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WHEAT GENOTYPES ASSESSMENT FOR SALINITY TOLERANCE USING MULTIVARIABLE SELECTION APPROACHES

S. M. Arain*, M. Faheem, K. A. Laghari and M. A. Sial

Nuclear Institute Of Agriculture (Nia), Tando Jam, Po Box 70060, Pakistan
*Corresponding Author E-mail: saimamir_nia@yahoo.com

ABSTRACT

The salinity tolerance indices, principal component analysis, and cluster analysis were employed to evaluate the 16 wheat genotypes for agro-morphological traits under normal and saline (834-1850ppm/pH 7.3-7.5 soils) conditions for two consecutive years 2015 and 2016 at the Nuclear Institute of Agriculture (NIA), Tando Jam, Sindh, Pakistan. Combined analysis of variance revealed significant variations among the studied genotypes. Moreover, a significant interaction of genotype by year was observed only between grain yield and grains per spike indicated importance of the trait for improvement of grain yield in wheat. Correlation of Ys (yield under stress) and Yp (yield under non-stress) with tolerance index (TOL), stress stability index (SSI), yield stability index (YSI) and yield index (YI) indicated that mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM) and STI (stress tolerance index) were found as better indicators of Ys and Yp. The principal component analysis revealed two components that justified 73.23% of the total variation. Bi-plot and cluster analyses classified the genotypes i.e., V3-10-9, V3-10-31, and V3-10-32 based on MP, GMP, STI, and HM indices as stable and high yielding, while C3-98-8 and V2-10-15 based on YSI and YI. These genotypes could be exploited directly in the varietal release program and or as a source of potential donors to stack genes for salinity tolerance.

Keywords: Genotype by environment interactions, salinity tolerance, stress selection indices, principal component analysis, Bi-plot, cluster analysis, correlation, wheat

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INTRODUCTION

Wheat (*Triticum* spp.) is a staple food cereal crop, playing a major role in strengthening for escalating global population. Since global food needs are estimated to rise by 70-110% until 2050 (Tilman *et al.,* 2011; Pradhan *et al.,*2015), land degradation, urban growth, and seawater infliction are increasing over time, thus agricultural productivity from saline soils has become imperative to achieve the required food gains. Wheat is the primary food source of people in Pakistan, which occupies around 9.0 million hectares of cultivated land of the country, with the production of 25 m tons this year with an increase of 2.5% (GOP, 2020). Wheat production of the country increased from 7.29 million tons in 1970 to 24.3 M tons in 2019, showing an average annual growth rate of 2.83% (Anonymous, 2019). Although, world wheat production has reached 761.5 million tons, with an increase of below 1%, must be increased by at least 1.7% annually to nourish 870 million under-nourished human populations (FAO, 2020). Moreover, the United Nations (UN) has projected a rise of 9.73 and 11.2 billion in the global population by 2050 and 2100, respectively (FAO, 2017). Hence, a further increase in wheat productivity is imperative to meet the growing food requirements in the face of shrinking land area under cultivation, increasing population and environmental swings. To this end, there are various selection tools to distinguish suitable genotypes for their performance subjected to stress and optimal conditions (Fischer and Maurer, 1978; Rosielle and Hamblin, 1981; Fernandez, 1992).

Soil salinization is a major global constraint significantly reducing wheat productivity and sustainability, specifically in arid and semi-arid regions. Approximately 0.3 million hectares of farmland become salt affected annually; another 20–46 Mha are facing an annual decline in productivity (FAO-ITPS-GSP, 2015). The main cause for increasing the saline soils are a natural phenomenon and human practices viz. fluctuating precipitations, increased exterior evaporation, weathering of rocks, irrigation using salty water and substandard management, of which 20% of all cultivated and33 percent of irrigated land faces secondary salinization (Shrivastava and Kumar, 2015). It has been projected that over 50% of arable lands would be facing salinization by 2050 (Jamil *et al.,* 2011).Salt accumulation poses harmful effects on growth and developmental processes of plant life (Rahneshan *et al.,* 2018), seed germination, enzymatic reactions (Seckin *et al.,* 2009), bio-synthesis and cell division (Javid *et al.,* 2011),reduced plant height, number of spikelets/spike, late spike emergence, tip sterility, and poor fertility, resulting in decreased final yield and quality deterioration (Shrivastava and Kumar, 2015). In Pakistan, soil salinity is among the major problems in the agriculture sector, mainly in irrigated agricultural areas with poor drainage systems. Pakistan has lost about 10 Mha of the salt-affected area containing 12.9% of land in the country (FAO, 2008).

The principal component analysis (PCA) has been exploited for screening based on multiple stress indices (Majidi *et al.,* 2011; Khan and Kabir, 2015; Korshid, 2016) and for minimizing the multiple dimensions of the studied variables (Johnson and Wichern, 2007). However, stress indices have been efficiently exploited for the identification of water stress tolerant wheat genotypes (Khakwani *et al.,* 2011), low nitrogen environment (Tyagi *et al.,* 2020), however comparatively less research based on stress indices has been carried out for tolerance against salinity.

Developing salinity tolerance merely on a yield basis is difficult due to its complicated heritability and quantitative nature. Hence, it is critical to explore the suitable selection indices to distinguish high yielding, and stable wheat genotypes for saline areas. These indices reflect the plant response under stress concerning yield under stress (Ys) and potential yield under non-stress (Yp). The present study was carried out with the objectives to a) identify salinity tolerant bread wheat genotypes under field conditions, b) determine the effectiveness of selection indices to categorize the salinity stress tolerant and sensitive genotypes, and c) evaluate correlation networking among the yield under stress, non-stress, and selection indices. To this end the present research was accomplished to screen and discriminate the wheat genotypes tolerant to saline environments based on the stress tolerance selection indices using multivariate analyses approaches.

MATERIAL AND METHODS

Plant materials and experimental procedures: The field evaluation was carried out at the Nuclear Institute of Agriculture (NIA), Tando Jam, Sindh, Pakistan in two consecutive crop seasons 2015and 2016. A set of 16 genotypes along with four check cultivars (Kiran-95, NIA-Sunahri, Chakwal, Bhittai) in each crop season were evaluated under saline (S) (ranges 834-1850ppm/pH 7.3-7.5) and non-saline (NS) soil Individual genotype was sown in 4 rows of 2-meter length each, with row to row distance of 30 cm, in three replications. Nitrogen fertilizer (46%) was applied as urea @ 130 kg ha^{-1} and phosphorus using DAP (46% P_2O_5 and 18% N) @ 90 kg/ha. All DAP was applied at the time of sowing and nitrogen was applied in three splits following irrigations. The irrigation was applied at intervals of 21 days (tillering, booting, heading and grain filling stage) in each crop season, keeping in view the need for the crop to escape water stress. Standard management practices were adopted to get a healthy crop.

The phenotypic assessment of yield traits: Observations were documented on grain yield and five yield-related traits under S and NS conditions. At maturity, five randomly selected plants per replicate were harvested from the two central rows to collect the data on yield and other agronomic traits, viz., days to heading (DH), plant height (PH), and spike length (SL) following Arain *et al.* (2017). Data on spikelets per spike (SPS), grains per spike (GPS), and main spike yield (g) were recorded after harvest from the main tillers of the five randomly selected plants. Data on grain yield were determined from two central rows in grams, and, later was converted to yield in kg per hectare

Evaluation of selection indices based on yield under stress and non-stress conditions: To identify the best performing genotypes under stress conditions, several selection indices based on yield under S and NS conditions are suggested based on the mathematical associations between the two environments (Clarke *et al.,* 1984). In the current study, eight selection indices i.e.,., tolerance index (TOL), Mean productivity (MP), harmonic mean (HM), geometric mean productivity (GMP), stress susceptibility index (SSI), Stress tolerance index (STI), yield stability index (YSI) and yield index (YI) were employed to select the best performing stress tolerant wheat genotypes subjected to S and NS field conditions (Table 1).

These indices were calculated according to the following formulas:

1. Reduction % of grain yield (RPGY) = RPGY = $(Yp - Ys) / Yp \times 100$ (Choukan *et al.,* 2006).
2. Tolerance index $TL = (Yp + Y)$ (Rosielle and Hamblin, 1981).
3. Mean productivity $M = (Y + Y +) / 2$ (Rosielle and Hamblin, 1981).
4. Harmonic mean $H = 2(Y i \times Y)/(Y + Y)$i) (Bouslama and Schapaugh, 1984).
5. Geometric mean productivity $G = (Ys - Yp)^{0.5}$ (Fernandez, 1992).
6. Stress susceptible index $SSI = (1Ysi/Ypi)/SI$ (Fischer and Maurer, 1978). Where Stress intensity (SI) was calculated as SI= $1 - (Ys/Yp)$ and SSI value < 1 is more tolerant to stress conditions.
7. Stress tolerance index $S = (Ypi \times Ysi) / Yp2$ (Fernandez, 1992).
8. Yield stability index $YSI = YS / YP$ (Bouslama and Schapaugh, 1984).
9. Yield index $YI = Ysi/Ymp$ (Gavuzzi*et al.,* 1997).

Where in these equations, Ysi and Ypi are yields of individual genotype under S and NS conditions, respectively. However, Ys and Yp are average yields of all genotypes under S and NS conditions, respectively.

Statistical analysis: The combined ANOVA was performed using statistical software CoStat version 1.7 (http://www.cohort.com/costat.html) to determine differences among genotypes, environments and years for each agronomic trait. Subsequently, means were separated using the LSD test at a 5% level of probability. Multivariate statistical analysis, comprising correlation (Pearson coefficients), the principal component and cluster analysis (Ward's method) were performed using Multi-Variate Statistical Package (MVSP3.1) (Kovach 1999) Kovach Computing Services, Wales, UK.

RESULTS AND DISCUSSION

Pooled analysis of variance and genotype by environment interaction: The results of the combined analysis of variance (ANOVA) are presented in Table 2. The genotype, environment effect and genotype by environment interactions were significant for all the investigated traits. A significant difference between the grain yield of genotypes in S and NS environments depicted the presence of sufficient genetic variability and the opportunity of selection for suitable genotypes under both environments. Significant genotype and environment interaction under S and NS conditions was also reported previously, for plant height, grain yield and NDVI data in wheat (Hitz *et al.,* 2017), and for GY and test weight (Šarčević *et al.,* 2014). Hence, to improve the environmental stress sensitive traits , however, genotype by interactions.

Grain yield and phenotypic variation: The comparison of variability expressed by means and range for GY and its components under both S and NS conditions during two years is is given in Table 3 and 6. A wide range of variability was detected in the genotypes for all the evaluated traits under both environments. Grain yield and all studied traits were significantly affected under stress as compared to non-stress conditions in both crop seasons . A significant decrease in yield and other traits in wheat under stress were reported previously (Akçura *et al.,* 2011; Hasan *et al.,* 2015).The comparison of average grain yield reduction in the wheat genotypes under S and NS conditions was 41.23% in 2015, 41.33% in 2016, with an average decline of 41.28%, over the years. The grain yield of all the 16 wheat genotypes under S and NS conditions in both crop seasons is presented in Table 5). Genotype C3-98-8 was least affected by stress with the lowest reduction (23.2%) and V3-10-29 was most affected with the highest reduction (57.3%). In reference to grain yield in 2015, the top four highest yielding genotypes under saline environment were V3-10-9, C3-98-8, V2-10-15,and V3-10-31. However, V3-10-29, V3-10-34, Kiran-95 and Chakwal were the lowest yielding genotypes (Table 6). Under NS conditions, the wheat genotypes V3-10-29, C7-98-4, Kiran-95 and NIA-Sunahri produced the highest yield, followed by V3-10-32, V3-10-12, and V3-10-31, However, the lowest yielding genotypes were V3-10-29, V3-10-34, Kiran-95 and Chakwal, followed by NIA-Sunahri and V2-10-3. In 2016, four highest yielding genotypes under stress were V3-10-9, C3-98-8, V2-10-15 and V3-10-31, followed by the V2-10-5 and C4-98-6,

However, the genotype Chakwal, followed by V3-10-29, Kiran-95, and V3-10-34 were the lowest yielding. Genotypes V3-10-9, C3-98-8, V2-10-15, and V2-10-5 performed best concerning the grain yield subject to stress in both crop seasons.

Recognition of best wheat genotypes based on stress indices: There are several ways to select high yielding genotypes, like screening of genotypes under stress; and that high yielding genotypes can sustain yields subject to stress conditions (Khayatnezhad *et al.,* 2010; Barati *et al.,* 2020). Another way is to select genotypes based on their performance under both stressed and favorable environments (Nouri *et al.,* 2011; Anwaar *et al.,* 2020). The strong associations among the stress indices suggested that these indices can be used for discriminating the superior genotypes under stress and non-stress conditions. According to criteria for sensitivity and tolerance, greater values for MP, GMP, HM, STI, YSI and YI would be required and lower estimates for TOL and SSI indicates tolerance under stress. The SSI and TOL dependent selection was accomplished for the stressed conditions. The SSI index is being used to differentiate stress tolerant and sensitive genotypes and to portray year-by-year changes among the genotypes and their levels. Among the genotypes, the V3-10-9 was found most tolerant based on greater values for all the selection indices and lower TOL and SSI and highest yield under stress condition with lower reduction (31%). Genotype C3-98-8 was selected as tolerant for showing highest YSI value and lowest TOL, and reduction (23.19%). The improved yield, under salinity conditions, of the selected wheat genotypes could be due to multiple responses of the plant systems with subsequent assimilates transformation towards the sink. Similarly, greater values of GMP and YSI and MP, GMP, and STI have been employed to discriminate the stress-tolerant high yielding genotypes (Mohammadi *et al.,* 2010; Singh *et al.,* 2017). The selection indices TOL, SSI, YSI, and GMP have been found efficient for the selection of bread wheat genotypes under stress and non-stress conditions (Singh *et al.,* 2017, 2018), and durum wheat (Mohammadi, 2016). The genotype V3-10-29 had a greater value for TOL and produced the lowest yield under stress indicated as the susceptible genotype. However, a higher TOL index is an indicator of lower stress tolerance and decreased yield under stress (Akçura *et al.,* 2011). The genotype C4-98-6 showed a desirable SSI value (0.8) less than 1 but exhibited lower yield, suggesting considering other indices for salinity tolerance for more precise selection. Liu *et al.* (2017) stated to use other indices aside from DSI to evaluate the grain yield performance under drought stress. Collectively based on MP, GMP, HM, and STI, the genotypes V3-10-9, V3-10-32, V3-10-31, and C3-98-8 were the best performing and based on YSI and YI, V3-10-9, C3-98-8, and V2-10-15 were selected. However, based on TOL and SSI V3-10-9, V3-10-31, C3-98-8, and V2-10-5 were collectively selected.

MULTIVARIATE ANALYSES

Correlation coefficient analysis: To find out the most valuable indices for use as selection criteria and to identify the desirable genotype under stress, the associations of Ys and Yp with all the stress selection indices was determined (Table 5). Correlation analysis depicted a negative but weak association (r= -0.022) between Yp and Ys, whereas, MP, GMP, HM, STI, YSI, and YI had a strong positive association with Ys, and a negative association with TOL and SSI. Dadbakhsh *et al.* (2011) also reported a significant negative association between TOL and yield under stress. Mean productivity, SSI, and STI showed significant positive correlation with Yp and positive but non-significant association with GMP, and HM. However, the TOL significantly correlated with SSI. The mean productivity, GMP, HM, STI were efficient predictors under stress and non-stress conditions. These indices have already been reported as the most efficient selection criteria to identify the superior genotypes for stress afflicted environments (Fernandez, 1992). A negative correlation was observed between Yp and Ys (Slo-Se Mardeh *et al.,* 2006), in contrast, a positive correlation was also reported (Korshid, 2016).

The positive responses revealed by some genotypes subjected to stress environments could be attributed to adapting mechanisms. Like genotypes with less reduction under stress as shown byV3-10-9, C3-98-8, V2-10-15. Association analysis revealed a significant negative correlation ($r = -0.57^{*}$) of TOL with YS and positive ($r = 0.83^{**}$) with Yp. The positive relationship between TOL and Yp and the negative between TOL and Ys indicates that TOL-based selection will cause a decrease in crop yield under unfavorable environments (Khayatnezhad *et al.,* 2010). MP was significantly correlated with Ys and Yp, and it is used as a tolerance measure for moderately stressful environments.

There was a strong positive relationship between MP and GMP ($r = 0.82^{**}$). While GMP is calculated relying on MP, thus, higher MP values discriminate higher-yielding stress tolerant wheat cultivars (Fernandez, 1992, Dorostkar *et al.,* 2015 Anwaar *et al.,* 2020). SSI showed a significant negative association ($r = -0.76^{**}$) with Ys but a positive association ($r = 0.66^{**}$) with Yp. SSI has been extensively applied to recognize the stress-sensitive and tolerant genotypes by researchers worldwide (Tyagi *et al.,* 2020; Anwaar *et al.,* 2020). Positive relationships of these indices with grain yield under particular production systems authenticate the efficiency of these indices for the selection of stress-tolerant genotypes.

Bi-plot analysis: Selection using a collection of indices may furnish a more trusted standard for measuring stress tolerance in wheat, while correlation coefficients help to identify the extent of the overall interrelationship among the traits (Talebi *et al.,* 2009; Nouri *et al.,* 2011). Hence, a more reliable technique than correlation studies, such as biplot is desirable to discriminate superior genotypes collectively for both stress and non-stress conditions. Since different indices depict variable outcomes, hence, a biplot was generated based on the first PC1 and PC2 (Fig.1: right). The first two components interpreted 73.23% of overall variation, the first component expressed 44.21% of the total variation and had a strong positive association to MP, STI, HM, GMP, YSI, YI, Ys and Yp, thus described as a salt tolerance region (Table 6). The second component explained 29.02% of total variation and had a strong association with TOL and SSI and was entitled to as the salt-sensitive region. According to biplot analysis the wheat genotypes V3-10-9, V3-10-31 and V3-10-32 were recognized as stable genotypes with high yield concerning desirable levels of MP, STI, HM, and GMP indices, whereas, the genotypes C3-98-8, V2-10-15 in relation with YSI, and YI. This was largely due to yield capacity and tolerance region (Fig. 1: right). The GMP, STI, and HM indices were considered equally valuable to differentiate drought susceptible and tolerant safflower genotypes for both moderate and intensive stress environments (Majidi *et al.,* 2011). However, the genotypes V2-10-3, C4-98-6, Bhittai and Chakwal were considered moderately sensitive genotypes due to higher TOL and SSI and low yield and stress-sensitive regions (Fig. 1: left). The indices like TOL, YSI, and SSI could be used efficiently in selecting the tolerant genotypes i.e., C3-98-8, V2-10-15, that might be recommended for salinity stressed environments. The indices TOL, SSI, GMP, and YSI have been exploited for the identification of tolerant wheat genotypes under both stress and non-stress setups (Singh *et al.,* 2017). Thus, stress indices with a strong significant association with grain yield in both environments can be exploited for the identification of tolerant wheat genotypes (Tyagi *et al.,* 2020).

Cluster analysis: Cluster analysis based on their yield under stress, its components and selection indices, classified the genotypes in five groups with 1, 4, 6, 4, and 1 genotype (s), respectively (Fig.2). Group-1 comprised one genotype V3-10-9, which produced the highest yield, depicted tolerance based on low TOL and SSI. However, group-2 comprised of four genotypes possessing higher yield under stress. Group-3 contained six genotypes based on higher TOL and SSI, these genotypes produced more yield under non-stress conditions, however higher reduction under stress, thus classified as susceptible genotypes. Group-4 comprised of four genotypes (C3-98-8, V2-10-15, V3-10-31 and V3-10-32) that depicted moderate yield performance under stress and desirable level of selection indices (TOL, MP, GMP, HM, STI, YSI and YI), were identified as salt-tolerant genotypes. Group-5 had the lowest yielding genotype i.e., (Chakwal). Hence, the wheat genotypes V3-10-9, C3-98-8, V2-10-15, V3-10-31, and V3-10-32 have been identified as salt-tolerant genotypes based on their yield performance under stress and selection indices. The use of cluster analysis has been employed to screen the crop germplasm against stress tolerance (Mursalova *et al.,* 2015; Poudel *et al.,* 2017) and to explore the genetic diversity (Arain *et al.,* 2018).

Table 1.These indices were calculated according to the following formulas:

S/No.	Formulas to calculate indices	References
01	Reduction % of grain yield (RPGY) = RPGY $= (Ypi - Ysi) \;/\; Yp \;\times 100$	*(*Choukan *et al.,* 2006).
02	Tolerance index$TO = (Yp + Ys_i)$	(Rosielle and Hamblin, 1981).
03	Mean productivity$MP = (Yp + Ys_i +) \;/\; 2$	(Rosielle and Hamblin, 1981).
04	Harmonic mean$HM = 2(Yp \times Ys_i)/(Yp + Ys_i)$i)	(Bouslama and Schapaugh, 1984).
05	Geometric mean productivity $GM = (Ys - Yp)^{0.5}$	(Fernandez, 1992).
06	Stress susceptible index $SS = (1Ys_i/Yp)/SI$ Where Stress intensity (SI) was calculated as SI= $1 - (Y /Yp)$ and SSI value < 1 is more tolerant to stress conditions.	(Fischer and Maurer, 1978).
07	Stress tolerance index $ST = (Yp \times Ys_i) \;/\; Yp2$	(Fernandez, 1992).
08	Yield stability index $YS = YS \;/\; YP$	(Bouslama and Schapaugh, 1984).
09	Yield index $YI = Ys_i/Ym$ Where in these equations, Ysi and Ypi are yields of individual genotype under S and NS conditions, respectively. However, Ysand Ypare average yields of all genotypes under S and NS conditions, respectively.	(Gavuzzi*et al.,* 1997).

Table 2.Combined analysis of variance for yield and its attributes in 16 wheat genotypes planted under saline and non-saline conditions during two consecutive years 2015 and 2016.

SOV	DF	DH	PH	SL	SPS	GPS	MSY	GY
GENOTYPE	15	125.89 **	84.98**	2.93 **	13.24 **	103.73**	0.169 **	657947.**
TREATMENTS	1	7387.9**	15163.8 **	92.17 **	0.72E-2**	10683.1**	0.349E-01**	0.12E+09 **
REP	2	1.91	9.14	0.38	440.14	22.43	44.51	205333.
YEAR	1	8.76**	3.88	0.54	0.105	14.54	0.38E-02	2960.98
G×T	15	72.09**	118.8**	2.56**	16.35 **	91.70 **	0.212 **	685737.**
Y × G	15	0.99	2.23	0.132	0.88E-01	47.31 *	0.572E-01	4994.89
T×Y	1	5.01*	32.26	0.3E-01	0.234	7.93	0.243E	14.5232
G×T×Y	15	1.79 ns	0.97 **	0.181	0.158	41.95	0.711E	66066.6
RESIDUAL	126	1.09 ns	2.49	0.499E-01	0.231	25.58	0.508E	4713.68
TOTAL	191							

***Significant at 1%; *significant at 5%;ns, non-significant. SOV: Source of variation; DF: degrees of freedom; G × T: the interaction effect of genotype andtreatment.DH: days to heading; PH: plant height; SL: spike length; SPS: spikelets per spike; GPS: grains per spike; MSY: main spike yield+; GY= grain yield .*

Table 3. Mean, range and reduction percentage of yield and its attributes in 16 wheat genotypes planted under saline and non-saline conditions during two consecutive years 2015 and 2016.

year	Conditions	DH	Ph	SL	SPS	GPS	MSY	GY
	Non-stress							
	Mean	79.17	100.50	12.07	21.75	69.85	2.6346	3895.1
	Minimum	73.00	93.40	10.30	18.80	58.70	1.7520	5278.5
	Maximum	87.00	106.40	13.70	27.00	80.00	3.5210	2879.7
2015	**Salinity stress**							
	Mean	66.44	81.91	10.70	18.65	55.34	1.6646	2289.2
	Minimum	58.00	70.00	9.50	17.30	45.30	1.2420	2846.2
	Maximum	72.00	91.50	12.00	20.00	66.00	2.1000	1675.2
	Reduc.%	16	18.50	11.7	14.24	20.8	37.10	41.23
	Non-stress							
	Mean	78.42	99.97	12.16	21.63	69.71	2.6363	3887.8
	Minimum	73.00	91.00	10.10	18.40	50.40	1.8440	5208.3
	Maximum	86.00	106.80	13.80	26.60	90.20	3.4520	2708.3
2016	**Salinity stress**							
	Mean	66.33	83.01	10.8	18.67	54.39	1.6806	2280.8
	Minimum	60.00	91.40	9.50	17.40	43.50	1.0440	2870.8
	Maximum	71.00	69.20	12.50	20.30	65.00	2.1020	1666.7
	Reduc. %	15.4	16.95	11.2	13.7	22.1	36.25	41.33

Abbreviations:DH: days to heading; PH: plant height (cm); SL: spike length (cm); SPS: spikelets per spike; GPS: grains per spike; MSY: main spike yield (g); GY: grain yield (kgha^{-1}); R%: reduction percentage.

Table 4. Selection indices of sixteen bread wheat genotypes with grain yield performance under stress and non-stress environment.

Gen	Genotypes	Ys	Yp	TOL	SSI	MP	GMP	HM	STI	YSI	YI
1	V3-10-9	2821.4 ^{a}	4119.8 ^{abc}	1298.4 $^{d-h}$	0.76 ^{ef}	3470.6 ^{a}	181101 ^{a}	3348.9 ^{a}	0.77 ^{a}	0.69 ^{ab}	1.23 ^{a}
2	V3-10-12	2226.4 ^{cde}	4102.6 ^{abc}	1876.2 $^{b-e}$	1.11 $^{a-d}$	3164.5 $^{a-d}$	142454 ^{bcd}	2881.9 ^{bc}	0.60 ^{b}	0.55 $^{c-f}$	0.97 ^{cde}
3	V3-10-29	2008.3 ^{de}	4671.5 ^{a}	2663.2 ^{a}	1.37 ^{a}	3339.9 ^{ab}	137148 ^{bcd}	2803.9 ^{bc}	0.62 ^{b}	0.43 ^{f}	0.88 ^{de}
4	V3-10-32	2347.6 ^{bcd}	4108.3 ^{abc}	1760.8 $^{b-g}$	1.03 $^{b-e}$	3227.9 ^{abc}	150353 ^{bcd}	2980.9 ^{abc}	0.64 ^{ab}	0.58 $^{b-e}$	1.03 ^{bcd}
5	V3-10-34	2048.0 ^{de}	3903.0 ^{bcd}	1855.1 $^{b-f}$	1.13 $^{a-d}$	2975.5 ^{bcd}	127299 ^{de}	2665.5 ^{c}	0.52 ^{b}	0.53 $^{c-f}$	0.90 ^{de}
6	V3-10-31	2466.2 ^{abc}	3957.8 ^{bcd}	1491.6 $^{c-h}$	0.91 ^{cde}	3212.0 $^{a-d}$	155240 ^{abcd}	3038.4 ^{abc}	0.65 ^{ab}	0.63 ^{bcd}	1.08 ^{abc}
7	Kiran-95	2014.3 ^{de}	4212.7 ^{ab}	2198.4 ^{ab}	1.27 ^{ab}	3113.5 $^{a-d}$	130834 ^{cd}	2721.5 ^{c}	0.56 ^{b}	0.48 ^{ef}	0.88 ^{de}
8	NIA-Sunahri	2181.4 ^{cde}	4157.7 ^{abc}	1976.3 $^{a-d}$	1.15 ^{abc}	3169.6 $^{a-d}$	140640 ^{bcd}	2859.4 ^{bc}	0.61 ^{b}	0.53 ^{def}	0.95 ^{cde}
9	Chakwal	1835.0 ^{e}	3069.3 ^{e}	1234.3 $^{e-h}$	0.97 $^{b-e}$	2452.2 ^{e}	101456 ^{e}	2289.0 ^{d}	0.37 ^{c}	0.60 $^{b-e}$	0.80 ^{e}
10	Bhittai	2295.7 ^{cd}	3566.9 ^{cde}	1271.3 $^{e-h}$	0.86 $^{c-f}$	2931.3 ^{cd}	137094 ^{bcd}	2784.4 ^{bc}	0.54 ^{b}	0.65 $^{a-d}$	1.01 ^{cd}
11	V2-10-3	2196.4 ^{cde}	3708.2 ^{bcd}	1511.8 $^{b-h}$	0.99 $^{b-e}$	2952.3 ^{cd}	134111 ^{cd}	2749.8 ^{bc}	0.54 ^{b}	0.59 $^{b-e}$	0.96 ^{cde}
12	C3-98-8	2742.6 ^{ab}	3587.4 ^{cde}	844.8 ^{h}	0.57 ^{f}	3165.0 $^{a-d}$	164236 ^{ab}	3107.5 ^{ab}	0.65 ^{ab}	0.77 ^{a}	1.20 ^{ab}
13	C4-98-6	2251.8 ^{cd}	3416.8 ^{de}	1165.0 ^{fgh}	0.81 ^{def}	2834.3 ^{d}	131901 ^{cd}	2707.2 ^{c}	0.51 ^{bc}	0.67 ^{abc}	0.99 ^{cd}
14	V2-10-15	2562.4 ^{abc}	3694.2 ^{bcd}	1131.8 ^{gh}	0.74 ^{ef}	3128.3 $^{a-d}$	155747 ^{abc}	3024.9 ^{abc}	0.63 ^{ab}	0.70 ^{ab}	1.12 ^{abc}
15	C7-98-4	2213.5 ^{cde}	4297.2 ^{ab}	2083.7 ^{abc}	1.18 ^{abc}	3255.3 ^{abc}	145243 ^{bcd}	2921.2 ^{bc}	0.63 ^{ab}	0.52 ^{def}	0.97 ^{cde}
16	V2-10-5	2349.1 ^{bcd}	3689.7 ^{bcd}	1340.6 $^{d-h}$	0.86 $^{c-f}$	3019.4 ^{bcd}	142181 ^{bcd}	2855.8 ^{bc}	0.57 ^{b}	0.65 $^{a-d}$	1.03 ^{cd}

Note: *Means followed by different letters within a column for each trait have significant differences at the level of Tukey's, HSD test, P< 0.05.Stress stability index (SSI), tolerance index (TOL), mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), stress tolerance index (STI), yield stability index (YSI) and yield index (YI) based on potential yield under non-stress (Yp) and yield under-stress (Ys) conditions.*

Table 5. Correlation coefficients for grain yield under salinity stress and non-stress conditions along with stress tolerance indices.

Traits	Ys	Yp	TOL	MP	GMP	HM	SSI	STI	YSI
Yp	-0.02ns								
TOL	-0.57^{*}	0.83^{**}							
MP	0.55^{*}	0.82^{**}	0.37						
GMP	0.93^{**}	0.35	-0.22	0.82^{**}					
HM	0.90^{**}	0.42	-0.16	0.86^{**}	0.99^{**}				
SSI	-0.76^{**}	0.66^{**}	0.96^{**}	0.12	-0.46	-0.39			
STI	0.77^{**}	0.61^{*}	0.08	0.08	0.95^{**}	0.97^{**}	-0.18		
YSI	0.76^{**}	-0.66^{**}	-0.96^{**}	-0.13	0.45	0.39	-0.99^{**}	0.17	
YI	0.99^{**}	-0.02	-0.57^{*}	0.55^{*}	0.93^{**}	0.90^{**}	-0.76^{**}	0.77^{**}	0.76^{**}

* Significance at 5% (p = 0.05); **Significance at 1% (p = 0.01);Stress stability index (SSI), tolerance index (TOL), mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), stress tolerance index (STI), yield stability index (YSI) and yield index (YI) based on potential yield under non-stress (Yp) and yield under-stress (Ys) conditions.

Table 6. Yield performance of 16 bread wheat genotypes under saline stress and non-stress conditions and their reduction percentage during the year 2014-15 and 2015-16.

S/No.	Genotypes	2014-15			2015-16		
		Yp	**Ys**	**Reduction %**	**Yp**	**Ys**	**Reduction %**
1	V3-10-9	4142.4^{bcd}	2820.5^{a}	31.88^{cd}	4097.2^{a-f}	2822.2^{a}	31.10^{bc}
2	V3-10-12	4038.5^{b-e}	2230.5^{d-g}	44.58^{abc}	4166.7^{a-d}	2222.2^{c-f}	46.50^{ab}
3	V3-10-29	4724.9^{a}	2002.8^{gh}	57.30^{a}	4618.1^{a}	2013.9^{fg}	56.05^{a}
4	V3-10-32	4084.7^{bcd}	2396.5^{cde}	41.13^{a-d}	4131.9^{a-e}	2298.6^{c-f}	44.09^{abc}
5	V3-10-34	3951.9^{b-f}	2033.4^{fgh}	47.87^{abc}	3854.2^{b-g}	2062.5^{efg}	45.45^{abc}
6	V3-10-31	3957.3^{b-f}	2474.1^{bcd}	37.48^{bcd}	3958.3^{b-f}	2458.3^{bcd}	37.83^{abc}
7	Kiran-95	4189.2^{bc}	2000.8^{gh}	52.27^{ab}	4236.1^{abc}	2027.8^{efg}	52.21^{ab}
8	NIA-Sunahri	4148.7^{bcd}	2147.5^{efg}	48.12^{abc}	4166.7^{a-d}	2215.4^{c-f}	46.79^{ab}
9	Chakwal	3048.4^{h}	1829.8^{h}	39.81^{a-d}	3090.3^{h}	1840.3^{g}	39.88^{abc}
10	Bhittai	3522.8^{fg}	2271.9^{c-g}	35.29^{bcd}	3611.1^{e-h}	2319.4^{c-f}	35.67^{abc}
11	V2-10-3	3718.6^{d-g}	2205.3^{d-g}	40.86^{a-d}	3697.9^{c-g}	2187.5^{def}	40.86^{abc}
12	C3-98-8	3598.4^{efg}	2763.0^{ab}	23.2^{d}	3576.4^{fgh}	2722.2^{ab}	23.75^{c}
13	C4-98-6	3430.9^{gh}	2295.4^{c-g}	32.64^{cd}	3402.8^{gh}	2208.3^{c-f}	34.20^{abc}
14	V2-10-15	3707.9^{d-g}	2583.1^{abc}	30.32^{cd}	3680.6^{d-g}	2541.7^{abc}	30.74^{bc}
15	C7-98-4	4323.5^{ab}	2235.6^{d-g}	48.32^{abc}	4270.8^{ab}	2191.4^{def}	48.68^{ab}
16	V2-10-5	3733.7^{c-g}	2337.2^{c-f}	36.49^{bcd}	3645.8^{d-g}	2361.1^{cde}	34.22^{abc}
	LSD (5%)			19.19			21.85

Note: Means followed by different letters within a column for each trial have significant differences at the level of Tukey's, HSD test, P< 0.05,Yp: Yield under non-stress and Ys: Yield under stress conditions.

Table 7. PCs and the percent variance showed by each PC.

PC	Eigenvalue	% variance
1	7.07413	44.213
2	4.64236	29.015
3	1.67036	10.44
4	1.1159	6.9744
5	0.585197	3.6575
6	0.456343	2.8521
7	0.348956	2.181
8	0.0894498	0.55906
9	0.0147537	0.092211
10	0.0013399	0.0083744

11	0.000679372	0.0042461
12	0.000374199	0.0023387
13	0.000145388	0.00090867
14	1.46252E-05	9.1408E-05
15	1.11615E-11	6.9759E-11

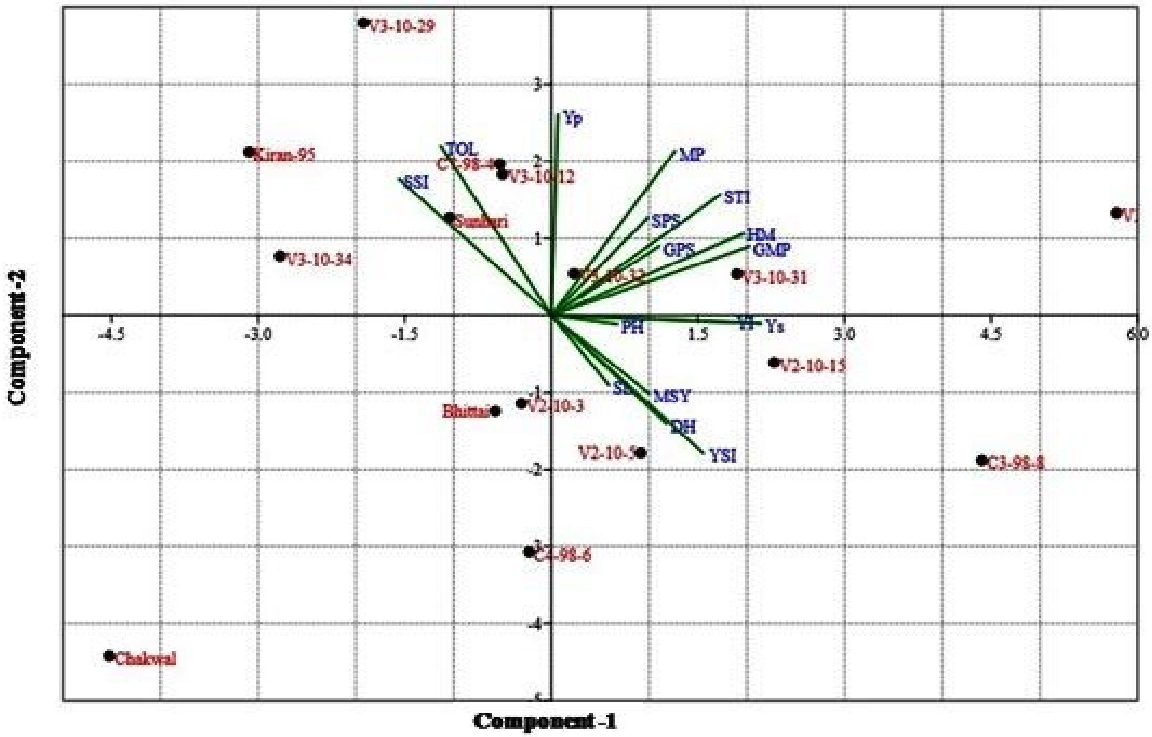

Fig.1. Principal component analysis based on grain yield, agronomic attributes and selection indices under stress conditions

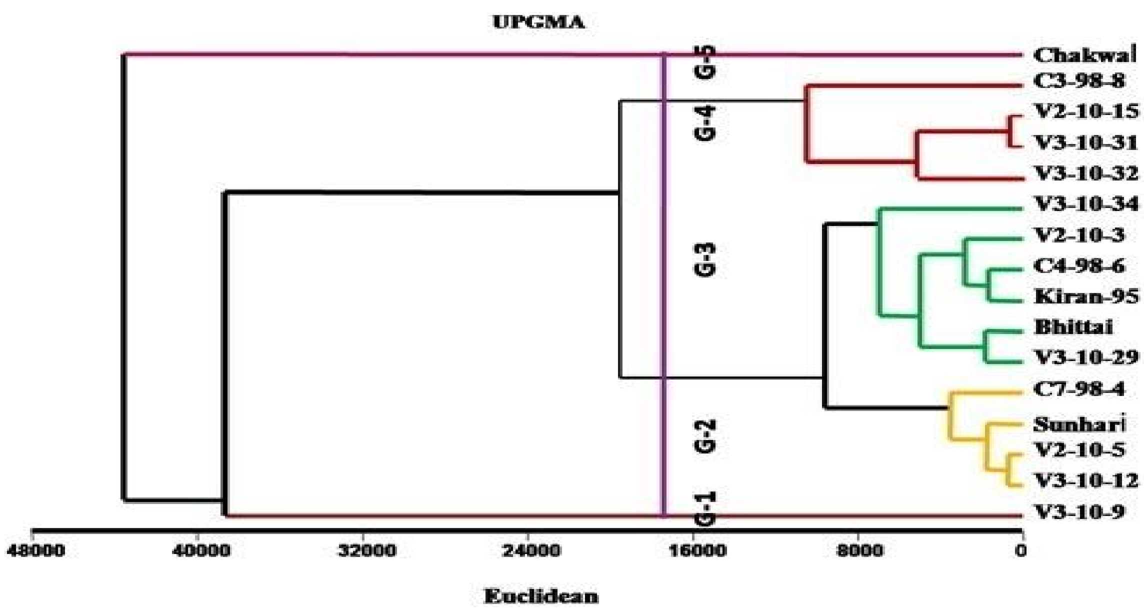

Fig. 2. Dendrogram resulting from cluster analysis of 16 bread wheat genotypes based on stress tolerance indices for grain yield and its components under salinity stress.

Conclusion: The present findings substantiate the presence of wide genetic variability among the studied genotypes in response to salinity stress. Results showed that stress indices can be employed for the efficient selection of salinity tolerant wheat genotypes. The genotypes V3-10-9, V3-10-31, and V3-10-32 concerning the MP, STI, HM, and GMP, whilst C3-98-8 and V2-10-15 are based on YSI and YI were the tolerant wheat genotypes. Hence, tolerant genotypes could be used as potential donors in breeding programs focused on salinity stress tolerance and to evolve new improved cultivars with higher yield for salinity stricken areas of Pakistan.

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