Current Research in Agricultural Sciences
2021 Vol. 8, No. 1, pp. 37-46.
ISSN(e): 2312-6418
ISSN(p): 2313-3716
DOI: 10.18488/journal.68.2021.81.37.46

HEAT TOLERANCE STABILITY OF BREAD WHEAT GENOTYPES UNDER EARLY AND LATE PLANTING ENVIRONMENTS THROUGH STRESS SELECTION INDICES

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Article History
Received: 18 January 2021
Revised: 22 February 2021
Accepted: 24 March 2021
Published: 12 April 2021

Keywords
Triticum aestivum L.
Stress selection indices
Normal
Late planting
Genotype × environment interaction
Correlation.

ABSTRACT

A field study was conducted with an objective to assess thirty six wheat cultivars for tolerance, stability and enhancing productivity under optimum and stressed planting environments at Cereal crops Research Institute (CCRI), Nowshera, Pakistan during 2017-18. Experiment was laid out in randomized complete block design using three replications. Pool analysis of variance exhibited highly significant ($p \leq 0.01$) variations among wheat genotypes, environments and G × E interactions for the under studied traits. In general, reduction in mean wheat genotypes for days to heading (19%) and grain yield (65%) was observed under stressed condition as compared to optimum planting environment. Across planting environments, highest grain yield was produced by wheat genotypes Pakistan-13 (3746 kg ha^{-1}) closely followed by two other genotypes Zincol-2016 (3712 kg ha^{-1}) and PR-122 (3671 kg ha^{-1}). Various stress selection indices viz tolerance (TOL), mean productivity (MP), harmonic mean (HM), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), stress susceptibility index (SSI) and yield stability index (YSI) were employed for each genotype under both environments. Correlation coefficient analysis unveiled that days to heading and grain yield had positive significant association with GM, HM MP, YI and STI. Aforementioned stress selection indices were found effective tools for identification of stress tolerant genotypes under delayed planting. On the basis of these selection indices, wheat genotypes i-e Zincol-16, Pirsabak-13, PR-122 and Pakistan-13 were found high yielding stress tolerant which could be sown under non-stressed and stressed conditions and could be used in future wheat breeding schemes.

Contribution/Originality: The paper's primary contribution is finding more stable, heat tolerant and high yielding bread wheat genotypes across normal and late planting environments. This study documents is vital to wheat breeders to suggest these genotypes for stress environments directly or to use for the development of new genotypes for the changing climatic conditions.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is member of cereal grass family Poaceae, an important staple food of about half of the world population. Wheat adds about 80% of the nutritional food value to our daily diet and consumed in countless ways by the population [1]. Consumption and demand of wheat is increasing day by day. This demand for food will have to be met by increasing yield per unit area or by devoting land to wheat [2].

There are numerous factors that affect grain yield viz environmental conditions (stressed and non-stressed conditions, heat stress, and coldness), accelerated phasic development, increase in respiration, accelerated senescence, sowing dates, reduction in photosynthesis,, varietal potential, poor agronomic management practices and their interactions [3]. Among these factors, heat stress is supreme, severely damaging grain yield and should be controlled by the breeder to overcome the drastic yield reduction in wheat. Wheat crop has been surviving such harsh conditions and stresses so that it can obtain various sensitive and stress perceiving mechanisms to regulate their physiology [4]. Nowadays, researchers are interested in crop responses towards environmental stresses like heat stress and it's a big dilemma for them to breed for heat tolerant genotypes. To resolve this issue, breeders use diverse strategies of selecting relative heat tolerance and resistant genotypes in the targeted environments while some go for the mid way and select genotypes under both targeted stress and non-stress conditions [5].

The utmost task of the plant breeders is assessment and identification of noval climatic resilient genotypes having wider adoptability and better performance over diversified agro climatic conditions especially heat stress. Genetic improvement in wheat and developing stress tolerant genotypes requires information about the germplasm and identify genotypes that can grow best under optimum and stressed conditions. Under such circumstances several stress indices are used by breeders when genotypes are evaluated among both conditions. Mean productivity (MP), tolerance (TOL), harmonic mean (HM), stress susceptibility index (SSI), stress tolerance index (STI), yield index (YI), geometric mean productivity (GMP) and yield stability index (YSI) have all been employed to find out stable and tolerant genotypes under non-stress and stress conditions.

The diversified response of genotypes to environmental conditions is termed as genotype by environment interactions which play a crucial role in determination of the genotypes under various environments. Presence or lack of significant genotype by environment interactions helps us in development of stable, high yielding genotypes for wider or specific agro-ecological adaptations [6]. There are different types of genotypes, some adopt themselves to broader environments while other lacks adaptability to diverse conditions and genotypes with consistent performance over wider range are consider more stable and high yielding [7]. The main theme of this specific breeding program is to understand the importance and causes of G × E interactions at all stages so that be used in selection and identification of desirable genotypes for that environments. In the current scenario, present experiment was conducted to investigate genotype by environment interactions and identify stress tolerant genotypes under optimum and stressed condition through stress selection indices.

2. MATERIALS AND METHODS

The experimental trial was conducted at Cereal Crops Research Institute (CCRI), Pirsabak-Nowshera, Pakistan (740 E and latitude 320 N) on a silt loam soil (pH=7.8) with an elevation of 288 meters, during Crop season 2017-18. The genetic material compromised a total of thirty six wheat genotypes (six advance lines and thirty wheat cultivars) were acquired from all provinces of Pakistan Table 1. Breeding material was evaluated in a randomized complete block design (RCBD) with three replications as independent experiments under normal planting (non-stressed) and late planting (stressed) conditions. Individual genotype was planted in four rows per plot, with three meters length and row to row spacing of 30 cm in each environment. The optimum date of planting was 09 November, 2017 while, late planting was made on December 18, 2017. Standard cultural practices and crop husbandry practices were kept same for all the entries of wheat throughout the growing season in both the experiments.

2.1. Statistical Analysis

The collected data on days to maturity and grain yield were statistically analyzed according to the procedure suggested by Gomez and Gomez [8] using computer software SAS and SPSS package. Subsequently computing significant differences among the genotypes, environments and genotype × environment interactions, the means were further equated by using least significant difference (LSD) test at 5% level of probability. Beside this, the normal and late planting conditions were assumed as non-stress and stressed conditions to work out the following stress selection indices.

$$\text{Mean productivity (MP)} = \frac{X_n + X_l}{2} \quad [9]$$

$$\text{Tolerance (TOL)} = X_n - X_l \quad [9]$$

$$\text{Harmonic mean (HM)} = 2\left(\frac{X_n \times X_l}{X_n + X_l}\right) \quad [10]$$

$$\text{Geometric mean productivity (GMP)} = \sqrt{X_n \times X_l} \quad [11]$$

$$\text{Trait index (TI)} = \frac{X_l}{\bar{X}_l} \quad [12]$$

$$\text{Stress tolerance index (STI)} = \frac{X_n + X_l}{(X_n)^2} \quad [11]$$

$$\text{Stress susceptibility index (SSI)} = 1 - \frac{\left(\frac{X_l}{X_n}\right)}{1-\left(\frac{\bar{X}_l}{\bar{X}_n}\right)} \quad [12]$$

$$\text{Trait stability index (TSI)} = \frac{X_l}{X_n} \quad [13]$$

Where;

X_n = Mean of a genotype for that trait in normal planting.

X_l = Mean of a genotype for that trait in late planting.

$\bar{X}_n$ = Grand mean for a particular trait in normal planting.

$\bar{X}_l$ = Grand mean for a particular trait in late planting.

3. RESULTS AND DISCUSSION

3.1. Analysis of Genotypic Variation

Pool analysis of variance across both planting conditions (non-stressed and stressed) exhibited highly significant ($p \leq 0.01$) differences among the wheat genotypes, environments and genotype × environment interactions for days to heading and grain yield Table 2. The above results suggested that there is a substantial an inherent genetic variability existed among the genotypes. Significance of genotype by environment interactions revealed that these genotypes perform better and thus a sufficient scope is present for selecting various quantitative traits for improvement. Considerable amount of highly significant genetic diversity for wheat genotypes was also reported by Poudel, et al. [14]. Highly significant results for various wheat genotypes were indicated by Mehraban, et al. [15]; Jaiswal, et al. [16].

3.2. Means and Stress Selection Indices

3.2.1. Days to 50% Heading

Days to heading and maturity are likely important in wheat crop because the plants can be protected from the forth coming stress conditions and insect pests attack due to early heading and maturity.

Table-2. Mean squares for days to heading and grain yield in wheat genotypes evaluated under normal (non-stressed) and late (stressed) sown conditions.

Sources of Variation	df	Days to heading	Grain yield
Environment	1	35805.38**	125795906**
Genotypes	35	26.29**	780914.9**
Genotypes × Environment	35	8.03*	359782.5**
Error	140	5.29	123716.2
CV	-	2.13	11.25

Note: *, ** = Significant at 5% and 1% level of probability, respectively, NS = Non-Significa.

Table-3. Mean performance and stress selection indices of wheat genotypes for days to heading evaluated under normal (non-stressed) and late (stressed) sown environments.

Genotypes	Days to heading (Days)		MP	TOL	HM	GMP	YI	STI	SSI	YSI
	Normal	Late								
PR-114	160	135	147.50	25.00	146.44	146.97	1.01	1.20	0.96	0.84
PR-118	163	134	148.00	29.00	146.58	147.29	1.00	1.21	3.92	0.82
PR-119	161	136	148.08	25.17	147.01	147.55	1.01	1.21	3.44	0.84
PR-122	163	134	148.42	28.83	147.02	147.71	1.00	1.22	3.89	0.82
PR-123	159	132	145.17	27.33	143.88	144.52	0.98	1.16	3.78	0.83
PR-124	160	134	146.92	26.83	145.69	146.30	1.00	1.19	3.68	0.83
Paseena-17	159	134	146.08	25.17	145.00	145.54	1.00	1.18	3.48	0.84
Khaista-17	163	136	149.17	27.33	147.91	148.54	1.01	1.23	3.69	0.83
Wadan-17	160	135	147.25	25.50	146.15	146.70	1.00	1.20	3.50	0.84
Pakhtunkhwa-15	159	133	145.92	26.83	144.68	145.30	0.99	1.18	3.70	0.83
Pirsabak-15	159	132	145.50	27.00	144.25	144.87	0.99	1.17	3.73	0.83
Pirsabak-13	161	133	146.75	27.50	145.46	146.10	0.99	1.19	3.76	0.83
Shahkar-13	158	135	146.25	23.50	145.31	145.78	1.00	1.19	3.27	0.85
Pirsabak-08	160	131	145.42	28.17	144.05	144.73	0.98	1.17	3.88	0.82
Pirsabak-05	159	134	146.25	24.50	145.22	145.74	1.00	1.18	3.39	0.85
Insaf	161	138	149.25	23.50	148.32	148.79	1.03	1.23	3.21	0.85
NIFA-Aman	158	132	144.92	25.83	143.77	144.34	0.99	1.16	3.59	0.84
NIFA-Lalma	163	135	148.58	28.17	147.25	147.91	1.00	1.22	3.80	0.83
Borlaug-16	162	136	148.75	25.50	147.66	148.20	1.02	1.22	3.47	0.84
Zincol-16	160	134	146.92	26.83	145.69	146.30	1.00	1.19	3.68	0.83
Pakistan-13	161	136	148.33	25.67	147.22	147.78	1.01	1.22	3.50	0.84
Ujala	161	135	147.92	25.83	146.79	147.35	1.01	1.21	3.53	0.84
Faisalabad-08	157	135	146.00	22.00	145.17	145.59	1.01	1.18	3.08	0.86
Fateh Jhang	160	137	148.25	23.50	147.32	147.78	1.02	1.22	3.23	0.85
Ehsan	161	135	147.50	26.00	146.35	146.93	1.00	1.20	3.56	0.84
Johar-16	157	132	144.08	25.17	142.98	143.53	0.98	1.15	3.53	0.84
Gold-16	164	136	149.83	27.67	148.56	149.19	1.02	1.24	3.71	0.83
Ghaneemat-e-IBGE	157	132	144.50	25.00	143.42	143.96	0.99	1.16	3.50	0.84
KT-2000	161	135	147.92	25.17	146.85	147.38	1.01	1.21	3.44	0.84
KT-17	162	134	147.75	27.83	146.44	147.09	1.00	1.21	3.78	0.83
Israr-17	163	133	147.92	29.83	146.41	147.16	0.99	1.21	4.02	0.82
Shahid-17	158	132	144.75	25.50	143.63	144.19	0.99	1.16	3.56	0.84
NARC-11	157	130	143.33	26.33	142.12	142.73	0.97	1.14	3.69	0.83
Amin-10	159	136	147.25	23.50	146.31	146.78	1.01	1.20	3.25	0.85
Dharabi-11	162	135	148.17	27.33	146.91	147.54	1.00	1.21	3.71	0.83
Benazir	158	133	145.67	25.33	144.57	145.11	0.99	1.17	3.51	0.84
Means	159.99	133.91	146.95	26.09	145.79	146.37	1.00	1.19	3.51	0.84

Note: TOL = Tolerance index. MP = Mean productivity, STI = Stress tolerance index, TSI = Trait stability index, TI = Trait index

Mean wheat genotypes and their interactions for days to heading ranged from 103 t0 112 days and 91 to 125 days, respectively Table 3. Average over test environments, the minimum days to heading were counted for genotype Shahid-17 (103) days whereas maximum were recorded for genotype Fateh Jhang (112 days).

Likewise, for genotype by environment interaction, wheat genotype shahid-17 (91 days) revealed minimum days to heading while maximum were exhibited by genotype Ehsan (125 days). In general, late planted wheat genotypes took minimum days to heading (95 days) as compared to optimum planting (121 days) resulted in a decline of 19.4% across both conditions. Wheat genotype Shahid-17 performed far better and out classed all other under both environments and their interactions.

For days to heading data regarding stress selection indices are present in Table 4. In regard of mean productivity, most tolerant genotypes were Fateh Jhang (111.58 days), Ehsan (111.50 days) and KT-2000 (111.00 days) while least tolerance were observed in genotypes Shahid-17 (103.25 days) and Ghaneemat-e-IBGE(104.42 days). Minimal favorable TOL index was recoded in genotypes Faisalabd-08 (21.00 days), Johar-16 (21.00 days) and Gold-16 (21.50 days) while unfavorable least tolerant genotypes were Israr-17 (30.17 days), Pirsabak-08 (29.50 days) and PR-119 (29.00 days). In concern with harmonic mean, superior most tolerant genotypes were Gold-16 (148.56 days), Insaf (148.32 days) and Khaista (147.91 days) while least tolerance were identified in genotypes NARC-11(142.12 days), Johar-16 (142.98 days) and Ghanemat-e-IBGE (143.42 days). Based on Geometric mean productivity, maximum values were displayed by genotypes Gold-16 (149.19 days), Insaf (148.79 days) and Khaista-17 (148.54 days) whereas least tolerant genotypes were NARC-11 (142.73 days), Johar-16 (143.53 days) and Ghanemat-e-IBGE (143.96 days). Likely, maximum yield index value was observed for most tolerant wheat genotypes Borlaug-16, Fateh Jhang and KT-2000 with the same value of (1.04) each, while least tolerant genotypes were Shahid-17 (0.96) Pirsabak-08 (0.97) and PR-124 (0.98). Stress tolerance index determines the performance of genotypes under both conditions and larger value of STI shows greater stress tolerance and yield potential of genotypes. Similarly for stress tolerance index, the most tolerant wheat genotypes were Fateh Jhang (1.36), Ehsan (1.35) and KT-2000 (1.35) while less tolerance was observed in genotypes Shahid-17 (1.16) and Ghaneemat-e-IBGE (1.19). Stress Susceptibility Index values less than one (< 1) shows that genotypes are most stress tolerant under both conditions. In terms of stress susceptibility index, minimum favorable values were calculated for wheat genotypes PR-115 (0.96), Faisalabad-08 (3.08) and Insaf (3.21) while maximum unfavorable values were determined for least tolerant genotypes Israr-17 (4.02), PR-118 (3.92) and PR-122 (3.89). In terms of yield stability index, the top ranked most tolerant wheat genotypes were Faisalabad-08 Johar-16 and Gold-16 with the same value (0.82) while least tolerant genotypes were Pirsabak-08 (0.76), Israr-17 (0.76) and PR-119 (0.77). Our findings are in line with Poudel and Poudel [17] who disclosed alike results for decline in days to heading under two environments through stress selection indices. Due to less availability of water and photosynthetic activities, wheat crop did not perform well and thus accelerated days to heading under stressed conditions [18]. Alike findings for days to heading under optimum and late sowing was also computed by Ali, et al. [19].

3.2.2. Grain Yield

The wheat genotypes varied from 2469 to 3746 kg ha^{-1} whereas genotype × environment interactions ranged from 1596 to 4767 kg ha^{-1} Table 5. Averaged over, maximum grains were produced by wheat genotype Pakistan-13 (3746 kg ha^{-1}). However, minimum was obtained from genotype NAARC-11 (2469 kg ha^{-1}). Under test environments, normal planting (3888 kg ha^{-1}) environment gave higher gran yield than late sowing (2362 kg ha^{-1}) environment. For genotype environment linkage, maximum grain yield was produced by wheat genotype Israr-17 (4767 kg ha^{-1}) whereas minimum yield was calculated for genotype Ghaneemat-e-IBGE (1596 kg ha). Wheat genotype Israr-17 and Pakistan-13 produced higher grain yield across both test environments and their interactions (GEI).

Table-4. Mean performance and stress selection indices of wheat genotypes for grain yield evaluated under normal (nonstressed) and late (stressed) sown environments.

Genotypes	Grain yield (kg ha^{-1})		MP	TOL	HM	GMP	YI	STI	SSI	YSI
	Normal	Late								
PR-114	4395.83	2063.50	3229.67	2332.33	2808.59	3011.78	0.87	1.63	1.35	0.47
PR-118	4329.17	2695.83	3512.50	1633.33	3322.62	3416.24	1.14	2.09	8.28	0.62
PR-119	4120.83	2179.17	3150.00	1941.67	2850.79	2996.66	0.92	1.61	10.35	0.53
PR-122	4183.33	3158.33	3670.83	1025.00	3599.28	3634.88	1.34	2.37	5.38	0.75
PR-123	4154.17	2525.00	3339.58	1629.17	3140.89	3238.71	1.07	1.88	8.61	0.61
PR-124	3604.17	2608.33	3106.25	995.83	3026.44	3066.08	1.10	1.68	6.07	0.72
Paseena-17	4725.00	2212.50	3468.75	2512.50	3013.78	3233.27	0.94	1.87	11.68	0.47
Khaista-17	3937.50	2700.00	3318.75	1237.50	3203.39	3260.56	1.14	1.91	6.90	0.69
Wadan-17	3879.17	2450.00	3164.58	1429.17	3003.23	3082.85	1.04	1.70	8.09	0.63
Pakhtunkhwa-15	3287.50	2333.33	2810.42	954.17	2729.43	2769.63	0.99	1.37	6.37	0.71
Pirsabak-15	3416.67	2529.17	2972.92	887.50	2906.68	2939.61	1.07	1.55	5.70	0.74
Pirsabak-13	3333.33	2825.00	3079.17	508.33	3058.19	3068.66	1.20	1.69	3.35	0.85
Shahkar-13	3358.33	2418.83	2888.58	939.50	2812.19	2850.13	1.02	1.46	6.14	0.72
Pirsabak-08	4650.00	2637.50	3643.75	2012.50	3365.87	3502.05	1.12	2.20	9.50	0.57
Pirsabak-05	3708.33	2562.50	3135.42	1145.83	3030.73	3082.63	1.08	1.70	6.79	0.69
Insaf	3237.50	2141.67	2689.58	1095.83	2577.96	2633.18	0.91	1.24	7.43	0.66
NIFA-Aman	3562.50	2316.67	2939.58	1245.83	2807.58	2872.83	0.98	1.48	7.68	0.65
NIFA-Lalma	4733.33	2562.50	3647.92	2170.83	3324.96	3482.70	1.08	2.17	10.07	0.54
Borlaug-16	4137.50	1966.67	3052.08	2170.83	2666.08	2852.56	0.83	1.46	11.52	0.48
Zincol-16	4454.17	3029.17	3741.67	1425.00	3605.99	3673.20	1.28	2.42	7.03	0.68
Pakistan-13	4554.17	2937.50	3745.83	1616.67	3571.40	3657.58	1.24	2.40	7.80	0.65
Ujala	3512.50	2504.17	3008.33	1008.33	2923.84	2965.79	1.06	1.58	6.30	0.71
Faisalabad-08	3695.83	2154.17	2925.00	1541.67	2721.86	2821.60	0.91	1.43	9.16	0.58
Fateh Jhang	3762.50	1783.33	2772.92	1979.17	2419.76	2590.33	0.76	1.20	11.55	0.47
Ehsan	4216.67	2670.83	3443.75	1545.83	3270.28	3355.89	1.13	2.02	8.05	0.63
Johar-16	3079.17	1987.50	2533.33	1091.67	2415.73	2473.83	0.84	1.10	7.79	0.65
Gold-16	4262.50	2348.33	3305.42	1914.17	3028.29	3163.82	0.99	1.79	9.86	0.55
Ghaneemat-e-IBGE	3758.33	1595.83	2677.08	2162.50	2240.38	2449.01	0.68	1.08	12.64	0.42
KT-2000	3445.83	2177.50	2811.67	1268.33	2668.63	2739.22	0.92	1.34	8.08	0.63
KT-17	4162.50	2716.67	3439.58	1445.83	3287.64	3362.76	1.15	2.03	7.63	0.65
Israr-17	4766.67	2357.67	3562.17	2409.00	3154.88	3352.34	1.00	2.01	11.10	0.49
Shahid-17	3283.33	2116.67	2700.00	1166.67	2573.97	2636.23	0.90	1.25	7.80	0.64
NARC-11	3166.67	1770.83	2468.75	1395.83	2271.45	2368.05	0.75	1.01	9.68	0.56
Amin-10	3862.50	2033.67	2948.08	1828.83	2664.46	2802.68	0.86	1.41	10.40	0.53
Dharabi-11	3400.00	1825.00	2612.50	1575.00	2375.12	2490.98	0.77	1.11	10.17	0.54
Benazir	3841.67	2137.50	2989.58	1704.17	2746.72	2865.58	0.90	1.47	9.74	0.56
Means	3888.31	2362.02	3125.17	1526.29	2921.92	3021.22	1.00	1.66	8.22	0.61

Note: TOL = Tolerance index. MP = Mean productivity, STI = Stress tolerance index, TSI = Trait stability index, TI = Trait index

For grain yield data regarding stress selection indices are present in Table 4. In regard of mean productivity, most tolerant genotypes were Pakistan-13 (3745.83 kg ha^{-1}), Zincol-16 (93741.67 kg ha^{-1}) and PR-122 (3670.83 kg ha^{-1}) while least tolerance was observed in genotypes NARC-11 (2468.75 kg ha^{-1}), Johar-16 (2533.33 kg ha^{-1}) and

Dharabi-11 (2612.50 kg ha^{-1}). Minimal favorable TOL index was recoded in genotypes Pirsabak-13 (508.33 kg ha^{-1}), Pirsabak-15(887.50 kg ha^{-1}) and Pakhtunkha-15 (954.17 kg ha^{-1}) while unfavorable least tolerance was indicated by genotypes Paseena-17 (2512.50 kg ha^{-1}), Israr-17 (2332.33 kg ha^{-1}) and PR-114 (2409.00 kg ha^{-1}). In concern with harmonic mean, superior most tolerant genotypes were Zincol-16 (3605.99 kg ha^{-1}), PR-122 (3599.28 kg ha^{-1}) and Pakistan-13 (3571.40 kg ha^{-1}) while least tolerance was identified in genotypes Ghaneemat-e-IBGE (2240.38 kg ha^{-1}), NARC-11 (2271.45 kg ha^{-1}) and Dharbi-11 (2375.12 kg ha^{-1}). Based on Geometric mean productivity, maximum values were displayed by genotypes Zincol-16 (3673.20 kg ha^{-1}), Pakistan-13 (3657.58 kg ha^{-1}) and PR-122 (3834.88 kg ha^{-1}) whereas least tolerant genotypes were NARC-11(2368.05 kg ha^{-1}), Ghaneemat-e-IBGE (2449.01 kg ha^{-1}) and Dharbi-11(2490.98 kg ha^{-1}). Likely, maximum yield index value was observed for most tolerant wheat genotypes PR-122 (1.34), Zincol-16 (1.28) and Pakistan-13 (1.24) while less tolerance was recorded in genotypes Ghaneemat-e-IBGE (0.68), NARC-11 (0.75) and Fateh Jhang (0.76). Similarly for stress tolerance index, the most tolerant wheat genotypes were Pakistan-13 (2.42), Zincol-16 (2.40) and PR-122 (2.37) whereas least tolerant genotypes were NARC-11 (1.01), Ghaneema-e-IBGE (1.08) and Johar-16 (1.10). Stress Susceptibility index values less than one (< 1) shows that genotypes are most stress tolerant under both conditions. In terms of stress susceptibility index, minimum favorable values were calculated for wheat genotypes PR-115 (1.35), Pirsabak-13 (3.35) and PR-122(5.38) while maximum unfavorable values were determined for least tolerant genotypes Ghaneemat-e-IBGE (12.64), Paseena-17 (11.68) and Borlug-16 (11.52). Stress tolerance index determines the performance of genotypes under both conditions and larger value of STI shows greater stress tolerance and yield potential of genotypes. In terms of yield stability index, the top ranked most tolerant wheat genotypes were Pirsabak-13 (0.85), PR-122 (0.75) and Pirsabak-15 (0.74) while least tolerant genotypes were Ghaneemat-e-IBGE (0.42), Fateh Jhang (0.47) and Paseena-17 (0.47). Similar investigations regarding reduction in grain yield and stress selection indices under normal and late plating was also recorded by Ishaq, et al. [20]. Reduced grain yield under stressed conditions due to low photosynthetic activities and lesser water availability was concluded by Schmidt, et al. [21]. Our results are also in conformation with Khalil, et al. [22] who recorded reduced grain yield in wheat genotypes under stressed environments.

3.3. Correlation Analysis

For optimum planting, days to heading revealed significant positive association with MP (r=0.875**), TOL (r=0.608**), HM (r=0.826**), GM (r=0.851**), YI (r=0.471**), STI (r=0.860**) and correlation was significant negative with TSI (r= -0.509**). Likewise under late planting, days to heading disclosed significant positive correlation with MP (r= 0.847**), HM (r=0.892**), GM (r=0.871**), YI (r=0.951**), STI (r=0.852**), YSI (r=0.432**) and significant negative with TOL (r= -0.357*) Table 5.

Table-5. Correlation coefficient for days to heading and grain yield in wheat genotypes evaluated under normal (non-stressed) and late (stressed) sown conditions.

Selection indices	Days to heading		Grain yield	
	Normal	Late	Normal	Late
MP	0.875**	0.847**	0.883**	0.774**
TOL	0.608**	-0.357*	0.722**	-0.360*
HM	0.826**	0.892**	0.686**	0.934**
GMP	0.851**	0.871**	0.791**	0.869**
TI	0.471**	0.951**	0.385*	0.999**
STI	0.860**	0.852**	0.790**	0.866**
SSI	0.222^{ns}	-0.292^{ns}	0.249^{ns}	-0.500**
TSI	-0.509**	0.432**	-0.419*	0.669**

Note: *, ** = Significant at 5% and 1% level of probability, respectively, NS = Non-Significant.

For optimum planting, grain yield depicted significant positive relation with MP (r=0.883**), TOL (r=0.722**), HM (r=0.686**), GM (r=0.791**), YI (r=0.385*), STI (r=0.790**) and significant negative correlation with YSI (r=-

0.419*). Similarly under late planting, grain yield indicated significant positive association with MP (r=0.774**), HM (r=0.934**), GM (r=0.869**), YI (r=0.999**), STI (r=0.866**), YSI (r=0.669**) and significant negative relationship with TOL (r=-0.360*) and SSI (r=-0.500**). Similar findings were also disclosed by Dwivedi, et al. [23] for grain yield. Significant positive association of grain yield with different parameters was also reported by Khairnar and Bagwan [24]; Siddhi, et al. [25].

4. CONCLUSIONS AND RECOMMENDATIONS

Analysis of variance revealed significant divergence among the tested genotypes under both planting environments (non-stressed and stressed) suggesting that these genotypes were having broader genetic base. Best genotypes in concern with grain yield were Pakistan-13, Zincol-16 and PR-122 under optimum and delayed planting. Decline in days to heading and grain yield was recorded when planting was delayed as compared to timely (non-stressed) planting. Stress selection indices are found adequate tools for identification of desirable high yielding stable genotypes across both normal and stressed planting conditions. According to stress selection indices, high yielding stable and stress tolerant genotypes were i-e Zincol-16, Pirsabak-13, PR-122 Pakistan-13 that could be sown in both optimum and late planting conditions. Under both test environments (non-stress and stressed), positive significant association of days to heading and grain yield with stress selection indices i-e GM, HM MP, YI and STI disclosed that these indices are more effective in determination of genotypes under various environments (non-stress and stressed).

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Acknowledgement: All the authors of this study are very thankful to CCRI (Cereal Crops Research Institute-Nowshera) and CIMMYT (International Maize and Wheat Improvement Centre-México) for the provision of genetic material, conduction of the experiment and full support throughout.

REFERENCES

[1] S. W. Van Es, "Too hot to handle, the adverse effect of heat stress on crop yield," *Physiologia Plantarum*, vol. 169 (4), pp. 499-500, 2020. Available at: https://doi.org/10.1111/ppl.13165.

[2] T. Hura, "Wheat and Barley: Acclimatization to abiotic and biotic stress," *International Journal of Molecular Science*, vol. 21 (7) pp. 21 – 19, 2020. Available at: https://doi:10.3390/ijms21197423.

[3] A. E. Habti, D. Fleury, N. Jewell, T. Garnett, and P. J. Tricker, "Tolerance of combine drought and heat stress is associated with transpiration and water soluble carbohydrates in wheat grains," *Frontier Plant Science*, vol. 11 (5), pp. 2-9, 2020. Available at: https://doi: 10.3389/fpls.2020.568693

[4] P. K. Singh, S. Prasad, A. K. Verma, B. Lal, R. Singh, S. P. Singh, and D. K. Dwivedi, "Screening for heat tolerant traits in wheat (Triticum aestivum L.) genotypes by physio-biochemical markers," *International Journal Current Microbiology and Applied Science*, vol. 9 (2), p. 2335 – 2343, 2020. Available at: https://doi.org/10.20546/ijcmas.2020.902.265.

[5] M. Janni, M. Gullì, E. Maestri, M. Marmiroli, B. Valliyodan, H. T. Nguyen, and N. Marmiroli, "Molecular and genetic bases of heat stress responses in crop plants and breeding for increased resilience and productivity," *Journal of Experimental Botany*, vol. 71 (13), pp. 3780-3802, 2020. Available at: https://doi:10.1093/jxb/eraa034.

[6] S. A. Khan and G. Hassan, "Heritability and correlation studies of yield and yield related traits in bread wheat," *Sarhad Journal of Agriculture*, vol. 33 (1), pp. 103-107, 2017.

[7] R. K. Bhardwaj, S. S. Gautam, and R. R. Saxena, "Adaptation of G × E interaction of wheat genotypes in chhattisgarh state through regression analysis," *International Journal of Current Microbiology and Applied Science*, vol. 7 (2), p. 4598 – 4604, 2018.

[8] K.A. Gomez and A.A. Gomez. *Statistical procedures for Agricultural Research.* Canada: John Wiley and Sons Inc. pp: 20-30, 1984.

[9] A. Hossain, R. Sears, T. S. Cox, and G. Paulsen, "Desiccation tolerance and its relationship to assimilate partitioning in winter wheat," *Crop Science*, vol. 30 (2), pp. 622-627, 1990.

[10] K. A. Schneider, R. Rosales-Serna, F. Ibarra-Perez, B. Cazares-Enriquez, J. A. Acosta-Gallegos, P. Ramirez-Vallejo, N. Wassimi, and J. D. Kelly, "Improving common bean performance under drought stress," *Crop Science*, vol. 37 (3), pp. 43-50, 1997.

[11] G. C. J. Fernandez, "*Effective selection criteria for assessing plant stress tolerance. In Proceedings of the international symposium on adaptation of vegetable and other food crops in temperature and water stress"*. Tainan, Taiwan: AVRDC Publication, 1992.

[12] P. Gavuzzi, F. Rizza, M. Palumbo, R. Campanile, G. Ricciardi, and B. Borghi, "Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals," *Canadian Journal of Plant Science*, vol. 77(3), pp. 523-531, 1997.

[13] M. Bouslama and W. Schapaugh Jr, "Stress tolerance in soybeans. I. Evaluation of three screening techniques for heat and drought tolerance," *Crop Science*, vol. 24 (2), pp. 933-937, 1984.

[14] M. R. Poudel, S. Ghimire, M. P. Pandey, K. H. Dhakal, D. B. Thapa, and H. K. Poudel, "Evaluation of wheat genotypes under irrigated, heat stress and drought conditions," *Journal of Biological Today's World*, vol. 9 (1), pp. 212, 2020.

[15] A. Mehraban, A. Tobe, A. Gholipouri, E. Amiri, A. Ghafari, and M. Rostaii, "Evaluation of drought tolerance indices and yield stability of wheat cultivars to drought stress in different growth stage," *World Journal of Environmental Bioscience*, vol. 7 (1), pp. 8 – 14, 2018.

[16] B. Jaiswal, S. Prasad, R. Rani, S. Singh, A. Kumar, A. Kumar, and R. K. Yadav, "Evaluation of wheat (T. aestivum l.) lines at reproductive stage for heat stress tolerance," *International Journal of Current Microbiology and Applied Science*, vol. 7 (3), pp. 1350 – 1357, 2018.

[17] P. B. Poudel and M. R. Poudel, "A Review of Heat stress effects and tolerance in Wheat," *Journal of Biology and Today's World*, vol. 9 (4), pp. 1-6, 2020. Availaable at: https://doi:10.35248/2322-3308.20.09.217.

[18] S. Schittenhelm, T. Langkamp-Wedde, M. Kraft, L. Kottmann, and K. Matschiner, "Effect of two-week heat stress during grain filling on stem reserves, senescence, and grain yield of European winter wheat cultivars," *Journal of Agronomy and Crop Science*, vol. 206 (1), pp. 722-733, 2020. Available at: https: //doi:10.1111/jac.12410.

[19] A. Ali, Z. Ullah, N. Ali, and M. M. Anjum, "Evaluation of wheat advanced lines for agronomic traits under vary sowing dates," *Journal of Agriculture Research and Technology*, vol. 7 (1), p. 1 – 12, 2017.

[20] M. Ishaq, G. Ahmad, K. Afridi, M. Ali, T. U. Khan, I. A. Shah, M. Khalid, N. Ahmad, B. Iqbal, B. Ahmad, M. A. Qureshi, A. Saleem, M. Miraj, and K. Din, "Assessment of genetic potential and stress selection indices for important yield related traits in bread wheat (T. aestivum L.)," *Pure and Applied Biology*, vol. 35 (5), pp. 22 – 38, 2018. Available at: http://dx.doi.org/10.19045/bspab.2018.700129.

[21] J. Schmidt, J. Claussen, N. Worlein, A. Eggert, D. Fleury, T. Garnett, and S. Gerth, "Drought and heat stress tolerance screening in wheat using computed tomography," *Plant Methods*, vol. 16 (15), p. 2 – 7, 2020. Available at: https://doi.org/10.1186/s13007-020-00565-w.

[22] I. H. Khalil, A. Wahab, D. Nayab, S. S. Ghani, M. Alam, Z. Ullah, and W. U. Khan, "Heritability and selection response for morphological and yield traits in normal and late planted wheat," *International Journal of Agriculture and Environmental Research*, vol. 2 (4), pp. 202 – 211, 2017.

[23] R. Dwivedi, S. Prasad, B. Jaiswal, A. Kumar, A. Tiwari, S. Patel, G. Pandey, and G. Pandey, "Evaluation of wheat genotypes (Triticum aestivum L.) at grain filling stage for heat tolerance," *International Journal of Pure & Applied Bioscience*, vol. 5 (2), pp. 971-975, 2017.

[24] S. Khairnar and J. Bagwan, "Studies on genetic variability parameters and character association in bread wheat (Triticum aestivum L.) under timely and late sown environments of irrigated condition," *Electronic Journal of Plant Breeding*, vol. 9 (1), pp. 190-198, 2018.

[25] S. Siddhi, J. B. Patel, and N. Patel, "Stability analysis in bread wheat (T. aestivum L.)," *Journal of Pharmacology and Phytochemistry*, vol. 7 (4), pp. 290-297, 2018.

Table-1. Detail of wheat advance lines of CCRI and cultivars used in the study.

S.No.	Cultivars	Institution/ Sources	S.No.	Cultivars	Institution/ Sources
1	PR-114	CCRI, Pirsabak	19	Borlaug-16	NARC, Islamabad
2	PR-118	CCRI, Pirsabak	20	Zincol-16	NARC, Islamabad
3	PR-119	CCRI, Pirsabak	21	Pakistan-13	NARC, Islamabad
4	PR-122	CCRI, Pirsabak	22	Ujala	AARI, Faisalabad
5	PR-123	CCRI, Pirsabak	23	Faisalabad-08	AARI, Faisalabad
6	PR-124	CCRI, Pirsabak	24	Fateh Jhang	BARI, Chakwal
7	Paseena-17	CCRI, Pirsabak	25	Ehsan	AARI, Faisalabad
8	Khaista-17	CCRI, Pirsabak	26	Johar-16	AARI, Faisalabad
9	Wadan-17	CCRI, Pirsabak	27	Gold-16	AARI, Faisalabad
10	Pakhtunkhwa-15	CCRI, Pirsabak	28	Ghaneemat-e-IBGE	AUP, Peshawar
11	Pirsabak-15	CCRI, Pirsabak	29	KT-2000	BARS, Kohat
12	Pirsabak-13	CCRI, Pirsabak	30	KT-17	BARS, Kohat
13	Shahkar-13	CCRI, Pirsabak	31	Israr-17	ARI, D.I.Khan
14	Pisabak-08	CCRI, Pirsabak	32	Shahid-17	ARI, D.I.Khan
15	Pirsabak-05	CCRI, Pirsabak	33	NARC-11	NARC, Islamabad
16	Insaf	NIFA, Peshawar	34	Amin-10	ARS S. Naurang
17	NIFA-Aman	NIFA, Peshawar	35	Dharabi-11	BARI Chakwal
18	NIFA-Lalma	NIFA, Peshawar	36	Benazir	ARI. Tandojam