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Performance of parents and their crosses for heat tolerance using different physiological and yield traits in durum wheat (*Triticum durum* Desf.) across the environments

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Abstract
The present investigation was done on mean performance often genetically dissimilar parents and their 45 F_1's. The observations were recorded on twenty one characters *viz*., plant height (cm), flag leaf length (cm), flag leaf width (cm), flag leaf area (cm^2), peduncle length (cm), total number of tillers plant^{-1}, total number of productive tillers plant^{-1}, spike length (cm), spikelet's spike^{-1}, grains spike^{-1}, spike weight productive tiller^{-1} (g), grain weight spike^{-1} (g), biological yield plant^{-1} (g), economic yield plant^{-1} (g), harvest index (%), test weight (g), protein content (%), proline content (µg/100 mg fresh leaf tissue), chlorophyll content estimation (mg/g), chlorophyll stability index, heat injury (%),days to 50% heading, days to maturity, grain filling period and leaf canopy temperature (°C) which were recorded on plot basis. Present investigation concluded that the overall study on physiological and yield traits of the genotypes *viz.*, parents HI-8737, HI-8498, NIDW-295, PDW-274, PDW-233, PDW-314 and PDW-291 and crosses NIDW-295 x PDW-274, HI-8737 x HI-8498, PDW-274 x PDW-291 and PDW-233 x PDW-314 were observed better for maximum number of characters indicating their high tolerance to heat stress under late sowing conditions.

Keywords: Half diallel, single cross hybrids, phenotypic performance, durum wheat

Introduction

Durum wheat currently represents 8 to 10% of the wheat grown and produced worldwide. It is however, concentrated in relatively small geographical areas where it often plays a major role in the food security of urban populations and nutrition of urban communities. More than 80% of the spring durum cultivars released in the developing world are semi dwarf types from CIMMYT and ICARDA (Abdlulaziz Al-Doss *et al*. 2011) [1]. The productivity of durum wheat is often limited by an array of abiotic stresses that avoid a successful growth and a complete grain filling. Heat stress due to increased temperature is an agricultural problem in many areas of the world. Post-anthesis high temperature stress in wheat is a major cause of yield reduction in many wheat-growing regions of the world. Some attempts to develop heat-tolerant genotypes via conventional plant breeding protocols have been successful tools to develop crops with improved heat tolerance (Sehgal *et al*. 2018) [6].

Durum wheat mostly grown in the temperate environmental conditions. However, it is predominantly consumed in tropical and subtropical regions of the world. In subtropical regions it is cultivated in winter season but exposed to high temperature stress at the end of the season *i.e.* at grain filling stage, resulting shriveled and thin grains. Heat stress is one of the major limiting factors for growth and productivity in wheat crop particularly in warmer region. The optimum temperature for wheat crop has been reported between 18 ^{0}C to 24 ^{0}C with minimum and maximum growth temperature of 3^0 to 4 ^{0}C and 30^0 to 32 ^{0}C respectively. While for anthesis and grain filling, optimum temperature range is 12-22 ^{0}C (Sabella *et al*. 2020) [2].

In a breeding program, knowledge of the degree of genetic diversity among parental materials for key selection traits will facilitate the development of high yielding stress tolerant durum wheat cultivars. Thus, the correct choice of parents employed in the development of the basic population can influence the final result of the artificial selection and promote a better allocation of financial resources during the whole process of adjusting genotypes to a given environment. However, to confirm such expectations, it is necessary that the parents combine high means with an increase invariability for the characters under selection.

Therefore, selection of desirable genotypes and choice of breeding procedures for genetic improvement of any crop is largely dependent on the knowledge of type and relative amount of genetic components. Considering the importance of the crop, there is a need to generate more information on genetic variability and others genetic components of yield and its associated characters.

Material and Methods

Ten wheat genotypes were selected as parents on the basis of their diverse geographical origin, morpho-physiological characters *viz.,* earliness, high yield potential, heat tolerance, wide variation and their adaptability for different agro-climatic zones of India. These genotypes were crossed in diallel fashion (excluding reciprocals) to develop forty five crosses during *Rabi* 2015-16.The experimental trials were conducted at three different locations *viz*., the Instructional Research Farm, Rajasthan College of Agriculture, Udaipur, College of Technology and Agriculture Engineering, Udaipur and Agriculture Research Sub-Station, Vallabhnagar during *Rabi* 2016-17. All necessary facilities for cultivation of successful crop including field preparation, inputs, irrigation facilities and labours were provided from the AICRP on wheat and barley, Rajasthan Collage of Agriculture, Udaipur. These ten parents along with fourty five crosses and two checks were evaluated by single row in three replications with randomized block design sown in row length of 3.0 meters with spacing 22.5 x 10 cm during *Rabi* 2016-17 at three different locations. The experiments were conducted under irrigated conditions. Recommended crop production practices were followed to raise the successful healthy crop. The observations were recorded on five randomly selected competitive plants in each replication for twenty one characters *viz*., plant height (cm), flag leaf length (cm), flag leaf width (cm), flag leaf area (cm^2), peduncle length (cm), total number of tillers $plant^{-1}$, total number of productive tillers $plant^{-1}$, spike length (cm), spikelet's $spike^{-1}$, grains $spike^{-1}$, spike weight productive $tiller^{-1}$ (g), grain weight $spike^{-1}$ (g), biological yield $plant^{-1}$ (g), economic yield $plant^{-1}$ (g), harvest index (%), test weight (g), protein content (%), proline content (µg/100 mg fresh leaf tissue), chlorophyll content estimation (mg/g), chlorophyll stability index, heat injury (%), remaining characters *viz*., days to 50% heading, days to maturity, grain filling period and leaf canopy temperature (°c) which were recorded on plot basis.

Results and Discussion

Per se performance of parents and their crosses

The mean performance of parents and crosses for different characters are presented in Table 1-3. The salient features of each character are described in the separates heading.

Days to 50% heading

Over the environments the parent NIDW-295 (68.11 days) and cross HI-8663×PDW-291 (71.67 days) were early in heading. In pool, the earliest parent was NIDW-295 (68.11 days) while parent PDW-291 (75.78 days) was the latest in heading among the parents. The hybrid HI-8663×PDW-291 (71.67 days) took the least days to 50% heading while HI-8498×PDW-291 (79.56 days) was very late in heading.

Days to maturity

Over the environment early maturity was observed in parent NIDW-295 and WH-896 (106.44 days) and in cross RAJ-1555×PDW-291 (106.56 days). The observed range in the mean performance of days to maturity for parents in pool was from 106.44 (NIDW-295 and WH-896) to 112.22 (PDW-314 andPDW-291), whereas for hybrids it varied from 106.56 (RAJ-1555×PDW-291) to 115.22 (NIDW-295× PDW-274).

Grain filling period

On pool basis longest Grain filling period was observed in parent PDW-291 (25.22) and in cross HI-8737×WH-896 (26.22). Among the crosses longer grain filling period was observed for crosses HI-8737×WH-896 (31.00) in E_1 and (23.00) in E_3 and NIDW-295× PDW-291in E_2 (28.00).

Plant height (cm)

Over the environments, among parents PDW-291 (82.97 cm) and among crosses HI-8498×WH-896 (81.16 cm) had minimum plant heights were observed on pool basis. On pool basis the most dwarf parent was PDW-291 (82.97 cm) and the tallest was RAJ-1555 (90.47 cm) while hybrids ranged from HI-8498×WH-896 (81.16 cm) to WH-896×PDW-314 (92.93 cm) for plant height.

Flag leaf length (cm)

On pool basis long flag leaf length were observed in parent RAJ-1555 (23.79 cm) and in cross PDW-314×PDW-291 (29.85 cm).In pool the shortest Flag leaf was observed in PDW-274 (21.12 cm) in parents and in NIDW-295× HI-8498 (18.56 cm) in hybrids while the longest spike in parent was for RAJ-1555 (23.79 cm) and in hybrids for PDW-314×PDW-291 (29.85 cm). Also reported by Reddy *et al.* (2008) [9]

Flag leaf width (cm)

Over the environments maximum flag leaf width was recorded for parents HI-8663 (2.16 cm) and for cross RAJ-1555×PDW-291 (2.20 cm). The observed range in the mean performance of flag leaf width in pool for parents was from 1.68 cm (PDW-291) to 2.16 cm (HI-8663), whereas for hybrids it varied from 1.70 cm (HI-8663×PDW-233) to 2.20 cm (RAJ-1555×PDW-291).

Flag leaf area (cm^2)

Over the environments maximum flag leaf area was recorded for parents HI-8498 (38.68 $cm^{2)}$ and for cross PDW-314×PDW-291 (49.02 cm^2). The observed range in the mean performance of flag leaf area in pool for parents was from 29.19 cm^2 (PDW-314) to 38.68 cm^2 (HI-8498), whereas for hybrids it varied from 24.62 cm^2 (NIDW-295× HI-8498) to 49.02 cm^2 (PDW-314×PDW-291).

Peduncle length (cm)

On pool basis long peduncle were observed in parent PDW-314 (26.65 cm) and in cross HI-8498×PDW-314 (25.76 cm).The observed range in the mean performance of peduncle length in pool for parents was from 24.12 cm (NIDW-295) to 26.65 cm (PDW-314), whereas for hybrids it varied from 21.14 cm (HI-8498×WH-896) to 25.76 cm (HI-8498×PDW-314).

Total Number of tillers $plant^{-1}$

On pool basis highest effective tillers $plant^{-1}$ was observed in parent WH-896 (29.08) and in cross PDW-274×PDW-291 (31.65). Among the crosses, highest number of effective tillers plant^{-1} was observed for crosses PDW-274×PDW-291 (35.87) in E_1, and (34.94) in E_2 and PDW-274×PDW-291in E_3 (24.14).

Total Number of productive tillers plant^{-1}

On pool basis highest total number of productive tillers plant^{-1} was observed in parent WH-896 (23.87) and in cross PDW-274×PDW-291 (26.97). Among the parents, WH-896 in E_1 (27.60) and in E_3 (22.72) and HI-8737 E_2 (25.47), had highest total number of productive tillers plant^{-1}. Among the crosses, highest total number of productive tillers plant^{-1} was observed for crosses PDW-274×PDW-291 (32.26) in E_1 and (29.34) in E_2 and RAJ-1555×PDW-291 in E_3 (20.57).

Spike length (cm)

On pool basis the long spikes were observed in parent HI-8663 (9.84 cm). In pool the shortest panicle was observed in WH-896 (6.73 cm) in parents and in HI-8498×PDW-291 (7.09 cm) in hybrids while the longest spike in parent was for HI-8663 (9.84 cm) and in hybrids for HI-8737×HI-8663 (10.45 cm).

Number of spikelets spike^{-1} (g)

On pool basis long spikes were observed in parent PDW-274 (21.16) and in cross WH-896×PDW-233 (23.71). Among crosses, WH-896×PDW-233 had consistently long spikes in three environments *i.e.* 25.71 in E_1, 23.11 in E_2 and 22.32 in E_3.

Number of grains spike^{-1} (g)

Over the environments highest grains spike^{-1} among parents was in HI-8663 (80.11) and among cross in HI-8498×HI-8663 (84.89). These above genotypes produced higher number of grains spike^{-1} indicates the ability to produce higher yield under their respective environmental conditions. The observed range in the mean performance of number of grains spike^{-1} in pool for parents was from 39.86 (WH-896) to 80.11 (HI-8663), whereas for hybrids it varied from 40.17 (HI-8498×PDW-272) to 84.89 (HI-8498×HI-8663), similar study also reported by Gami *et al.* (2010) [8].

Spike weight productive tiller^{-1} (g)

Over the environments highest spike weight productive tiller^{-1} among parents was in HI-8737 (5.77) and among cross in HI-8737×HI-8663 (5.71). Parent PDW-233 in E_1 (6.32), and E_3 (5.78) and HI-8737 E_2 (5.68) had highest spike weight productive tiller^{-1} among parents and cross WH-896×PDW-274 in E_1 (6.74), HI-8498×PDW-272 in E_2 (6.79) and HI-8737×HI-8663 in E_3 (7.35) among the hybrids.

Grain weight spike^{-1} (g)

Over the environments highest grains spike^{-1} among parents was in PDW-233 (4.32) and among cross in HI-8498×HI-8663 (4.60). Parent PDW-233 in E_1 (4.94), and E_3 (4.80) and PDW-314 E_2 (4.48) had highest grain weight spike^{-1}among parents and cross WH-896×PDW-274 in E_1 (5.13), WH-896×RAJ-1555 in E_2 (5.28) and HI-8737×HI-8663 in E_3 (6.37) among the hybrids.

Biological yield plant^{-1} (g)

High biomass production is an important selection criterion for improving grain yield under heat stress. Parental range for biological yield plant^{-1} in pool was from 207.24 g (HI-8663) to 112.82 g (PDW-291). The highest biological yield plant^{-1} producing hybrid was NIDW-295×PDW-274 (211.76 g) while the lowest was HI-8737×RAJ-1555 (104.95 g).

Economic yield plant^{-1} (g)

The grain yield per se is an important selection criterion for heat stress. Over the environments highest grain yield plant^{-1} was recorded for parent HI-8663 (73.52 g) and cross HI-8737×HI-8498 (73.88 g). In pool, among hybrids HI-8737×HI-8498 (73.88 g) yielded the highest and the lowest was recorded by HI-8737×PDW-291 (31.10 g) while among parents PDW-291 (45.86 g) yielded the lowest while HI-8663 recorded maximum grain yield (73.52 g) Similar Study also reported by Hussain *et al.* (2007) [7].

Harvest index (%)

The range of harvest index in pool for parents varied from 35.15% (HI-8663) to 40.54% (PDW-291) and in hybrids it was from 28.78% (PDW-314×PDW-291) to 45.39% (HI-8498×WH-896). The harvest index of cross HI-8737×HI-8498 in E_1 (51.60%), HI-8498×WH-896 in E_2 (54.15%) and HI-8663×PDW-314 in E_3 (46.14%) were highest among crosses.

Test weight (g)

The grain weight is most sensitive yield component for high temperature and could be used as one of the reliable trait to judge responsiveness of genotypes to high temperature. Over the environments maximum 1000-grain weight was recorded for parents PDW-233 (70.99 g) and cross HI-8737×HI-8498 (67.49 g). The lowest limit for test weight in pool for parents was 42.67 g (HI-8663) and the highest was 70.99 g (PDW-233) while in hybrids it was ranged from 41.74 g (WH-896×PDW-314) to 67.49 g (HI-8737×HI-8498).

Protein content (%)

The mean values of total protein content in pool for parents varied from 11.14% (RAJ-1555) to 12.49% (HI-8498) whereas for hybrids it varied from 11.24% (NIDW-295× HI-8498) to 13.02% (HI-8663×PDW-314).Whereas among crosses, cross PDW-274×PDW-291 in E_1 (13.30%) and E_3 (13.58%) and HI-8737×PDW-314 in E_2 (13.61%) environments were maximum total protein content in grain.

Proline content (µg)

The range of proline content in pool for parents was from 14.75 µg (PDW-314) to 19.68 µg (RAJ-1555) and in hybrids it was from 12.80 µg (NIDW-295× PDW-233) to 19.67 µg (RAJ-1555×PDW-274).

Chlorophyll content (mg)

Higher retention of leaf chlorophyll under hot environment is often regarded as an expression of heat tolerance. Over the environments maximum chlorophyll content was recorded for parent PDW-314 (2.70 µg/g) and cross RAJ-1555×PDW-274 (2.84 µg/g). These genotypes showed high chlorophyll content of flag leaf at anthesis period indicates their opportunity for the fixation of photosynthate to developing grains under their respective environmental conditions. In pool, the range of chlorophyll content of parents was from 1.95 µg/g (RAJ-1555) to 2.70 µg/g (PDW-314) and in hybrids it was from 1.93 µg/g (NIDW-295× RAJ-1555) to 2.84 µg/g (RAJ-1555×PDW-274).

Chlorophyll stability index

The range of chlorophyll stability index in pool for parents was from 11.89% (HI-8663) to 16.53% (PDW-314) and in hybrids it was from 11.36% (HI-8737×RAJ-1555) to 16.71% (WH-896×PDW-274). Among crosses, cross WH-896×PDW-274 in E_1 (17.88), E2 (15.49) and E3 (16.76) had higher chlorophyll stability index.

Heat Injury (%)

Wheat genotypes expressed variability to high ambient temperatures with respect to heat injury (membrane thermo-stability). The observed range in the mean performance of heat injury for parents in pool was from 35.74 (HI-8663) to 43.84% (PDW-291), whereas for hybrids it varied from 31.03 (RAJ-1555×PDW-274) to 49.51 (HI-8663×PDW-274). Among crosses, RAJ-1555×PDW-274 in E_1 (25.81%) and E_2 (25.81%) and HI-8498×WH-896 in E_3 (31.61%) had minimum heat injury.

Leaf canopy temperature

Leaf canopy temperature regarded as important mechanism of heat escape. The range of canopy temperature in pool for parents varied from 14.90 ^{0}C (PDW-314) to 16.84 ^{0}C (NIDW-295) and in hybrids it was from 14.55 ^{0}C (HI-8663×PDW-233) to 18.25 ^{0}C (HI-8737×NIDW-295). These genotypes showed low canopy temperature at grain filling stage under late and very late sowing condition suggesting their tolerance to high temperature arise due to late sowing.

Any implication of plant breeding for genetic improvement of crop based on breeder object response pre-breeding for enhancement of genotypes. Based on results obtained from present study, it is concluded that superior cross combination/genotypes as per breeding object of breeder can be utilized for development of wheat genotypes for different environments. These findings supported by Kumar *et al.*, (2013), Kumar *et al.*, (2016) and Kumar *et al.*, (2017) [5, 3]. Present investigation concluded that the overall study on yield, yield contributing and physiological characters of the genotypes *viz.*, parents HI-8737, HI-8498, NIDW-295, PDW-274, PDW-233, PDW-314 and PDW-291 and crosses NIDW-295 x PDW-274, HI-8737 x HI-8498, PDW-274 x PDW-291 and PDW-233 x PDW-314 were observed better for maximum number of characters indicating their high tolerance to heat stress under late sowing conditions. Similar study also reported by Thomas *et al*. (2017).

Table 1: Mean performance of different characters of durum wheat genotypes under heat stress across the environments

SN	Genotype	Days to 50% heading	Days to maturity	Grain Filling periods	Plant height (cm)	Flag Leaf Length (cm)	Flag leaf width (cm)	Flag Leaf area (cm^2)	Peduncle length (cm)
1	HI-8737	71.33	107.56	22.44	87.00	22.54	1.92	33.69	24.32
2	NIDW-295	68.11	106.44	24.78	89.98	22.64	1.73	30.23	24.12
3	HI-8498	70.11	108.22	24.89	82.61	23.52	2.12	38.68	25.81
4	HI-8663	75.56	110.44	23.00	88.13	23.25	2.16	39.66	25.08
5	WH-896	71.78	106.44	21.22	89.22	22.71	1.83	32.19	24.76
6	RAJ-1555	71.22	108.56	22.89	90.47	23.79	1.90	35.47	25.79
7	PDW-274	73.11	109.22	23.22	89.55	21.12	1.78	29.38	25.35
8	PDW-233	74.22	112.11	24.67	89.06	22.51	1.83	31.68	24.98
9	PDW-314	75.11	112.22	24.00	87.44	21.68	1.75	29.19	26.65
10	PDW-291	75.78	112.22	25.22	82.97	23.08	1.68	30.46	25.12
11	HI-8737×NIDW-295	72.44	109.22	24.44	84.38	21.51	1.80	30.28	25.65
12	HI-8737×HI-8498	75.00	110.67	24.78	90.26	18.96	1.84	27.28	25.08
13	HI-8737×HI-8663	77.00	111.33	24.89	88.35	19.89	1.95	30.79	25.24
14	HI-8737×WH-896	75.33	113.67	26.22	88.39	25.03	1.88	36.12	25.41
15	HI-8737×RAJ-1555	74.44	110.89	24.11	88.73	18.64	1.89	28.60	23.46
16	HI-8737×PDW-274	75.33	112.00	24.67	86.64	21.73	1.87	31.84	25.81
17	HI-8737×PDW-233	75.56	111.44	24.67	84.98	22.18	2.04	36.32	24.51
18	HI-8737×PDW-314	77.44	111.56	23.89	85.15	22.16	1.93	33.12	24.27
19	HI-8737×PDW-291	78.11	111.89	23.67	86.74	23.20	1.80	32.11	22.57
20	NIDW-295× HI-8498	75.56	111.11	23.44	84.81	18.56	1.73	24.62	21.94
21	NIDW-295× HI-8663	76.78	111.56	23.33	84.60	22.13	1.86	31.78	22.94
22	NIDW-295× WH-896	76.11	110.56	22.67	88.83	23.49	1.89	34.94	23.46
23	NIDW-295× RAJ-1555	75.22	111.11	23.44	86.72	21.92	1.95	35.00	22.13
24	NIDW-295× PDW-274	78.11	115.22	25.22	87.23	23.06	1.89	33.48	22.59
25	NIDW-295× PDW-233	76.33	113.33	25.67	86.25	22.31	1.86	30.85	22.84
26	NIDW-295× PDW-314	76.78	112.89	25.22	81.54	19.70	1.78	26.88	22.54
27	NIDW-295× PDW-291	77.78	113.22	26.00	83.39	22.46	1.88	33.14	22.13
28	HI-8498×HI-8663	77.89	111.44	23.67	87.75	25.90	2.08	43.41	25.09
29	HI-8498×WH-896	76.89	111.78	24.22	81.16	21.95	2.09	36.84	21.14
30	HI-8498×RAJ-1555	73.67	110.00	23.78	89.06	23.64	2.06	37.67	24.28
31	HI-8498×PDW-272	75.33	109.00	23.44	86.39	21.32	2.12	33.42	24.65
32	HI-8498×PDW-233	76.22	109.11	23.33	88.07	25.02	2.04	39.41	24.09
33	HI-8498×PDW-314	79.33	112.00	24.67	89.07	25.43	1.89	36.43	25.76
34	HI-8498×PDW-291	79.56	111.44	23.78	89.85	21.95	1.86	31.67	24.85
35	HI-8663×WH-896	73.56	109.11	23.56	90.21	24.11	1.75	33.07	24.27
36	HI-8663×RAJ-1555	73.33	108.67	23.33	91.72	24.48	2.00	35.78	24.89
37	HI-8663×PDW-274	73.44	108.22	23.22	88.32	22.93	2.03	35.42	23.02
38	HI-8663×PDW-233	75.89	109.44	23.56	87.67	24.70	1.70	27.74	22.81

SN	Genotype	Days to 50% heading	Days to maturity	Grain Filling periods	Plant height (cm)	Flag Leaf Length (cm)	Flag leaf width (cm)	Flag Leaf area (cm^2)	Peduncle length (cm)
39	HI-8663×PDW-314	76.67	110.33	23.44	87.46	23.89	1.82	33.88	23.45
40	HI-8663×PDW-291	71.67	107.00	22.44	83.47	24.40	1.76	33.45	24.46
41	WH-896×RAJ-1555	74.11	108.22	23.33	89.50	22.89	1.82	31.44	25.49
42	WH-896×PDW-274	76.22	110.44	24.56	89.44	22.90	1.87	33.03	23.01
43	WH-896×PDW-233	77.22	110.44	24.00	89.63	22.45	1.90	32.41	23.10
44	WH-896×PDW-314	78.56	110.44	24.33	92.93	24.92	1.78	34.04	22.34
45	WH-896×PDW-291	74.56	107.44	23.89	86.70	25.43	1.82	35.21	24.10
46	RAJ-1555×PDW-274	75.78	109.56	24.33	90.75	24.34	2.05	39.22	22.64
47	RAJ-1555×PDW-233	74.78	108.78	23.89	87.61	24.19	2.08	39.11	23.03
48	RAJ-1555×PDW-314	76.33	108.33	23.33	82.80	28.09	2.15	44.10	24.49
49	RAJ-1555×PDW-291	76.11	106.56	22.56	88.83	25.37	2.20	44.83	24.82
50	PDW-274×PDW-233	78.22	110.78	22.78	90.29	26.95	2.13	44.25	25.75
51	PDW-274×PDW-314	78.67	110.67	23.00	91.60	24.81	2.06	40.54	24.05
52	PDW-274×PDW-291	78.89	112.11	24.11	89.77	23.78	2.12	40.46	24.78
53	PDW-233×PDW-314	77.56	109.78	23.78	91.67	26.37	1.91	37.98	24.35
54	PDW-233×PDW-291	76.33	108.78	23.67	83.79	25.24	2.11	41.20	22.31
55	PDW-314×PDW-291	75.22	108.22	24.00	82.37	29.85	2.12	49.02	23.01
56	HI 8627	66.67	105.67	25.89	92.29	24.53	2.11	38.70	23.56
57	MPO 1215	70.56	110.22	26.78	97.17	25.22	2.17	42.30	24.28
	PM	72.63	109.34	23.63	87.64	22.68	1.87	33.06	25.20
	FM	76.12	110.44	23.96	87.44	23.43	1.94	35.16	23.83
	CM	68.61	107.94	26.33	94.73	24.88	2.14	40.50	23.92
	GM	73.91	108.19	23.55	86.28	22.94	1.90	34.44	23.64
	SE	1.24	1.17	0.46	2.22	0.65	0.05	1.48	0.69
	CD5%	3.45	3.27	1.28	6.17	1.81	0.15	4.12	1.92
	CD1%	4.55	4.30	1.68	8.13	2.38	0.20	5.42	2.52
	CV	5.04	3.26	5.84	7.72	8.49	8.58	12.89	8.75

PM-Population Mean, FM-F_1 Mean, CM-Check Mean, GM-Grand Mean, SE- Standard Error, CD- Critical Difference, CV- Critical Variance.

Table 2: Mean performance of different characters of durum wheat genotypes under heat stress across the environments

SN	Genotype	Total No. of tillers plant^{-1}	No. of Prod. Tillers plant^{-1}	Spike length (cm)	No. of Spiklets spike^{-1}	No. of grain spike^{-1}	Spike weight productive tiller^{-1} (g)	Grain weight spike^{-1} (g)	Biological Yield Plant^{-1} (g)
1	HI-8737	23.68	19.47	8.24	20.15	76.79	5.77	4.24	158.73
2	NIDW-295	25.39	20.36	8.44	18.55	66.75	4.59	3.63	133.96
3	HI-8498	15.88	12.29	7.43	20.78	40.54	3.63	2.68	160.38
4	HI-8663	19.91	16.05	9.84	21.04	80.11	5.17	3.98	207.24
5	WH-896	29.08	23.87	6.73	17.47	39.86	3.33	2.20	146.64
6	RAJ-1555	23.69	19.41	7.79	19.08	57.11	4.23	3.12	169.08
7	PDW-274	18.33	15.32	7.62	21.16	60.21	5.00	3.50	128.77
8	PDW-233	26.28	22.80	8.45	20.60	78.05	5.32	4.32	159.80
9	PDW-314	25.88	21.89	7.36	21.08	69.64	3.89	3.57	126.17
10	PDW-291	17.08	13.82	7.63	18.14	59.25	4.33	3.02	112.82
11	HI-8737×NIDW-295	19.91	16.55	8.34	21.07	69.47	5.28	3.95	162.19
12	HI-8737×HI-8498	20.44	17.55	7.48	20.34	52.27	4.82	3.91	180.16
13	HI-8737×HI-8663	25.70	21.31	10.45	21.99	81.07	5.71	4.17	174.90
14	HI-8737×WH-896	18.00	14.61	7.89	20.02	49.90	4.32	3.31	165.26
15	HI-8737×RAJ-1555	25.42	22.36	7.31	19.42	50.88	4.68	3.85	104.95
16	HI-8737×PDW-274	15.32	12.66	8.47	21.45	51.88	4.57	3.51	121.27
17	HI-8737×PDW-233	19.86	16.54	8.19	20.64	63.63	4.89	4.10	110.85
18	HI-8737×PDW-314	18.63	14.81	8.23	19.60	59.56	4.92	3.87	160.62
19	HI-8737×PDW-291	24.12	20.71	7.15	20.89	54.05	4.12	2.83	109.58
20	NIDW-295× HI-8498	16.37	12.56	8.01	20.61	52.67	4.36	3.19	206.62
21	NIDW-295× HI-8663	15.91	12.80	10.22	20.18	76.67	5.21	4.11	148.45
22	NIDW-295× WH-896	19.88	16.25	7.87	19.70	57.04	4.35	3.53	127.75
23	NIDW-295× RAJ-1555	21.73	18.30	7.59	18.76	61.61	4.66	3.48	176.62
24	NIDW-295× PDW-274	27.02	22.17	8.46	20.19	64.46	5.09	3.75	211.76
25	NIDW-295× PDW-233	19.52	15.26	9.30	18.95	60.99	4.72	3.94	163.59
26	NIDW-295× PDW-314	19.18	16.20	7.82	20.56	60.41	4.47	3.27	173.13
27	NIDW-295× PDW-291	20.09	16.15	7.67	17.71	47.03	4.55	2.96	155.74
28	HI-8498×HI-8663	21.27	17.67	9.27	21.51	84.89	5.67	4.60	168.84
29	HI-8498×WH-896	23.30	20.06	8.10	20.99	57.39	4.61	3.64	120.71
30	HI-8498×RAJ-1555	14.37	11.47	7.35	20.50	53.91	4.48	3.41	119.01
31	HI-8498×PDW-272	21.53	17.24	7.36	18.07	40.17	4.68	2.66	146.68
32	HI-8498×PDW-233	20.92	17.76	8.57	20.68	69.03	4.74	4.03	175.25

SN	Genotype	Total No. of tillers plant-1	No. of Prod. Tillers plant-1	Spike length (cm)	No. of Spiklets spike-1	No. of grain spike-1	Spike weight productive tiller-1 (g)	Grain weight spike-1 (g)	Biological Yield Plant-1 (g)
33	HI-8498×PDW-314	13.26	10.77	8.33	18.89	77.19	4.55	3.97	124.98
34	HI-8498×PDW-291	25.77	22.04	7.09	22.87	54.15	3.92	2.92	169.33
35	HI-8663×WH-896	23.36	20.50	8.05	22.22	60.71	4.42	3.30	165.59
36	HI-8663×RAJ-1555	20.29	16.99	9.36	20.23	55.35	4.94	3.83	110.99
37	HI-8663×PDW-274	19.75	16.65	8.92	21.30	74.97	5.44	4.26	154.14
38	HI-8663×PDW-233	23.33	20.04	9.20	21.74	66.14	5.02	3.98	117.65
39	HI-8663×PDW-314	17.35	13.79	7.87	19.51	65.10	4.62	3.67	110.46
40	HI-8663×PDW-291	18.44	15.51	8.94	21.89	77.23	4.22	3.83	124.84
41	WH-896×RAJ-1555	22.82	19.87	7.54	20.86	55.59	3.98	3.99	167.59
42	WH-896×PDW-274	26.74	23.04	8.91	22.14	80.97	5.46	4.25	167.52
43	WH-896×PDW-233	16.58	13.18	8.96	23.71	71.64	4.74	3.81	187.24
44	WH-896×PDW-314	19.00	15.26	7.61	21.33	71.52	4.54	3.49	149.25
45	WH-896×PDW-291	17.98	15.15	7.57	21.92	65.14	4.21	3.36	134.12
46	RAJ-1555×PDW-274	22.36	18.31	7.58	21.46	65.30	4.67	3.21	172.65
47	RAJ-1555×PDW-233	25.10	22.36	9.14	21.34	74.71	4.61	3.37	137.04
48	RAJ-1555×PDW-314	21.44	18.80	8.27	19.65	60.79	4.10	2.98	126.87
49	RAJ-1555×PDW-291	23.51	20.77	7.69	19.93	56.51	4.82	4.05	163.64
50	PDW-274×PDW-233	28.87	24.90	8.67	19.90	57.01	4.61	3.54	177.90
51	PDW-274×PDW-314	22.13	19.82	8.34	21.66	74.75	5.57	4.34	171.77
52	PDW-274×PDW-291	31.65	26.97	8.43	19.36	69.80	4.48	3.49	197.67
53	PDW-233×PDW-314	27.03	22.96	8.68	20.75	74.39	5.32	3.57	200.64
54	PDW-233×PDW-291	17.06	14.12	9.40	19.55	76.59	4.88	3.89	161.25
55	PDW-314×PDW-291	19.53	16.89	8.56	21.01	61.29	4.41	3.54	112.85
56	HI 8627	22.35	19.47	11.87	19.05	54.71	3.59	2.68	106.67
57	MPO 1215	17.72	12.44	8.34	19.42	53.19	3.51	2.72	169.86
	PM	22.52	18.53	7.95	19.81	62.83	4.53	3.43	150.36
	FM	21.15	17.77	8.32	20.60	63.68	4.72	3.66	153.11
	CM	20.03	15.96	10.10	19.23	53.95	3.55	2.70	138.27
	GM	21.05	17.60	8.18	20.10	62.15	4.57	3.53	150.13
	SE	0.68	0.69	0.16	0.47	1.88	0.12	0.13	4.31
	CD5%	1.89	1.91	0.44	1.30	5.22	0.34	0.36	11.98
	CD1%	2.49	2.51	0.58	1.71	6.87	0.45	0.47	15.77
	CV	9.69	11.69	5.83	6.99	9.05	8.13	10.87	8.60

PM-Population Mean, FM-F_1 Mean, CM-Check Mean, GM-Grand Mean, SE- Standard Error, CD- Critical Difference, CV- Critical Variance.

Table 3: Mean performance of different characters of durum wheat genotypes under heat stress across the environments

SN	Genotype	Economic yield Plant-1 (g)	Harvest Index (%)	Test weight (g)	Protein Content (%)	Proline Content (µg)	Chlorophyll content (mg)	Chlorophyll Stability Index	Heat Injury Index (%)	Leaf Canopy Temperature (0C)
1	HI-8737	55.79	35.48	50.28	11.64	17.47	2.65	15.59	36.60	16.63
2	NIDW-295	48.18	36.96	60.52	11.82	18.34	2.61	16.53	36.47	16.84
3	HI-8498	61.96	38.61	56.75	12.49	18.36	2.55	14.95	37.88	16.51
4	HI-8663	73.52	35.15	42.67	11.51	18.47	2.60	11.89	35.74	16.34
5	WH-896	59.15	39.93	63.97	11.59	18.93	2.57	12.01	36.57	16.47
6	RAJ-1555	64.00	37.63	60.45	11.14	19.68	1.95	12.42	36.72	15.58
7	PDW-274	51.39	40.17	55.56	12.39	15.29	1.97	13.65	41.40	15.89
8	PDW-233	62.09	38.85	70.99	11.75	15.32	2.50	14.95	41.80	15.22
9	PDW-314	45.88	38.00	56.79	12.43	14.75	2.70	16.53	41.96	14.90
10	PDW-291	45.86	40.54	60.41	12.20	16.25	2.26	14.83	43.84	15.95
11	HI-8737×NIDW-295	66.42	41.58	45.13	12.12	16.18	2.81	15.36	41.78	18.25
12	HI-8737×HI-8498	73.88	41.57	67.49	12.59	16.27	2.54	14.95	44.44	16.68
13	HI-8737×HI-8663	55.42	31.80	62.82	11.96	18.49	2.02	13.42	34.12	16.59
14	HI-8737×WH-896	61.42	36.79	50.45	11.89	18.87	2.04	16.71	36.07	16.81
15	HI-8737×RAJ-1555	41.48	39.60	64.18	12.07	18.45	2.11	11.36	34.91	16.38
16	HI-8737×PDW-274	41.14	33.51	57.64	12.41	17.53	2.32	12.13	34.42	17.83
17	HI-8737×PDW-233	38.86	34.80	62.06	12.58	17.58	2.54	15.59	36.79	16.70
18	HI-8737×PDW-314	64.16	39.20	61.97	12.50	17.74	2.81	15.36	36.14	15.78
19	HI-8737×PDW-291	31.10	28.89	60.35	11.50	18.39	2.52	15.00	32.09	16.68
20	NIDW-295× HI-8498	70.45	33.51	58.74	11.24	18.53	2.54	15.01	35.11	16.43
21	NIDW-295× HI-8663	44.19	29.45	59.85	11.62	18.57	2.28	15.30	33.91	17.38
22	NIDW-295× WH-896	47.62	37.39	58.87	11.87	17.83	2.84	15.12	42.25	15.84
23	NIDW-295× RAJ-1555	52.69	29.92	56.32	12.12	17.99	1.93	11.48	40.22	16.90
24	NIDW-295× PDW-274	73.04	34.04	55.10	11.74	18.10	2.06	11.60	42.08	16.35
25	NIDW-295× PDW-233	56.51	34.37	60.86	11.70	12.80	2.65	14.71	39.99	16.62

SN	Genotype	Economic yield Plant^{-1} (g)	Harvest Index (%)	Test weight (g)	Protein Content (%)	Proline Content (µg)	Chlorophyll content (mg)	Chlorophyll Stability Index	Heat Injury Index (%)	Leaf Canopy Temperature (^{0}C)
26	NIDW-295× PDW-314	58.47	33.54	57.80	12.10	13.89	2.61	15.89	42.17	16.97
27	NIDW-295× PDW-291	54.50	34.50	59.70	12.22	13.50	2.55	13.30	41.98	17.05
28	HI-8498×HI-8663	56.43	33.42	56.83	11.75	15.06	2.60	15.30	41.92	16.90
29	HI-8498×WH-896	54.62	45.39	48.13	11.54	14.51	2.57	16.53	39.87	16.49
30	HI-8498×RAJ-1555	43.86	36.98	46.41	11.96	14.25	1.95	14.95	42.00	16.12
31	HI-8498×PDW-272	45.69	30.86	58.96	11.78	15.44	1.97	11.89	46.07	16.58
32	HI-8498×PDW-233	62.57	35.65	61.59	11.96	15.99	2.50	12.01	45.22	15.91
33	HI-8498×PDW-314	46.66	37.55	62.06	12.43	15.38	2.70	12.42	45.25	16.13
34	HI-8498×PDW-291	65.32	38.45	56.93	12.02	18.51	2.26	13.65	40.26	16.36
35	HI-8663×WH-896	50.73	30.55	51.47	11.79	18.39	2.81	15.12	41.12	15.70
36	HI-8663×RAJ-1555	39.13	35.18	49.52	12.23	18.08	2.54	14.95	40.92	16.14
37	HI-8663×PDW-274	61.23	39.91	65.03	12.52	13.76	2.02	16.53	49.51	15.90
38	HI-8663×PDW-233	37.16	31.68	57.61	12.33	13.44	2.04	14.83	46.26	14.55
39	HI-8663×PDW-314	46.21	42.26	55.57	13.02	13.55	2.11	14.95	46.73	15.66
40	HI-8663×PDW-291	50.14	40.92	55.03	11.58	15.03	2.32	13.42	35.24	15.22
41	WH-896×RAJ-1555	53.76	32.83	52.10	12.08	15.43	2.54	11.48	37.85	16.66
42	WH-896×PDW-274	50.91	30.18	49.32	11.91	15.52	2.81	16.71	37.03	15.88
43	WH-896×PDW-233	55.29	29.48	62.19	11.53	18.97	2.52	11.36	32.56	16.77
44	WH-896×PDW-314	46.77	31.70	41.74	11.47	17.93	2.54	12.13	33.70	15.86
45	WH-896×PDW-291	44.55	34.20	54.13	11.44	18.17	2.28	15.89	34.57	15.85
46	RAJ-1555×PDW-274	55.59	32.46	44.19	11.81	19.67	2.84	11.60	31.03	15.40
47	RAJ-1555×PDW-233	45.36	36.43	50.77	11.86	19.22	1.94	13.30	33.07	15.52
48	RAJ-1555×PDW-314	46.43	36.75	51.10	11.79	19.04	2.06	16.53	33.63	15.62
49	RAJ-1555×PDW-291	62.40	38.25	55.20	11.79	19.26	2.70	14.95	32.56	14.69
50	PDW-274×PDW-233	66.59	38.30	56.94	11.79	19.23	2.26	14.71	33.59	15.09
51	PDW-274×PDW-314	55.39	35.06	59.64	11.80	19.31	2.81	11.89	34.11	16.47
52	PDW-274×PDW-291	68.92	35.17	42.13	12.86	18.87	2.54	12.01	33.91	15.98
53	PDW-233×PDW-314	71.02	35.31	61.93	12.46	18.85	2.02	15.89	35.76	15.91
54	PDW-233×PDW-291	51.35	32.69	64.00	12.69	18.88	2.04	12.42	36.91	15.20
55	PDW-314×PDW-291	32.42	28.78	56.97	11.91	16.92	2.11	13.30	39.57	15.28
56	HI 8627	32.72	30.97	49.17	11.75	16.33	1.74	10.25	39.56	15.87
57	MPO 1215	45.00	26.51	52.00	12.03	16.70	1.73	10.19	40.00	15.77
	PM	56.78	38.13	57.84	11.89	17.29	2.44	14.34	38.90	16.03
	FM	53.29	35.13	56.15	12.01	17.05	2.39	14.07	38.42	16.20
	CM	38.86	28.74	50.58	11.89	16.51	1.74	10.22	39.78	15.82
	GM	52.59	34.72	55.19	11.77	16.79	2.34	13.72	37.78	15.88
	SE	1.24	1.37	1.69	0.15	0.30	0.04	0.26	0.73	0.42
	CD5%	3.44	3.81	4.71	0.41	0.84	0.12	0.72	2.03	1.17
	CD1%	4.53	5.01	6.20	0.54	1.10	0.15	0.95	2.67	1.54
	CV	7.06	11.82	9.20	3.78	5.36	5.40	5.66	5.79	7.93

PM-Population Mean, FM-F_1 Mean, CM-Check Mean, GM-Grand Mean, SE- Standard Error, CD- Critical Difference, CV- Critical Variance.

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