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EVALUATION OF STRESS SELECTION INDICES FOR MORPHOLOGICAL TRAITS IN BREAD WHEAT

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SUMMARY

The research carried out under irrigated conditions during 2017–2018 estimated stress selection indices for morphological studies in wheat. Twenty wheat genotypes along with two checks (Pakhtunkhwa-2015 and Pirsabak-13) planted at Cereal Crops Research Institute (CCRI), Pirsabak Nowshera, Pakistan, had two sowing dates, i.e., regular plantation made on 24 November and late plantation on 25 December 2017, in a randomized complete block design with three replications. Nine stress tolerance indices, viz., tolerance index (TOL), mean productivity (MP), harmonic mean (HM), stress susceptibility index (SSI), stress intensity (SI), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), and yield stability index (YSI) served as the basis for computation on each trait and every genotype under stress and non-stress conditions. Grain yield demonstrated a positive relationship with MP, GMP, HM, and STI under stress and non-stress conditions, which can serve as a better indicator for testing tolerant wheat genotypes. Overall, the maximum value of MP, HM, GMP, and STI, for days to heading displayed in genotype CDRI-PV-1: 113.00, 112.12, 112.56, 1.30; days to maturity in genotype PS-28 with 151.00, 149.24, 150.11, 1.28; for plant height in genotype PS-28 with 108.00, 107.94, 107.88, 1.27: for grain yield in cultivar PS-34 with 3983.89, 3958.96, 3934.18, 2.25, and for biological yield in genotype PS-23 with 11250.00, 10999.44, 10754.46, and 1.80, which specify that they are most stable and tolerant genotypes across both the planting conditions. Analysis of variance revealed highly significant differences among genotypes for most traits. Based on stress selection indices and mean performance in this experiment, PS-23, PS-33, PS-34, and PS-28 genotypes showed the best performance, and genotype Inq-91/FS(f8) resulted as the most stable performance and tolerance in stress conditions compared with other genotypes in stress selection indices. These genotypes could be beneficial in future wheat breeding programs to enhance the grain yield stability in bread wheat.

Keywords: Bread wheat, stress selection indices, stress and non-stress environments, optimum and late sowing, abiotic stress conditions

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Key findings: Overall, the wheat genotypes PS-23, PS-33, PS-34, and PS-28, depicted the best performances, and genotype Inq-91/FS(f8) proved stress tolerant under stress conditions and the most stable genotype compared with other cultivars in grain yield.

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INTRODUCTION

Bread wheat is a self-pollinating crop in the true grass family Gramineae, the largest cereal crop widely grown as a staple food (Mollasadeghi and Shahryari, 2011). It provides nutrition to 36% of the global population and contributes 20% food calories. The wheat crop grows in irrigated and rainfed conditions (Siddiqui, 2008). In Pakistan, wheat crops occupied an area of about 9.2 million (9,205,500) ha during 2014, with a provisional yield estimated at 25 million (25,086,000) t and per unit yield estimated at 2,725 kg ha^{-1} (Anonymous, 2014). In Khyber Pakhtunkhwa, Pakistan, wheat cultivation occupied an area of 732,600 ha during 2014, with the production of 1.26 million (1,259,900) t at a per unit yield of 1,720 kg ha^{-1}. The District Swabi, Pakistan attained a record production of 91,624 t from an area of 46,991 ha, with a per unit yield of 1,950 kg ha^{-1} (Anonymous, 2014).

Wheat is an important commodity worldwide grown in more than 240 million ha, higher than any other crop, with a world trade greater than all other crops combined (Curtis, 1982). Globally, wheat is the leading source of vegetable protein in human food, having higher protein content than corn, rice, and other major cereals, in terms of total production tonnages used for food (Farhood *et al*., 2022). World demand for wheat by 2020 looms at 840 million to 1 billion t (Rosegrant *et al*., 2001). But with production environments and natural resources continuously shrinking and deteriorating because of climatic changes, increasing water resources shortage, and worsening eco-environment, wheat production significantly decreases (Singh and Chaudhary, 2006; Zulkiffal *et al*., 2022).

Heat stress is a severe hazard to agricultural output worldwide due to high ambient temperatures (Hall, 2001). Higher than normal temperatures have an impact on plant function and productivity. Short heat shocks (≥35°C) during the post-anthesis stage can considerably affect grain weight and grain quality in wheat (Wardlaw and Wrigley, 1994) and decrease grain quality (Randall and Moss, 1990; Savin *et al*., 1996). According to Ansari (2002), wheat planted in mid-November produces more tillers $plant^{-1}$ and grain output than wheat planted in mid- and late-December. A significant improvement in spring wheat yields can result from better breeding techniques and advanced agronomic procedures.

One of the core goals that plant breeders hope to accomplish includes choosing different genotypes under environmental stress conditions to utilize genetic variability to improve stress-tolerant cultivars for stress-tolerant genotypes. Basing on yield in stress and non-stress situations led to the development of many selection indices (Clarke *et al*., 1984). Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the yield disparities between non-stress and stress situations, with mean productivity (MP) as the average yield of these two environments. They discovered a link between mean productivity (MP) and yield under stress (Ys), implying that selecting based on MP could boost average yield in both stress and non-stress situations. The genotype stress susceptibility index (SSI), as proposed by Fischer and Maurer (1978), refers to the ratio of genotypic performance under stress and non-stress situations. They proposed SSI as a method for assessing yield stability in changeable environments, taking into account changes in both prospective and actual yields.

Breeders interested in relative performance frequently employ the geometric mean productivity (GMP) indicator (Ramirez and Kelly, 1998). GMP use can evaluate the extent or degree of vulnerability in both stressed and non-stressed settings to prevent the impacts of stress variation across years (Fernandez, 1992; Kristin *et al*., 1997; Mitra, 2001). In light of the preceding facts and numbers, the recent research prevailed with the following goals, i.e., a) screening of wheat genotypes based on the performance under normal and stress conditions, b) study stress selection indices and their relative efficiencies in the improvement of yield in wheat, and c) identify and select high yielding wheat genotypes under stress conditions.

MATERIALS AND METHODS

Experimental site, material and design

Conduct of the research occurred during 2017–2018 under irrigated conditions at the Cereal Crops Research Institute (CCRI), Pirsabak Nowshera, Pakistan (located at 340 north latitude, 720 east longitude, and 2880 altitude). The experimental material comprised 20 wheat genotypes, including two check cultivars (Pakhtunkhwa-2015 and Pirsabak-13), planted under two different sowing dates, i.e., regular planting on 24 November and late planting on 25 December 2017 in a randomized complete block design (RCBD) with three replications. Each plot consisted of four rows of 1.5-m length, with row spacing at 30 cm and a plot area of 9 m^2. Details of the parental genotypes appear in Table 1. A row between adjacent plots provided a reserved fallow to facilitate data recording. All the entries from sowing until harvesting received standard and same agronomic practices and inputs, with the genotypes grown under uniform conditions to minimize environmental variations.

Table 1. Wheat genotypes used in the study during 2017–2018 at CCRI, Pirsabak Nowshera, Pakistan.

No	Genotypes	Breeding Station	No.	Genotypes	Breeding Station
1.	Inq-91/FS(f8)	NIFA Pesh.	11.	PS-33	CCRI Pirsabak
2.	SRN-13121	NIFA Pesh.	12.	PS-34	CCRI Pirsabak
3.	CT-13052	NIFA Pesh.	13.	PS-35	CCRI Pirsabak
4.	CT-13169	NIFA Pesh.	14.	AUP-05814	PBG (UAP)
5.	DN-120	ARI D.I. Khan	15.	AUP-07014	PBG (UAP)
6.	DN-122	ARI D.I. Khan	16.	CDRI-PV-1	NARC Islamabad
7.	DN-123	ARI D.I. Khan	17.	CDRI-PV-2	NARC Islamabad
8.	PS-22	CCRI Pirsabak	18.	CDRI-SA-12	NARC Islamabad
9.	PS-23	CCRI Pirsabak	19.	Pakhtunkhwa-2015	CCRI Pirsabak
10.	PS-28	CCRI Pirsabak	20.	Pirsabak-13	CCRI Pirsabak

Data recorded

Data recording on various parameters at the appropriate time used standard procedure for days to heading, days to maturity, plant height (cm), biological yield, and grain yield (kg ha^{-1}).

Stress selection indices

The experiment with typical planting and late planting considered as non-stress and stress environments, respectively, determined the following selection indices. Let the Y_p = Yield of a given genotype in a non-stress environment; Y_S = Yield of a given genotype in a stress environment; Y_p = mean yield under a non-stress environment; and Y_s = mean yield under a stress environment. The following stress tolerance indices calculations resulted from these four measurements.

Tolerance Index (TOL) as done by Rosielle and Hamblin (1981): TOL = (Yp - Ys)

Mean productivity (MP) as calculated by Rosielle and Hamblin (1981): MP = (Ys + Yp) / 2

Where: Yp and Ys = the yield of each cultivar, non-stressed and stressed, respectively.

Harmonic mean (HM) (Kristin *et al.,* 1997): HM = 2(Yp × Ys) / (Yp + Ys)

Stress intensity (SI) (Fisher and Maurer, 1978): SI = 1 - (Ŷs/Ŷp), while SSI = 1 - (Ys/Yp)/SI

Where: SSI is stress susceptibility index and Ŷs and Ŷp are the means of all genotypes under stress and well non-stress environments, respectively.

Geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992; Kristin *et al.,* 1997): GMP = (Yp × Ys) $^{1/2}$, STI = (Yp × Ys)/(Ŷp)

Table 2. Stress selection indices for days to heading in wheat genotypes evaluated during 2017–2018at CCRI, Pirsabak Nowshera, Pakistan.

Genotypes	TOL	MP	HM	SI	SSI	GMP	STI	YI	TSI / YSI
Inq-91/FS(f8)	18.33	108.50	107.73	0.17	0.93	108.11	1.20	1.00	0.84
SRN-13121	17.67	107.17	106.44	0.05	3.34	106.80	1.17	0.99	0.85
CT-13052	21.00	107.83	106.81	0.05	3.90	107.32	1.18	0.98	0.82
CT-13169	22.33	111.50	110.38	0.05	4.00	110.94	1.26	1.01	0.82
DN-120	22.33	111.50	110.38	0.05	4.00	110.94	1.26	1.01	0.82
DN-122	19.67	108.17	107.27	0.05	3.66	107.72	1.19	0.99	0.83
DN-123	19.00	106.50	105.65	0.05	3.60	106.08	1.15	0.98	0.84
PS-22	23.00	110.17	108.97	0.05	4.15	109.56	1.23	1.00	0.81
PS-23	19.33	107.00	106.13	0.05	3.64	106.56	1.16	0.98	0.83
PS-28	20.00	109.00	108.08	0.05	3.69	108.54	1.20	1.00	0.83
PS-33	19.67	107.50	106.60	0.05	3.68	107.05	1.17	0.99	0.83
PS-34	22.00	112.00	110.92	0.05	3.93	111.46	1.27	1.02	0.82
PS-35	17.67	106.17	105.43	0.05	3.37	105.80	1.14	0.98	0.85
AUP-05814	19.67	110.17	109.29	0.05	3.60	109.73	1.23	1.01	0.84
AUP-07014	20.33	111.17	110.24	0.05	3.68	110.70	1.25	1.02	0.83
CDRI-PV-1	20.00	113.00	112.12	0.05	3.57	112.56	1.30	1.04	0.84
CDRI-PV-2	18.33	107.83	107.05	0.05	3.44	107.44	1.18	1.00	0.84
CDRI-SA-12	19.00	105.83	104.98	0.05	3.62	105.41	1.14	0.97	0.84
Pakhtunkhwa-2015	19.33	108.00	107.13	0.05	3.61	107.57	1.18	0.99	0.84
Pirsabak-13	19.33	107.67	106.80	0.05	3.62	107.23	1.18	0.99	0.84

Yield index (YI) (Gavuzzi *et al.,* 1997; Lin *et al.,* 1986): YI = Ys/$\hat{Y}$s

Yield stability index, YSI = Ys/Yp (Bouslama and Schapaugh, 1984)

RESULTS

Days to heading

As TOL is the difference between the performance of a genotype under non-stress and stress environments, the genotypes that exhibit minimum values of TOL will be more stable. In the data, TOL showed a rate of 17.67 for SRN-13121 and PS-35, which shows that they are more stable than the other genotypes. The genotype CDRI-PV-1 showed maximum values of MP (113.00), HM (112.12), GMP (112.56), and STI (1.30), which indicates it was the most stable genotype across both the planting conditions. Similarly, the other stable genotypes, i.e., AUP-07014, PS-34, DN-120, and CT-13169, also exhibited the desired levels of MP, HM, GMP, and STI. The selection index YI with maximum values reflects the best performer under a stress environment. CRDI-PV-1 provided the best genotype, with a YI value of 1.04, followed by AUP-07014 (1.02), and PS-34 with 1.02 YI. The genotype CDRI-SA-12 displayed the inferior genotype with 0.97 YI. Stress susceptibility index estimation comes from the relative performance of genotypes under stress to their performance under non-stress conditions. The genotype with high YSI values will have the best performance under stress and non-stress environments and can serve as an indicator of a resistant genotype. Based on YSI, the desirable genotypes emerged as SRN-13121 and PS-35 with a YSI value of 0.85. The stress susceptibility index (SSI) estimates the degree of susceptibility or reduction in yield of a genotype under stress conditions. Genotypes showed that SSI less than one are more resistant to stress conditions. Based on SSI, the best performer in the study results showed that the genotype Inq-91/FS(f8) (0.93) proved highly stress tolerant and PS-22 with 4.15 because the greater the value will be, the most less stress tolerance. Stress intensity SI results here was approximately similar, with the desirable genotypes shown by SRN-13121, followed by CT-13052, CT-13169, and DN-120; all 19 genotypes have the same result (0.05), except Inq-91/FS(f8) (0.17) (Table 2). However, this index just calculates to measuring drought stress intensity in each experiment and has no efficiency in measuring stress intensity in different genotypes.

Days to maturity

The tolerance index TOL for days to maturity ranged from 28.33 to 32.67. The maximum value of TOL appeared for PS-28 and AUP-05814, followed by PS-22 and AUP-07014 with 22.33 TOL. The studied stress indices found the lowest TOL in CT-13052, followed by PS-

33, CDRI-PV-1, and Pirsabak-13. Therefore, these genotypes had a lower yield reduction in stress conditions. A higher TOL value linked with PS-28 and AUP-05814 indicates that this genotype had a higher yield reduction under heat- stressed conditions and higher heat susceptibility. The genotype PS-28 showed maximum values of MP (151.00), GMP (150.11), STI (1.28), and HM (149.24). It indicated that it was the most stable genotype across both planting conditions. Similarly, the other stable genotypes PS-22, CT-13169, CT-13169, and PS-28 also exhibited the desired levels of MP, HM, GMP, and STI, signifying that with the increase of these indices, yield under timely sowing conditions would also increase. Stress intensity SI results showed approximately similar, and based on this, the desirable genotypes resulted with SRN-13121, followed by CT-13052, CT-13169, and DN-120. All 19 genotypes gave the same result (0.05) except Inq-91/FS(f8). However, this index only calculates for measuring drought stress intensity in each experiment, with no efficiency in measuring stress intensity in different genotypes. The YI with maximum values revealed the best performance under stress environments. CT-13169 is the best genotype with a YI value of 1.02, followed by PS-34 and PS-28 with 1.02 YI. The genotypes DN-123, CDRI-PV-1, and CDRI-SA-12 scored the inferior genotypes with YI (0.97) (Table 3).

The stress susceptibility index (SSI) evaluates the degree of susceptibility or reduction in yield of a genotype under stress conditions. Genotypes showed that an SSI less than one is more resistant to stress conditions while a greater than one shows less tolerance. Based on the SSI, the genotype Inq-91/FS(f8) (1.02) gave the best performance, and AUP-05814 with 4.15 presented the most susceptible to stress. The basis of yield stability index (YSI) estimation relies on the relative yield of genotypes under normal and late conditions. Genotypes with high YSI values will have high yield under both environments, which can indicate a resistant genotype. The YSI value higher than one indicates better performance of a genotype under stress than under normal and vice versa. According to YSI, the desirable genotypes revealed CT-13052, DN-122, PS-33, PS-35, and CDRI-PV-1 (0.82), along with the check, Pirsabak-13, with a YSI value of 0.82.

Plant height

The tolerance index TOL of plant height ranged from 0.00 to 14.00. The maximum TOL (16.67) came from AUP-05814, whereas the minimum TOL (0.00) was from Inq-91/FS(f8). The genotype PS-28 showed maximum values of MP (108.00), GMP (107.94), STI (1.27), and HM (107.88). Inversely, another stable cultivar, PS-33, and the genotype Pirsabak-13 have presented the minimum values of MP (91.50), HM (91.39), GMP (91.45), and STI (0.91). Regarding the yield stability index, the stable genotype is Inq-91/FS(f8) with 1.00 YSI, followed by CDRI-PV-1 (0.96). The

Table 3. Stress selection indices for days to maturity in wheat genotypes evaluated during 2017–2018 at CCRI, Pirsabak Nowshera, Pakistan.

Genotypes	TOL	MP	HM	SI	SSI	GMP	STI	YI	TSI / YSI
Inq-91/FS(f8)	31.33	148.67	147.02	0.19	1.02	147.84	1.24	1.00	0.81
SRN-13121	30.67	147.67	146.07	0.05	4.13	146.87	1.22	1.00	0.81
CT-13052	28.33	147.17	145.80	0.05	3.86	146.48	1.22	1.00	0.82
CT-13169	31.00	150.83	149.24	0.05	4.09	150.03	1.28	1.02	0.81
DN-120	31.00	148.50	146.88	0.05	4.15	147.69	1.24	1.00	0.81
DN-122	29.67	147.83	146.34	0.05	4.00	147.09	1.23	1.00	0.82
DN-123	30.00	145.33	143.79	0.05	4.11	144.56	1.19	0.98	0.81
PS-22	32.33	150.83	149.10	0.05	4.25	149.96	1.28	1.01	0.81
PS-23	32.00	147.33	145.60	0.05	4.30	146.46	1.22	0.99	0.80
PS-28	32.67	151.00	149.23	0.05	4.29	150.11	1.28	1.01	0.80
PS-33	29.00	146.83	145.40	0.05	3.95	146.12	1.21	1.00	0.82
PS-34	30.33	150.50	148.97	0.05	4.02	149.73	1.27	1.02	0.82
PS-35	30.67	147.67	146.07	0.05	4.13	146.87	1.22	1.00	0.81
AUP-05814	32.67	148.00	146.20	0.05	4.37	147.10	1.23	0.99	0.80
AUP-07014	32.33	149.50	147.75	0.05	4.29	148.62	1.25	1.00	0.80
CDRI-PV-1	29.33	150.00	148.57	0.05	3.91	149.28	1.26	1.02	0.82
CDRI-PV-2	29.67	145.50	143.99	0.05	4.06	144.74	1.19	0.98	0.81
CDRI-SA-12	29.67	145.50	143.99	0.05	4.06	144.74	1.19	0.98	0.81
Pakhtunkhwa-2015	30.67	147.33	145.74	0.05	4.14	146.53	1.22	0.99	0.81
Pirsabak-13	29.33	145.67	144.19	0.05	4.02	144.93	1.19	0.99	0.82

Table 4. Stress selection indices for plant height in wheat genotypes evaluated during 2017–2018 at CCRI, Pirsabak Nowshera, Pakistan.

Genotypes	TOL	MP	HM	SI	SSI	GMP	STI	YI	TSI / YSI
Inq-91/FS(f8)	0.00	93.67	93.67	0.09	0.00	93.67	0.96	0.98	1.00
SRN-13121	9.67	99.83	99.60	0.05	2.03	99.72	1.09	0.99	0.91
CT-13052	6.00	102.00	101.91	0.05	1.25	101.96	1.14	1.04	0.94
CT-13169	11.00	92.83	92.51	0.05	2.46	92.67	0.94	0.91	0.89
DN-120	10.00	100.67	100.42	0.05	2.08	100.54	1.11	1.00	0.91
DN-122	10.33	95.83	95.55	0.05	2.25	95.69	1.00	0.95	0.90
DN-123	5.33	100.00	99.93	0.05	1.14	99.96	1.09	1.02	0.95
PS-22	5.33	100.67	100.60	0.05	1.13	100.63	1.11	1.02	0.95
PS-23	12.67	107.33	106.96	0.05	2.45	107.15	1.26	1.06	0.89
PS-28	7.33	108.00	107.88	0.05	1.44	107.94	1.27	1.09	0.93
PS-33	13.67	107.83	107.40	0.05	2.62	107.62	1.27	1.06	0.88
PS-34	11.33	99.00	98.68	0.05	2.38	98.84	1.07	0.98	0.89
PS-35	13.67	101.83	101.37	0.05	2.76	101.60	1.13	0.99	0.87
AUP-05814	16.67	99.67	98.97	0.05	3.39	99.32	1.08	0.96	0.85
AUP-07014	13.67	96.50	96.02	0.05	2.90	96.26	1.01	0.94	0.87
CDRI-PV-1	4.33	99.83	99.79	0.05	0.93	99.81	1.09	1.02	0.96
CDRI-PV-2	8.33	99.17	98.99	0.05	1.77	99.08	1.07	0.99	0.92
CDRI-SA-12	5.00	103.50	103.44	0.05	1.04	103.47	1.17	1.06	0.95
Pakhtunkhwa-2015	14.00	105.33	104.87	0.05	2.74	105.10	1.21	1.03	0.88
Pirsabak-13	6.33	91.50	91.39	0.05	1.47	91.45	0.91	0.92	0.93

genotype Inq-91/FS(f8) has a minimum value of 0.00 for SSI, and AUP-05814 showed a maximum value of 3.39. The highest selection index YI surfaced for the genotype PS-28 (1.09) and the lowest (0.91) for CT-13169. The stress intensity SI in the study results values is almost the same for all, except Inq-91/FS(f8) with 0.09 (Table 4).

Biological yield

The maximum tolerance index (TOL) appeared in genotypes AUP-05814 and AUP-07014 at 5555.56, whereas the minimum TOL came for genotype Inq-91/FS(f8) (1077.78). Genotype PS-23 showed the maximum MP (11250.00), HM (10754.46), GMP (10999.44), and STI (1.80), whereas the minimum came from genotype AUP-07014 with MP (8611.11), HM (7715.05), GMP (8150.78), and STI (0.99). The maximum stress intensity SI emerged in genotype Inq-91/FS(f8) with values of 0.32. In these results the SI showed similarity for all except Inq-91/FS(f8) (0.32). Meanwhile, the cultivar Inq-91/FS(f8) gave the minimum SSI at 0.34, whereas the maximum in cultivar AUP-07014 at 10.71. The results on YI minimum genotype are AUP-07014 (0.71), with maximum genotypes coming from SRN-13121, CT-13052, PS-28, and PS-34 at 1.12. The minimum YSI turned up in genotype AUP-07014 (0.51), and the maximum YSI from Inq-91/FS(f8) at 0.89 (Table 5).

Grain yield plant^{-1}

The TOL for grain yield ranged from 244.44 to 2050.00, with the maximum TOL observed for AUP-07014 (2050.00), followed by AUP-05814 (1957.78). The minimum TOL resulted for Inq-91/FS(f8) (244.44), followed by CDRI-PV-2 (412.22) as the least stress tolerant, which shows that they are more stable genotypes as compared with others. The TOL index is the difference in yield under non-stress and stress environments, therefore, the higher the value of TOL, the higher the yield reduction under stress and the stress sensitivity. The genotypes that exhibit minimum values of TOL show more stability. The cultivar PS-34 showed maximum values for MP (3983.89), HM (3934.18), GMP (3958.96), and STI (2.25), specifying it as the most stable and tolerant genotype across the planting conditions. Similarly, genotypes PS-23, PS-28, PS-22, and DN-123 also exhibited the desired levels of MP, HM, GMP, and STI. Likewise, genotype CDRI-SA-12 showed susceptibility.

Genotypes showing SSI <1 are more resistant to stress conditions. Based on SSI, genotype Inq-91/FS(f8) (0.74) revealed highly stress tolerant compared with the others. The YI calculation depends on the yield of a genotype to the mean yield of all the tested genotypes under stress environments. The YI classified genotype PS-34 (1.34), followed by Inq-91/FS(f8) (1.24) as the most tolerant,

Table 5. Stress selection indices for biological yield in wheat genotypes evaluated during 2017–2018 at CCRI, Pirsabak Nowshera, Pakistan.

Genotypes	TOL	MP	HM	SI	SSI	GMP	STI	YI	TSI / YSI
Inq-91/FS(f8)	1077.78	9427.78	9396.98	0.32	0.34	9412.36	1.31	1.08	0.89
SRN-13121	3611.11	10972.22	10675.11	0.05	6.21	10822.64	1.74	1.12	0.72
CT-13052	1944.44	10138.89	10045.66	0.05	3.84	10092.17	1.51	1.12	0.83
CT-13169	4444.44	9722.22	9214.29	0.05	8.17	9464.85	1.33	0.91	0.63
DN-120	4055.56	8972.22	8513.93	0.05	8.10	8740.07	1.13	0.85	0.63
DN-122	5000.00	9722.22	9079.37	0.05	8.98	9395.30	1.31	0.88	0.59
DN-123	3611.11	10694.44	10389.61	0.05	6.34	10540.93	1.65	1.08	0.71
PS-22	3888.89	10555.56	10197.37	0.05	6.83	10374.92	1.60	1.05	0.69
PS-23	4722.22	11250.00	10754.46	0.05	7.62	10999.44	1.80	1.08	0.65
PS-28	3333.33	10833.33	10576.92	0.05	5.86	10704.36	1.70	1.12	0.73
PS-33	4722.22	10416.67	9881.48	0.05	8.12	10145.55	1.53	0.98	0.63
PS-34	2777.78	10555.56	10372.81	0.05	5.11	10463.78	1.63	1.12	0.77
PS-35	3888.89	10555.56	10197.37	0.05	6.83	10374.92	1.60	1.05	0.69
AUP-05814	5555.56	10000.00	9228.40	0.05	9.55	9606.45	1.37	0.88	0.57
AUP-07014	5555.56	8611.11	7715.05	0.05	10.71	8150.78	0.99	0.71	0.51
CDRI-PV-1	2777.78	10277.78	10090.09	0.05	5.23	10183.50	1.54	1.08	0.76
CDRI-PV-2	3611.11	10694.44	10389.61	0.05	6.34	10540.93	1.65	1.08	0.71
CDRI-SA-12	3611.11	8750.00	8377.43	0.05	7.51	8561.69	1.09	0.85	0.66
Pakhtunkhwa-2015	4166.67	10694.44	10288.60	0.05	7.16	10489.56	1.63	1.05	0.67
Pirsabak-13	4444.44	9722.22	9214.29	0.05	8.17	9464.85	1.33	0.91	0.63

Table 6. Stress selection indices for grain yield in wheat genotypes evaluated during 2017–2018 at CCRI, Pirsabak Nowshera, Pakistan.

Genotypes	TOL	MP	HM	SI	SSI	GMP	STI	YI	TSI / YSI
Inq-91/FS(f8)	244.44	3388.89	3384.48	0.31	0.22	3386.68	1.65	1.24	0.93
SRN-13121	1170.00	3231.67	3125.77	0.05	6.73	3178.28	1.45	1.00	0.69
CT-13052	494.44	3401.67	3383.70	0.05	2.98	3392.67	1.65	1.20	0.86
CT-13169	1373.33	3186.67	3038.70	0.05	7.79	3111.81	1.39	0.95	0.65
DN-120	1948.89	2824.44	2488.26	0.05	11.27	2651.03	1.01	0.70	0.49
DN-122	1448.89	3067.78	2896.70	0.05	8.39	2981.01	1.28	0.89	0.62
DN-123	957.78	3457.78	3391.45	0.05	5.34	3424.46	1.68	1.13	0.76
PS-22	864.44	3577.78	3525.56	0.05	4.73	3551.57	1.81	1.19	0.78
PS-23	1460.00	3786.67	3645.94	0.05	7.10	3715.64	1.98	1.16	0.68
PS-28	1364.44	3653.33	3525.94	0.05	6.91	3589.07	1.85	1.13	0.69
PS-33	1567.78	3335.00	3150.75	0.05	8.36	3241.56	1.51	0.97	0.62
PS-34	890.00	3983.89	3934.18	0.05	4.41	3958.96	2.25	1.34	0.80
PS-35	1033.33	3372.22	3293.06	0.05	5.83	3332.41	1.59	1.08	0.73
AUP-05814	1957.78	2846.67	2510.05	0.05	11.24	2673.07	1.03	0.71	0.49
AUP-07014	2050.00	2636.11	2237.56	0.05	12.30	2428.67	0.85	0.61	0.44
CDRI-PV-1	1096.67	2842.78	2737.01	0.05	7.10	2789.39	1.12	0.87	0.68
CDRI-PV-2	412.22	3440.56	3428.21	0.05	2.48	3434.38	1.69	1.23	0.89
CDRI-SA-12	808.89	2116.67	2039.39	0.05	7.05	2077.67	0.62	0.65	0.68
Pakhtunkhwa-2015	1190.00	3541.67	3441.71	0.05	6.32	3491.33	1.75	1.12	0.71
Pirsabak-13	1855.56	3178.89	2908.11	0.05	9.92	3040.49	1.33	0.85	0.55

whereas AUP-07014 (0.61), followed by CDRI-SA-12 (0.65) showed less tolerance. The YSI estimation depends on the relative yield of genotypes under stress to their yield under non-stress conditions. A genotype with a high YSI value will have a high yield under stress and non-stress environments and could indicate a resistant genotype. A YSI value greater than one indicates better performance of a genotype under stress than normal. According to YSI, the desirable genotypes indicate Inq-91/FS(f8) (0.93), followed by CDRI-PV-2 (0.89), whereas, Pirsabak-13 (0.50), followed by DN-120 (0.49) as the undesirable genotypes. Stress intensity is almost similar in all genotypes (0.05) except Inq-91/FS(f8) (0.31) (Table 6).

DISCUSSION

The selection of genotypes with better yield under stress (biotic or abiotic) is a prime objective of every breeding program. Plant breeders have long strived to feed an increasing population around the globe. Wheat genotypes with superior performance under non-stress environment might perform less under stress conditions regarding grain yield. However, at maturity, maximum grain yield appeared related to total dry biomass in drought stress (Fischer & Wood, 1979). As the crop is prone to several sources of stress, such as lodging, pre-harvest sprouting, hail, and biological challenges, knowing when the crop reaches physiological maturity proves critical in particular situations (Calderini and Reynolds, 2000). Yield reduction can decline to 10% due to stress during the maturing phase (Bauder, 2001). Under non-stress conditions, Ehdaie and Shakiba (1996) discovered no link between the stress susceptibility index (SSI) and grain yield in wheat. Drought-resistant genotypes have high GMP and STI values while having a low SSI score. As a result, a combination of multiple indicators can help identify and select genotypes that most adapt to stress and non-stress environments.

The highest tolerance index (TOL) revealed in genotype AUP-05814 showed a higher yield reduction under stress conditions and a higher drought sensitivity for plant height. A negative value of TOL showed more yield in stress than in irrigated conditions. Genotypes for MP, HM, GMP, and STI observed almost identical ranks, and these results aligned with the findings of Saba *et al*. (2001) for MP, HM, GMP, and STI. In these results, genotype PS-28 showed the same in these indices for plant height. Similarly, PS-33 displayed a stable genotype. As production falls with rising SSI for plant height under stress, TOL and SSI indices are suitable criteria to identify wheat genotypes with low yield and drought tolerance. No significant relationship existed between the TOL and MP, HM, GMP, STI, or YI. It had a strong and favorable relationship with SSI. It showed that SSI and TOL were equally capable of performing stress tolerance tests. The HM, GMP, STI, YI, and STI were all substantially and positively linked with mean productivity (MP) (Link *et al*., 1999). HM also had a positive and significant genotypic connection with GMP, STI, YI, and STI, based on the study calculations. SSI had a strong and negative relationship with YSI and a weak negative association with GMP, STI, YI, and STI, even though STI and genotype yield had a significant and positive relationship for plant height both under stress and irrigated circumstances. Therefore, these results gain support from Faheem et al., (2016), who found that a genotype with the lowest SSI and YSI value greater than unity performs better under stress than normal and vice versa for plant height.

Biological yield is an essential yield characteristic in wheat. However, stress circumstances may have a greater impact on this feature, and cultivars that perform well in terms of biological yield in a non-stressed environment may perform less as well in a stressed environment (Afiuni and Mahlouji, 2006). Higher biomass at maturity has been linked to the highest production under water stress. Drought circumstances cause biological yield reduction to a higher level (Ashraf *et al*., 2008). The genotype RWM-9313 did not show any remarkable reduction in yield when planted late and seemed to possess tolerance to high temperatures to some extent. Early seeded wheat crops almost always produce higher yields (Arain *et al*., 1999), with proof of this refers to the tolerance index (TOL), yield stability index (YSI), stress susceptibility index (SSI), and high stress intensity (SI) of the genotype Inq-91/FS(f8) showing the most stable performance in stress compared with other genotypes. Based on MP, HM, STI, and GMP, the best performer in the studied genotypes is PS-23. Similarly, in the study, the best performer based on YI was genotype SRN-13121, followed by CT-13052 for biological yield. The highest values of TOL and SSI among the stress tolerance indicators signify more susceptibility to stress, hence, minimal values of TOL and SSI are preferable. According to Golabadi *et al*. (2006), genotypes with low yield under non-stress settings and high yield under stress conditions gain favor via selection based on these two indices. On the other hand, selection based on GMP and STI resulted in genotypes with higher stress tolerance and yield potential (Fernandez, 1992).

Modern high-yielding wheat cultivars seemed better adapted to favorable growth conditions, but older cultivars and landraces have a more consistent yield under dry stress (Mardeh *et al*., 2006). Also, from the anthesis through the maturity stage, the lack of water supply occurs, usually resulting in poor assimilation, lower photosynthate translocation to the grain, and increased respiratory losses (Acevedo, 1990; Shpiler and Blum, 1991). In such cases, STI, GMP, and MP use screened drought-tolerant high-yielding genotypes (Mohammadi *et al*., 2003). Comparing this with the study, genotype PS-34 stood out as the best, with stable performance based on MP, HM, GMP, and STI. According to TOL, genotype Inq-91/FS(f8) was most tolerant to stress conditions in the study findings. The SSI proved to be a more effective index for distinguishing resistant genotypes when the stress was severe, however, no indicators could specifically identify cultivars with high yield under both normal and late planting conditions. Based on SSI, genotype Inq-91/FS(f8) was highly stress-tolerant in the experiments. They performed better in more favorable circumstances, according to the findings of this study, which indicated that breeders should select indices based on the stress level in the target habitat. When stress is high, SSI is recommended as a valuable indicator for wheat breeding, while recommending MP, GMP, TOL, HM, and STI proves best when stress is less severe.

CONCLUSIONS

From the total tested genotypes in stress and non-stress conditions, the Inq-91/FS(f8), AUP-05814, and PS-34, followed by PS-28, demonstrated as the superior lines for future wheat breeding programs and set for release as a new variety after conducting yield and multi-location trials.

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