva JA, Mohammadi R. Assessment of yield, yield-related traits and drought tolerance of durum wheat genotypes (*Triticum turjidum* var. durum Desf.). Australian Journal of Crop Science. 2011; 5(1):8.
9. Fischer RA, Maurer R. Drought resistance in spring wheat cultivars. I. Grain yield responses. Australian Journal of Agricultural Research. 1978; 29(5):897-912.
10. Guttieri MJ, Stark JC, O'Brien K, Souza E. Relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. Crop Science. 2001; 41(2):327-35.
11. Fernandez GC. Effective selection criteria for assessing plant stress tolerance. In Proceeding of the International Symposium on Adaptation of Vegetables and other Food Crops in Temperature and Water Stress, Aug. 13-16, Shanhua, Taiwan, 1992, 257-270.
12. Ramirez-Vallejo P, Kelly JD. Traits related to drought resistance in common bean. Euphytica. 1998; 99(2):127-36.
13. Schneider KA, Rosales-Serna R, Ibarra-Perez F, Cazares-Enriquez B, Acosta-Gallegos JA, Ramirez-Vallejo P *et al*. Improving common bean performance under drought stress. Crop Science. 1997; 37(1):43-50.
14. Bansal KC, Sinha SK. Assessment of drought resistance in 20 accessions of *Triticum aestivum* and related species I. Total dry matter and grain yield stability. Euphytica. 1991; 56(1):7-14.
15. Mitra J. Genetics and genetic improvement of drought resistance in crop plants. Current science. 2001; 25:758-63.
16. Nouri A, Etminan A, Teixeira da Silva JA, Mohammadi R. Assessment of yield, yield-related traits and drought tolerance of durum wheat genotypes (*Triticum turjidum* var. durum Desf.). Australian Journal of Crop Science. 2011; 5(1):8.
17. Bouslama M, Schapaugh WT. Stress tolerance in soybeans. I. Evaluation of three screening techniques for

heat and drought tolerance 1. Crop science. 1984; 24(5):933-7.
18. Gavuzzi P, Rizza F, Palumbo M, Campanile RG, Ricciardi GL, Borghi B. Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Canadian Journal of Plant Science. 1997; 77(4):523-31.
19. Ghobadi M, Ghobadi ME, Kahrizi D, Zebarjadi A, Geravandi M. Evaluation of drought tolerance indices in dryland bread wheat genotypes under post-anthesis drought stress. International Journal of Agricultural and Biosystems Engineering. 2012; 6(7):528-32.
20. Mardeh AS, Ahmadi A, Poustini K, Mohammadi V. Evaluation of drought resistance indices under various environmental conditions. Field Crops Research. 2006; 98(2-3):222-9.
21. Talebi R, Fayaz F, Naji AM. Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* Desf.). General and applied plant physiology. 2009; 35(1/2):64-74.
22. Khodarahmpour Z, Choukan R, Bihamta MR, Majidi Hervan E. Determination of the best heat stress tolerance indices in maize (*Zea mays* L.) inbred lines and hybrids under Khuzestan province conditions. Journal of Agricultural Science and Technology. 2011; 13(1):111-21.
23. Moghaddam A, Hadizadeh MH. Study use of compression stress in drought stress tolerance varieties selection in maize (*Zea mays* L.). J Crop Sci. 2000; 2(3):25-38.
24. Mohammadi M, Karimizadeh R, Abdipour M. Evaluation of drought tolerance in bread wheat genotypes under dryland and supplemental irrigation conditions. Australian Journal of Crop Science. 2011; 5(4):487.
25. Khan AA, Kabir MR. Evaluation of spring wheat genotypes (*Triticum aestivum* L.) for heat stress tolerance using different stress tolerance indices. Cercetari Agronomice in Moldova. 2014; 47(4):49-63.
26. Hassan MI, Mohamed EA, El-rawy MA, Amein KA. Evaluating interspecific wheat hybrids based on heat and drought stress tolerance. Journal of crop science and biotechnology. 2016; 19(1):85-98.
27. Kamrani M, Hoseini Y, Ebadollahi A. Evaluation for heat stress tolerance in durum wheat genotypes using stress tolerance indices. Archives of Agronomy and Soil Science. 2018; 64(1):38-45.
28. Mohammadi R, Abdulahi A. Evaluation of durum wheat genotypes based on drought tolerance indices under different levels of drought stress. Journal of Agricultural Sciences. 2017; 62(1):1-4.
29. Gajghate R. Evaluation of bread wheat (*Triticum aestivum* L.) genotypes for terminal heat tolerance under different environments (Unpublished master's thesis). ICAR-IARI, New Delhi, 2017.