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WHEAT (*TRITICUM AESTIVUM* L.) DROUGHT TOLERANCE INDICES UNDER WATER STRESS CONDITIONS

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SUMMARY

Ten wheat varieties, Benazir, Hamal Fakir, TD-I, NIA Sunder, TJ-83, Marvi-2000, NIA Amber, Sarsabz, Kiran-95, and Imdad-05, sown in split-plot design (SPD) with three replications, underwent well-watered and water-stress influences at the time of anthesis, at the Botanical Garden, Department of Plant Breeding and Genetics, Sindh Agriculture University, Tandojam, during 2022–2023. The observed traits included days to 1st booting, days to 90% heading, days to 90% maturity, peduncle length (cm), plant height (cm), tillers plant^{-1}, spike length (cm), spikelets spike^{-1}, grains spike^{-1}, seed index (1000-grain weight, g), grain yield plant^{-1} (g), biological yield plant^{-1} (g), and harvest index (%). Based on drought tolerance indices, the result demonstrated that genotypes, treatments, and genotypes ×treatments significantly affected yield and its contributing traits. The genotypes, such as Imdad-05, NIA Amber, and TD-1, considerably exhibited drought tolerance, whereas Marvi-2000 and Kiran-95 were susceptible. The grain yield expressed positive and significant association toward other traits, such as days to 1st booting, days to 90% heading, days to 90% maturity, peduncle length, plant height, tillers plant^{-1}, spike length, spikelets spike^{-1}, grains spike^{-1}, seed index grain weight, grain yield plant^{-1}, biological yield plant^{-1}, and harvest index. Seven indices calculated grain yield in Yp and Ys appeared significantly and positively associated with the first three components mentioned at about 95.76% of the total variability and directly connected with the STI, GMP, TOL, and MP, namely, Imdad-05, NIA Sunder, and TD-1 considered as highly drought-tolerant; Marvi-2000 and Benazir, as moderately tolerant, and NIA Amber and Kiran-95 were the susceptible ones.

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Keywords: Wheat (*Triticum aestivum* L.), well-watered and stressed-conditions, drought, indices, yield-related traits

Key findings: Wheat (*Triticum aestivum* L.) varieties, Imdad-05, NIA Sunder, TD-1, and Benazir, proved best performers against drought conditions that could benefit future breeding programs for hybrid crop development.

INTRODUCTION

Among the top three global food crops, wheat ranks as the top, based on Australian main crops, and has a significant export value due to its high-growing demand (Cai *et al*., 2019) to ensure food security locally and globally to achieve sustainable productivity. Wheat production also requires an immense increase to fulfill all food requirements (Cai *et al*., 2019). How to increase yields in both large and small amounts is a challenging problem for wheat producers during this present time. Precision agriculture can boost harvests on a small scale inside a paddock by enabling targeted wheat production, as proposed by Li *et al.* (2022). However, for this to be successful, the need to grasp variations ultimately requires the field yield assessment. One of the first steps to know the primary components that could restrict bringing deviation in a negative sense are usually elements, such as soil erosion (characterized as within-field yield loss), soil restrictions (soil sodicity and salinity usually causing poor growth of plant reducing yields in many seasons) as opposed to other causes of unusual variation, mostly just like diseases, seasonally affecting the entire field, as suggested by Ulfa *et al*. (2022). Additionally, the influence of specific soil limitations on crop growth may vary depending on climatic circumstances; for example, soil salinity may always have a higher impact on yield in dry climates (Ulfa *et al*., 2022).

Developing crop varieties with the ability to survive in less available water and tolerance against drought can contribute to the economic requirements, as one of the easy ways to ensure future food security for the growing world population was a concern by Shao *et al*. (2006). The assessment of drought tolerance should wholly depend on grain production in both situations of stressed or non-stressed since the response of a selection under influential stress circumstances frequently requires that the yield under these conditions be optimal and constant as needed. It might benefit guiding a selection of different genotypes that provide outputs in dry and irrigated environments, according to Talebi *et al*. (2020).

Kirigwi *et al*. (2004) said that considering the semi-arid area of Pakistan, where most wheat cultivation happens as a rainfed crop, there are more wheat production opportunities for growing due to rainfall availability every year and also among sites within years. However, most growers have faced water scarcity problems for many decades needing the introduction of different agronomic techniques to bring variation to boost production, as recommended by Mitra (2001) to compare yield products of diverse cultivars in irrigated and non-irrigated environments, which is an initial step for finding a favorable genotype for erratic rainfed environment, as hypothesized by Nouri *et al*. (2011), as drought stress reduces crop yield, including a significant impact on wheat output and sustainability.

For evaluating drought-tolerant genotypes, drought indices have received evaluation to reduce drought to minimize the risk of yield loss, according to Mitra (2001), who said these indexes help determine genetic sensitivity to drought or drought resistance. On the other hand, Hall (1993) hypothesized that yield may decrease from genotypes while comparing them under mixed water circumstances. Blum (1988) added that measuring a genotype's drought susceptibility is typically a function of the yield’s minimization during unfavorable environments, albeit the different genotypes’ yield potential assumingly muddled the numbers. A popular place to start selecting the best genotypes while identifying the required additional resources and requisites is according to genotypes' yield performance in irrigated and non-irrigated conditions (Kirigwi *et al*., 2004). Researchers Betran *et al*. (2003) felt that selection usually occurred under the influences of favorable and stressful settings. Others have selected a middle ground and believed the selection process is better under suitable and water-treated conditions, as Nouri *et al*. (2011) revealed.

MATERIALS AND METHODS

The study arrangement was in a split-plot design for two irrigation treatments, such as water and non-water stress, to examine drought-tolerant indices of wheat genotypes. Experiments commenced at the Botanical Garden, Department of Plant Breeding and Genetics, Sindh Agriculture University, Tandojam, during 2022–2023. The water regimes served as prime factors, while the varieties were subfactors. The irrigation regime as the non-stressed treatment has sufficient irrigation, completing the required six irrigations, while in stressed treatment, inducing water stress continued at the time of anthesis by withholding water about 30 days from initiation of anthesis until the grain period to reach near the grain-filling stage. The assessment of wheat traits used in the experiment focused on days to 1st booting, days to 90% heading, days to 90% maturity, peduncle length (cm), plant height (cm), tillers plant^{-1}, spike length (cm), spikelets spike^{-1}, grains spike^{-1}, seed index (1000-grain weight, grain yield plant^{-1} [g]), biological yield plant^{-1} (g), and harvest index (%). Astonishing fluctuations were evident on the chosen traits due to different water treatments, and impacts fell on the selected varieties as screening of these through drought indices ensued.

Statistical analysis

The acquired data incurred analysis of variance (ANOVA) by Gomez and Gomez (1984), with drought tolerance indices calculated with the formula developed by various indices such as (SSI) determined by Fisher and Maurer (1978) and mean productivity (MP) and tolerance index (TOL) by Rosielle and Hamblin (1981), stress tolerance index (STI) by Fernandez (1992), geometric mean productivity (GMP) by Fernandez (1992), yield index (YI) by Gavuzzi *et al*. (1997), and yield stress index (YSI) by Bouslama and Schapaugh (1984I). The principal components and biplot analysis employed the Minitab 15.0 version (Tigkas *et al.*, 2022).

RESULTS AND DISCUSSION

Days to 1st booting

Wheat genotypes and water regimes - significantly interacted to impact the number of days to reach time to boot (Table 1). Under the water stress condition, all the wheat genotypes needed equal period for booting stage, which is the same in the non-stress condition. The maximum days to 1st booting appeared in Imdad-05, Kiran-95, and Benazir, and minimum days occurred in Sarsabz, TJ-83, and Hamal Fakir under the non-stress condition, while maximum days counted resulted in Kiran-95, NIA Amber, and Imdad-05 under the stressed surrounding. Similar results by Huang *et al.* (2020) in the non-stress condition at 90% had recorded days ranging 51–55, which was the same in stress-situation days, showing an equal response as in the non-stress (51–55 days).

Days to 90% heading

Water regimes are the factor that directly affects the number of days to reach heading time. The water-stress circumstances revealed all wheat genotypes required different times to appear in the heading stage, which is also distinct in the non-stress condition (Table 1). Based on the results, the maximum days to 90% heading resulted in Marvi-2000, NIA Sunder, and NIA Amber under the non-stress condition. As for the stressed setting, the utmost days came from NIA Amber, Marvi-2000, and Kiran-95. Zarei *et al.* (2021) and

Table 1. Mean performance for days to 1st booting and days to 90% heading of wheat genotypes grown under non-drought and drought situations.

Genotypes	Days to 1st booting			Days to 90% heading		
	Non-stress	Water stress	R.D*	Non-stress	Water stress	R.D*
Benazir	54.93	54.53	-0.40	64.13	61.27	-0.14
Hamal Fakir	51.73	51.40	-0.33	61.00	61.00	0.00
TD-1	50.60	51.67	1.07	58.67	55.33	-3.34
NIA Sunder	54.40	53.60	-0.80	65.07	61.00	-4.07
TJ-83	51.47	51.80	0.33	61.20	60.33	-0.87
Marvi-2000	54.13	54.13	0.00	65.13	62.00	-3.13
NIA Amber	54.73	55.13	0.40	64.87	62.17	-2.70
Sarsabz	51.47	51.67	0.20	56.53	54.80	-1.73
Kiran-95	55.07	55.00	-0.07	63.80	61.33	-2.47
Imdad-05	55.13	55.00	-0.13	61.53	60.00	-1.53
Mean	53.46	53.39	-0.07	62.19	59.92	-2.27
LSD 5% (T)	0.74			1.30		
LSD (5%) (G)	0.64			0.78		
LSD (5%)(T x G)	0.90			1.11		

Table 2. Mean performance for days to 90% maturity and plant height of wheat genotypes grown under water-treated and non-water treated conditions.

Genotypes	Days to 90% maturity			Plant height		
	Non-stress	Water stress	R.D*	Non-stress	Water stress	R.D*
Benazir	128.20	119.60	-8.60	94.00	85.07	-8.93
Hamal Fakir	125.27	123.13	-2.14	72.60	69.27	-3.33
TD-1	121.20	115.07	-6.13	59.00	51.67	-7.33
NIA Sunder	126.13	121.73	-4.40	94.67	91.00	-3.67
TJ-83	125.27	120.73	-4.54	86.47	82.20	-4.27
Marvi-2000	124.13	121.80	-2.33	86.47	81.00	-5.47
NIA Amber	120.87	115.93	-4.94	86.60	74.93	-11.67
Sarsabz	116.00	113.00	-3.00	75.73	70.33	-5.40
Kiran-95	122.93	119.20	-3.73	84.67	75.33	-9.34
Imdad-05	123.33	120.67	-2.66	76.27	69.67	-6.60
Mean	119.08	119.08	0.00	81.64	75.04	-6.60
LSD 5% (T)	1.57			0.51		
LSD (5%) (G)	1.60			1.08		
LSD (5%) (T x G)	2.26			1.52		

Farhood *et al*. (2022) reported similar results in non-stress conditions at days to 90% heading between 56 and 65 days, and in stress situations, days required differed compared with non-stress at 54 to 62.

Days to 90% maturity

Wheat genotypes and water treatments are the opposite in affecting the many days needed to attain the period of anthesis and physical maturity (Table 2). In water deficit, all wheat genotypes took a minimum time to get near anthesis over unknown conditions. According to the results, genotypes Benazir, NIA Sunder, and Hamal Fakir denoted maximum days to 90% maturity under normal conditions. Meanwhile, in water scarcity, Hamal Fakir, NIA Sunder, and Marvi-2000 took more days to a 90% maturity. However, Sarsabz and TD-1 took minimum days in non-stress situations, and TD-1 and NIA Amber were 90% matured under stress settings. Comparable results from Frih *et al.* (2021) stated a finding at 90% physiological maturity manifested in 116 to 128 days in water stress, with physical maturity estimated at 115 to 121 as earlier in opposite to stress.

Table 3. Mean performance for the peduncle length and tillers $plant^{-1}$ of wheat genotypes grown under water-treated and non-water treated conditions.

Genotypes	Peduncle length			Tillers $plant^{-1}$		
	Non-stress	Water stress	R.D*	Non-stress	Water stress	R.D*
Benazir	36.13	34.60	-1.53	7.67	5.70	-1.97
Hamal Fakir	36.20	34.73	-1.47	9.30	7.07	-2.23
TD-1	36.33	35.53	-0.80	9.67	7.97	-1.70
NIA Sunder	36.67	35.67	-1.00	8.53	8.40	-0.13
TJ-83	32.07	29.33	-2.74	8.27	6.77	-1.50
Marvi-2000	36.20	34.07	-2.13	7.93	6.60	-1.33
NIA Amber	37.53	35.67	-1.86	11.40	9.52	-1.88
Sarsabz	30.67	28.93	-1.74	8.06	6.41	-1.65
Kiran-95	35.80	31.60	-4.20	11.47	9.47	-2.00
Imdad-05	35.13	32.00	-3.13	9.40	7.83	-1.57
Mean	35.27	33.21	-2.06	9.17	7.57	-1.59
LSD 5% (T)	0.84			0.41		
LSD (5%) (G)	0.76			0.93		
LSD (5%) (T x G)	1.08			1.31		

Plant height (cm)

Usually, a declared maximum height has a low value due to lodging as a breeding aspect, while minimum height is valuable under the stressed and non-stressed. The results in Table 2 present the cultivars NIA Sunder, Benazir, and Kiran-95 displaying a maximum undesirable plant height under non-stress conditions; however, Hamal Fakir and TD-1 appeared with the minimum plant height under a water-stress condition. In water scarcity, the unfavorable plant height emerged in genotypes NIA Sunder, Benazir, and TJ-83, with a plant height average reduced by 6.60. Hence, the superior in this trait was minimum height observed in Hamal Fakir, TD-1, and Imdad-05, highlighted as desirable plants for under water stress conditions; therefore, these cultivars proved drought-fighters, agreeing with the results by Nikzad *et al.* (2022) and Tamrazov (2022), who also examined that the (5.98%) decline in plant height occurred in water-stopped conditions.

Peduncle length (cm)

More peduncles mean more grains, wherein most research revealed that the peduncle length is also crucial in maintaining a biological yield. As a result, the measuring range of peduncle length was from 30.67 to 37.53 in non-stressed. Likewise, in stress conditions, the peduncle length was 28.93 to 35.67. On mean values, water stress caused a -2.06 peduncle length reduction in stressed situations. The maximum length came from NIA Amber, NIA Sunder, and TD-1 in non-stressed among the genotypes, as provided in Table 3. Inversely, for water scarcity, the genotypes NIA Sunder and Sarsabz maintained their position of producing a maximum peduncle length. Therefore, these genotypes proved to be drought-resistant cultivars. Similarly, Banerjee *et al.* (2020) obtained equal results. According to his experiment, a reduction was -2.03 under the water-stress condition.

Tillers $plant^{-1}$

From the viewpoint of scientists, high tillers in wheat are the most desired trait because of a direct proportion to high yield. As a result of the non-stressed, the documented tillers $plant^{-1}$ had values of 7.67 to 11.47 from manual counting. However, in stressed conditions, the tillers were 5.70 to 9.52. For mean values, water scarcity caused a -1.59 tiller reduction per plant. According to genotypes, Kiran-95, NIA Amber, and TD-1 in non-stressed had given many tillers per plant (Table 3). Similarly, under stress, the genotypes Kiran-95, NIA Amber, and NIA Sunder also maintained their position on creating more tillers; therefore, these genotypes proved to be drought-resistant cultivars. Darzi-Ramandi *et al*. (2016) and Khare *et al.* (2020) reported the same experience (16.5%) loss of tillers under the influence of water-deficit conditions due to the loss of tillers and a decrease in grain weight by 8.0%.

Spike length (cm)

Usually considered an essential part of reproduction, many researchers have recommended that wheat's spike length is a morphologic trait positively correlated with the plant's grain yield. Analyses of this data shown in Table 4 denoted that spike length measurement ranged from 8.53 to 14.00 in the normal irrigated condition, while in non-irrigated, it was from 7.60 to 12.00, with a recorded mean decrease of -1.56. The highest spike length was evident in NIA Amber, Marvi-2000, and Kiran-95 in regular watering, and they maintained their spike length also in water scarcity. Therefore, these genotypes are more resistant to stress by exhibiting drought tolerance than other genotypes. Guttieri *et al*. (2001) obtained the same result with a decrease of -1.33 in water-scarcity conditions; however, non-stressed gave a higher spike length.

Table 4. Mean performance for the spike length and spikelets spike^{-1} of wheat genotypes grown under non-irrigated and water-irrigated conditions.

Genotypes	Spike length			Spikelets spike^{-1}		
	Non-stress	Water stress	R.D*	Non-stress	Water stress	R.D*
Benazir	10.73	9.80	-0.93	19.93	18.53	-1.40
Hamal Fakir	8.53	7.60	-0.93	14.53	12.47	-2.06
TD-1	11.60	9.47	-2.13	19.47	17.60	-1.87
NIA Sunder	10.67	9.07	-1.60	20.60	18.53	-2.07
TJ-83	12.07	9.67	-2.40	18.07	15.20	-2.87
Marvi-2000	12.47	11.13	-1.34	18.40	15.60	-2.80
NIA Amber	14.00	12.00	-2.00	20.87	17.26	-3.61
Sarsabz	11.60	10.53	-1.07	17.00	15.07	-1.93
Kiran-95	12.33	10.60	-1.73	18.73	15.73	-3.00
Imdad-05	11.33	9.84	-1.49	21.00	16.33	-4.67
Mean	11.53	9.97	-1.56	18.86	16.23	-2.62
LSD 5% (T)	0.46			0.63		
LSD (5%) (G)	0.50			0.61		
LSD (5%) (T x G)	0.71			0.87		

Spikelets per spike

The average of spikelets spike^{-1} was 18.86 under non-stressed, and in stressed conditions, it was 16.23. Computing the reduction difference showed the value of -2.62 due to water stress (Table 4). Less deduction emerged in genotypes Benazir, TD-1, and Sarsabz, with more decrease of the trait in Imdad-05, NIA Amber, and Kiran-95. The first group of genotypes occurred as water stress-resistant. However, the latter types are drought susceptible based on Nawaz *et al.* (2020), who stated that stress of water could significantly reduce the spike length of wheat; hence, the ratio of the wheat spike that is less parallels with the ratio of spikelets spike^{-1} that is also low, agreeing with the results by Badr and Bruggemann (2020) who observed about 12.76% reduction in number of spikes under water stress condition, and an increased wheat spikes with more number of irrigations.

Grains spike^{-1}

It is a highly essential trait, referring to a scientific approach usually under water stress reduces the plant's grains spike^{-1} influentially

Table 5. Mean performance for grains spike^{-1} and grain yield plant^{-1} of wheat genotypes treated with water and water-deficit conditions.

Genotypes	Grains spike^{-1}			Grain yield plant^{-1}		
	Non-stress	Water stress	R.D*	Non-stress	Water stress	R.D*
Benazir	53.67	50.60	-3.07	24.27	21.60	-5.02
Hamal Fakir	42.27	39.53	-2.74	22.50	20.41	-0.90
TD-1	56.07	52.40	-3.67	20.77	19.25	-0.36
NIA Sunder	60.87	55.60	-5.27	22.10	18.88	-3.22
TJ-83	55.20	51.27	-3.93	25.23	22.37	-2.86
Marvi-2000	54.27	52.80	-1.47	20.00	17.00	-3.00
NIA Amber	55.67	49.00	-6.67	25.49	22.60	-2.89
Sarsabz	51.00	47.47	-3.53	24.48	21.93	-2.55
Kiran-95	57.20	51.53	-5.67	22.33	19.00	-3.33
Imdad-05	62.27	57.53	-4.74	28.12	21.00	-7.12
Mean	54.84	50.77	-4.07	23.52	20.40	-3.12
LSD 5% (T)	0.38			0.95		
LSD (5%) (G)	0.86			0.77		
LSD (5%) (T x G)	1.21			1.10		

(Table 5). The lesser reduction was apparent in the following genotypes: Marvi-2000, Hamal Fakir, and Benazir, and a maximum decrease in NIA Amber, Kiran-95, and NIA Sunder under the water-stress condition, respectively. Meanwhile, in well-watered settings, the highest grains spike^{-1} resulted in genotypes Imdad-05, followed by NIA Sunder and Kiran-9, where Hamal Fakir, chased by Sarsabz and Benazir, contained lesser grains. In stress situations, maximum grains per spike were notable in Imdad-05, NIA Sunder, and Marvi-2000, with minimum grains found in Hamal Fakir, Sarsabz, and Benazir. Thus, they proved drought-resistant, with similar results observed by Badr and Bruggemann (2020).

Grain yield plant^{-1} (g)

Grain yield plant^{-1} is also one of the chief characteristics valuable in the world economic perspective. In this observation, the average reduction appeared at -3.12 due to a water-stress effect (Table 5). The highest grain yield plant^{-1} appeared in Imdad-05, NIA Amber, and TJ-83 under a non-stress condition, while less grain yield per plant came from the following genotypes: Marvi-2000, TD-1, and NIA Sunder. On the other side, the genotypes showing a high grain yield per plant were NIA Amber, TJ-83, and Sarsabz, considered resistant to water-stress conditions, with similar results noted by Clarke *et al.* (1992), who stated that yield is prone to decrease in stress, often at the time flower heading and soil dough stages. The drought stress, usually during maturation, caused a 10% decline point in yield. Inversely, moderate strain mainly affected the plant's harvest during the vegetative stage, according to Abou-Elwafa and Shehzad (2021), who documented a 31% loss in grain yield compared with the unaccepted stressed condition.

Seed index (1000-grain wt. g)

Under the irrigated situation, the mean value for the seed index was 38.32 g, whereas in the water-scarce condition, it was 31.86 g, as shown in Table 6. The decreases in seed index occurred in Benazir, TJ-83, and Marvi-2000, with a similar result given by Sami *et al*. (2020). According to him, drought caused the most loss in 1000 kernels' weight, and water shortage relatively decreased the weight of kernels, the percentage of dry matter aggregation, and the number of kernels. Jatoi *et al*. (2019, 2022) also reported same results in the wheat genotypes.

Table 6. Mean performance for seed index, biological yield plant^{-1}, and harvest index of wheat genotypes grown under non-stressed and water-stressed conditions.

Genotypes	Seed index			Biological yield plant^{-1}			Harvest index		
	Non-stress	Water stress	R.D*	Non-stress	Water stress	R.D*	Non-stress	Water stress	R.D*
Benazir	35.09	32.33	-2.76	47.67	43.67	-4.00	50.95	49.46	-1.49
Hamal Fakir	35.65	29.97	-5.68	43.33	41.67	-1.66	52.02	49.07	-2.95
TD-1	35.65	30.33	-5.32	41.33	38.88	-2.45	50.26	49.51	-0.75
NIA Sunder	40.00	29.11	-10.89	43.00	43.33	-0.33	51.40	43.56	-7.84
TJ-83	35.49	31.19	-4.30	51.33	45.67	-5.66	49.15	49.00	-0.15
Marvi-2000	34.00	29.00	-5.00	41.00	39.00	-2.00	48.82	43.63	-5.19
NIA Amber	40.00	32.73	-7.27	47.33	46.33	-1.00	53.85	48.79	-5.06
Sarsabz	41.00	34.00	-7.00	47.67	46.22	-1.45	51.36	47.46	-3.90
Kiran-95	42.00	34.00	-8.00	45.33	43.00	-2.33	49.28	44.17	-5.11
Imdad-05	44.33	36.00	-8.33	54.00	42.33	-11.67	52.06	49.61	-2.45
Mean	38.32	31.86	-6.46	46.19	43.01	-3.18	50.91	47.42	-3.48
LSD 5% (T)	0.72			2.38			0.66		
LSD 5%(G)	0.88			1.25			2.13		
LSD5%(x G)	1.25			1.76			3.02		

Biological yield plant^{-1} (g)

The biological yield is another vital parameter concerning matter accumulation in the plant system. Based on many researchers, if bio-yield is abundant in water-stressed conditions, such is a desirable trait, with conforming results mentioned in Table 6. The satisfactory biological yield plant^{-1} appeared in genotypes Imdad-05, TJ-83, and Sarsabz under a non-stressed condition, while in water stress, a high biological yield plant^{-1} came from cultivars NIA Amber, Sarsabz, and TJ-83, which are desirable from a breeding perspective. Moreover, the unwanted biological yield plant^{-1} was evident with Marvi-2000, NIA Sunder, and TD-1 under a non-stress setting, with Marvi-2000 and Hamal Fakir demonstrating an undesired biological yield plant^{-1} in an unfavorable condition. Therefore, groups that give low biological yield plant^{-1} are negligible, with similar results stated by Jimenez-Berni *et al*. (2018). The ground biological yield plant^{-1} has shown to be significantly influenced by the combined effect of water regimes and wheat cultivars, causing water deficit as stress above ground, consequently reducing biological yield plant^{-1} for the rest of the wheat genotypes.

Harvest index (%)

The average harvest index reduced (-3.48) due to water scarcity, while less reduction emerged in some cultivars, for instance, TJ-83, TD-1, and Benazir. On the other hand, an extended decline occurred in NIA Sunder, Marvi-2000, and Kiran-95 (Table 6). Hence, these highlighted two groups of genotypes, which could be distinctly the high-ranking as drought-tolerant and the latter as the highly susceptible ones. These similar consequent confirmations also have reports expressed by Jatoi *et al*. (2019, 2022), who concluded that the average HI decreased due to water stress; however, this deduction was lesser in tolerant genotypes, respectively.

Tolerance indices for drought

Comparison among genotypes based on resistance

In response to the scrutiny of state-of-the-art selected indices for wheat cultivars' selection to determine resistance against drought conditions, the indicators proved more reliable concerning grain yield in water-restricted conditions than regular environments, with the discussion results as follows.

Table 7. The mean value of grain yield plant^{-1} in non-stress (SSI) and yield in stress (MP) for stress susceptibility index (TOL) and mean productivity (GMP) of wheat genotypes under both conditions.

Genotypes	SSI	Rank	MP	Rank	TOL	Rank	GMP	Rank
Benazir	0.83	7	22.93	5	2.68	7	22.90	5
Hamal Fakir	0.70	9	21.46	6	2.09	9	21.43	6
TD-1	0.55	10	20.01	9	1.52	10	20.00	9
NIA Sunder	1.10	4	20.49	7	3.22	3	20.43	8
TJ-83	0.85	5	23.80	3	2.86	6	23.76	3
Marvi-2000	1.13	2	18.50	10	3.00	4	18.44	10
NIA Amber	0.85	6	24.04	2	2.89	5	24.00	2
Sarsabz	0.78	8	23.21	4	2.55	8	23.17	4
Kiran-95	1.12	3	20.67	8	3.33	2	20.60	7
Imdad-05	1.91	1	24.56	1	7.12	1	24.30	1

Stress susceptibility index (SSI)

For measuring the yield stability, scientists Fischer and Maurer (1978) discovered stress susceptibility, an index undergoing the estimation of the changes in yield both potentially and improbable under an exposure environment (Table 7). The genotypes with SSI <1 refer to more resistant genotypes under stressed and water-stressed conditions. Based on the SSI, results indicated highly resistant are TD-1 (0.55), Hamal Fakir (0.70), and Sarsabz (0.78), whereas Imdad-05 (1.9), Marvi-2000 (1.13), and Kiran-95 (1.12) were most susceptible, with similar results stated by Ahmed *et al.* (2020).

Mean productivity (MP)

Rosielle and Hamblin (1981) on mean productivity (MP) indicated an average of genotypes yield under uncertain water-stressed and non-given stressed situations (Table 7). The genotypes containing optimum data value of MP rates were notably more suitable. From this index, the Imdad-05 (24.56), NIA Amber (24.04), and TJ-83 (23.80) are the genotypes bearing the highest values. On the other hand, TD-1 (20.01), NIA Sunder (20.49), and Marvi-2000 (18.50) showed the lowest values (Table 7), with similar findings presented by Alhag *et al*. (2021).

Tolerance index (TOL)

The eminent researchers Rosielle and Hamblin (1981) developed the tolerance index (TOL). This index helps determine the cultivars' yield productivity differences. With the value of this index as more significant when it is less, as shown in Table 7, TD-1 (1.52), Hamal Fakir (2.09), and Sarsabz (2.55) displayed lesser values of TOL; hence, they achieved the top positions. Inversely, Imdad-05 (7.12), Kiran-95 (3.33), and NIA Sunder (3.22) incurred a high value of TOL and were more susceptible to waterless conditions, with analogous results declared by Khare and Shukla (2020).

Geometric mean productivity (GMP)

This tool is mainly helpful to researchers who are interested in comparative performance (Table 7). Subsequently, the water-deficit condition changes in the field of environments in past decades, as quoted by Ramirez and Kelly (1998). Genotypes with higher values of GMP are most desirable. In these studies, the genotypes such as Imdad-05 (24.30), TJ-83 (23.76), and Sarsabz (23.17) got the highest rank due to higher values of GMP, with similar findings detected by Ali and El-Sadek (2016).

Table 8. Stress tolerance index (STI), Yield index (YI), and Yield stress index (YSI) for identifying most resistant wheat genotypes under watered and water-stressed conditions.

Genotypes	STI	Rank	YI	Rank	YSI	Rank
Benazir	0.02	1	1.06	4	0.89	4
Hamal Fakir	0.01	10	1.00	6	0.91	2
TD-1	0.01	9	0.94	7	0.93	1
NIA Sunder	0.01	8	0.93	8	0.85	7
TJ-83	0.02	2	1.10	2	0.89	6
Marvi-2000	0.01	7	0.83	10	0.85	8
NIA Amber	0.02	3	1.11	1	0.89	5
Sarsabz	0.02	4	1.07	3	0.90	3
Kiran-95	0.01	6	0.93	9	0.85	9
Imdad-05	0.02	5	1.03	5	0.75	10

Stress tolerance index (STI)

A scientist named Fernandez (1992) discovered the stress tolerance index (STI) on account of determining the stress-tolerance potential of genotypes for higher yield. Subsequently, it has become a preferred vintage but reliable tool. By reference, an optimum STI indicates the cultivars with optimized data values are tolerant to drought stress. This study results showed the genotypes Imdad-05 (0.02), Sarsabz (0.02), and Benazir (0.02) as considerably drought-resistant because of having large STI values. Meantime, Hamal Fakir (0.01), TD-1 (0.01), and NIA Sunder (0.01) had susceptibility to drought with low STI values, as highlighted in Table 8. The same results came from Anwaar *et al.* (2020).

Yield index (YI)

Gavuzzi *et al*. (1997) termed Yield Index (YP) as a yield measurement formula index that evaluates the productivity and stability of chosen cultivars in both well-watered and non-watered circumstances. As a reference, if the genotypes get higher values of this index, it is more suitable for stressed conditions. The genotypes NIA Amber (1.11), TJ-83 (1.10), and Sarsabz (1.07) have shown as tolerant due to containing high values, but Kiran-95 (0.93), NIA Sunder (0.93), and Marvi-2000 (0.83) were low in range, therefore revealed as susceptible to drought (Table 8), with nearly the same consequence met by Yarahmadi *et al.* (2020).

Comparing genotypes based on tolerance indices

Employing various drought-tolerant indices approaches, the genotypes Imdad-05, NIA Sunder, and Marvi-2000 showed high values for STI, GMP, TOL, and MP, and lower values resulted in Kiran-95, NIA Sunder, and Hamal Fakir for SSI, YI, and YSI, which expressed that the genotypes performed equally best in both irrigated and non-irrigated conditions (Table 8) and are moderately performing genotypes under unfavorable and favorable conditions. Yarahmadi *et al*. (2020) reported those genotypes with high GMP are often likely to have phenomenal yield variations. They described a similar rank observed in the HM, MP, and TOL and also suggested these parameters have been sufficient for screening drought-tolerant genotypes. Anwaar *et al.* (2020) indicated that GMP, MP, and STI values are more likely better traits for selecting more high-yielding wheat cultivars. Although, TOL and SSI values are superior indices to describe tolerance levels. According to Sanchez-Reinoso *et al.* (2020), SSPI, RDI, and DI indices would be advantageous as the most desirable highlighter to evaluate drought-sustaining cultivars in genotypes of wheat, concerning Khayatnezhad and Gholamin (2020) on SSI as phenomenal for evaluating drought tolerance in wheat genotypes when historically finding a variation under the combination of stressed and non-stressed conditions.

Principal component analysis with biplot diagram

Results revealed that three components explained about 95.76% of total variability directly associated with STI, GMP, TOL, and MP. The second dimension of PCA 2 could be a stressed-resistant dimension, and this is most optimal for use in separating drought-tolerant genotypes from drought-susceptible, as the genotypes in Figures 1-3. Hence, genotypes Imdad-05, NIA Sunder, and TD-1 belonged to group 'A' genotypes, and other genotypes, such as Kiran-95 and NIA Amber are higher in PCA1 along with lower in PCA2. Meanwhile, PCA1 has genotypes that performed well under stress conditions, i.e., genotypes Marvi-2000 and Benazir in this category. Moreover, a fourth group with a low value of PCA1 and PCA2 attained recognition as minimum performing in non-stress and water-stress environments. The genotype plotted in this group is Hamal Fakir. Finally, Imdad-05, NIA Sunder, and TD-1 have appeared high-yielding under favorable and unfavorable conditions, with these varieties ranking drought-tolerant. Sahar *et al.* (2016) revealed related results from multiple analyses, acquiring 68% and 32% variability for PCA1 and PCA2, respectively.

Figure 1. Score Plot of SSI and YSI consequently demonstrated that variety Imdad-05 and NIA Sunder are highly-drought tolerant compared with others; therefore, they fell in first category, while Kiran-95 and NIA-Amber followed in second because they highlighted as moderately tolerant to drought. Marvi-2000 and Benazir were in the third category due to showing less adaptability against water-deficit conditions, and Hamal Fakir is in last due to showing a worse performance under drought situation. SSI= Stress susceptibility index, YSI= Yield stability index.

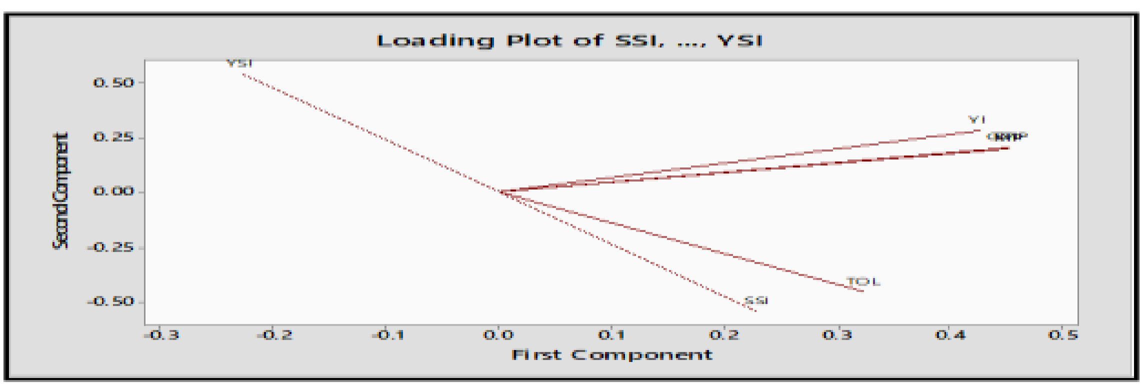

Figure 2. Loading Plot of SSI and YSI demonstrated correlation among drought indices, in which YI is correlated with GMP, while TOL is correlated with SSI. YSI is not correlated with any of the drought indices. SSI= Stress susceptibility index, YSI= Yield stability index, YI= Yield index, TOL= Tolerance index.

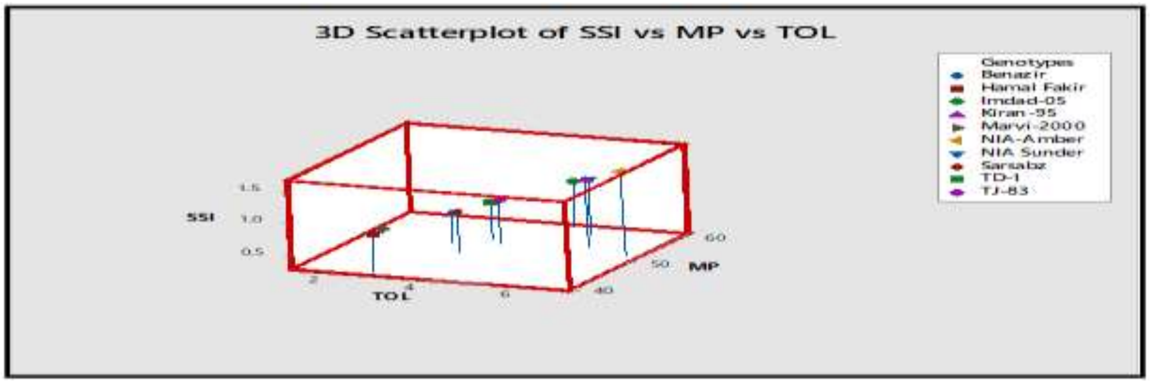

Figure 3. 3D Scatter Plot showed varieties which were top performers with values of SSI, TOL, and MP drought indices, in which NIA Amber, NIA Sunder, and TJ-83 are best performers under stress condition. SSI= Stress susceptibility index, TOL= Tolerance index, MP= Mean productivity.

CONCLUSIONS

Genotypes NIA Sunder, Imdad-05, and Benazir emerged as best performers under stress conditions at the anthesis for most studied traits. From drought-tolerant indices, the best cultivars were Imdad-05, NIA Sunder, and TD-1, at first category ranking, with Marvi-2000 and Benazir as moderately tolerant, and NIA Amber and Kiran-95 were susceptible.

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