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***Full Length Article***

# Comparison of Different Tolerance Indices and PCA Biplot Analysis for Assessment of Salinity Tolerance in Lentil (*Lens Culinaris* L.) Genotypes

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## Abstract

Lentil is very important legume crop and affected by salinity stress. This study was planned to sort out the lentil germplasm for salinity tolerance. Four different salinity treatments were used ($S_{0mM}$, $S_{50mM}$, $S_{100mM}$, $S_{150mM}$) in hydroponic culture and root length (RL), shoot length (SL), root weight (RW), shoot weight (SW), total proteins contents (PC), α-amylase (A.A), total soluble sugars (TSS) sodium ions ($Na^+$), potassium ions ($K^+$) and sodium to potassium ratio ($Na^+/K^+$) were used as criteria for selection. Principle component analysis (PCA) based biplot, rank sum (RS) scores, integrated selection index (ISI) and integrated scoring (IS) were used as statistical analysis for sortation of lentil genotypes for salinity tolerance and to compare the results of different indices with each other and with PCA based biplot. Analysis of variance showed that genotypes, salinity treatments and their interactions for all subjected traits were significantly different from each other. PCA based biplot showed that $Na^+$, $Na^+/K^+$, $K^+$ and TSS under $S_{0mM}$, RW, SW, RL, SL, $K^+$, $Na^+/K^+$ and $Na^+$ under $S_{50mM}$, SL, SW, RL, RW, $Na^+$, $K^+$, $Na^+/K^+$ under $S_{100mM}$, TSS, SL, RL, RW, $Na^+$, $K^+$, $Na^+/K^+$ under $S_{150mM}$ were most discriminating parameters for evaluation of lentil genotypes under respective salinity treatment. PCA biplot showed that Masoor 2002, NL20-3-3, NL9775, NARC11-2 and ILL5888 under $S_{0mM}$; Masoor 2002, NL9775, ILL5888 and ILL6024 under $S_{50mM}$; Masoor 2002, NL0196, NL20-3-3, NL9775 under $S_{100mM}$; Masoor 2002, Masoor 2009, NL9775, NL0196, NL0188 and NL20-3-3 under $S_{150mM}$ were tolerant. Masoor 2002, NL 20-3-3, LN 0188, M93 and NL9775 were declared to be salt tolerant by RS, ISI and IS. Results of RS, ISI, IS and PCA Biplot were comparable and equally valid as these declared unanimously Masoor 2002, NL 20-3-3, LN 0188, M93 and NL9775 as salt tolerant at early growth stages. Genotypes NARC 11-4 and Marka 209 were relatively susceptible against salinity. These tolerant and susceptible lentil genotypes could be used as further evaluation against salinity on physiological and biochemical basis. © 2017 Friends Science Publishers

**Keywords:** Integrated selection index (ISI); Rank sum (RS) score; Integrated scoring (IS); Principle component analysis

## Introduction

Leguminoseae is very important family of flowering plants and comprised of four subfamilies named as Caesalpinoideae, Mimosoideae, Papilionoideae and Swartzioideae. Leguminous crops have utmost fame of being inexpensive source of energy, protein, minerals and vitamins. Combination of cereals and legumes make the balanced diet for human. Among legumes, lentil was component part of ancient Egyptian cropping system and as old as emmer and einkorn wheat (Harlan, 1992). Lentil along with other legumes is important food component of the South Asia, Middle East and North Africa.

Area under lentil cultivation is 4.6 m ha with 4.2 m tons production and average yield of 1095 kg $ha^{-1}$ yield (FAO, 2010). Canada, India, Turkey, Iran, Bangladesh, China, Syria and Nepal are the main lentil producers and it is liked due to fast cooking ability and nutrient composition being enriched with proteins, fats, iron, cobalt, iodine, lysine and arginine (Bhatty, 1988; Kowieska and Petkov, 2003). Among different leguminous crops, lentil (*Lens culinaris* L.) is also very important crop of Pakistan where, per capita consumption is 15 kg per year. Fixation of atmospheric nitrogen in rhizosphere and improvement of soil fertility are the other important features of lentil (Crook *et al.*, 1999). It is diploid species with estimated haploid genome size of 4063 Mbp (Arumuganathan and Earle, 1991).

Lentil is mainly grown during winter on marginal lands and rainfed areas of Pakistan. Importance of lentil is continuously increasing due to increasing the demand of lentil across the world. In Pakistan, 22,500 ha are under the lentil cultivation with 11,600 tons production during 2012 which was about 12.8% less than the previous year (Government of Pakistan, 2011). Area under lentil is lower due to its competition with staple cereals and efforts are targeted to enhance the per unit area production. Significant

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varietal differences were reported in lentil genotypes for number of branches, plant height, number of seeds per pod, number of pods per plant, biological yield and harvest index (Karadavut and Genc, 2010). Differential responses of various lentil varieties for numerous traits showed that existing variability is providing the opportunity of targeted selection.

Different biotic (rust, wilt and blight) and abiotic (drought, low temperature and salinity) stresses are threatening the lentil crop across the globe depending upon the climatic regimes of the concerned regions. Genetic variation among different lentil genotypes was observed for drought, low temperature, salinity, nutrient deficiency and toxicity (Fratini and Pérez De La Vega, 2011). Development of salinity tolerant germplasm is very important to expand the cultivation of lentil in the driers areas with poor soils. Salinity is among the main stresses, which badly affect the seedling growth and development of different crops (Atak *et al.*, 2006; Kaya *et al.*, 2006).

Plant seedlings are more severely affected by salinity stress because seed germination and seedling roots are present in the upper layer of soil (Almansouri *et al.*, 2001). Sodium chloride causes the severely harmful effects on the morphological, physiological and biochemical characteristics of crop plants (Arshi *et al*., 2002; Sairam and Tyagi, 2004; Parida and Das, 2005). With the extensive use of irrigation system, salt affected area is increasing day by day. Evaluation of seedlings for salinity tolerance is effective due to following critical reasons; seedling parameters have higher heritability relative to other stages (Ashraf, 1994), salt accumulations mostly occurred in the upper soil layer due to capillary rise of water and evaporation (El- Monem and Sharaf, 2014). Mechanism of salinity tolerance is variable even with in species or between genotypes thus, there is dire need to evaluate the lentil germplasm for salinity tolerance preferably at seedling stage (Lutts *et al*., 1995; Almansouri *et al*., 2001). Different biometrical tools have been used for the evaluation of lentil genotypes for salinity tolerance. Use of more than one biometrical tool provides precise, validated and reliable results. Therefore, present study, biplot analysis, ranking scores, integrated selection index (ISI) and integrated scoring (IS) were used for evaluation of lentil genotypes for salinity tolerance.

## Materials and Methods

### Plant Growth Conditions and Salinity Treatments

Present research experiment was conducted in the research area of Plant Breeding and Genetics Department, University of Agriculture Faisalabad, Pakistan during 2014. Greenhouse experiment was conducted using triplicated completely randomized design. Total fifteen lentil genotypes were used in current study including; NL 96476, Masoor 2002, NL 20-3-3, NL 96700, M 93, Masoor 2009, NL 0196, ILL 5888, NL 0188, NARC 11-2, Marka 209, NARC 11-4, NL 96505, ILL 6024 and NL 9775. Seeds of each cultivar were grown in sand filled trays and later on transferred to the hydroponic growth culture after seedling establishment for application of salinity treatments. Hydroponic growth culture was supplemented with full strength Hoagland's growth solution (Hoagland and Arnon, 1950) and plants were stabilized for 2 days in growth media. Hoagland's solution was renewed after every fifteen days. Four different salinity treatments used are as following:

$S_{0mM}$ = 0 mM NaCl Solution,
$S_{50mM}$ = 50 mM NaCl solution,
$S_{100mM}$ =100 mM NaCl solution,
$S_{150mM}$ =150 mM NaCl solution.

Salinity treatments were applied two days after transplanting in hydroponic culture with an incremental dose of 25 mM on daily basis until or unless desired level is attained in separate treatments. Experiment was continued for 40 days after transplantation in hydroponic growth media and then crop was harvested. After harvesting, data were recorded for following morphological and biochemical traits; root length (RL; cm), shoot length (SL; cm), root weight (RW; g), shoot weight (SW; g), α-amylase (A.A; $mgg^{-1}$; Rick and Stegbauer, 1974), total soluble protein contents (PC; $mgg^{-1}$; Bradford, 1976), total soluble sugars (TSS; mg $g^{-1}$; Dubois *et al*., 1956), K ions ($K^+$; ppm; Hald, 1947), Na ions ($Na^+$; ppm; Hald, 1947) and Na/K ratio (Na/K) were recorded.

### Statistical Analysis

Lentil genotypes and different salinity treatments were two different factors therefore; two factor factorial treatment structure under completely randomized design (CRD) was used for analysis of variance (Steel and Torrie, 1997) for estimation of treatments, genotypes and their interaction effects. Principle Component Analysis (PCA) based Biplots (Gabriel, 1971) were made for each salinity treatment separately. PCA transformed the raw data into unit-less variables and also distribute variability into different factors or principle components. Among different factors, only those factors were considered for further studies which have eigenvector value greater than one. Biplot was drawn by using principle factors, which have most of variability. Biplot was two dimensional scatter diagram which depicted the scattering pattern of genotypes and traits.

### Salinity Tolerance Indices

Three different tolerance indices i.e. Ranked scoring (RS; Farshadfar, 2012), Integrated Scoring Index (ISI; Farshadfar *et al.*, 2012a; Farshadfar, 2012; Khalili *et al.*, 2012) and Integrated Scoring (IS; Ahmed *et al*., 2013) were used in current study for evaluation of relative performance of lentil genotypes under four different salinity treatments.

**Ranked Scoring (RS)**

Ranked scoring was estimated for each genotype on the basis of all studied traits under all treatments separately. Genotypes having the highest mean values were given highest rank scores whereas, genotypes having lowest means as lowest rank scores. Mean rank scores were estimated from the rank scores of four salinity treatments. Standard deviation of ranks (SDR; $S_i^2$) were estimated with following formula:

$$S_i^2 = \frac{\sum_{j=1}^{m}(R_{ij} - \bar{R}_{i.})^2}{l-1}$$

Where, $R_{ij}$ is the rank of salinity tolerance indicator, $\bar{R}_{i.}$ is the mean rank across all salinity tolerance indicators for the each genotype, *l* is number of variables.

Rank sum for genotypes were estimated by using rank mean and standard deviation of rank with the help of following formula:

Rank Sum (RS) = Rank mean ($\bar{R}$) + Standard deviation of rank (SDR).

**Integrated Selection Index (ISI)**

This index is based on the factor analysis whose factor values are used for estimation of integrated selection index (Farshadfar *et al.,* 2012a; Farshadfar, 2012; Khalili *et al.,* 2012; Khalili *et al.*, 2013).

Formula ….(1): Sij= (Xij – μj)/ σj
Formula…..(2): MPij= (Sijd + Sijw)/2
Formula…..(3): ISIi= b1MPi1+ b2MPi2+…+ bjMPij

Formula -1: standardized the values of different traits to the unit value,

Formula-2: estimate the appearance of genotype for each parameter,

Formula-3: integrates the performance of genotypes for all traits.

Where, Sij= is the standardized value of trait j (j =1 to 10) in cultivar i under normal and salinity stress, Xij = measured value of cultivar i for trait j, μj = mean value of trait j for all genotypes, σj= the standard deviation of parameter j, MPij= the mean productivity of parameter j for genotype i,

bj = weight value of parameter j, bj= was measured from the average contribution to factor 1, ISI = integrated selection index.

**Integrated Scoring (IS)**

Integrated scoring was reported by Ahmed *et al*. (2013) and used 0.125 as factor for standardization or normalization of data because they studied 8 parameters. We modified integrated scoring formula regarding our parameters, as we have 10 traits thus, we used 0.10 as factor for standardization. However, for weighting different traits differently, normalization factor can further be modified accordingly. Modified formula for integrated scoring is as following:

Integrated score = absolute values of [(Shoot length × 0.10) + (Root length × 0.10) + (Shoot weight × 0.10) + (Root weight × 0.10) + (α-amylase contents × 0.10) + (Total protein contents × 0.10) + (Total soluble sugars × 0.10) + (K ions × 0.10) + (Na ions × 0.10) + (Na/K × 0.10)].

## Results

**Analysis of Variance**

Genotypes and salinity treatments were two distinct factors to access the significant differences among genotypes (G) and treatments (T). Thus, two factor factorial analysis of variance revealed significant differences among genotypes for shoot length (SL), root length (RL), shoot weight (SW), root weight (RW), α-amylase (A.A), total protein contents (PC), total soluble sugars (TSS), potassium ions ($K^+$), sodium ions ($Na^+$) and sodium to potassium ratio ($Na^+/K^+$). Salinity treatments ($S_{0mM}$: 0.00 mM, $S_{50mM}$: 50 mM, $S_{100mM}$: 100 mM, $S_{150mM}$:150 mM) were also significantly different in their effects on lentil genotypes and interaction (G×T) were also significantly different from each other for subjected traits (Table 1).

**Principle Component Analysis (PCA)**

Principle component analysis (PCA) was used for data reduction and transforming the raw data into principle components/principal factors. Principal component analysis transformed the raw variable data into distinct principal factors representing the different proportions of the data variability. These factors (Fs) are equal to the number of studied variables thus, in current study PCA transformed the raw data into 10 factors (Fs) with the pattern that first factor (F1) contributed the most variability and last factor (Fn) contributed the least variability. Factor 1, 2 and 3 have effectively transformed the raw data, extracted significant variability and considerable for further data analysis due to having more than 1 eigenvector value. Factor 4 to 10 had eigenvector value less than 1 for most of factors and therefore, not effective for further consideration in order to interpret the results. Whole variability of the data was partitioned into different factors which could be visualized by cumulative variability. Cumulative variability of three factors (F 1, 2 and 3) was 74.56%, 75.50%, 80.25% and 72.03% under $S_{0mM}$, $S_{50mM}$, $S_{100mM}$ and $S_{150mM}$, respectively (Table 2).

Different traits have different pattern of contribution for principal factors. For F1, all traits were negatively contributing except PC, $K^+$, $Na^+$, $Na^+/K^+$, whereas for F2 only A.A and $K^+$ were negatively contributing, whereas for F3 RL, A.A, TSS and $Na^+/K^+$ were positively contributing under $S_{0mM}$ (Table 3). PC, TSS, $Na^+$ and $Na^+/K^+$

**Table 1:** Mean squares for morphological and biochemical parameters of lentil based on two factor factorial analysis of variance

| SOV | DF | SL (cm) | RL (cm) | SW (g) | RW (g) | A.A (mg $g^{-1}$) | PC (mg $g^{-1}$) | TSS (mg $g^{-1}$) | $K^+$ (ppm) | $Na^+$ (ppm) | $Na^+/K^+$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Replication (R) | 2 | 3.41** | 15.35** | 0.006** | 0.025** | 0.0027** | 0.014** | 0.013** | 3811.5 | 1054.4 | 0.00042 |
| Genotypes (G) | 14 | 44.57** | 47.56** | 0.0142** | 0.035** | 0.0141** | 0.267** | 0.239** | 11610** | 2795** | 0.8532** |
| Treatments (T) | 3 | 56.64** | 145.62** | 0.0629** | 0.552** | 0.0521** | 0.202** | 0.699** | 59653** | 48929** | 9.6401** |
| G×T | 42 | 15.25** | 18.50** | 0.0149** | 0.013** | 0.0143** | 0.338** | 0.279** | 233.5** | 184** | 0.1183** |
| Error | 118 | 3.17** | 8.71** | 0.0070** | 0.009** | 0.050** | 0.07** | 0.021** | 15.2 | 7.1 | 0.00112 |

SL: shoot length, RL: root length, RW: root weight, SW: shoot weight, A.A: α-amylase, PC: total soluble protein contents, TSS: total soluble sugars. *: significant at 5% level of significance, **: significant at 1% level of significance

**Table 2:** Principle factors of principle component analysis and their eigenvalues, variability and cumulative variability for four different salinity treatments

| | | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Eigenvalue | $S_{0mM}$ | 4.571 | 1.586 | 1.298 | 1.067 | 0.650 | 0.394 | 0.252 | 0.123 | 0.050 | 0.009 |
| | $S_{50mM}$ | 4.251 | 2.054 | 1.245 | 0.833 | 0.639 | 0.621 | 0.253 | 0.079 | 0.022 | 0.003 |
| | $S_{100mM}$ | 3.543 | 3.101 | 1.382 | 0.861 | 0.477 | 0.309 | 0.244 | 0.070 | 0.009 | 0.004 |
| | $S_{150mM}$ | 3.816 | 2.022 | 1.365 | 1.001 | 0.771 | 0.432 | 0.385 | 0.191 | 0.015 | 0.001 |
| Variability (%) | $S_{0mM}$ | 45.71 | 15.87 | 12.98 | 10.67 | 6.496 | 3.944 | 2.519 | 1.229 | 0.496 | 0.091 |
| | $S_{50mM}$ | 42.51 | 20.54 | 12.45 | 8.333 | 6.394 | 6.206 | 2.527 | 0.793 | 0.222 | 0.026 |
| | $S_{100mM}$ | 35.43 | 31.02 | 13.82 | 8.606 | 4.773 | 3.088 | 2.440 | 0.701 | 0.093 | 0.045 |
| | $S_{150mM}$ | 38.16 | 20.22 | 13.65 | 10.01 | 7.710 | 4.322 | 3.850 | 1.911 | 0.153 | 0.014 |
| Cumulative variability % | $S_{0mM}$ | 45.71 | 61.57 | 74.56 | 85.23 | 91.72 | 95.66 | 98.18 | 99.41 | 99.91 | 100.0 |
| | $S_{50mM}$ | 42.51 | 63.05 | 75.50 | 83.83 | 90.22 | 96.43 | 98.96 | 99.75 | 99.97 | 100.0 |
| | $S_{100mM}$ | 35.43 | 66.44 | 80.25 | 88.86 | 93.63 | 96.72 | 99.16 | 99.86 | 99.96 | 100.0 |
| | $S_{150mM}$ | 38.17 | 58.39 | 72.03 | 82.04 | 89.75 | 94.07 | 97.92 | 99.83 | 99.99 | 100.0 |

$S_{0mM}$: normal conditions, $S_{50mM}$: 50mM NaCl solution, $S_{100mM}$: 100mM NaCl solution, $S_{150mM}$: 150mM NaCl solution, F1: Principle factor1, F2: Principle factor2, F3: Principle factor3, F4: Principle factor4, F5: Principle factor5, F6: Principle factor6, F7: Principle factor7, F8: Principle factor 8, F9: Principle factor 9, F10: Principle factor10

**Table 3:** Contribution of morphological and biochemical traits in the principle factors under different salinity treatments (Factor Loading values)

| | $S_{0mM}$ | | | $S_{50mM}$ | | | $S_{100mM}$ | | | $S_{150mM}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F1 | F2 | F3 | F1 | F2 | F3 | F1 | F2 | F3 |
| SL | -0.813 | 0.267 | -0.114 | -0.746 | -0.068 | -0.028 | -0.282 | 0.797 | -0.305 | 0.556 | 0.266 | 0.616 |
| RL | -0.347 | 0.504 | 0.443 | -0.152 | 0.829 | 0.256 | -0.164 | 0.742 | 0.573 | -0.459 | 0.622 | -0.150 |
| SW | -0.802 | 0.169 | -0.211 | -0.673 | 0.454 | 0.287 | -0.455 | 0.748 | 0.052 | 0.328 | 0.389 | 0.735 |
| RW | -0.778 | 0.359 | -0.162 | -0.498 | 0.779 | 0.119 | -0.410 | 0.641 | 0.430 | -0.039 | 0.735 | -0.386 |
| A.A | -0.258 | -0.139 | 0.722 | -0.365 | -0.284 | 0.733 | -0.333 | -0.744 | 0.242 | -0.602 | 0.083 | 0.368 |
| PC | 0.125 | 0.275 | -0.667 | 0.504 | -0.235 | 0.638 | 0.486 | 0.378 | -0.480 | -0.360 | -0.470 | -0.076 |
| TSS | -0.241 | 0.798 | 0.187 | 0.321 | 0.489 | -0.304 | -0.184 | -0.411 | 0.580 | 0.104 | 0.791 | -0.216 |
| $K^+$ | -0.861 | -0.427 | -0.051 | -0.932 | -0.154 | -0.151 | -0.937 | -0.218 | -0.232 | -0.942 | -0.027 | 0.121 |
| $Na^+$ | 0.922 | 0.304 | -0.062 | 0.862 | 0.315 | 0.049 | 0.949 | 0.143 | 0.194 | 0.963 | -0.112 | -0.121 |
| $Na^+/K^+$ | 0.900 | 0.312 | 0.104 | 0.932 | 0.227 | 0.140 | 0.949 | 0.107 | 0.239 | 0.934 | -0.087 | -0.236 |

SL: shoot length, RL: root length, RW: root weight, SW: shoot weight, A.A: α-amylase, PC: total soluble protein contents, TSS: total soluble sugars, $S_{0mM}$: normal conditions, $S_{50mM}$: 50mM NaCl solution, $S_{100mM}$: 100mM NaCl solution, $S_{150mM}$: 150mM NaCl solution, F1: Principle factor1, F2: Principle factor2, F3: Principle factor3

were positively contributing for F1; RL, SW, RW, TSS, $Na^+$ and $Na^+/K^+$ were positively contributing for F2; SL, TSS and $K^+$ were having negative contribution for F3 while all other traits were positively contributing under $S_{50mM}$ (Table 3). All studied traits were negatively contributing for F1 except PC, $Na^+$ and $Na^+/K^+$; only A.A, TSS and $K^+$ were negatively contributing for F2; SL, PC and $K^+$ were negatively contributing for F3 under $S_{100mM}$ (Table 3). Similarly positive and negative contribution of studied traits for three main factors F1, F2 and F3 under $S_{150mM}$ was also given in found (Table 3).

**Biplot 2-D Graphical Analysis**

Biplot analysis was accomplished with the help of two main principle factors (F1 and F2) for each salinity treatment ($S_{0mM}$, $S_{50mM}$, $S_{100mM}$ and $S_{150mM}$). Genotypes and variables were merged in single biplot graph to further facilitate the visualization. PCA biplot for $S_{0mM}$ explained the 61.57% of total variability and depicted that $Na^+$, $Na^+/K^+$, $K^+$ and TSS were most discriminating traits (Fig. 1-$S_{0mM}$). PCA biplot for $S_{50mM}$ explained the 63.05% of total variability, showing that RW, SW, RL, SL, $K^+$, $Na^+/K^+$ and $Na^+$ were most discriminating parameters (Fig. 1- $S_{50mM}$).

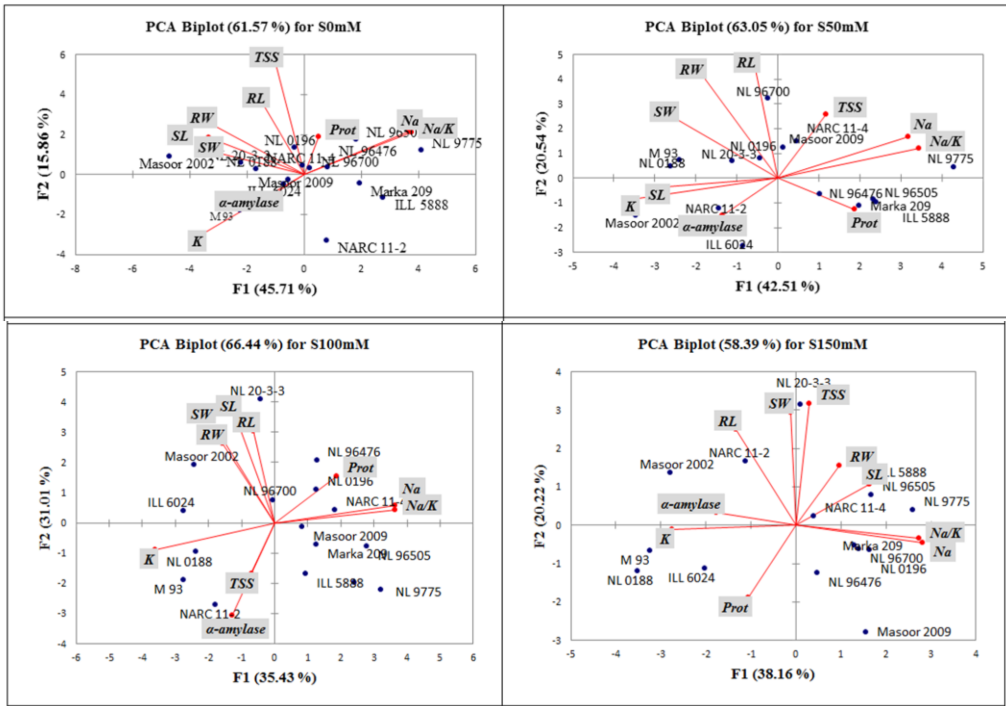


**Fig. 1:** Principal component 2-D biplot graphs for various traits of lentil genotypes under $S_{0mM}$, $S_{50mM}$, $S_{100mM}$ and $S_{150mM}$. SL: shoot length, RL: root length, RW: root weight, SW: shoot weight, α-amylase: alpha amylase, Prot: total soluble protein contents, TSS: total soluble sugars, K: potassium ions, Na: Sodium ions, Na/K: sodium to potassium ratio

PCA biplot for $S_{100mM}$ showed the 66.44% of total variability, reflecting that SL, SW, RL, RW, $Na^+$, $K^+$, $Na^+/K^+$ were most discriminating variables among all studied traits (Fig. 1-$S_{100mM}$). PCA biplot for $S_{150mM}$ explained 58.39% of total variability and represented that TSS, SL, RL, RW, $Na^+$, $K^+$, $Na^+/K^+$ were most discriminating traits (Fig. 1- $S_{150mM}$).

Genotypes NL 20-3-3, Masoor 2002, NL 9775, NARC11-2 ILL5888 were present farthest away from the biplot origin showing better performance with reference to other genotypes under $S_{0mM}$. NL96700, Masoor 2009 and NARC11-4 were present closer to biplot origin and reflecting that these genotypes have least variability for studied traits under $S_{0mM}$ (Fig. 1-$S_{0mM}$). Masoor 2002, NL 9775 and ILL5888, ILL6024 were present farthest away from the biplot origin, showing better performance relative to other genotypes under $S_{50mM}$ (Fig. 1-$S_{50mM}$).

Genotypes Masoor 2002, NL 0196, NL 20-3-3 and NL9775 were most distinct or farthest away from the biplot origin reflecting much better performance compared to the rest of genotypes. NL96700 was located in the biplot origin and reflecting the least variability under $S_{100mM}$ (Fig. 1-$S_{100mM}$). Genotypes NL9775, Masoor 2002, Masoor 2009, NL 0196, NL 0188 and NL 20-3-3 were located farthest away from biplot origin showing most variability and performed much better compared to other genotypes under $S_{150mM}$. Genotypes NARC 11-4 were irresponsive genotype against studied variables under $S_{150mM}$ due to presence at the origin of biplot graph (Fig. 1-$S_{150mM}$).

## Salinity Tolerance Indices

Genotypes were ranked on the basis of single trait for each salinity treatment separately. Ranking scores of all traits for particular salinity treatment was subjected to average ranking score showing the mean performance of genotypes (Table 4 and 5). This showed that no genotype was consistent for ranking scores across all studied morphological and biochemical traits. For example; Masoor 2002 had highest score for SL under $S_{0mM}$, $S_{50mM}$ and $S_{100mM}$ but not under $S_{150mM}$. In case of RL, this genotype had highest score only under $S_{0mM}$ but lowered under $S_{50mM}$, $S_{100mM}$ and $S_{150mM}$. Masoor 2002 ranged from 11 to 14 scores for different salinity treatments, in case of SW. Scores for Masoor 2002 were high for RW (3 to 14), A.A (5 to 14), PC (1 to 13), TSS (1 to 14), $K^+$ (11 to 14), $Na^+$ (1 to 5) and $Na^+/K^+$ (1 to 5) under subjected four different salinity treatments (Table 4). Similarly, the results of other genotypes for studied traits on the basis of four salinity treatments were not consistent. Thus, evaluation of genotypes on the basis of individual traits was not feasible (Table 5).

Genotypes NL 9775, Masoor 2002, NL0188 and M 93 had highest values for ranking scores showing that these genotypes were relatively salt tolerant. Highest ranking scores of these genotypes shows higher mean values for the studied traits under four salinity ($S_{0mM}$, $S_{50mM}$, $S_{100mM}$ and $S_{150mM}$) treatments. NL 96476, IL6024 and NARC 11-4 had

**Table 4:** Ranking score of 15 lentil genotypes for morphological and biochemical traits under four different salinity treatments

| | SL (cm) | | | | RL (cm) | | | | SW (g) | | | | RW (g) | | | | A.A (mg $g^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $S_{0}$ mM | $S_{50}$ mM | $S_{100}$ mM | $S_{150}$ mM | $S_{0}$ mM | $S_{50}$ mM | $S_{100}$ mM | $S_{150}$ mM | $S_{0}$ mM | $S_{50}$ mM | $S_{100}$ mM | $S_{150}$ mM | $S_{0}$ mM | $S_{50}$ mM | $S_{100}$ mM | $S_{150}$ mM | $S_{0}$ mM | $S_{50}$ mM | $S_{100}$ mM | $S_{150}$ mM |
| NL 96476 | 6 | 10 | 11 | 10 | 12 | 7 | 10 | 13 | 1 | 4 | 13 | 7 | 7 | 3 | 9 | 13 | 5 | 2 | 2 | 10 |
| Masoor 2002 | 15 | 15 | 14 | 3 | 15 | 9 | 12 | 14 | 14 | 14 | 12 | 11 | 14 | 8 | 13 | 3 | 14 | 12 | 5 | 13 |
| NL 20-3-3 | 14 | 14 | 15 | 9 | 9 | 10 | 13 | 15 | 13 | 12 | 15 | 14 | 12 | 9 | 14 | 9 | 1 | 13 | 1 | 5 |
| NL 96700 | 3 | 3 | 4 | 12 | 14 | 15 | 14 | 4 | 6 | 13 | 9 | 4 | 9 | 15 | 15 | 10 | 6 | 10 | 14 | 6 |
| M 93 | 10 | 13 | 12 | 5 | 8 | 12 | 3 | 11 | 12 | 6 | 5 | 10 | 10 | 13 | 6 | 4 | 12 | 4 | 12 | 7 |
| Masoor 2009 | 12 | 9 | 10 | 4 | 10 | 11 | 9 | 2 | 10 | 10 | 6 | 3 | 6 | 12 | 8 | 1 | 15 | 8 | 6 | 1 |
| NL 0196 | 11 | 12 | 13 | 15 | 5 | 8 | 5 | 3 | 15 | 11 | 11 | 6 | 13 | 14 | 10 | 6 | 2 | 9 | 7 | 4 |
| ILL 5888 | 9 | 5 | 3 | 14 | 4 | 1 | 4 | 8 | 3 | 1 | 10 | 9 | 2 | 1 | 1 | 15 | 3 | 3 | 13 | 3 |
| NL 0188 | 13 | 11 | 7 | 1 | 2 | 6 | 6 | 9 | 11 | 15 | 8 | 2 | 11 | 11 | 12 | 2 | 11 | 7 | 11 | 14 |
| NARC 11-2 | 2 | 8 | 2 | 11 | 1 | 5 | 1 | 10 | 4 | 9 | 7 | 12 | 1 | 6 | 3 | 14 | 10 | 11 | 15 | 8 |
| Marka 209 | 4 | 6 | 9 | 8 | 3 | 2 | 7 | 5 | 7 | 8 | 4 | 1 | 3 | 2 | 7 | 11 | 7 | 14 | 10 | 11 |
| NARC 11-4 | 5 | 7 | 6 | 2 | 7 | 14 | 11 | 7 | 9 | 7 | 3 | 15 | 8 | 10 | 5 | 7 | 9 | 5 | 3 | 12 |
| NL 96505 | 7 | 4 | 8 | 6 | 13 | 3 | 2 | 12 | 5 | 5 | 2 | 8 | 5 | 5 | 2 | 8 | 8 | 1 | 4 | 9 |
| ILL 6024 | 8 | 2 | 5 | 7 | 11 | 4 | 15 | 6 | 8 | 2 | 14 | 5 | 15 | 7 | 11 | 12 | 4 | 15 | 8 | 15 |
| NL 9775 | 1 | 1 | 1 | 13 | 6 | 13 | 8 | 1 | 2 | 3 | 1 | 13 | 4 | 4 | 4 | 5 | 13 | 6 | 9 | 2 |
| | PC (mg $g^{-1}$) | | | | TSS (mg $g^{-1}$) | | | | $K^+$ (ppm) | | | | $Na^+$ (ppm) | | | | $Na^+/K^+$ (ppm) | | | |
| | $S_{0}$ mM | $S_{50}$ mM | $S_{100}$ mM | $S_{150}$ mM | $S_{0}$ mM | $S_{50}$ mM | $S_{100}$ mM | $S_{150}$ mM | $S_{0}$ mM | $S_{50}$ mM | $S_{100}$ mM | $S_{150}$ mM | $S_{0}$ mM | $S_{50}$ mM | $S_{100}$ mM | $S_{150}$ mM | $S_{0}$ mM | $S_{50}$ mM | $S_{100}$ mM | $S_{150}$ mM |
| NL 96476 | 10 | 6 | 15 | 15 | 9 | 6 | 5 | 2 | 7 | 7 | 5 | 6 | 9 | 7 | 7 | 7 | 8 | 7 | 7 | 10 |
| Masoor 2002 | 2 | 13 | 4 | 1 | 14 | 1 | 6 | 9 | 14 | 13 | 12 | 11 | 1 | 1 | 5 | 2 | 1 | 2 | 5 | 4 |
| NL 20-3-3 | 7 | 4 | 14 | 9 | 7 | 14 | 3 | 15 | 9 | 10 | 10 | 10 | 3 | 6 | 6 | 6 | 5 | 6 | 6 | 6 |
| NL 96700 | 11 | 7 | 2 | 5 | 5 | 12 | 7 | 4 | 8 | 6 | 9 | 7 | 7 | 9 | 10 | 10 | 10 | 8 | 11 | 7 |
| M 93 | 6 | 8 | 5 | 14 | 4 | 11 | 8 | 6 | 15 | 15 | 15 | 15 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 1 |
| Masoor 2009 | 1 | 10 | 10 | 12 | 8 | 5 | 13 | 3 | 10 | 9 | 6 | 3 | 8 | 14 | 8 | 13 | 9 | 10 | 8 | 13 |
| NL 0196 | 12 | 1 | 7 | 8 | 10 | 3 | 1 | 8 | 5 | 5 | 7 | 8 | 11 | 10 | 13 | 11 | 11 | 11 | 12 | 9 |
| ILL 5888 | 13 | 3 | 9 | 6 | 1 | 15 | 9 | 12 | 3 | 3 | 8 | 9 | 13 | 11 | 9 | 8 | 14 | 12 | 9 | 8 |
| NL 0188 | 15 | 2 | 12 | 13 | 15 | 8 | 12 | 10 | 13 | 14 | 14 | 14 | 4 | 3 | 2 | 3 | 3 | 3 | 2 | 2 |
| NARC 11-2 | 8 | 9 | 3 | 4 | 2 | 7 | 10 | 11 | 12 | 12 | 13 | 13 | 5 | 4 | 3 | 4 | 4 | 4 | 3 | 3 |
| Marka 209 | 5 | 14 | 6 | 3 | 6 | 10 | 11 | 7 | 4 | 2 | 4 | 4 | 12 | 12 | 11 | 12 | 13 | 13 | 13 | 11 |
| NARC 11-4 | 9 | 5 | 11 | 11 | 12 | 9 | 2 | 5 | 6 | 8 | 3 | 5 | 10 | 8 | 12 | 9 | 7 | 9 | 10 | 12 |
| NL 96505 | 14 | 11 | 13 | 2 | 11 | 4 | 4 | 14 | 2 | 4 | 2 | 2 | 14 | 13 | 15 | 14 | 12 | 14 | 14 | 14 |
| ILL 6024 | 4 | 12 | 1 | 10 | 3 | 2 | 14 | 1 | 11 | 11 | 11 | 12 | 6 | 5 | 4 | 5 | 6 | 5 | 4 | 5 |
| NL 9775 | 3 | 15 | 8 | 7 | 13 | 13 | 15 | 13 | 1 | 1 | 1 | 1 | 15 | 15 | 14 | 14 | 15 | 15 | 15 | 15 |

SL: shoot length, RL: root length, RW: root weight, SW: shoot weight, A.A: α-amylase, PC: total soluble protein contents, TS: total soluble sugars, $S_{0mM}$: normal conditions, $S_{50mM}$: 50mM NaCl solution, $S_{100mM}$: 100mM NaCl solution, $S_{150mM}$: 150mM NaCl solution

**Table 5:** Ranking scores, Integrated Selection Index and Integrated Scores for lentil genotypes

| | Rank Scoring (RS) | | | | | | | Integrated Selection Index (ISI) | | | | Integrated Scoring (IS) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $S_{0mM}$ | $S_{50mM}$ | $S_{100mM}$ | $S_{150mM}$ | $\bar{R}$ | SDR | RS | $S_{50mM}$ | $S_{100mM}$ | $S_{150mM}$ | $\overline{ISI}$ | $S_{0mM}$ | $S_{50mM}$ | $S_{100mM}$ | $S_{150mM}$ | $\overline{IS}$ |
| NL 96476 | 7.40 | 5.90 | 8.40 | 9.30 | 7.75 | 0.189 | 7.94 | 8.76 | 7.77 | 9.99 | 8.84 | 27.03 | 25.83 | 24.89 | 25.43 | 25.79 |
| Masoor 2002 | 10.40 | 8.80 | 8.80 | 7.10 | 8.78 | 3.629 | 12.38 | 16.6 | 15.8 | 16.33 | 16.24 | 31.73 | 28.20 | 27.52 | 26.74 | 28.55 |
| NL 20-3-3 | 8.00 | 9.80 | 9.70 | 9.80 | 9.33 | 0.004 | 9.33 | 14 | 15 | 15 | 14.67 | 27.78 | 26.53 | 25.28 | 25.53 | 26.28 |
| NL 96700 | 7.90 | 9.80 | 9.50 | 6.90 | 8.53 | 0.042 | 8.57 | 11 | 11 | 12 | 11.33 | 27.27 | 26.24 | 26.11 | 25.61 | 26.31 |
| M 93 | 8.10 | 8.50 | 6.80 | 7.40 | 7.70 | 2.920 | 10.62 | 16 | 14.54 | 14.33 | 14.96 | 30.87 | 29.69 | 27.29 | 29.43 | 29.32 |
| Masoor 2009 | 8.90 | 9.80 | 8.40 | 5.50 | 8.15 | 0.106 | 8.26 | 11 | 10 | 11.4 | 10.80 | 28.22 | 27.60 | 25.03 | 24.90 | 26.44 |
| NL 0196 | 9.50 | 8.40 | 8.60 | 7.80 | 8.58 | 0.096 | 8.67 | 13 | 12 | 13 | 12.67 | 26.45 | 25.37 | 25.81 | 25.81 | 25.86 |
| ILL 5888 | 6.50 | 5.50 | 7.50 | 9.20 | 7.18 | 1.932 | 9.11 | 11.3 | 12.7 | 11.7 | 11.90 | 25.33 | 23.43 | 24.77 | 25.96 | 24.87 |
| NL 0188 | 9.80 | 8.00 | 8.60 | 7.00 | 8.35 | 3.858 | 12.21 | 12 | 13.4 | 13.2 | 12.87 | 30.53 | 29.41 | 27.16 | 28.89 | 29.00 |
| NARC 11-2 | 4.90 | 7.50 | 6.00 | 9.00 | 6.85 | 0.274 | 7.12 | 11.2 | 10.5 | 12.3 | 11.33 | 28.86 | 28.23 | 25.46 | 28.29 | 27.71 |
| Marka 209 | 6.40 | 8.30 | 8.20 | 7.30 | 7.55 | 1.875 | 9.42 | 9.87 | 9.8 | 8.88 | 9.52 | 25.04 | 23.40 | 25.47 | 25.40 | 24.83 |
| NARC 11-4 | 8.20 | 8.20 | 6.60 | 8.50 | 7.88 | 0.073 | 7.95 | 8.66 | 7.65 | 7.89 | 8.07 | 26.78 | 26.28 | 25.47 | 24.77 | 25.83 |
| NL 96505 | 9.10 | 6.40 | 6.60 | 8.90 | 7.75 | 0.616 | 8.37 | 7.5 | 8.4 | 7.9 | 7.93 | 25.79 | 24.35 | 24.55 | 25.30 | 24.99 |
| ILL 6024 | 7.60 | 6.50 | 8.70 | 7.80 | 7.65 | 0.636 | 8.29 | 8.7 | 8.9 | 9.6 | 9.07 | 29.33 | 26.93 | 25.85 | 27.00 | 27.28 |
| NL 9775 | 7.30 | 8.60 | 7.60 | 8.40 | 7.98 | 5.236 | 12.98 | 15.2 | 15.7 | 14.8 | 15.23 | 29.32 | 27.86 | 28.73 | 27.67 | 28.29 |

$\bar{R}$: Mean rank of four treatment ranks, SDR: standard deviation of ranks, RS: rank sum, $\overline{ISI}$; mean integrated selection index for three salinity treatments, $\overline{IS}$,: mean integrated scoring for four treatments

lowest ranking scores which showed that these genotypes were relatively susceptible to the salinity stress. These genotypes had lowest mean values for subjected traits under four salinity treatments and got lowest ranking scores showing susceptibility of these to salinity stress (Table 5).

Integrated selection index (ISI) was used for sortation of genotypes as tolerant and susceptible against salinity stress. Masoor 2002, M93, NL9775, NL 20-3-3 and NL 0188 were found to be tolerant due to highest values for ISI scores. NL 96476, NARC 11-4, NL 96505 and ILL6024 were susceptible to salt stress due to least ISI scores (Table 5). Integrated scoring (IS) was also used for categorization of lentil genotypes as tolerant or susceptible. M 93, NL 9775, NL 0188 and Masoor 2002 scored the highest values for IS compared to other genotypes and declared as tolerant to wide range of salinity levels. ILL 5888, Marka 209 and NL 96505 scored the lowest IS and classified as susceptible to salinity stress among all studied lentil genotypes (Table 5).

## Discussion

With the extensive increase in global population demand for cost effective protein sources has dramatically increased. Lentil being the pulse crop is rich source of proteins of plant origin. As with the extensive use of irrigation water in agriculture and global climatic changes, salt affected area is increasing with the passage of time. The evaluation of lentil germplasm against salinity stress was very effective tool to cope the salinity stress and to equilibrate the demand supply curve of protein from lentil crop by exploiting the saline area. Plant growth and development in terms of morphological and biochemical parameters is adversely affected in response to stressful environments at different stages of growth and development (Anjum *et al*., 2011; Aslam *et al*., 2013, 2014; Naveed *et al*., 2014). Thus, choice of morphological and biochemical traits in present study can be effective and efficient for evaluation of lentil genotypes. Diverse salinity treatments ($S_{0mM}$, $S_{50mM}$, $S_{100mM}$ and $S_{150mM}$) were used for evaluation of lentil genotypes for selection of tolerant genotypes for broader range of saline conditions. Significant differences were found for morphological and biochemical traits among genotypes, salinity treatments and their interactions of present study have been also reported by El-Hendawy *et al*. (2005) and Kausar *et al*. (2012).

Multivariate analysis has numerous advantages such as accuracy for genotypic ranking is increased as multiple traits are subjected to analysis simultaneously. Ranking of genotypes is also made simultaneously under several salinity treatments for assessment of salinity tolerance which gives generalized tolerance over broader salinity levels (Zeng *et al*., 2002). In current study, use of more than one statistical tools also validated the results for salinity tolerance of lentil genotypes.

Principle component analysis has been extensively used in research to partition the observed variability of data into principle factors by data transformation. This analysis is very effective for selection of genotypes under salinity stress. Biplots and genotypic selections were made separately for four different salinity treatments. Yan and Tinker (2005; 2006) and (Maqbool *et al.*, 2015a, b; 2016) also evaluated the manipulation of biplots for evaluation of crop plants across diverse environmental conditions. Most of the variability was demonstrated by three factors (F1, F2 and F3). Among these three factors, only F1 and F2 depicted the highest variability thus, biplots were made by using F1 and F2 factors. It was also previously reported by (Maqbool *et al.*, 2015a, b; 2016) that first and second principal factors were representing the most of data variability. PCA biplots for $S_{0mM}$, $S_{50mM}$, $S_{100mM}$ and $S_{150mM}$ unanimously declared that NL20-3-3, Masoor2002 and NL9775 were tolerant against wide range of salinity stress. Genotype Masoor 2009 showed susceptibility under lower stress levels whereas; it was tolerant against extreme salt level. It showed that Masoor 2009 modulated the tolerance mechanism against extreme salt stress rather than lower level of stress.

Use of integrated selection index (ISI), integrated scoring (IS) and ranked sum (RS) scoring were proved effective to evaluate the lentil genotypes under four different salinity treatments due to inconsistent and differential responses of genotypic traits. Thus, it is validated that morphological and biochemical parameters are effective criteria for evaluation of genotypes at early growth stages with exploitation of integrated indices (Khalili *et al*., 2013). In the integrated indices for salinity tolerance, lentil genotypes were subjected to comparative evaluation under normal and stressful conditions, which is very effective tool for evaluation. Whereas, some researchers advocated that selection of stress tolerant genotypes should be made under normal environment only (Rajaram and Van Ginkle, 2001; Betran *et al*., 2003) or under stressful environment only (Rathjen, 1994; Ceccarelli and Grando, 2000). Evaluation of genotypes under normal and stress condition then subjecting the data for evaluation of comparative performance is essence of this experiment, which made the selection effective.

Rank sum (RS) scores were based on the average rank of the genotypes for all traits and treatments. Every trait is given importance for evaluation of genotypes and this is effective than using just crop yield which ignored all other traits. NL9775, Masoor 2002, NL0188 and M93 were tolerant to salt stress due to highest mean ranks on basis of all studied trait and all of four salinity treatments. NL 96505, Marka 209 and IL5888 were found to be susceptible to salt stress as these genotypes have lowest mean ranks. These genotypes might have higher mean value for particular trait under specific salinity treatment but these scored lowest ranks on the basis of all traits and treatments. Ranking scores were also manipulated by several researchers for evaluation of different crops (Khalili *et al*., 2012; Farshadfar and Elyasi, 2012; Farshadfar *et al*., 2012a).

Masoor 2002, M93, NL9775, NL 20-3-3 and NL0188 were found to be salt tolerant as these genotypes had highest ISI value whereas, NARC 11-4, ILL5888 and Marka 209 were susceptible with lowest ISI values. ISI comprised of multiple formulae which subjected the data to standardization, performance of genotypes for each trait and followed by integration of performance. ISI is effectively used by numerous researchers for assessment of tolerance against different stresses (Farshadfar *et al*., 2012a; Farshadfar, 2012; Khalil *et al*., 2013).

Integrating scoring (IS) was used by Ahmed *et al*. (2013) for evaluation of wild and cultivated barley genotypes against combined effects of drought and salinity tolerance. IS gives the equal importance to every trait and different factors are used for multiplication depending upon the number of traits. M93, NL9775, NL0188 and Masoor 2002 were relatively salt tolerant lentil genotypes as these scored the highest IS values whereas, N96505, IL 5888 and Marka 209 were relatively susceptible against salinity stress due to lower IS scores.

Different abiotic stress tolerance indices like, superiority index (Pi), stress tolerance index (STI), geometric mean productivity (GMP), stress susceptibility index (SSI), mean productivity (MP), stress tolerance (TOL) and harmonic mean (HM) were manipulated and compared by different researchers for different crop plants (Akçura *et al.*, 2011; Farshadfar *et al.*, 2012b; Esmaeilpour *et al.*, 2015; Maqbool *et al.*, 2015a; 2016). However, comparison of PCA biplot, rank sum (RS) score, integrated scoring index (ISI) and integrating scoring (IS) for evaluation of salinity tolerance was distinct and novel attempt in present study. Results of these statistical tools were also comparable for wide range of salinity stress in lentil genotypes. PCA biplot and studied indices unanimously and comparably selected the Masoor 2002, NL 20-3-3, LN 0188, M93 and NL9775 as salt tolerant genotypes.

## Conclusions

It is concluded that morphological (RL, SL, RW, SW), biochemical (A.A, PC, TS) and mineral traits ($Na^+$, $K^+$ and $Na^+/K^+$) of lentil genotypes were significantly affected by salinity stress. Effects of four salinity treatments ($S_{0mM}$, $S_{50mM}$, $S_{100mM}$, $S_{150mM}$ NaCl solution) were also significantly different on the performance of lentil genotypes. Change of genotypic ranking for different traits showed that use of univariate statistical tools was ineffective for evaluation of lentil performance across different salinity treatments. Use of several tolerance indices and multivariate analysis for evaluation of lentil genotypes were proved effective for concise selection of salt tolerant genotypes. Masoor 2002, NL 20-3-3, LN 0188, M93 and NL9775 were unanimously declared salt tolerant by PCA based biplot, ISI, IS and RS. Salt tolerance of these lentil genotypes at seedling stage will facilitate the establishment of plants at early growth stage and can tolerate the uppermost salt effected soil layers. Genotypes NARC 11-4 and Marka 209 were relatively susceptible against salinity. These tolerant and susceptible lentil genotypes could be used as contrasting parent in hybridization breeding program for genetic improvement of lentil against salinity tolerance.

## References


Ahmed, I.M., H. Dai, W. Zheng, F. Cao, G. Zhang, D. Sun and F. Wu, 2013. Genotypic differences in physiological characteristics in the tolerance to drought and salinity combined stress between Tibetan wild and cultivated barley. *Plant Physiol. Biochem.,* 63: 49-60

Akçura, M., F. Partigoç and Y. Kaya, 2011. Evaluating of drought stress tolerance based on selection indices in Turkish bread wheat landraces. *J. Anim. Plant Sci.,* 21: 700-709

Almansouri, M., J.M. Kinet and S. Lutts, 2001. Effect of salt and osmotic stresses on germination in durum wheat (*Triticum durum* Desf.). *Plant Soil,* 7: 243-254

Anjum, S.A., X. Xie, L. Wang, M.F. Saleem, C. Man and W. Lei, 2011. Morphological, physiological and biochemical responses of plants to drought stress. *Afr. J. Agric. Res.,* 6: 2026-2032

Arshi, A., M.Z. Abdin and M. Iqbal, 2002. Growth and metabolism of *Senna* as affected by salt stress. *Biol. Plant.,* 45: 295-298

Arumuganathan, K. and E.D. Earle, 1991. Nuclear DNA content of some important plant species. *Plant Mol. Biol.,* 9: 208-218

Ashraf, M., 1994. Organic substances responsible for salt tolerance in *Eruca sativa*. *Biol. Plant.,* 36: 255-259

Aslam, M., K. Ahmad, M.A. Maqbool, S. Bano, Q.U. Zaman and G.M. Talha, 2014. Assessment of adaptability in genetically diverse chickpea genotypes (*Cicer arietinum* L.) based on different physio-morphological standards under ascochyta blight inoculation. *Int. J. Adv. Res.,* 2: 245-255

Aslam, M., M.A. Maqbool, S. Akhtar and W. Faisal, 2013. Estimation of genetic variability and association among different physiological traits related to biotic stress (*Fusarium oxysporum* L.) in chickpea. *J. Anim. Plant Sci.,* 23: 1679-1685

Atak, M., M.D. Kaya, G. Kaya, Y. Cikili and C.Y. Ciftci, 2006. Effects of NaCl on the germination, seedling growth and water uptake of triticale. *Turk. J. Agric. For.,* 30: 39-47

Betran, F.J., D. Beck, M. Banziger and G.O. Edmeades, 2003. Genetic analysis of inbred and hybrid grain yield under stress and non-stress environments in tropical maize. *Crop Sci.,* 43: 807-817

Bhatty, R.S., 1988. Composition and quality of lentil (*Lens culinaris* Medik.): a review. *Can. Inst. Food Sci. Technol. J.,* 21: 144–160

Bradford, M.M., 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Anal. Biochem.,* 72: 248–254

Ceccarelli, S. and S. Grando, 2000. Selection environment and environmental sensitivity in barley. *Euphyt.*, 57: 157-167

Crook, D.G., R.H. Ellis and R.J. Summerfield, 1999. Winter sown lentil and its impact on subsequent cereal crop. *Aspects Appl. Biol.,* 56: 241–248

DuBois, M., K.A. Gilles, J.K. Hamilton, P.A. Rebers and F. Smith, 1956. Colorimetric method for determination of sugars and related substances. *Anal. Chem.,* 28: 350–356

El-Hendawy, S.E., Y. Hu, G. M. Yakout, A. M. Awad, S. E. Hafiz and U. Schmidhalter, 2005. Evaluating salt tolerance of wheat genotypes using multiple parameters. *Europ. J. Agron.,* 22: 243–253

El- Monem, A. and M. Sharaf, 2014. Tolerance of Five Genotypes of Lentil to NaCl-Salinity Stress. *New York Sci. J.,* …..: 70-80

Esmaeilpour, A., M.C.V. Labeke, R. Samson, S. Ghaffaripour and P.V. Damme, 2015. Comparison of biomass production-based drought tolerance indices of pistachio (*Pistacia vera* L.) seedlings in drought stress conditions. *Int. J. Agri. Agri. R.,* 7: 36-44

FAO, 2010. *Faostat, Fao Statistical Database*. Retrieved from http://www.fao.org

Farshadfar, E., 2012. Application of integrated selection index and rank sum for screening drought tolerant genotypes in bread wheat. *Int. J. Agric. Crop Sci.,* 4: 325-332

Farshadfar, E. and P. Elyasi, 2012. Screening quantitative indicators of drought tolerance in bread wheat (*Triticum aestivum* L.) landraces. *Eur. J. Exp. Biol.,* 2: 577-584

Farshadfar, E., S. Jalali and M. Saeidi, 2012a. Introduction of a new selection index for improvement of drought tolerance in common wheat (*Triticum aestivum* L.). *Eur. J. Exp. Biol.,* 2: 1181-1187

Farshadfar, E., B. Jamshidi and M. Aghaee, 2012b. Biplot analysis of drought tolerance indicators in bread wheat landraces of Iran. *Int. J. Agric. Crop Sci.,* 4: 226-233

Fratini, R. and M. Pérez De La Vega, 2011. Genetics of economic traits in lentil: seed traits and adaptation to climatic variations. *Grain Leg.,* 56: 1-60

Gabriel, K.R., 1971. The biplot graphic of matrices with application to principal component analysis. *Biometrics,* 58: 453-467

Government of Pakistan, 2011. *Economic Survey of Pakistan 2011-2012*, p: 23. Finance Division, Economic Advisory Wing, Islamabad, Pakistan

Hald, P.M., 1947. The flame photometer for the measurement of sodium and potassium in biological materials. *J. Biol. Chem.,* 167: 499-510

Harlan, J.R., 1992. *Crops and Man*, 2nd edition. American Society of Agronomy, Madison, Wisconsin, USA

Hoagland, D.R. and D. Arnon, 1950. *The Water Culture Method for Growing Plants Without soil*. Circular 347, California Agricultural Experiment Station, University of California Berkeley, Berkeley, USA

Karadavut, U. and A. Genc, 2010. Relationships between chemical composition and seed yield of some Lentil (*Lens culinaris*) cultivars. *Int. J. Agric. Biol.,* 12: 625–628

Kausar, A., M.Y. Ashraf, I. Ali, M. Niaz and Q. Abbass, 2012. Evaluation of sorghum varieties/lines for salt tolerance using physiological indices as screening tool. *Pak. J. Bot.,* 44: 47-52

Kaya, M.D., G. Okcu, M. Atak, Y. Cili and O. Kolsarici, 2006. Seed treatments to overcome salt and drought stress during germination in sunflower (*Helianthus annus* L.). *Eur. J. Agron.,* 24: 291-295

Khalili, M., A.P. Aboughadareh and M.R. Naghavi, 2013. Screening of drought tolerant cultivars in barley using morpho-physiological traits and Integrated Selection Index under water deficit stress condition. *Adv. Crop Sci.,* 3: 462–471

Khalili, M., M.R. Naghavi, A.R.P. Aboughadareh and J. Talebzadeh, 2012. Evaluating of Drought Stress Tolerance based on selection indices in spring canola cultivars (*Brassica napus* L.). *J. Agric. Sci.,* 4: 78-85

Kowieska, A. and K. Petkov, 2003. Lentils (*Lens culinaris* Medic.) estimation based on macro and microelements content. *Zywienie Czowieka i Metabolism,* 3: 1012-1014

Lutts, S., J.M. Kinet and J. Bouharmont, 1995. Changes in plant response to NaCl during development of rice (*Oryza sativa* L.) varieties differing in salinity resistance. *J. Exp. Bot.,* 46: 1843-1852

Maqbool, M.A., M. Aslam, H. Ali, T.M. Shah, B. Farid and Q.U. Zaman, 2015a. Drought tolerance indices based evaluation of chickpea advanced lines under different water treatments. *Res. Crops,* 16: 336-344

Maqbool, M.A., M. Aslam, H. Ali, T.M. Shah and B.M. Atta, 2015b. GGE biplot analysis based selection of superior chickpea (*Cicer arietinum* L.) inbred lines under variable water environments. *Pak. J. Bot.,* 47: 1901-1908

Maqbool, M.A., M. Aslam, H. Ali and T.M. Shah, 2016. Evaluation of advanced chickpea (*Cicer arietinum* L.) accessions based on drought tolerance indices and SSR markers against different water treatments. *Pak. J. Bot.,* 48: 1421-1429

Naveed, S., M. Aslam, M. A. Maqbool, S. Bano, Q. U. Zaman and R.M. Ahmad, 2014. Physiology of high temperature stress tolerance at reproductive stages in maize. *J. Anim. Plant Sci.,* 24: 1141-1145

Parida, A. and A.B. Das, 2005. Salt tolerance and salinity effects on plants. *Ecotoxicol. Environ. Saf.,* 60: 324-349

Rajaram, S. and M.V. Ginkle, 2001. Mexico, 50 years of international wheat breeding. *In: The World Wheat Book: A History of Wheat Breeding*, pp: 579-604. Bonjean, A.P. and W.J. Angus, (eds.). Lavoisier Publishing, Paris, France

Rathjen, A.J., 1994. The biological basis of genotype × environment interaction: its definition and management. *Proc. of the Seventh Assembly of the Wheat Breeding Society of Australia*, Adelaide, Australia

Rick, W. and H.P. Stegbauer, 1974. Methods of enzymatic analysis. *In: Chemic.* Bergmeyer, H.U., (ed.). Verlag. Weinheim and Academic Press, New York, London

Sairam, R.K. and A. Tyagi, 2004. Physiology and molecular biology of salinity stress tolerance in plants. *Curr. Sci.,* 86: 407-421

Steel, R.G.D. and J.H. Torrie, 1997. *Principles and Procedures of Statistics: A Biometrical Approach*, 3rd edition. McGraw-Hill, New York

Yan, W. and N.A. Tinker, 2005. An integrated system of biplot analysis for displaying, interpreting and exploring genotype by- environment interactions. *Crop Sci.,* 45: 1004-1016

Yan, W. and N.A. Tinker, 2006. Biplot analysis of multi-environment trial data: principles and applications. *Can. J. Plant Sci.,* 86: 623–645

Zeng, L., M.C. Shannon and C.M. Grieve, 2002. Evaluation of salt tolerance in rice genotypes by multiple agronomic parameters. *Euphyt.,* 127: 235–245

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