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# APPLICATION OF STRESS SELECTION INDICES FOR ASSESSMENT OF NITROGEN TOLERANCE IN WHEAT (*Triticum aestivum* L.)

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## ABSTRACT

To identify desirable genotypes best suited to limited nitrogen availability based on stress selection indices, thirty wheat varieties were field tested under with ($N^+$) and without nitrogen ($N^0$) conditions at New Developmental Research Farm, The University of Agriculture Peshawar, Pakistan during 2013-14 crop season. Fifteen stress tolerance indices *viz.* tolerance index (TOL), mean productivity (MP), harmonic mean (HM), stress susceptibility index (SSI), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), yield stability index (YSI), low nitrogen tolerance index (LNTI), nitrogen stress index (NSI), nitrogen index (NI), stress susceptibility percentage index (SSPI), modified stress tolerance index (MSTI= K1STI and K2STI), relative nitrogen index (RNI) were computed based on grain yield of each genotype under stress ($N^0$) and non-stress ($N^+$) conditions. Grain yield under both stress and non-stress condition had positive association with MP, GMP, HM, and STI and could be used as better indicator for screening wheat genotypes for nitrogen tolerance. In addition, TOL, SSI, LNTI, NSI, SDI, SSPI and K1STI had significant positive relationship with grain yield under non-stress, while NI had positive correlation with grain yield under stress condition. Cluster analysis showed genotypes Tatara-96, Pirsabak-05,and Shahkar-13 as tolerant, whereas, genotypes Faisalabad-08, NARC-11, Aas-11-11, Khyber-87, Pirsabak-08, Punjab-11, Atta Habib, Ghaznavi-98, Saleem-2000, Sulaiman-96, Sehar-06, ARRI, and Janbaz-09 as semi tolerant and Pirsabak-04, Dharabi-11, Bathoor-08-08, Barsat-10, Watan-93, Pirsabak-13, Nowshehra-96, Amin-10, Siran-10, Pirsabak-85 and Kohat-2000 as semi susceptible. Similarly, Inqilab-91, Hasham-08 and Pak-81 as nitrogen stress sensitive. Principal component analysis (PCA) and three dimensional bi-plot partitioned genotypes into four groups. Group A included genotypesTatara-96, Shahkar-13, Pirsabak-05, Saleem-2000, Ghaznavi-98, Sehar-06, Janbaz-09 and Suleeman-96. Group-B included Khyber-87, Aas-11-11, NARC-11, Faisalabad-08, Atta Habib, Punjab-11, ARRI, and Pirsabak-08. Group C included genotypes KT-2000, Pirsabak-85, Nowshehra-96, Amin-10, Siran-10, Pirsabak-13and Group D comprised genotypesInqilab-91, Hasham-08, Pak-81, Pirsabak-04, Dharabi-11, Barsat, Bathoor-08 and Watan-93. Based on multiple analysis, wheat genotypes *viz.*Tatara-96, Pirsabak-05, and Shahkar-13, were found tolerant to nitrogen stress and could be used as parents in hybridization scheme for development of nitrogen use efficient cultivars.

**Key word:** Wheat, stress selection indices, nitrogen tolerance, principal component analysis.

## INTRODUCTION

Wheat is one of the most demanded cereals in the world. Its production is not matching with the increasing pace of human population. Its production is altered by various environmental stresses. With the steady growth in population, particularly in the developing countries, and the declining agricultural land, there is a dire need to boost up wheat production to keep pace with the growing population.

Nitrogen (N) is an essential element both for plant development and crop yield. However, since green revolution, farmers tended to maximize N fertilization to maximize crop yield (Hirel *et al.* 2007). Crop production is not cost-effective both with over and under-use of N fertilizers. High consumption of N-fertilizer is also environment damaging, as excess N lost by leaching into groundwater and runoff into surface water, ammonia volatization and production of $NO_x$ gases from denitrification, pollute the atmosphere (Conley *et al.*2009). Under-use of N fertilizers results in modest crop yield which is not cost-effective and the whole dependent population are malnourished.

Selection of different genotypes under environmental stress conditions is one of the main tasks of plant breeders for exploiting the genetic variations to improve the stress-tolerant cultivars. For selection of stress tolerant lines/genotypes, many selection indices have been formulated on the basis of yield under stress and non-stress conditions (Clarke *et al.* 1984). Tolerance (TOL) and mean productivity (MP), stress susceptibility index (SSI) (Fischer and Maurer, 1978), geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992) have all been employed under various conditions. In addition, to improve the efficiency of STI, a modified stress tolerance index (MSTI) was suggested by Farshadfar and Sutka (2002). In order to identify stable genotype under stress and non-stress conditions indices like yield index (YI), yield stability index (YSI) and stress susceptibility percentage index (SSPI) were proposed by Gavuzzi *et al.* (1997), Bouslama and Schapaugh (1984) and Moosavi *et al.* (2008), respectively. Recently, Low-N tolerance index (LNTI) is introduced which is defined as grain yield reduction under low-N stress in comparison with that under optimal condition in the same trial. The present experiment was designed to screen and identify nitrogen stress tolerant genotypes of wheat based on stress selection indices.

## MATERIALS AND METHODS

**Experimental site, materials and design:** The present study was undertaken at New Developmental Research Farm, The University of Agriculture Peshawar, Pakistan during 2013-14 crop season. Experimental material comprising thirty genotypes (seed was procured from various research institutes of the country; Table 1) were evaluated under two levels of fertilization i.e., stress ($N_0$; without nitrogen) and non-stress ($N^+$; N @ 120 kg $ha^{-1}$) conditions. Material was planted in randomized complete block design with three replications under each level of nitrogen. Each plot had 6 rows of 5 meter length each with 30 cm row to row spacing (9 $m^2$). At harvest, grain yield under stress ($N^0$) and non-stress ($N^+$) was measured from central 4 rows of each plot and was converted into kg $ha^{-1}$.

**Stress Selection Indices:** The experiment of with and without nitrogen application was considered as non-stress and stress environments respectively to determine the following selection indices. Let the $Y_P$ = Yield of a given genotype in non-stress environment; $Y_S$= Yield of a given genotype in stress environment; $\bar{Y}_P$= mean yield under non-stress environment and $\bar{Y}_S$= mean yield under stress environment. The following stress tolerance indices were calculated from these four measurements.

1. Tolerance Index (TOL) (Rosielle and Hamblin, 1981)

$$TOL = Y_P - Y_S$$

2. Mean Productivity (MP) (Rosielle and Hamblin, 1981)

$$MP = \frac{Y_P + Y_S}{2}$$

3. Harmonic Mean (HM) (Kristin *et al*., 1997)

$$HM = \frac{2\,(Y_P \times Y_S)}{Y_P + Y_S}$$

4. Stress Susceptibility Index (SSI) (Fischer and Maurer, 1978)

$$SSI = 1 - Y_S/Y_P) \,/\, 1 - (\bar{Y}_S/\bar{Y}_P)$$

5. Geometric Mean Productivity (GMP) (Fernandez, 1992)

$$GMP = \sqrt{(Y_P \times Y_S)}$$

6. Stress Tolerance Index (STI) (Fernandez, 1992)

$$STI = \frac{(Y_P \times Y_S)}{(\bar{Y}_P)^2}$$

7. Yield Index (YI) (Gavuzzi *et al.,* 1997)

$$YI = \frac{Y_S}{\bar{Y}_S}$$

8. Yield Stability Index (YSI) (Bouslama and Schapaugh, 1984)

$$YSI = \frac{Y_S}{Y_P}$$

9. Low Nitrogen Tolerance Index (LNTI) (Francisco *et al.*, 2010)

$$LNTI = 1-\left(\frac{Y_S}{Y_P}\right) \times 100$$

10. N stress index (NSI) (Farshadfar *et al.,* 2013)

$$NSI = \frac{(Y_P - Y_S)}{(\bar{Y}_S - \bar{Y}_P)}$$

11. SDI (Farshadfar *et al.*, 2013)

$$SDI = \frac{Y_P - Y_S}{Y_S}$$

12. Nitrogen index (NI) (Lan,1988)

$$NI = [Y_S \times \left(\frac{Y_S}{Y_P}\right)]/\bar{Y}_S$$

13. Stress susceptibility percentage index (SSPI) (Moosavi *et al.*, 2008)

$$SSPI = [Y_P - Y_S/(2\bar{Y}_P)] \times 100$$

14. Modified stress tolerance index (MSTI/ KiSTI) (Farshadfar and Sutka, 2002)

$$K1 = \frac{(Y_P)^2}{(\bar{Y}_P)^2}$$

$$K2 = \frac{(Y_S)^2}{(\bar{Y}_S)^2}$$

15. Relative nitrogen index (RNI) (Fischer *et al.*, 1998)

$$RNI = (Y_S/Y_P)/(\bar{Y}_S/\bar{Y}_P)$$

**Statistical analysis:** Correlation among stress selection indices and grain yield under stress and non-stress conditions (Singh and Chaudhery, 1997), cluster analysis following wards methods (Everitt *et al*. 2000) and principal component analysis (Jolliffe, 2002) to group genotypes into tolerant, semi sensitive and sensitive were performed using computer software SPSS ver.20.

## RESULTS AND DISCUSSION

Results of different selection indices calculated are presented in Tables 2 & 3. TOL is the difference of yield under non stress and stress condition, therefore the greater the value of TOL, the larger the yield reduction under stress and higher the stress sensitivity and vice versa. TOL index identified genotype Tatara-96 (4295 kg $ha^{-1}$), Pirsabak-05 (3838 kg $ha^{-1}$) and Aas-11-11 (3555 kg $ha^{-1}$) the most tolerant, whereas, genotype Pak-81 (1216 kg $ha^{-1}$), Siran-10 (1316 kg $ha^{-1}$) and Hasham-08 (1349 kg $ha^{-1}$) the least stress tolerant. Mean productivity index (MP) exhibited the mean performance of a genotype across two environments. Based on MP genotypes Tatara-96 (3570 kg $ha^{-1}$), Shahkar-13 (3487 kg $ha^{-1}$) and Pirsabak-05 (3319 kg $ha^{-1}$) were most tolerant, while, genotype Inqilab-91 (1371 kg $ha^{-1}$), Hasham-08 (1397 kg $ha^{-1}$) and Pak-81 (1562 kg $ha^{-1}$) the least stress tolerant. Similarly, GMP identified genotype Shahkar-13 (3019 kg $ha^{-1}$), Tatara-96 (2852 kg $ha^{-1}$) and Pirsabak-05 (2707 kg $ha^{-1}$) the most tolerant, whereas, least tolerant genotype were Inqilab-91 (1187 kg $ha^{-1}$), Hasham-08 (1224 kg ha-

$^{1}$) and Pak-81 (1438 kg ha$^{-1}$). According to HM, genotypes Shahkar-13 (2614 kg ha$^{-1}$), Tatara-96 (2279 kg ha$^{-1}$) and Pirsabak-05 (2209 ha$^{-1}$) were found high stress tolerant, whereas, genotype Inqilab-91 (1028 kg ha$^{-1}$), Hasham-08 (1072 kg ha$^{-1}$) and Pak-81 (1325 kg ha$^{-1}$) were found as least tolerant. Stress susceptibility index (SSI) estimates the degree of susceptibility or reduction in yield of a genotype under stress condition. Genotype showed SSI < 1 are more resistant to stress conditions. Based on SSI, genotype Siran-10 (0.74), Amin-10 (0.76) and Pirsabak-85 (0.78) were highly stress tolerant.Stress tolerance index (STI) is used to identify genotypes that produce high yield under both stress and non-stress environment. The larger the value of STI for a genotype under stress environment, the higher was it stress tolerance and yield potential (Fernandez, 1992). STI grouped genotype Shahkar-13 (6.89), Tatara-96 (6.15) and Pirsabak-05 (5.54) as the most resistant, while, Inqilab-91 (1.07), Hasham-08 (1.13) and Pak-81 (1.56) were least tolerant genotypes. Yield index (YI) ranks genotypes based on its performance under stress ($N^0$) environment only. YI is calculated based on yield of a genotype to mean yield of all the tested genotype under stress environment. YI ranked genotypes Shahkar-13 (1.51), Tatara-96 (1.24) and Pirsabak-05 (1.22) as the most tolerant, whereas, Inqilab-91 (0.60), Hasham-08 (0.63) and Aas-11-11 (0.65) were found least tolerant to nitrogen stress. Yield stability index (YSI) is estimated based on the relative yield of genotypes under stress to its yield under non stress condition. Genotype having high YSI values will have high yield under both stress and non-stress environment and could be an indicator of nitrogen resistant genotype. YSI value greater than 1 indicates better performance of a genotype under stress than normal and vice versa. According to YSI the desirable genotypes were Siran-10 (0.50), Amin-10 (0.48) and Pirsabak-85 (0.47), whereas, Aas-11 (0.17), NARC-11 (0.22) and Atta Habib (0.24) as the undesirable genotypes .Low nitrogen tolerance index (LNTI) identified genotype Aas-11-11 (83%), NARC-11 (78%) and Atta Habib (76%) as the most tolerant under stress conditions, while, Siran-10 (50%), Amin-10 (52%) and Pirsabak-85 (53%) as the least tolerant genotypes. Nitrogen stress index (NSI) ranked genotype Tatara-96 (1.72), Pirsabak-05 (1.54) and Aas-11-11 (1.43) as the most tolerant, whereas, genotype Pak-81 (0.49), Siran-10 (0.53) and Hasham-08 (0.54) as the least relative stress tolerant genotypes. Genotype Aas-11 (0.83), NARC-11 (0.78) and Atta Habib (0.76) displayed relative high values of SDI, while, Siran-10 (0.50), Amin-10 (0.52) and Pirsabak-85 (0.53) showed lower estimates of SDI. Maximum values of nitrogen index (NI) was recorded for genotype Siran-10 (0.56), Amin-10 and Pirsabak-85 (0.54 each), whereas, minimum NI was observed for Aas-11 (0.11), NARC-11 (0.19) and Inqilab-91 (0.20). Stress susceptibility percentage (SSPI) shows the percent susceptibility of a genotype under stress calculated on the basis of reduction in yield under stress and non-stress conditions. SSPI indicated genotype Tatara-96 (59.0%), Pirsabak-08 (52.7%) and Aas-11-11 (48.5%) are the most susceptible genotypes to nitrogen stress, whereas, genotype Pak-81 (16.7%), Siran-10 (18.1%) and Hasham-08 (18.5%) are the least effected by nitrogen stress according to SSI values. According to K1STI, genotype Tatara-96 (2.56), Pirsabak-05 (2.07) and Shahkar-13 (2.07) as the most tolerant genotypes. On the other hand, genotype Shahkar-13 (2.30), Tatara-96 (1.53) and Pirabak-05 (1.48) were found most tolerant according to K2STI. Relative nitrogen index (RNI) grouped genotype Siran-10 (1.49), Amin-10 (1.44) and Pirsabak-85 (1.40) as the most tolerant genotypes, whereas, Aas-11 (0.52) and Atta Habib (0.73) as sensitive genotypes (Table 3).

**Correlation analysis:** To determine the most effective indices to be used as selection criterion for identifying desirable genotype under stress, correlation among yield under both stress and non-stress environment with all the calculated stress selection indices was determined. Correlation analysis depicted that grain yield under non-stress ($N^+$) had strong positive association with TOL(r = 0.97), MP (r = 0.98), GMP (r =0.89), HM (r = 0.72), SSI (r = 0.66), STI (r = 0.88), YI (r = 0.50), LNTI (r = 0.66), NSI (r = 0.97), SDI (r = 0.66), SSPI (r = 0.97), K1STI (r = 0.99) and K2STI (r = 0.51), whereas, significant negative association with YSI (r = -0.66) and RNI (r =-0.66). In addition, grain yield under stress ($N^0$) had significant positive relationship with MP (r = 0.66), GMP (r = 0.83), HM (r =0.96), STI (r = 0.82), NI (r = 0.75), K1STI (r = 0.50) and K2STI (r = 0.99). Positive relationship of these indices with grain yield under respective production system showed that selection of genotypes based on these indices provide suitable criteria (Table 4).

**Cluster analysis:** Cluster analysis grouped genotypes into three categories i.e. tolerant, semi-tolerant, semi-sensitive and sensitive genotypes. Cluster analysis grouped genotype Tatara-96, Pirsabak-05 and Shahkar-13 in tolerant group, whereas, Faisalabad-08, NARC-11, Aas-11-11, Khyber-87, Pirsabak-08, Punjab-11, Atta Habib, Ghaznavi-98, Saleem-2000, Sulaiman-96, Sehar-06, ARRI and Janbaz-09-09 were placed in semi tolerant group. Genotypes Pirsabak-04, Dharabi-11-11, Bathoor-08-08, Barsat-10, Watan-93, Pirsabak-13, Nowshehra-96, Amin-10, Siran-10, Pirsabak-85, and Kohat-2000 were placed in semi susceptible group. On the other hand, Inqilab-91, Hasham-08and Pak-81 were grouped as susceptible genotypes (Figure 1).

**Principal component analysis and three dimensional plots:** Based on these indices the tested genotypes can be classified into four groups on their performance in stress and non-stress environments: cultivars express uniform superiority in both stress and non-stress conditions (Group A), cultivars perform favorably only in non-stress conditions (Group B), cultivars gives relatively higher yield only in stress conditions (Group C), and cultivars perform poorly in both stress and non-stress conditions (Group D). The optimal selection criterion should distinguish Group A from the other three groups (Fernandez, 1992). PCA grouped genotypes into four categories based on the performance under stress and non-stress condition. Group A includes genotypes Tatara-96, Shahkar-13, Pirsabak-05, Saleem-2000, Ghaznavi-98, Sehar-06, Janbaz-09 and Suleeman-96 which showed uniform superiority under both stress and non-stress condition. Genotype Khyber-87, Aas-11-11, NARC-11, Faisalabad-08, Atta Habib, Punjab-11, ARRI, and Pirsabak-08 showed superior performance under non-stress condition and were placed in Group B. On the other hand, genotype yielded relatively higher under stress only are grouped in Group C .i.e. KT-2000, Pirsabak-85, , Nowshehra-96, Amin-10, Siran-10, Pirsabak-13, while genotype poor yielded under both conditions are grouped in Group D, that include genotype Inqilab-91, Hasham-08, Pak-81, Pirsabak-04, Dharabi-11, Barsat, Bathoor-08 and Watan-93(Figure 3). Similarly, three dimensional plots among Yp, Ys with MP, GMP and STI constructed are presented in Figure 3, 4 and 5, respectively. Distribution of genotypes based on PCA analysis was confirmed through three dimensional plots.

**Table. List of wheat varieties evaluated**

| S. No | Genotypes/Varieties | Breeding Centre |
|---|---|---|
| 1 | Pak-81 | CCRI, Pirsabak |
| 2 | Pirsabak-85 | CCRI, Pirsabak |
| 3 | Khyber-87 | CCRI, Pirsabak |
| 4 | Inqilab-91 | WRI, AARI, Faisalabad |
| 5 | Watan-93 | WRI, AARI, Faisalabad |
| 6 | Nowshehra-96 | CCRI, Pirsabak |
| 7 | Sulaiman-96 | CCRI, Pirsabak |
| 8 | Tatara-96 | NIFA, Peshawar |
| 9 | Ghaznavi-98 | AUP, Peshawar |
| 10 | KT-2000 | BARS, Kohat |
| 11 | Saleem-2000 | CCRI, Pirsabak |
| 12 | Pirsabak-04 | CCRI, Pirsabak |
| 13 | Pirsabak-05 | CCRI, Pirsabak |
| 14 | Seher-06 | WRI, AARI, Faisalabad |
| 15 | Bathoor-08-08 | NIFA Peshawar |
| 16 | Faisalabad-08 | WRI, AARI, Faisalabad |
| 17 | Hashim-08 | ARI, D.I. Khan |
| 18 | Pirsabak-08 | CCRI, Pirsabak |
| 19 | Janbaz-09-09 | AUP, Peshawar |
| 20 | Amin-10 | ARS, S. Naurang Bannu |
| 21 | Atta-Habib-10 | AUP, Peshawar |
| 22 | Barsat-10 | NIFA, Peshawar |
| 23 | Siran-10 | AUP, Peshawar |
| 24 | Aas-11-11 | RARI, Bahawalpur |
| 25 | ARRI-11 | RARI, Bahawalpur |
| 26 | Dharabi-11-11 | BARI, Chakwal |
| 27 | NARC-11 | NARC, Islamabad |
| 28 | Punjab-11 | WRI, AARI, Faisalabad |
| 29 | Pirsabak-13 | CCRI, Pirsabak |
| 30 | Shahkar-13 | CCRI, Pirsabak |

**Table 2. Means and selection indices for grain yield (kg ha$^{-1}$) of 30 wheat genotypes evaluated under with (Yp) and without nitrogen (Ys) condition during Rabi 2013-14**

| Genotype | Yp | Ys | TOL | MP | GMP | HM | SSI | STI | YI | YSI |
|---|---|---|---|---|---|---|---|---|---|---|
| Pak-81 | 2170 | 953 | 1216 | 1562 | 1438 | 1325 | 0.82 | 1.56 | 0.83 | 0.44 |
| Pirsabak-85 | 2859 | 1337 | 1522 | 2098 | 1955 | 1822 | 0.78 | 2.89 | 1.16 | 0.47 |
| Khyber-87 | 3845 | 1032 | 2813 | 2439 | 1993 | 1628 | 1.07 | 3.00 | 0.90 | 0.27 |
| Inqilab-91 | 2056 | 686 | 1370 | 1371 | 1187 | 1028 | 0.97 | 1.07 | 0.60 | 0.33 |
| Watan-93 | 3492 | 1068 | 2423 | 2280 | 1931 | 1636 | 1.01 | 2.82 | 0.93 | 0.31 |
| Nowshehra-96 | 3531 | 1321 | 2210 | 2426 | 2160 | 1923 | 0.91 | 3.53 | 1.15 | 0.37 |
| Sulaiman-96 | 3952 | 1270 | 2682 | 2611 | 2240 | 1922 | 0.99 | 3.80 | 1.10 | 0.32 |
| Tatara-96 | 5718 | 1423 | 4295 | 3570 | 2852 | 2279 | 1.10 | 6.15 | 1.24 | 0.25 |
| Ghaznavi-98 | 4197 | 1312 | 2885 | 2754 | 2346 | 1999 | 1.00 | 4.16 | 1.14 | 0.31 |
| KT-2000 | 3105 | 1378 | 1727 | 2242 | 2069 | 1909 | 0.81 | 3.24 | 1.20 | 0.44 |
| Saleem-2000 | 4149 | 1325 | 2824 | 2737 | 2345 | 2009 | 0.99 | 4.16 | 1.15 | 0.32 |
| Pirsabak-04 | 3080 | 1075 | 2005 | 2078 | 1820 | 1594 | 0.95 | 2.50 | 0.93 | 0.35 |
| Pirsabak-05 | 5238 | 1399 | 3838 | 3319 | 2707 | 2209 | 1.07 | 5.54 | 1.22 | 0.27 |
| Seher-06 | 4022 | 1219 | 2803 | 2621 | 2214 | 1871 | 1.02 | 3.71 | 1.06 | 0.30 |
| Bathoor-08 | 3210 | 1041 | 2169 | 2126 | 1828 | 1572 | 0.99 | 2.53 | 0.91 | 0.32 |
| Faisalabad-08 | 4489 | 1121 | 3368 | 2805 | 2243 | 1794 | 1.10 | 3.80 | 0.97 | 0.25 |
| Hashim-08 | 2071 | 723 | 1349 | 1397 | 1224 | 1072 | 0.95 | 1.13 | 0.63 | 0.35 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pirsabak-08 | 3787 | 1032 | 2755 | 2409 | 1977 | 1622 | 1.06 | 2.95 | 0.90 | 0.27 |
| Janbaz-09 | 3825 | 1339 | 2486 | 2582 | 2264 | 1984 | 0.95 | 3.87 | 1.16 | 0.35 |
| Amin-10 | 2730 | 1306 | 1424 | 2018 | 1888 | 1766 | 0.76 | 2.70 | 1.14 | 0.48 |
| Atta-Habib-10 | 4086 | 1000 | 3087 | 2543 | 2021 | 1607 | 1.10 | 3.09 | 0.87 | 0.24 |
| Barsat-10 | 2810 | 974 | 1837 | 1892 | 1654 | 1446 | 0.96 | 2.07 | 0.85 | 0.35 |
| Siran-10 | 2611 | 1295 | 1316 | 1953 | 1839 | 1731 | 0.74 | 2.56 | 1.13 | 0.50 |
| Aas-11 | 4307 | 752 | 3555 | 2530 | 1800 | 1281 | 1.21 | 2.45 | 0.65 | 0.17 |
| ARRI-11 | 3889 | 1146 | 2743 | 2518 | 2111 | 1771 | 1.03 | 3.37 | 1.00 | 0.29 |
| Dharabi-11 | 3056 | 1076 | 1980 | 2066 | 1814 | 1592 | 0.95 | 2.49 | 0.94 | 0.35 |
| NARC-11 | 4408 | 988 | 3420 | 2698 | 2087 | 1614 | 1.13 | 3.29 | 0.86 | 0.22 |
| Punjab-11 | 3875 | 997 | 2878 | 2436 | 1966 | 1586 | 1.09 | 2.92 | 0.87 | 0.26 |
| Pirsabak-13 | 3469 | 1168 | 2301 | 2319 | 2013 | 1748 | 0.97 | 3.06 | 1.02 | 0.34 |
| Shahkar-13 | 5231 | 1742 | 3489 | 3487 | 3019 | 2614 | 0.97 | 6.89 | 1.51 | 0.33 |
| Mean | 3642 | 1150 | 2492 | 2396 | 2034 | 1732 | 0.98 | 3.24 | 1.00 | 0.33 |

Stress intensity (SI) =0.68

**Table 3. Means and selection indices for grain yield (kg ha$^{-1}$) of 30 wheat genotypes evaluated under with (Yp) and without nitrogen (Ys) condition during Rabi 2013-14**

| Genotype | Yp | Ys | LNTI | NSI | SDI | NI | SSPI | K1STI | K2STI | RNI |
|---|---|---|---|---|---|---|---|---|---|---|
| Pak-81 | 2170 | 953 | 56 | 0.49 | 0.56 | 0.36 | 16.7 | 0.35 | 0.69 | 1.32 |
| Pirsabak-85 | 2859 | 1337 | 53 | 0.61 | 0.53 | 0.54 | 20.9 | 0.62 | 1.35 | 1.40 |
| Khyber-87 | 3845 | 1032 | 73 | 1.13 | 0.73 | 0.24 | 38.6 | 1.11 | 0.81 | 0.81 |
| Inqilab-91 | 2056 | 686 | 67 | 0.55 | 0.67 | 0.20 | 18.8 | 0.32 | 0.36 | 1.00 |
| Watan-93 | 3492 | 1068 | 69 | 0.97 | 0.69 | 0.28 | 33.3 | 0.92 | 0.86 | 0.92 |
| Nowshehra-96 | 3531 | 1321 | 63 | 0.89 | 0.63 | 0.43 | 30.3 | 0.94 | 1.32 | 1.12 |
| Sulaiman-96 | 3952 | 1270 | 68 | 1.08 | 0.68 | 0.35 | 36.8 | 1.18 | 1.22 | 0.96 |
| Tatara-96 | 5718 | 1423 | 75 | 1.72 | 0.75 | 0.31 | 59.0 | 2.46 | 1.53 | 0.75 |
| Ghaznavi-98 | 4197 | 1312 | 69 | 1.16 | 0.69 | 0.36 | 39.6 | 1.33 | 1.30 | 0.94 |
| KT-2000 | 3105 | 1378 | 56 | 0.69 | 0.56 | 0.53 | 23.7 | 0.73 | 1.44 | 1.33 |
| Saleem-2000 | 4149 | 1325 | 68 | 1.13 | 0.68 | 0.37 | 38.8 | 1.30 | 1.33 | 0.96 |
| Pirsabak-04 | 3080 | 1075 | 65 | 0.80 | 0.65 | 0.33 | 27.5 | 0.72 | 0.87 | 1.05 |
| Pirsabak-05 | 5238 | 1399 | 73 | 1.54 | 0.73 | 0.33 | 52.7 | 2.07 | 1.48 | 0.80 |
| Seher-06 | 4022 | 1219 | 70 | 1.12 | 0.70 | 0.32 | 38.5 | 1.22 | 1.12 | 0.91 |
| Bathoor-08 | 3210 | 1041 | 68 | 0.87 | 0.68 | 0.29 | 29.8 | 0.78 | 0.82 | 0.97 |
| Faisalabad-08 | 4489 | 1121 | 75 | 1.35 | 0.75 | 0.24 | 46.2 | 1.52 | 0.95 | 0.75 |
| Hashim-08 | 2071 | 723 | 65 | 0.54 | 0.65 | 0.22 | 18.5 | 0.32 | 0.40 | 1.05 |
| Pirsabak-08 | 3787 | 1032 | 73 | 1.11 | 0.73 | 0.24 | 37.8 | 1.08 | 0.81 | 0.82 |
| Janbaz-09 | 3825 | 1339 | 65 | 1.00 | 0.65 | 0.41 | 34.1 | 1.10 | 1.36 | 1.05 |
| Amin-10 | 2730 | 1306 | 52 | 0.57 | 0.52 | 0.54 | 19.6 | 0.56 | 1.29 | 1.44 |
| Atta-Habib-10 | 4086 | 1000 | 76 | 1.24 | 0.76 | 0.21 | 42.4 | 1.26 | 0.76 | 0.73 |
| Barsat-10 | 2810 | 974 | 65 | 0.74 | 0.65 | 0.29 | 25.2 | 0.60 | 0.72 | 1.04 |
| Siran-10 | 2611 | 1295 | 50 | 0.53 | 0.50 | 0.56 | 18.1 | 0.51 | 1.27 | 1.49 |
| Aas-11 | 4307 | 752 | 83 | 1.43 | 0.83 | 0.11 | 48.8 | 1.40 | 0.43 | 0.52 |
| ARRI-11 | 3889 | 1146 | 71 | 1.10 | 0.71 | 0.29 | 37.7 | 1.14 | 0.99 | 0.88 |
| Dharabi-11 | 3056 | 1076 | 65 | 0.79 | 0.65 | 0.33 | 27.2 | 0.70 | 0.88 | 1.06 |
| NARC-11 | 4408 | 988 | 78 | 1.37 | 0.78 | 0.19 | 46.9 | 1.46 | 0.74 | 0.67 |
| Punjab-11 | 3875 | 997 | 74 | 1.15 | 0.74 | 0.22 | 39.5 | 1.13 | 0.75 | 0.77 |
| Pirsabak-13 | 3469 | 1168 | 66 | 0.92 | 0.66 | 0.34 | 31.6 | 0.91 | 1.03 | 1.01 |
| Shahkar-13 | 5231 | 1742 | 67 | 1.40 | 0.67 | 0.50 | 47.9 | 2.06 | 2.30 | 1.00 |
| Mean | 3642 | 1150 | 67 | 1.00 | 0.67 | 0.33 | 34.21 | 1.06 | 1.04 | 0.98 |

Stress intensity (SI) =0.68

**Table 4. Correlation coefficient of yield under non-stress and stress with various selection indices**

| Selection indices | YN+ (Yield under non-stress) | YN0(Yield under stress) |
|---|---|---|
| YN+ | | $0.50^{**}$ |
| TOL | $0.97^{**}$ | $0.28^{NS}$ |
| MP | $0.98^{**}$ | $0.66^{**}$ |
| GMP | $0.90^{**}$ | $0.83^{**}$ |
| HM | $0.72^{**}$ | $0.96^{**}$ |
| SSI | $0.66^{**}$ | $-0.30^{NS}$ |
| STI | $0.88^{**}$ | $0.82^{**}$ |
| YI | $0.50^{**}$ | $1.00^{**}$ |
| YSI | $-0.66^{**}$ | $0.30^{NS}$ |
| LNTI | $0.66^{**}$ | $-0.30^{NS}$ |
| NSI | $0.97^{**}$ | $0.28^{NS}$ |
| SDI | $0.66^{**}$ | $-0.30^{NS}$ |
| NI | $-0.16^{NS}$ | $0.75^{**}$ |
| SSPI | $0.97^{**}$ | $0.28^{NS}$ |
| K1STI | $0.99^{**}$ | $0.50^{**}$ |
| K2STI | $0.51^{**}$ | $0.99^{**}$ |
| RNI | $-0.66^{**}$ | $0.30^{NS}$ |

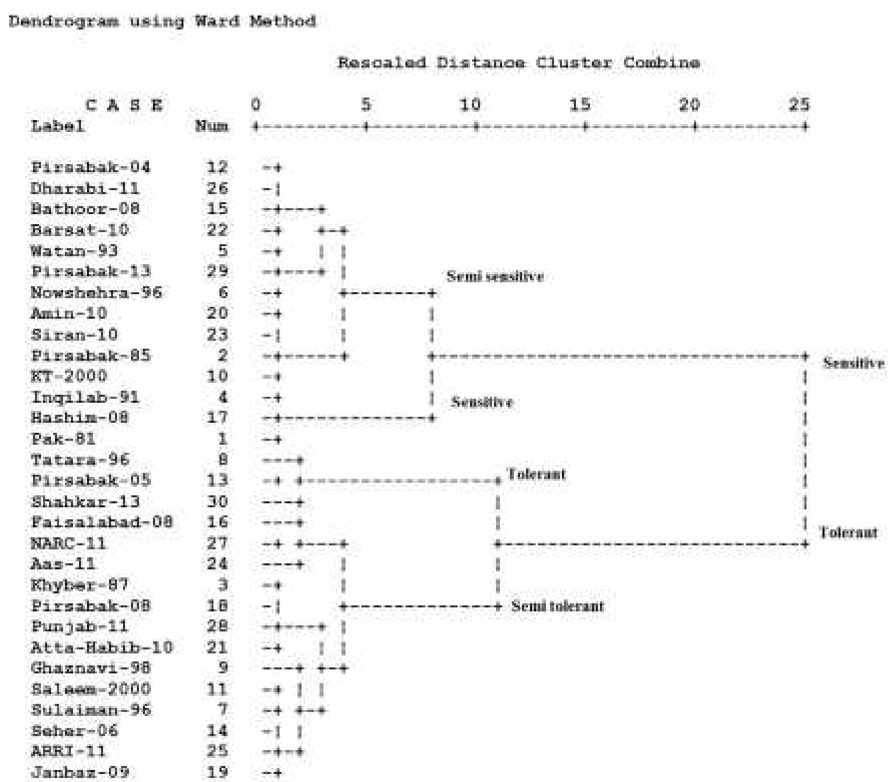


**Fig 1. Dendogram using ward method showing genotypes grouped into three cluster based on stress selection indices.**

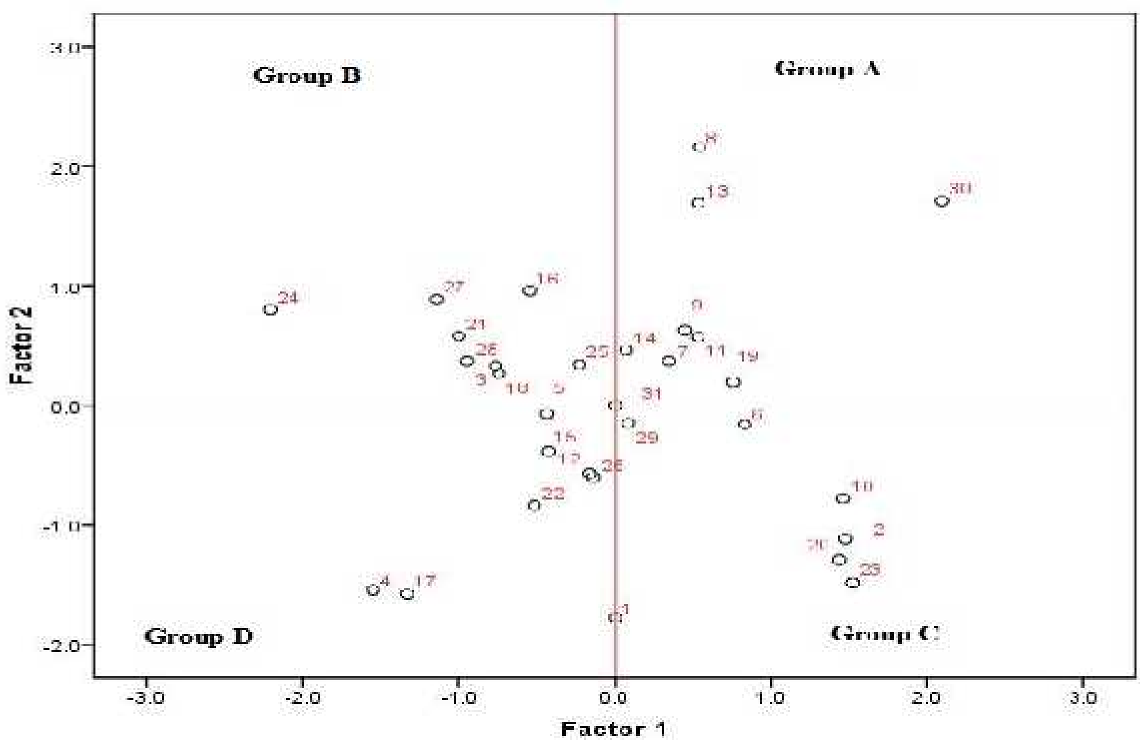


**Fig 2. Principal component analysis showing distribution of genotypes based on stress selection indices.**

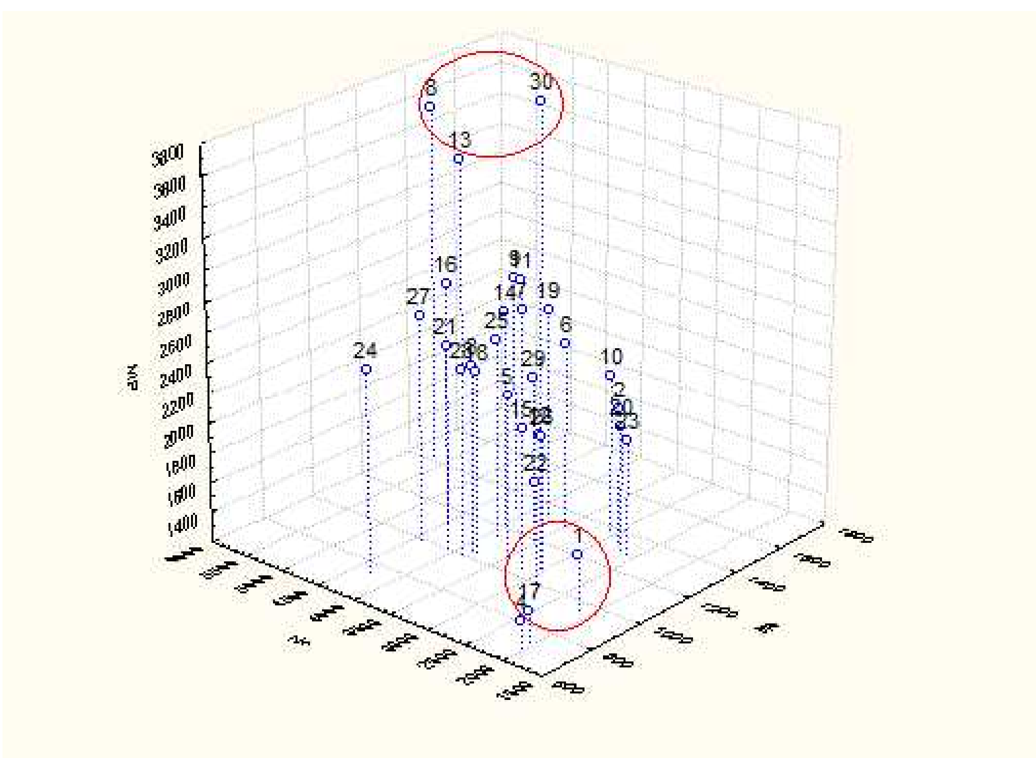

**Fig 3. Three dimensional bi-plot showing interrelationship of Yp, Ys and MP.**

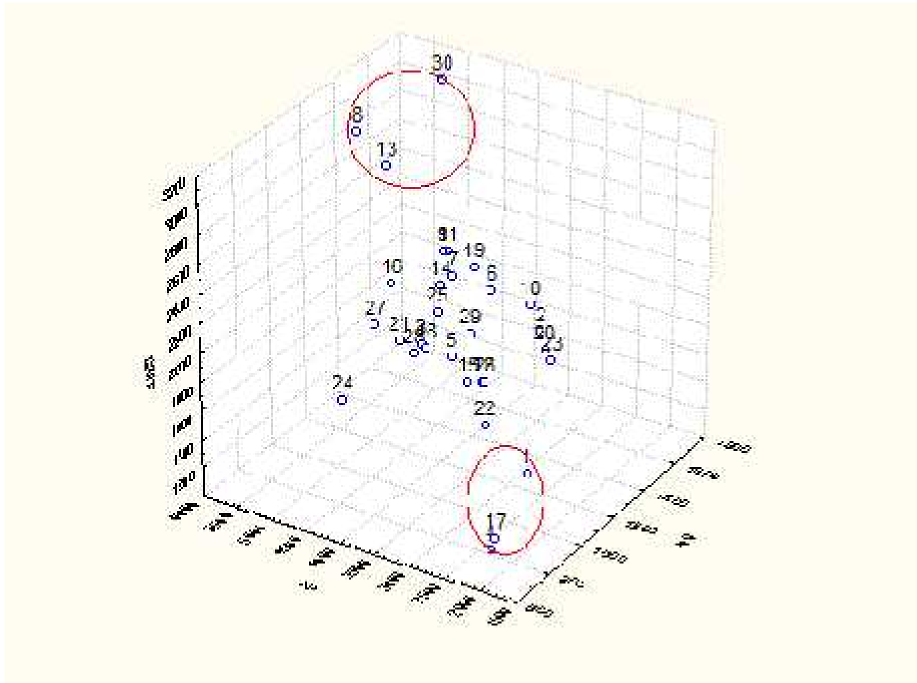

**Fig 4. Three dimensional bi-plot showing interrelationship of Yp, Ys and GMP.**

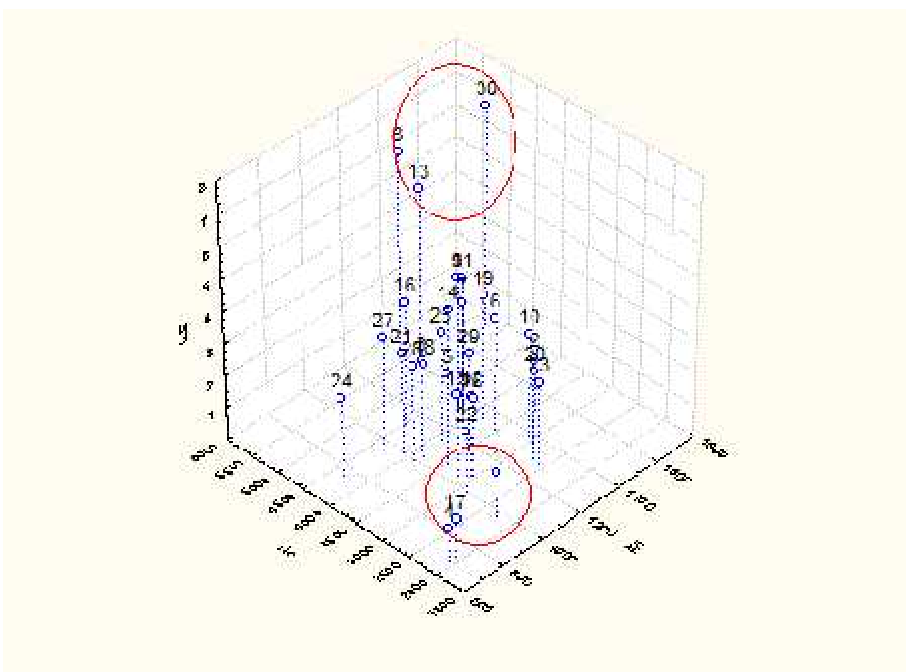

**Fig 5. Three dimensional bi-plot showing interrelationship of Yp, Ys and STI.**

## DISCUSSION

Selection of genotypes with better yield under stress (biotic or abiotic) is prime objective of every breeding program. Plant breeders are striving since long to feed increasing population around the globe. Breeding for nitrogen stress is new concept in developing countries, as nitrogen is major element for crop growth and development. Development of nitrogen responsive varieties boost wheat yield, however high consumption of N-fertilizer is also environment damaging, as excess N lost by leaching into groundwater and runoff into surface water, plus ammonia volatization and production of $NO_x$ gases from denitrification pollute the atmosphere

(**Conley** *et al.* 2009). That is why, selection of genotypes/varieties that perform well under limiting nitrogen condition is of prime importance. Stress selection indices provide an opportunity to assess tolerance of wheat genotypes to nitrogen stress. Previously, stress selection indices is frequently used in experiment related to selection of genotypes for drought tolerance. In this experiment an attempt has been made to apply stress selection indices for assessment of nitrogen tolerance in wheat. Based on the performance under non-stress (Yp) and stress (Ys), fifteen stress selection indices were computed. Correlation analysis depicted that grain yield under non-stress ($N^+$) had strong positive association with TOL, MP, GMP, HM, SSI, STI, LNTI, NSI, SDI, SSPI, K1STI, whereas, significant negative association with YSI, NI and RNI. In addition, grain yield under stress ($N^0$) had significant positive relationship with MP, GMP, HM, STI, YSI, NI, K2STI and RNI, while significant negative correlation with SSI, LNTI and SDI. Similarly, Cluster analysis grouped genotypes in to tolerant i.e. genotype 6, 14, 12, 17, 27, 9, and 25. Genotype 1, 20, 13, 21, 24, 11, 15, 4, 30 and 19 were placed in semi tolerant group and genotypes found sensitive to nitrogen stress were 2, 7, 18, 16, 5, 23, 3, 22, 26, 29, 8, 28, and 10. Furthermore, Principal component analysis (PCA) partitioned genotypes into four groups (Fernandez, 1992). Classification made through PCA analysis were confirmed through three dimensional plots among Yp, Ys with MP, GMP and STI. Positive association of theses indices suggested that theses could be effectively used. Farshadfar *et al.,* (2001) also suggested that the most appropriate index for selecting stress tolerant cultivars is an index which has partly high correlation with seedyield under stress and non-stress conditions. Similarly, Dehghani *et al.* (2009) showed that GMP, MP and STI had positive correlation with yield under stress. Conversely, Ehdaie and Shakiba (1996) found that stress susceptibility index (SSI) and grain yield had no association under non stress condition in wheat. Genotype high value of GMP and STI, and low of SSI can be considered as drought tolerant. Hence, combination of various indices is thought to provide useful information/criterion regarding identification and selection of genotypes that are best suited to both stress and non-stress environments. In conclusion, results of current study indicate that MP, GMP and STI had similar ability to differentiate genotypes for drought sensitiveness and tolerance. These indices have strong association with yield under both stress and non-stress conditions. A combination of STI and GMP is a better predictor of yield under stress and could be recommended for screening wheat genotypes for drought tolerance.

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