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Identification of Wheat Genotypes for Water Stress Tolerance on the Basis of Morpho-Yield Traits

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Abstract. The grain yield in greater amount under water stress has always been the prime objective of most of the studies pertaining to the identification of potential genotypes of wheat tested for morpho-yield and physiological traits. Selection of genotypes was thus based on their mean performance under water stress conditions imposed on tillering stages. Eighteen popular wheat varieties were evaluated for days to 75% heading, days to 75% maturity, plant height, tillers/plant, spike length, spikelets/spike, grains/spike, seed index, grain yield/plant, biological yield/plant and harvest index. The wheat varieties, viz., Bhittai, Marvi-2000, NIA-Sarang, TD-1, NIA-Sunder, Inqilab and Khirman, were identified as tolerant to water stress. Grain yield per plant was positively significant associated with its related traits in stress and water stress environments. These traits should be improved through simple selection in lateral generations of segregation populations.

Keywords: grain yield, morphological traits, water stress, correlation, wheat genotypes

Introduction

The wheat breeders are concentrating to improve the yield potential of existing wheat varieties by developing their progenies with desirable genetic makeup in order to overcome the impact of adverse climatic conditions, scarcity of irrigation water and the consumption pressure of ever increasing population, moreover, drought stress restricts crop production in the world (Hafiz *et al*., 2019). So as to resolve this issue, crossing in all combinations among parent varieties is inevitable. Prior launching any hybridization program, the identification and selection of parents is a vital step which depends on the understanding of various characters, the same proves to be an important prerequisites for launching effective and efficient breeding program. The broader genetic base of the germplasm used in screening facilitates selection of suitable parents, hybrids from these are genetically different, therefore, could be grown in a variety of environments. Furthermore, genotypes tolerant to drought or water stress, thus, could also be used in crosses for genetic studies conferring ability to a genotypes (Hosseini, *et al*., 2019). Exactly the same practice is followed for having drought or water stress tolerant genotypes to cope up with the unavailability of irrigation water especially at the critical growth stages. The potential grain yield of the cereal crops could be well judged when grown in natural field under optimum conditions and evaluated through yield and yield associated agro–morphological traits (Sial *et al*., 2012). Thus present research is aimed to determine the potential genotypes under water stress environment for yield and its related traits.

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Materials and Methods

The study was conducted during 2018-2019 to analyze eighteen hexaploid wheat varieties for economically useful metrical traits through field performance under diallel mating design. The study comprised of wheat varieties *viz;* NIA- Amber, Bhittai, Khirman, Sassui, NIA- Sarang, Kiran-95, Inqilab, Marvi-2000, NIA-Sunder, Benazir, Hamal, Moomal, SKD-1, Sindhu, TD-1, Abadgar, Anmol-91 and Mehran. The experiment was carried out in randomized complete block design with two treatments: (non- stress and water stress at tillering stage) with three replications at the botanical garden, department of plant breeding and genetics, Sindh Agriculture University, Tandojam. In treatment one (non-stress) applied 6 irrigations as recommended normal plant growth and development while treatment two (water stress) applied 5 irrigations by withholding one irrigation at tillering stage. The genotypes were screened on the basis of drought tolerance at tillering stage for days to 75% heading, days to 75% maturity,

plant height, tillers/plant, spike length, spikelets/spike, grains/spike, seed index, grain yield/plant, biological yield /plant and harvest index. The analysis of variances was carried out according to Gomez and Gomez (1984) to figure out the significant difference among the genotypes, treatments and treatments x genotypes in Statistix 8.9 version. Whereas correlation were calculated according to Raghaverao (1983).

Results and Discussion

Mean squares from analysis of variance for various morpho-yield traits of wheat grown under water stress conditions. The genotypes were highly significant for all traits, such as days to 75% heading, days to 75% maturity, plant height, tillers/plant, spikelets/spike, grains/spike, seed index, grain/plant, biological yield/plant and harvest index. While non-significant for spike length. The treatments were highly significant for all the traits mentioned in Table 1. Plant height, tillers/plant, spikelets/spike, grains/spike, seed index, grain per/plant, biological/plant and harvest index. So far as the treatment interaction is concerned, the same was non-significant for days to 75% heading, days to 75% maturity and spike length. Whereas, highly significant for plant height, tillers/plant, spike length, spikelets/spike, grains/spike, seed index, grain yield/plant, biological yield/plant and harvest index. So far as the genotype x treatment interaction is concerned, the same was highly significant for days to 75% heading, days to 75% maturity and spike length. The genotype x treatments were non-significant in the case of physiological traits like relative water content, chlorophyll content and leaf area. Such studies where analysis of variance was used as a tool to split an observed aggregate variability found inside a data set into two parts were also conducted by Rasool *et al*. (2021) and Bedada *et al*. (2022). A similar research was also carried out by Regmi *et al*. (2021) to estimate the genetic parameters of fifty wheat genotypes. The analysis of variance showed highly significant differences among the genotypes for all the studied traits except spike length. This implies that, except for spike length, all other traits exhibited genetic variability.

Mean performance for morpho-yield traits of wheat genotypes grown under water stress conditions. The data regarding the mean performance of wheat varieties for morpho-yield traits are presented in Table 2. The character-wise performance is given here under.

***Days to 75% heading*.** The parent variety Bhittai took minimum days to 75% heading (70.00) under drought stress as per data shown in Table 2. The maximum reduction percentage for the trait being described was recorded for the variety Bhittai (-7.00), which confirms its susceptibility against drought. The minimum reduction percentage for the same trait was recorded for the variety Inqilab (-1.67), this confirms its resistance to withstand drought stress imposed at the tillering

Table 1. Combined/pooled ANOVA of wheat varieties under water stress and non-stress conditions

-	Source of variation				
-	Replication	Genotypes	Treatment	Genotypes treatment	Error
Degrees of freedom	02	17	01	17	34
Characters					
Days to 75%heading	25.98	37.69**	0.09NS	4.14NS	8.06
Days to 75% maturity	20.52	72.49**	1.12NS	3.84NS	9.98
Plant height	9.63	211.93**	225.62**	62.83**	30.50
Tillers/plant	0.06	2.22**	13.55**	2.05**	0.44
Spike length	0.11	0.71NS	1.29NS	1.51NS	1.50
Spikelets/spike	0.55	6.84**	67.98**	8.24**	0.63
Grains/spike	20.46	125.83**	1778.36**	109.01**	13.25
Seed index	15.35	24.21**	21.39**	12.970**	6.68
Grain yield/plant	20.24	38.90**	5140.17**	17.71**	7.86
Biological yield/plant	48.39	77.60**	3402.45**	17.84**	4.82
Harvest index	12.97	32.53**	693.83**	46.51**	15.74

*** = Significant (1 and 5%) probability levels separately. NS= Non-significant.

Table 2. Mean performance for days to 75% heading, days to 75% maturity of wheat varieties grown under water stress and non-stress conditions

Varieties	Days to 75% heading		R.D*	Days to 75 % maturity		R.D*
	Non stress	Stress at tillering		Non stress tillering	Stress at	
NIA-amber	75.89	73.66	-2.23	121.33	119.33	-2.00
Bhittai	77.00	70.00	-7.00	118.33	114.33	-4.00
Khirman	84.66	80.35	-4.31	118.00	115.67	-2.33
Sassui	82.33	77.71	-4.62	119.45	117.21	-2.24
NIA-sarang	78.33	76.33	-2.00	120.33	118.56	-1.77
Kiran-95	82.18	76.00	-6.18	122.33	118.67	-3.66
Inqilab	82.33	80.66	-1.67	119.33	115.46	-3.87
Marvi-2000	79.33	76.00	-3.33	114.25	107.33	-6.92
NIA-sunder	77.89	75.33	-2.56	118.67	116.33	-2.34
Benazir	83.20	78.00	-5.20	122.00	120.33	-1.67
Hamal	83.40	80.40	-3.00	119.00	116.00	-3.00
Moomal	81.66	77.66	-4.00	118.33	113.33	-5.00
SKD-1	77.00	74.66	-2.34	121.00	120.33	-0.67
Sindhu	77.66	73.56	-4.10	117.67	115.67	-2.00
TD-1	85.78	81.67	-4.11	121.33	119.67	-1.66
Abadgar	79.33	75.82	-3.51	118.00	114.34	-3.66
Anmol	81.30	79.30	-2.00	117.00	115.45	-1.55
Mehran	79.00	75.50	-3.50	119.67	115.67	-4.00
Mean	80.41	76.79	-3.61	119.00	116.54	-2.46
LSD (5%) (T)	1.08			1.21		
LSD (5%) (G)	3.26			3.63		
LSD (5%) (T x G)	4.62			5.14		

RD* = Relative decreases in water stress over non-stress.

stage. In case of non-stress, the minimum days to 75% heading were taken by the variety NIA-Amber (75.89). However, maximum days for the same character were taken by the variety TD-1 (85.78). Saima *et al*. (2017); Farshadfar and Amri (2016); Mehsen *et al*. (2014); Khan *et al*. (2011) conducted similar experiments over the quest for potential genotypes that can withstand harsh environments with higher yield.

***Days to 75% maturity*.** According to data taken for the trait days to 75% maturity as given in Table 2, the minimum days were taken by the variety Marvi-2000 (107.33) under water stress conditions. The maximum reduction percentage was recorded in the variety Marvi -2000(-6.92). However, minimum reduction percentage for the same trait was recorded for the variety SKD-1 (-0.67), hence proving susceptibility of Marvi -2000 and tolerance of SKD-1 towards drought stress imposed on tillering stage. In terms of minimum days taken by a variety to 75% maturity under non-stress, the variety Marvi-2000 stood early by taking 114.25 days however, Kiran-95 took maximum days to 75% maturity (122.33) and was found to be late maturing. These results are in accordance with those of (Shahid *et al*. (2022); Ahmed *et al*. (2019); Al-Otayk (2019); Hooshmandi (2019).

***Plant height (cm)*.** The parent variety Khirman (70.14) had minimum plant height under drought stress as per data shown in Table 3. The maximum reduction percentage for the trait being described was recorded for the variety Benazir (-10.33), which confirms its susceptibility against drought. The minimum reduction percentage was recorded for the variety Bhittai (-3.02); this confirms its resistance to withstand drought stress imposed at the tillering stage. In the case of non-stress, the minimum plant height was observed for the variety TD-1 (67.93). However, maximum plant height was observed in the variety NIA-Sarang (97.70). These results are in accordance with those of Jatoi *et al*. (2022), who reported significant differences were observed for plant height among wheat genotypes under adverse environments.

Table 3. Mean performance for plant height and tillers/plant of wheat varieties grown under water stress and non-stress conditions

Varieties	Plant height (cm)		R.D*	Tillers/plant		R.D*
	Non-stress	Water stress		Non-stress	Water stress	
NIA-amber	91.10	84.89	-6.21	11.30	9.87	-1.43
Bhittai	90.96	87.94	-3.02	12.63	10.08	-2.55
Khirman	78.20	70.14	-8.06	10.77	11.04	0.27
Sassui	81.95	75.29	-6.66	12.50	10.13	-2.37
NIA-sarang	97.70	90.97	-6.73	10.68	13.61	2.93
Kiran-95	95.72	88.00	-7.72	12.83	11.38	-1.45
Inqilab	89.08	83.62	-5.46	11.73	9.58	-2.15
Marvi-2000	81.41	73.98	-7.43	12.50	8.01	-4.49
NIA-sunder	91.59	82.87	-8.72	12.93	9.03	-3.90
Benazir	84.66	74.33	-10.33	10.23	10.59	0.36
Hamal	92.84	84.96	-7.88	11.19	12.56	1.37
Moomal	88.70	80.05	-8.65	11.05	11.03	-0.02
SKD-1	86.11	79.91	-6.20	10.75	9.30	-1.45
Sindhu	96.38	86.33	-10.05	11.94	9.43	-2.51
TD-1	67.93	62.33	-5.60	12.08	10.37	-1.71
Abadgar	94.63	88.24	-6.39	12.93	11.78	-1.15
Anmol	82.37	76.56	-5.81	10.85	9.12	-1.73
Mehran	93.05	86.83	-6.22	9.89	8.58	-1.31
Mean	88.02	80.96	-7.06	11.30	9.87	-1.43
LSD (5%) (T)	2.11			1.39		
LSD (5%) (G)	6.35			0.25		
LSD (5%) (T x G)	8.99			2.18		

RD* = Relative decreases in water stress over non-stress.

Tillers/plant. According to data given in Table 3 for the tillers/plant, the minimum tillers/plant were produced by the variety NIA-Sarang (13.61), followed by Hamal (12.56) and Abadgar (11.78). The maximum reduction percentage was recorded in the variety Marvi -2000(-4.49). However, minimum reduction percentage for the same trait was recorded in the variety Moomal (-0.02), hence proving susceptibility of Marvi -2000 and tolerance of Moomal towards drought stress imposed on tillering stage. In terms of minimum tillers/plant under non-stress was produced by the variety Mehran (9.89). However, maximum tillers/plant for the same character was produced by the variety Bhittai (12.93). The data presented in Table 3 and described above matches with the results of the study carried out by Afzel *et al*. (2023). Furthermore, the tillering phase of wheat (*Triticum aestivum* L.) is the most susceptible to water stress (Sarwar *et al*., 2023).

Spike length (cm). The parent variety Khirman, according to the data given in Table 4, measured the highest spike length (15.06) under stress conditions. The maximum reduction percentage for the character being described was recorded for the variety Bhittai (-5.04), which confirms its susceptibility against drought. However, the minimum reduction percentage for the same trait was recorded for the variety Khirman (-0.39); this confirms its resistance to withstand drought stress imposed at spike length. In the case of non-stress, the maximum spike length was measured in the variety Marvi-2000 (15.97). Whereas the minimum length for the same trait was measured in the variety NIA-Amber (12.43). Plant height, spike length and spike compactness are important agronomic traits that have a strong correlation with lodging and yield in wheat. Other researchers like Memon *et al*. (2022) reported that water stress is one of the major environmental constraints which affect the spike length.

Spikelets/spike. The maximum number of spikelets/spike (22.56), as given in Table 4, were counted in the variety NIA-Sarang, followed by Marvi-2000 (21.37) and Hamal (20.41). Meanwhile, the maximum reduction was recorded in the variety Sassui (-7.19), hence proving

Table 4. Mean performance for spike length and spikelets/spike and grains spike-1of wheat varieties grown under water stress imposed at tillering stage and non-stress conditions.

Parents	Spike length		R.D*	Spikelets/spike		R.D*
	Non-stress	Water stress		Non-stress	Water stress	
NIA-amber	12.43	11.84	-0.59	19.36	14.89	-4.47
Bhittai	17.30	12.26	-5.04	23.45	16.70	-6.75
Kirman	15.45	15.06	-0.39	19.69	16.38	-3.31
Sassui	12.47	13.90	1.43	21.82	14.63	-7.19
NIA-sarang	13.41	12.74	-0.67	19.79	22.56	2.77
Kiran-95	15.04	13.24	-1.80	22.02	15.23	-6.79
Inqlab	13.77	12.89	-0.88	21.72	14.98	-6.74
Marvi-2000	15.97	13.15	-2.82	18.81	21.37	2.56
NIA-sunder	13.15	12.47	-0.68	17.92	13.46	-4.46
Benazir	13.34	11.50	-1.84	22.20	17.99	-4.21
Hamal	12.96	11.38	-1.58	19.02	20.41	1.39
Moomal	13.75	12.69	-1.06	17.69	11.95	-5.74
SKD-1	15.38	13.80	-1.58	21.08	19.89	-1.19
Sindhu	15.81	13.82	-1.99	18.46	17.52	-0.94
TD-1	13.76	11.80	-1.96	20.42	13.95	-6.47
Abadgar	15.09	13.69	-1.40	19.52	19.94	0.42
Anmol	15.09	13.87	-1.22	19.03	17.62	-1.41
Mehran	13.84	11.22	-2.62	22.33	16.97	-5.36
Mean	14.33	12.85	-1.48	20.241	17.02	-3.09
LSD (5%) (T)	0.47			0.48		
LSD (5%) (G)	1.41			1.44		
LSD (5%) (T x G)	2.00			2.05		

RD* = Relative decreases in water stress over non-stress

susceptibility of Sassui and tolerance of Abadgar (0.42) towards drought stress imposed on the stage of spikelets/spike. In terms of maximum number of spikelets per spike under non-stress condition, the variety Bhittai recorded (23.45); however, Moomal counted the minimum number of spikelets per spike (17.69). The number of spikelets per spike has also been the choice of study by Protic *et al*. (2019).

***Grains/spike*.** The parent variety Kiran-95 produced maximum grains/spike (79.11) under drought stress, as shown in Table 5. The maximum reduction percentage for the trait being described was recorded for the variety Sassui (-14.78), which confirms its susceptibility against drought. The minimum reduction percentage for the same trait was recorded for the variety Hamal (-1.69); this confirms its resistance to drought stress imposed at the tillering stage. In the case of non-stress, the maximum number of grains was taken by the variety Kiran-95 (82.56). However, the minimum number of grains/spike for the same character was found by the variety NIA-Sunder (50.76). Our results are in accordance with those of Kara and Akman (2008) and Sheraz and Hassan (2017).

***Seed index (g)*.** The maximum seed index was given by the variety Sassui (42.33), followed by Khirman (38.66) and Bhittai (36.00), according to Table 5. The maximum reduction percentage was recorded in the variety Moomal (-14.67). However, minimum increases for the same trait were recorded for the variety Sassui (1.29), hence proving susceptibility of Moomal and tolerance of Sassui towards drought stress imposed on tillering stage, respectively. In terms of maximum seed index, it was produced by variety Marvi-2000 (44.29). However, SKD-1 produced the minimum number of grains (39.13). The thousand grain weight is least effected by mineral intake by the plants, however, such nutrients play a significant role in the composition of seeds, influencing seed germination rate and the production of vigorous seedlings, which is fundamental for the establishment of crop stand and yield (Marinho *et al*., 2022).

Table 5. Mean performance for number of grains spike and seed index of wheat varieties grown under water stress and non-stress conditions

Parents	Number of grains/spike		R.D.*	Seed index		R.D.*
	Non-stress	Water stress		Non-stress	Water stress	
NIA-amber	54.93	49.63	-5.30	40.17	33.66	-6.51
Bhittai	81.22	72.06	-9.16	44.06	36.00	-8.06
Kirman	72.09	68.02	-4.07	41.06	38.66	-2.39
Sassui	71.64	56.86	-14.78	41.04	42.33	1.29
NIA-sarang	73.77	65.69	-8.08	42.12	36.33	-5.79
Kiran-95	82.56	79.11	-3.45	44.27	37.00	-7.27
Inqilab	74.16	61.58	-12.58	40.92	27.66	-13.26
Marvi-2000	77.89	67.07	-10.82	44.29	31.66	-12.63
NIA-sunder	50.76	45.29	-5.47	40.12	28.66	-11.46
Benazir	60.10	50.00	-10.10	44.22	34.33	-9.89
Hamal	65.43	63.74	-1.69	41.33	32.50	-8.83
Moomal	62.52	59.50	-3.02	40.33	25.66	-14.67
SKD-1	70.12	64.85	-5.27	39.13	32.43	-6.70
Sindhu	62.15	59.69	-2.46	44.00	31.57	-12.33
TD-1	65.27	57.00	-8.00	43.16	29.00	-14.16
Abadgar	69.45	62.13	-7.32	44.00	25.00	-19.00
Anmol	60.19	56.75	-3.44	44.19	35.00	-9.19
Mehran	69.52	58.57	-10.95	39.33	33.66	-5.67
Mean	67.19	61.43	-5.75	42.10	32.84	-9.25
LSD (5%) (T)	1.39			0.99		
LSD (5%) (G)	7.60			2.97		
LSD (5%) (T x G)	11.90			4.20		

RD* = Relative decreases in water stress over non-stress.

Grain yield/plant (g). According to Table 6, the parent variety Hamal produced maximum grain yield/plant (42.67) under drought stress. The maximum reduction percentage for the trait being described was recorded for the variety Sassui (-13.69), which confirms its susceptibility against drought. The minimum reduction percentage for the same trait was recorded for the variety NIA-Sarang (-3.49); this confirms its resistance to withstand drought stress imposed at the tillering stage. In the case of non-stress, the maximum grain yield/plant was produced by the variety Sassui (48.08); however, the minimum grain yield/plant was produced by NIA-Amber (34.88). The grain yield in wheat depends upon heads per square foot, seeds per head and seed weight; using estimates of these parameters, the farmers can drive an estimated grain yield (Memon, 2022 and Jeff Edwards, 2017). Sarwar *et al*. (2023) also found that increasing drought intensity significantly impaired leaf physiology and grain yield of both studied genotypes. Compared with control, moderately and severely drought-stressed plants produced 25% and 45% less grain yield per spike, respectively.

Biological yield/plant (g). According to the same Table 6, the maximum biological yield/plant was produced by the variety Bhittai (64.00), followed by NIA-Sundar (62.37) and Khirman (53.19). The maximum reduction percentage was recorded in the variety TD-1 (-26.79). However, minimum reduction percentage for the same trait was recorded for the variety Khirman (-7.60), hence proving susceptibility of TD-1 and tolerance of Khirman towards drought stress imposed on tillering stage. In the case of non-stress, the maximum biological yield/plant was produced by the variety NIA-Sundar (76.53); however, the minimum biological yield/plant was produced by Bhittai (50.22). According to Memon *et al*. (2022), water stress is one of the major environmental constraints on wheat grain yield worldwide. And according to Lal *et al*. (2024) it is necessary to be evolved genetically stress-tolerant wheat genotypes that produce sustainable grain yields in water-

Table 6. Mean performance for grain/yield and biological/yield of wheat varieties grown under water stress and non-stress conditions

Varieties	Grain yield/plant		R.D*	Biological yield/plant		R.D*
	Non-stress	Water stress		Non-stress	Water stress	
NIA-amber	34.88	29.65	-5.23	71.66	52.59	-19.07
Bhittai	35.99	30.35	-5.64	50.22	64.00	13.78
Kirman	44.11	39.19	-4.92	60.79	53.19	-7.60
Sassui	48.08	34.39	-13.69	56.81	40.73	-16.08
NIA-sarang	41.15	37.66	-3.49	67.63	42.66	-24.97
Kiran-95	45.06	40.30	-4.76	68.66	48.33	-20.33
Inqilab	47.93	39.65	-8.28	65.46	47.67	-17.79
Marvi -2000	41.29	36.66	-4.63	56.24	32.43	-23.81
NIA-sunder	43.91	38.65	-5.26	76.53	62.37	-14.16
Benazir	48.1	39.53	-8.57	53.15	38.90	-14.25
Hamal	48.76	42.67	-6.09	72.92	52.73	-20.19
Moomal	41.15	34.50	-6.65	58.50	40.18	-18.32
SKD-1	47.73	40.00	-7.73	56.84	39.62	-17.22
Sindhu	44.34	39.34	-5.00	59.82	36.04	-23.78
TD-1	43.60	36.87	-6.73	63.08	36.29	-26.79
Abadgar	35.67	26.32	-9.35	51.17	40.98	-10.19
Anmol	37.41	28.51	-8.9	61.37	42.89	-18.48
Mehran	48.30	38.67	-9.63	64.00	50.71	-13.29
Mean	42.97	36.16	-6.81	61.94	45.68	-16.25
LSD (5%) (T)	0.842			1.08		
LSD (5%) (G)	2.52			3.25		
LSD (5%) (T x G)	3.57			4.60		

RD* = Relative decreases in water stress over non-stress.

scarce conditions. As per their findings, grain yield per plot was positively correlated with biological yield per plot in MS conditions.

Harvest index (%). According to Table 7, in case of stress, the maximum harvest index was produced by the variety Kiran-95 (56.65), however, the minimum harvest index was produced by Bhittai (35.42). According to data taken for the trait of harvest index, the maximum harvest index was produced by the variety Sassui (51.62), followed by Inqilab (51.51) and Sindhu (49.05). The maximum reduction percentage was recorded in the variety TD-1 (-18.05). However, minimum reduction percentage for the same trait was recorded for the variety NIA-Sarang (0.24), hence proving susceptibility of TD-1 and tolerance of NIA-Sarang towards drought stress imposed on tillering stage. According to research conducted by Sial *et al*. (2022) pertaining to the evaluation of selected wheat genotypes under drought, it was reported that the grain yield and harvest index were not significantly different from each other furthermore, through the cluster analysis, a group consisting of four wheat genotypes was declared drought tolerant and also Mandan *et al*. (2024) said that error free analysis is significant for getting drought resistant genotypes.

Correlation coefficient of yield and its traits in non-stress and water stress. The extent of correlation in conventional plant breeding or mendelian genetics between two variables or traits is important (Table 8). The results also revealed that the correlation of yield with its associated traits in non-stress and water stress at the tillering stage showed that grain yield established a significant negative association with days to 75% heading (-0.65**), days to 75% maturity (-0.77**) and plant height (-0.75**) in non-stress, while grain yield showed a significant positive association with other traits such as tillers/plant (0.56**), spike length (0.92**), spikelets/spike (0.68**), grains/spike(0.76**), seed index (0.89**), biological yield per plant (0.76**) and harvest index (0.92**) in non-stress. Whereas in stress

at tillering stage showed that grain yield/plant displayed significant positive association with days to 75% heading (0.31*), days to 75% maturity (0.70**), plant height (0.79**), tiller/plant (0.73**), spike length (0.95**), spikelets/spike (0.71**), grain/spike (0.79**), seed index (0.92**), biological yield (0.83**) and harvest index (0.70**). Similarly, the association of yield and yield-related traits was evaluated so as to determine the direct and indirect effects of yield-related traits on grain yield. This association sheds light on the mechanism involved in simultaneous modification of a group of traits; this is attributed to positive correlation. However, many studies have revealed negative correlation between traits as well; this describes the inverse proportion between two variable traits. Lal *et al*. (2024) and Munir *et al*. (2020) are the notable plant/agricultural experts who, from time to time, worked out the correlation between maximum phenological, morphological and physiological traits of wheat crops and other cereals. Their results are in accordance with those that are achieved through this research and described in the next passage.

Table 7. Mean performance for harvest index of varieties of wheat grown under non-stress and water stress conditions

Varieties	Harvest index (%)		R.D*
	Non-stress	Water stress	
NIA-amber	47.80	45.03	-6.77
Bhittai	35.42	42.41	6.99
Kirman	49.60	46.55	-3.05
Sassui	48.47	51.62	3.15
NIA-sarang	54.76	55.00	0.24
Kiran-95	56.65	48.67	-7.98
Inqlab	49.96	51.51	-16.45
Marvi-2000	52.94	35.77	-17.17
NIA-sunder	52.66	46.93	-10.73
Benazir	43.49	42.66	-0.83
Hamal	48.39	43.17	-10.22
Moomal	43.80	47.54	-7.26
SKD-1	52.61	43.45	-9.16
Sindhu	51.08	49.05	-4.03
TD-1	49.00	30.95	-18.05
Abadgar	50.33	38.57	-11.76
Anmol	46.76	42.04	-4.72
Mehran	49.08	41.70	-10.38
Mean	49.04	44.59	-7.12
LSD (5%) (T)		1.52	
LSD (5%) (G)		4.56	
LSD (5%) (T x G)		6.46	

RD* = Relative decreases in water stress over non-stress.

Table 8. Correlation coefficient of grain yield/plant with other yield related traits in non-stress and water stress of wheat genotypes.

Characters	Non-stress	Water-stress
Days to 75% heading	-0.65**	0.31*
Days to 75% maturity	-0.77**	0.70**
Plant height	-0.75**	0.79**
Prod. tillers/plant	0.56**	0.73**
Spike length	0.92**	0.95**
Spikelets/spike	0.68**	0.71**
Grains/spike	0.76**	0.79**
Seed index	0.89**	0.92**
Biological yield	0.76**	0.83**
Harvest index	0.92**	0.70**

*** = Significant (1 and 5%) probability levels individually.

Conclusion

The varieties Bhittai and Marvi-2000 were early for taking lesser days to 75% heading and days to 75% maturity, respectively, under a water stress environment. Under the same situation, the variety NIA-Sundar produced a higher biological yield; however, the grain yield was greater in Hamal. The grain yield per plant established strong associations with its associated traits in non-stress as well as stress environments. Such genotypes should be preferred for growing in such areas where growers facing the problem of water shortage at early stage of wheat crop.

Conflict of Interest. The authors declare that they have no conflict of interest.

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