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EVALUATION OF STRESS TOLERANCE INDICES IN A NUMBER OF ADVANCED GENOTYPES OF LENTIL (*LENS CULINARIS* MEDIK) UNDER RAINFED AND LOW IRRIGATION CONDITIONS

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Abstract

In order to evaluate the stress tolerance indices in some lentil genotypes, a split plot experiment was carried out in the form of a randomized complete block design with three replications and under rainfed and low irrigation conditions as the main factor and 12 genotypes as secondary factor in two regions, including Ardabil Agricultural Research Station and the central part of Germi city in the crop year 2015-2016. The examined traits included the number of days to 50% flowering, plant height, maturity time, number of pods per plant, number of empty pods per plant, primary and secondary branches, 100-seed weight, seed yield, harvest index, RWC index, seed protein content, proline accumulation content and soluble sugars content. Based on the seed yield under non-stress (YP) and stress (YS) condition, the quantitative stress tolerance indices such as: mean productivity (MP), tolerance index (TOL), geometric mean productivity (GMP), harmonic mean (HARM), stress susceptibility index (SSI) and stress tolerance index (STI) were calculated.

Analysis of variance revealed a significant difference between lentil genotypes in indices of GMP, MP, STI and HARM and stress and non-stress yields, indicating genetic diversity and selection of stress tolerance cultivars. Interaction effects of environmental conditions and genotype were statistically significant in TOL and SSI indices and in non-stress yield. Investigating the stress tolerance indices with regard to mean squares and simple correlation coefficients between these indices and seed yield showed that GMP, MP, STI and HARM indices were the most appropriate indices for stress tolerance evaluation in lentil genotypes in both rainfed and low irrigation conditions and selected to identify genotypes with high yield potential in both rainfed and low irrigation conditions. Based on the results obtained from comparisons of mean indices of stress tolerance, genotype ILL-2126 was identified as a stress tolerant genotype under rainfed conditions (with seed yield of 1388.02 kg/ha) and low irrigation conditions (with seed yield of 2159.77% kg/ha). Moreover, the ILL-2580 genotype showed the lowest water yield in both locations. Cluster analysis classified the genotypes into four groups and showed that the highest genetic gap belonged to ILL-2580 and ILL-2126 genotypes. Correlation of seed yield under stress condition (YS) with traits of seed protein content and proline accumulation content was positive and significant, and this correlation with total sugar was positive, and under stress conditions, it showed high correlation compared to Y_P. Plant height had the highest direct effect (0.84). The number of empty pods per plant showed the highest indirect effect through plant height (0.44) on the STI index. Factor analysis after varimax rotation grouped the data into three factors, justified a total of 69.5% of the total diversity.

Keywords: Lentil genotypes, stress tolerance index, irrigation conditions, yield and yield components

Introduction

Drought stress as the most important non-biological stress plays an important role in decreasing the production of crops in the world (Maroufi *et al*., 1998). Currently, major part of legume is produced in rainfed areas and low potential yield of the current cultivars, the limited use of agricultural inputs, adoption of inappropriate methods of production and the occurrence of biological and non-biological stress during the growing season, are considered as the important factors involved in decreasing the production and yield of these plants (Bayazid, 1995). Lentil with scientific name of *Lens culinaris* belongs to leguminous family. It is annual, long-day, spontaneous, and diploid plant (2n = 14) with an average of 28.5% protein. Lentil is a stress tolerant plant. Lentil is planted in the tropical regions of West Asia and North Africa in irrigation form during the winter (late December) (Sadeghi Pour, 2001). Lentil is planted in Iran mainly in rainfed form.

When the lentil faces stress, the sites forming the flower in the plant rapidly decrease, resulting reduced number of plant flowers. Stress leads to reduced yield through dewatering the pollen and reducing its germinating power when placed on the spittle (Jesani, 1988). Many studies have been conducted to identify stress tolerant cultivars as well as traits affecting the seed yield under normal conditions and stress conditions. The research conducted by Narouie Rad *et al*. (2008) on 153 lentils of hot and dry regions in terms of some morphological and phenology traits indicated a negative relationship between day to physiological maturity and seed yield. These researchers observed a high phenotypic correlation between plant height and seed yield under optimal irrigation conditions.

Lentil is one of the most important plants in rainfed cultivation system in West Asia and South Africa and a high quality protein source for human beings. In Mediterranean climate conditions, this plant usually grows in regions with low rainfall (300-400 mm per year). Dalbeer *et al*. (2013) reported that shortage of water and stress during the critical periods of growth and absence of stress tolerant cultivars in this plant led to reduced yield and economic disadvantage. Yield in stress conditions has not been an appropriate and accurate criterion for selecting stress tolerant genotypes due to the interaction effects of genotype × environment and the goal of preparing the stress tolerant cultivars is providing the cultivars which tolerate the stress better in comparison with other genotypes, and show lower yield drop in the same environmental conditions (Zabet *et al*., 2003).

Physiologists argue that in order to further improve the stress tolerant cultivars, it is necessary to identify the indices, which are effective in identifying the stability of cultivars' yield under stress conditions and they should be used as selection criteria (Nourmand *et al*., 2001). The main goal of these experiments is to select genotypes, which are compatible with both conditions. In examining the stress tolerant indices in sugar beet, Parvizi Almani (1998) introduced the stress tolerance index (STI) as an appropriate index for identifying and grouping the tolerant genotypes. In order to determine the most appropriate indices of stress susceptibility in white chickpea cultivars based on the correlation between yield in stress and non-stress conditions and stress tolerance indices, Samee Zadeh (1996) concluded that geometric mean productivity (GMP) and stress tolerant index (STI) are appropriate indices for estimating the yield and obtaining high yield cultivars. The objective of this research was to evaluate the genetic diversity of lentil cultivars in terms of stress tolerance, selection of the best stress tolerance indices, and identification of stress tolerant cultivars**.**

Noouri *et al*. (2013) observed a positive and significant correlation between seed yield and traits such as number of pods per plant, number of seeds per pod, biological yield and harvest index in a research conducted on 35 genotypes of lentil. Allah Moradi *et al*. (2013) showed that applying the stress at flowering stage had the most significant effect on seed yield, relative water content of leaves, stomata tolerance, proline and chlorophyll content. These researchers observed the highest seed yield in native populations under stress conditions. In a research carried out by Dalbeer *et al*. (2013), harvest index, biological yield, number of secondary branches and one hundred seed weight showed the highest direct positive effect on seed yield. The objective of this research was to identify stress tolerant genotypes based on quantitative indices of stress tolerance.

Materials and Methods

In order to evaluate the genetic diversity of lentil cultivars, screening of quantitative indices of stress tolerance, and identification of stress tolerant cultivars, 12 lentil genotypes were planted under rainfed and low irrigation conditions in a split plot form based on complete block design with three replications. The main factor was irrigation at two levels (low irrigation and rainfed) and secondary factor was genotypes in two separate regions of Ardabil Agricultural Research Station and the central district of Germi city with different conditions and climates. The cultivation was performed in both regions in the crop year 2015-2016 since December 27-30 in the Germi city and March 8 in Ardabil city. The Moghan (Germi) city is located in the northwest of Iran 110 km distant from the center of Ardabil province with a longitude of 48° 3', latitude of 39° 1' and the height of the city center (Germi city) from the open sea level is 1023 m. Germi city has a semi-arid climate with relatively hot summers and cold winters. The results of soil degradation at culture site showed that the soil pH was 48.6 and the clay was loose. The rainfall of 95-94 grams was 326 mm. The results of soil degradation at culture site of Germi city showed that the soil pH was 48.6 and its texture is clay loam. The rainfall of this city was reported 326 mm in 2015-2016.

Ardabil Agricultural Research Station is located 12 km distant from Ardabil city and has a climate with mild and cool summers and very cold winters. Winter temperature is often below zero and up to -25 °C, height above sea level is 1350 m, and its longitude and latitude are 48.20 and 38.15, respectively. The average annual rainfall is 310.9 mm, which does not have appropriate dispersion making the rainfed agriculture face stress. The soil pH in Ardebil was 7.91 and its texture was clay loam soil. The rainfall in the station was reported 300 mm in 2015-2016. In low irrigation treatment, all plots were simultaneously irrigated in 2 stages of flowering and pods filling stage, each time at 10 mm separately in each region, depending on the growth time. In the stress of rainfed treatment, no irrigation was performed until end of the harvest and only rainfall was used. Each experimental unit consisted of 4 lines of plantation with a length of 4 m, the rows spacing was 30 cm, and the number of plants per row was 133. To combat with weeds, weeding was performed in several stages.

The harvest of each genotype was carried out in accordance with its physiological treatment. To remove the marginal effect at this stage, two side lines and 0.5 m from the two ends of the middle line were removed and harvesting was performed manually. The seed yield was determined after threshing and separating seeds from straw based on seed weight in grams per square meter. The quantitative indices of stress tolerance were calculated using plant yield in low irrigation (YP) and stress (YS) conditions as follows:

- Stress severity (SI) and stress susceptibility index (SSI)

This index was calculated based on the equation proposed by Fisher and Maurer (1978).

$$SSI = \frac{1-\left[\frac{Ysi}{Ypi}\right]}{SI} \quad SI = 1-\left[\frac{\bar{Y}s}{\bar{Y}p}\right]$$

2- Tolerance index (TOL)

This index is obtained using the following equation (Rosely and Hamblin, 1981).

TOL= Ypi- Ysi

3-Mean Productivity Index (MP):

The above index is calculated using the following equation (Rosely and Hamblin, 1981).

$$MP = \frac{Ypi + Ysi}{2}$$

4-Geometric mean productivity (GMP) Index:

The following equation was used to calculate this statistical index (Fernandez, 1992).

$$GMP = \sqrt{(Ypi)(Ysi)}$$

5-Stress tolerance index (STI):

This index is calculated using the following formula (Fernandez 1992).

$$STI = \frac{(Ypi)(Ysi)}{(\bar{Y}p)^2}$$

6-Harmonic mean (HARM):

The harmonic mean is calculated using the following equation (Farshadfar, 2001).

$$HARM = \frac{2(Ypi \times Ysi)}{Ypi + Ysi}$$

In evaluating the yield of genotypes in two stressed and non-stressed conditions, Fernandez classified the plants into four groups in terms of reaction to these two conditions.

A- Genotypes having relative uniformity superiority in both stress and non-stress conditions (Group A)

B- Genotypes showing good yield only in optimal conditions (Group B)

C- Genotypes whose yield is relatively higher only under stress conditions (Group C)

D- Genotypes showing low yield in both of stress and non-stress conditions (Group D)

Then, Fernandez points out that an appropriate selection criterion for determination of stress tolerance is a criterion, which can distinguish the genotypes of Group A from other groups (Fernandez, 1992).

Phenology, morphological and physiological traits were measured and finally tolerant genotypes were determined for stress and non-stress conditions based on each region or regions with similar conditions. Simple variance analysis of traits was performed under two rainfed and low irrigation conditions. The experiment error uniformity test was also performed in two locations for composite analysis using the F-max test, or the ratio of the largest variance to the smallest variance. The traits with F-max of less than or equal to 5 were analyzed by composite variance analysis and traits with F-max of greater than 5 were analyzed by simple variance analysis. The mean comparisons were performed with Duncan's Multiple Range Test at the probability level of 5% with MSTATC software. SPSS software was used to determine linear correlation in some of the traits effective in stress tolerance indices and cluster analysis. Cluster analysis was used to group the genotypes based on superior indices, and the input method was used to draw the dendrogram.

Results and Discussion

Based on composite variance analysis table, the quantitative indices of stress tolerance and yield in low irrigation conditions and rainfed conditions (Table 1), HARM index showed a significant difference in two different environmental conditions of Ardabil and Germi at 5% level, and the Germi region obtained the highest rank in this index (Table 2). Examined genotypes, except for SSI and TOL, showed a significant difference in comparison to quantitative indices of stress tolerance in low irrigation and rainfed conditions. Mean comparison of simple effects of these stress tolerance indices (Table 3) showed that ILL-2126 genotype, as stress tolerant genotype, with a yield of 1388.02 kg / ha in rainfed condition showed the highest rank. Interaction effect of environmental conditions in the genotype showed that the ILL-2126 genotype with the seed yield of 2159.77 kg/ha in the irrigation conditions and in the Germi environment conditions showed the highest rank (Table 4).

Based on the values of stress tolerance indices and seed yield of genotypes studied in lentil in rainfed and low irrigation conditions (Table 5), stress intensity was obtained SI = 0.23. This indicates that the lentil seed yield decreases by 23% as a result of water shortage under the experiment conditions. In addition, as the SSI value is smaller, the stress tolerance would be higher. Thus, the tolerance or relative susceptibility of cultivars to stress can be determined by comparing their SSI values. Selection based on SSI leads to the selection of genotypes with low yield under normal conditions, but high yield in a stress conditions. Based on the SSI, the LOCAL CHECK genotype showed high stress tolerance under stress conditions compared to other genotypes and lower yields under normal conditions (Table 5).

In the TOL index, as the difference between the two stress and normal conditions is less than the selected variety, ILL-2580 would be more desirable in this study. Thus, selection for stress tolerance is associated with the least difference between Ysi and Ypi. On the other hand, high TOL indicates higher susceptibility of genotypes to stress. Thus, in order to select optimal genotypes, the lower value of TOL is considered as an appropriate selection criterion. Based on this index, the stress tolerance of ILL-2580 genotype showed the lowest difference of rainfed and irrigation yield (157.88 kg / ha) (Table 6). In terms of stress susceptibility index, as the yield values of a genotype are closer to each other under stress and non-stress conditions, the stress susceptibility of that cultivar is less, so the numerical value of the SSI index is smaller (Mostafaei, 1998).

Simple correlation coefficients between these indices and seed yield under irrigation and rainfed conditions showed that GMP, MP, STI and HARM indices had a positive and significant correlation with 1% probability level and they are the most appropriate indices for stress tolerance evaluation in lentil genotypes under stress conditions and identified for selection of genotypes with high yield potential in both rainfed and low irrigation conditions (Table 1-2). In general, indices showing high correlation with seed yield in two rainfed (stress) and low irrigation (non-stress) conditions are introduced as the best indices, and these indices are able to isolate and identify the genotype with high seed yields in both environments (Fernandez, 1992). When there is a significant difference between Yp, Ys, the MP index will have a bias toward the yield potential (Yp). In order to solve this problem, GMP index, which is calculated based on the geometric mean productivity of genotypes under stress and non-stress conditions, was presented by Fernandez (1992), which is calculated as follows.

$$GMP = \sqrt{(Ypi)(Ysi)}$$

This, the geometric mean productivity index (GMP) seems to be an appropriate index due to high genetic diversity and a significant correlation with seed yield for selection of stress tolerant cultivars. Compared to the MP, this index showed low susceptibility to very different values of Yp and Ys, so it is effective in identifying plants having high yields under stress and non-stress conditions (Mostafaei, 1998). The significant difference and genetic variation among different cultivars in terms of stress tolerance indices in chickpea (Amiri, 2001, Bayazid, 1995, and Parvizi Almani, 1998) are confirmed. Thus, genotypes with high levels of these indices are recognized as the most tolerant genotypes. These results are in line with those of research conducted by Zabet *et al.* (2003) on mung bean and Farshadfar *et al.* (2001) on chickpea.

Positive and significant correlation was found between MP, GMP, HARM and traits of number of days to 50% maturity, number of days to maturity, plant height, number of pods per plant, and yield per hectare. In fact, by early planting of the lentil, stress tolerance index in lentil can be increased (Tables 1 and 6). Correlation of days to 50% maturity, days to maturity, plant height and number of pods per plant with Y_S (yield stress) or rainfed showed positive and significant correlation, indicating the importance of expected culture in lentil in increasing the length of growth period and the increasing the efficiency of photosynthesis, and finally, increasing the yield under stress conditions.

Correlation of seed yield under stress condition (Y_S) or rainfed with seed protein content, proline accumulation was positive and significant, and its correlation with total sugar content was positive. Under stress conditions, correlation with mentioned traits was 0.37, 0.24, and 0.20%, respectively, in non-stress conditions; it was 0.10, 0.11, 0.15%, respectively (Table 6 and 7). In general, it could be concluded that in terms of physiological growth, the plant at the stress conditions, leading to decreased relative cell water content, the carbohydrates and protein become more concentrated and it increases its tolerance by increasing some of its osmotic regulators, including proteins, proline and total sugar. This result is in line with results of other researchers such as Daneshian *et al.* on soya, Claudia *et al.* (1388) in beans, Allah Moradi *et al.* in lentil (2013).

The relative water content of the cell (RWC) showed a positive correlation with Y_S with value of 0.18%. It could be concluded that a plant under water stress acts in more cautious and more controlled way during a series of physiological processes in controlling water outflow from the openings. The correlation of the number of branches with Y_S was positive (0.18), indicating that if a genotype has a greater number of branches under stress conditions, final potential would increase the plant yield, so those cultivars are appropriate in stress conditions, which have moderate number of secondary branches but filled pod. Harvest index showed a positive and significant correlation with low irrigation and rainfed yield. Relative water content of cell (RWC) showed a positive and significant correlation with days to 50% maturity, number of days to maturity, plant height and number of pods per plant. As the plant growth time is longer, the water content of cell would increase and final yield of plant in both stress and low irrigation conditions would increase.

Cluster Analysis

To group genotypes based on superior indices, cluster analysis was performed using UPGMA method or minimum Ward at least variance. This method determines the difference between genotypes from the lowest Euclidean distance. Based on the results obtained and based on quantitative stress tolerance indices, genotypes were grouped in four classes at Euclidean distance of 4. The first included genotypes 4, 9 and 8. The third group included genotype 1 and the fourth group included genotype 5 (Figure1 and Table 10). Based on Fernandez's classification, third cluster is placed in group A, the second cluster is placed in group B, the first cluster is placed in group C, and the fourth cluster is placed in group D. Cluster analysis of genotypes based on stress tolerance indices was also used by Seyedi *et al.* (2013) in chickpea.

The first group consisted of genotypes number 2, 11, 6, 10, 7, 12 and 3. The second group consisted of genotypes number 4, 9 and 8. The third group included genotype number (1) of the fourth group including genotype Number (5) were grouped (Fig. 1 and Table 10). According to Fernandez's division of the third cluster in group A, the second cluster in group B is the first cluster in group C and the fourth cluster in group D. Cluster analysis of genotypes based on stress tolerance indices by Seyedi *et al.* (2013) has been used in chickpea.

Multiple regression analysis and causality analysis

Multiple regression analysis was performed based on stepwise method for some of the traits affected the STI (Table 9). Finally, the traits that remained in the regression model included:

1. Number of day to maturity (X1)
2. Plant height (cm) (X2)
3. Number of empty pods per plant (X3)
4. Number of secondary branches (X4)
5. Weight of 100 seeds (g) (X5)
6. Harvest index (percentage) (X6)
7. Protein content (percentage) (X7)

The condition of remaining in the regression model was the significance of the regression coefficient (β).

Multiple regression equation of studied traits with standardized coefficients:

$$STI= -0.89(X_1)+ 0.84 (X_2)–0.32 (X_3)+37(X_4)+ 0.47(X_5) + 56(X_6)+ 0.56(X_7)$$

Multiple regression equation of studied traits examined with non-standardized coefficients and intercept**:**

$$STI= -3.4\ 0.09-(X_1)+0.06 (X_2)–0.03(X_3)+0.05(X_4) + 0.11(X_5)+ 0.03(X_6)+0.06(X_7)$$

Linear correlation analysis into direct and indirect effects is difficult for all traits. Thus, this analysis was performed for the traits, which have more contribution to the selective dependent variable (STI). The results of causality analysis are shown in Table (8). As seen, the plant height had the highest positive direct effect on STI, which its direct effect was 0.84 and the most positive indirect effect was related to the number of days to maturity through plant height, which it was estimated to be 0.69. The direct effect of protein content on the STI index was 0.56 and the indirect effects of this trait on STI index through the traits of number of days to maturity, number of pods, 100 seed weight and harvest index was estimated to be negative, but the linear correlation coefficient was finally estimated to be 0.20.

The direct effect of number of days to maturity on STI index was -0.89, but the linear correlation coefficient with indirect effects on STI through the measured traits was obtained 0.18**.** The results of causality analysis of traits related to the STI index showed that the least direct effect on STI among these traits belonged to the number of pods per plant with a coefficient of -0.32 and the lowest indirect effect was related to plant height with value of -0.03 through the harvest index trait (Table 8). In the causality analysis for these seven traits, the standardized explanation coefficient (R2) was estimated to be 40%. It means that independent variables of X1 ... X7 could explain 40% of the variance of the dependent variable of STI. What remain in the path analysis are unknown factors of Error term. The value of e represents the value of variance of variable, which independent variables in the regression model were unable to explain it.

The results of the above-mentioned causality analysis indicate that any increase and handling on plant height and harvest index, which have the most direct and final effects on the dependent variable of STI, will increase lentil performance in stress conditions. The higher the plant height, the more photosynthesized, the more food is stored in the seeds and the weight of the seeds increases, on the other hand, increasing the length of the root leads to the absorption of water and more nutrients in the plant, which ultimately with the performance Higher than the higher values of the two indicators that GMP and STI are criteria for determining stress tolerance. (The results are consistent with some of the findings of Gory *et al.* 1985, Pantalon *et al.*, 1996), which correlate the association of wide root systems with the increase of positive and significant seed composition.

The results of the causality analysis suggest that any increase and manipulation in plant height and harvest index, which had the most direct effects on the dependent variable of STI, increased lentil yield in stress conditions. As the plant height increases, more nutrients are stored in the seeds due to more photosynthesis and the weight of the seeds increases. In addition, increasing the length of the root leads to the absorption of more water and nutrients in the plant, which finally with having higher yield, it would have higher values of GMP and STI indices, which are criteria for determining stress tolerance. These results are consistent with some of the results of the research conducted by Gure *et al.* (1985) and Pantalone *et al.* (1996), who found significant and positive correlation between wide root system and an increase in seed compounds. The causality analysis of the traits affected the stress tolerance index (STI) is presented in Table 11.

Factor analysis

In the factor analysis, it is necessary to examine the results of Kaiser-Meyer test and the Bartlett Sphericity test. If the numerical value of the Kaiser-Meyer test is greater than 0.5, the sampling adequacy is confirmed. In the Bartlett Sphericity test, the status of the matrix of correlation among the variables is examined, and if it is significant, the correlation among the variables is appropriate for factor analysis. In the above-mentioned test, the numerical value of Kaiser-Meyer test was calculated to be 0.76. The results of the factor analysis are presented in Table 12. This table shows the variance of each factor in terms of its percentage and its importance in interpreting the general variations of the data and the rate of common aspects of the traits, indicating a part of the variance of that trait that is related to the common factors is presented.

Table 12 presents the results of factor analysis after Varimax rotation. In the mentioned table, the common aspect of most of the traits is high, indicating that the number of selected factors is appropriate and the selected factors have been able to justify the variations in the traits in a desirable manner. In order to determine the justifying factors of the traits studied, factors analysis based on the eigen values larger than one, and based on the principal component analysis, 3 factors entered in the model, which justified 69.5% of variation in total data. The factor coefficients larger than 0.5 (regardless of their mark) were considered as significant factor coefficients. In the first factor, justified 41.5% of the total variance, traits such as number of days to 50% flowering, number of days to maturity, plant height, number of filled pods per plant, number of empty pods per plant, proline accumulation content, number secondary branch, and seed protein content had positive and significant factor coefficients. The second factor, justified 14.2% of the total variance including traits such as harvest index, RWC, and soluble sugar content had positive factor coefficients and proline content had negative and significant factor coefficients. The third factor, justified 13.7 percent of the total variance, including traits such as 100 percent weight and number of primary branches had positive and significant factor load in the model.

The screen graph diagram shows the eigen value variations in relation to the factors (Diagram 1). The specific diagram of this research also shows that the three factors are adequate to justify the data of the research, since after third factor, variations of eigen value decreases and diagram becomes almost linear. As a result, three factors as important factors, which have the greatest role in explaining the variance of the data, can be extracted. Moreover, the scree graph diagram shows that there is genetic diversity among different genotypes in terms of traits studied, since as genetic diversity is greater, the lower percentage of variations in the method of factor analysis will be justified (Jensen 1988, Amiri *et al.*, 2001). In the three-dimensional diagram, the dispersion of the examined, compared to the first, second, and third factors, is shown (Diagram 2).

Table 1 : Composite variance analysis of quantitative indices of stress tolerance and yield in low irrigation and rainfed conditions in lentil genotypes

		Mean squares (MS)							
Source of variation	**df**	**YP**	**YS**	**STI**	**SSI**	**TOL**	**MP**	**GMP**	**HARM**
Environmental conditions	1	ns 01/498799	ns 36/1304279	ns 19/0	ns 03/0	ns 86/62	ns 34/854060	ns 71/914135	* 12/975986
Experimental error	4	03/246872	81/112915	08/0	02/0	54/116	46/127896	46/119053	96/113972
Treatment (genotype)	11	** 62/311911	* 53/113754	** 24/0	ns 15/0	ns 1/53	** 05/192954	** 26/183272	** 15/174350
Experimental conditions × treatment	11	* 05/99275	ns 15/80705	ns 08/0	* 22/0	* 51/76	ns 24/55046	ns 62/58099	ns 86/62621
Experimental error	44	39/42764	47/49275	05/0	12/0	54/30	22/31219	91/34860	63/38903
Coefficient of variations (%)		13.66	19	16/27	66/28	30	18/13	13/14	14/15

** and * ns represent the significance level at the level of 1 and 5%, respectively.

Table 2 : Comparison of the mean effects of environmental conditions of qualitative indices of stress tolerance on rainfed and low irrigation yield of lentil

Environmental conditions	HARM
Ardabil	1186.01 b
Germi	1418.86 a

Table 3 : Comparison of the mean effects of quantitative indices of stress tolerance on yield rainfed and irrigation yield of lentil genotypes

YS	HARM	GMP	MP	STI	genotype
1388.02 a	1611.55 a	1639.8 a	1668.81 a	1.19 a	ILL-2126
1010.27 bc	1125.95 bc	1151.11 bc	1180.36 cd	0.64 bc	ILL-9893
1194.93 ab	1333.82 ab	1351.08 ab	1368.82 abc	0.82 ab	Bila Savar (control)
1306.97 ab	1448.5 ab	1482.69 ab	1519.27 ab	0.9 ab	FILIP-2007-11L
876.31 c	932.26 c	943.46 c	955.25 d	0.38 c	ILL-2580
1117.72 abc	1221.76 bc	1229.13 bc	1236.59 bcd	0.66 bc	ILL-10023
1232.52 ab	1313.86 ab	1323 ab	1332.3 bc	0.77 bc	LOCAL CHECK
1206.92 ab	1375.29 ab	1400.09 ab	1426.01 abc	0.85 ab	ILL-10315
1281.83 ab	1433.56 ab	1449.95 ab	1466.64 abc	0.93 ab	ILL-10277
1081.38 bc	1257.73 bc	1282.58 b	1308.27 bc	0.71 bc	ILL-465
1134.29 abc	1255.81 bc	1266.72 b	1277.8 bc	0.7 bc	ILL-10721
1186.44 ab	1319.1 ab	1334.12 ab	1349.55 bc	0.78b	ILL-10837

*Based on Duncan's Multiple Range Test, means with similar letters in each column are not significantly different at 5% level

Table 4 : Comparison of the mean of interaction effect (environmental conditions × genotype) of quantitative indices of stress tolerance on rainfed and irrigation yield of lentil

Environmental conditions	genotype	TOL	SSI	YP
Ardabil	ILL-2126	608.04 ab	1.33 ab	1739.43bcd
	ILL-9893	117.96 de	0.38 abc	1202.65 gh
	Bila Savar (control)	439.49 abcd	1.01ab	1571.08bcdefg
	FILIP-2007-11L	756.14 a	1.51 ab	1772.91 bc
	ILL-2580	259.01 abcde	0.53 abc	1031.69 h
	ILL-10023	270.65 abcde	0.74 abc	1231.14 fgh
	LOCAL CHECK	417.22 abcd	0.99 ab	1535.67 bcdefg
	ILL-10315	626.67 ab	1.31 ab	1629.59 bcdef
	ILL-10277	349.15 ab	0.84 abc	1500.31 bcdefg
	ILL-465	478.25 abcd	1.29 ab	1363 defgh
	ILL-10721	221.7 bcde	0.52 abc	1415.87 cdefgh
	ILL-10837	212.9 cde	0.67 abc	1169.63 gh
Germi	ILL-2126	515.13 abc	1.26 ab	2159.77 a
	ILL-9893	562.37 ab	2.23 a	1498.23 bcdefg
	Bila Savar (control)	256.07 abcde	0.66 abc	1514.35 bcdefg
	FILIP-2007-11L	84.06 abcde	0.41 bc	1690.24 bcde
	ILL-2580	56.76 bcde	0.13 bc	1036.71 h
	ILL-10023	210.57 bcde	0.71 abc	1479.79 bcdefg
	LOCAL CHECK	-18.1 e	-0.18 c	1328.49 efgh
	ILL-10315	249.7 bcde	0.75 abc	1660.63 bcde
	ILL-10277	390.07 abcde	1.11 ab	1802.58 abc
	ILL-465	429.32 abcde	1.32 ab	1707.33 bcde
	ILL-10721	352.36 abcde	1.49 ab	1426.77 cdefgh
	ILL-10837	439.55 abcd	1.4 ab	1855.69 ab

*Based on Duncan's Multiple Range Test, means with similar letters in each column are not significantly different at 5% level

Table 5 : Estimating the susceptibility or tolerance of genotypes by different indices of stress tolerance

Genotype number	genotype	Yp	Ys	STI	SI	SSI	TOL	MP	GMP	HARM
1	ILL-2126	1949.61	1388.025	1.175766	0.231459	1.274596	561.585	1668.818	1643.776	1619.185
2	ILL-9893	1367.11	1010.275	0.601396	0.231459	1.238808	356.835	1188.693	1170.994	1153.744
3	Bila Savar (control)	1542.72	1194.935	0.806546	0.231459	0.960892	347.785	1368.828	1356.872	1345.048
4	FILIP-2007-11L	1731.7	1306.97	0.9675	0.231459	0.909458	424.73	1519.335	1492.229	1466.16
5	ILL-2580	1034.2	876.315	0.393326	0.231459	0.598933	157.885	955.2575	950.3861	945.5632
6	ILL-10023	1355.465	1117.555	0.657862	0.231459	0.77281	237.91	1236.51	1230.473	1224.472
7	LOCAL CHECK	1432.085	1232.52	0.769021	0.231459	0.45028	199.565	1332.303	1324.037	1315.875
8	ILL-10315	1645.11	1206.92	0.857418	0.231459	1.098022	438.19	1426.015	1404.554	1383.645
9	ILL-10277	1651.445	1281.835	0.91984	0.231459	1.00499	369.61	1466.64	1454.93	1443.315
10	ILL-465	1535.17	1081.385	0.72153	0.231459	1.312115	453.785	1308.278	1287.653	1267.403
11	ILL-10721	1421.33	1134.29	0.7123	0.231459	0.951471	287.04	1277.81	1269.215	1260.691
12	ILL-10837	1512.67	1186.445	0.787831	0.231459	0.96965	326.225	1349.558	1339.471	1329.466

Table 6 : Simple correlation coefficients between stress tolerance index and stress-related traits

	STI	SSI	TOL	MP	GMP	HARM	YP	YS	Days to flowering 50%	Days to maturity	Plant height	Number of filled pod in plant
STI	1											
SSI	05/0-	1										
TOL	04/0	**83/0	1									
MP	**87/0	02/0	15/0	1								
GMP	**88/0	04/0-	07/0	**99/0	1							
HARM	**88/0	11/0-	01/0-	**98/0	**99/0	1						
YP	**85/0	**38/0	**56/0	**90/0	**86/0	**81/0	1					
YS	**81/0	**38/0-	**34/0-	**87/0	**90/0	**93/0	**57/0	1				
Days to flowering 50%	2/0	01/0	18/0-	**36/0	**38/0	**38/0	22/0	**44/0	1			
Days to maturity	17/0	02/0	17/0-	**39/0	**40/0	**40/0	*24/0	**45/0	**99/0	1		
Plant height	**31/0	06/0-	11/0-	**53/0	**54/0	**55/0	**39/0	**56/0	**82/0	**82/0	1	
Number of filled pod in plant	21/0	04/0-	10/0-	**38/0	**39/0	**40/0	*27/0	**41/0	**76/0	**77/0	**62/0	1

**and * ns represent the significance level at the level of 1 and 5%, respectively.

Table 7 : Simple correlation coefficients between stress tolerance index and stress-related traits

	Number of empty pod in plant	Number of primary branch	Number of secondary branch	Weight of 100 seeds	Yield in hectare	Harvest index	RWC	Seed protein content	Proline accumulation	Soluble sugars
STI	06/0-	02/0	08/0	11/0	**40/0	*26/0	03/0	18/0	16/0	11/0
SSI	07/0-	*25/0	05/0-	08/0	08/0-	08/0	12/0	03/0-	04/0-	14/0-
TOL	09/0-	*35/0	11/0-	15/0	03/0	10/0	01/0	*24/0-	10/0-	03/0-
MP	07/0	12/0	13/0	03/0	**39/0	*39/0	20/0	*26/0	19/0	19/0
GMP	08/0	09/0	14/0	02/0	**40/0	**38/0	20/0	*28/0	21/0	20/0
HARM	09/0	06/0	15/0	01/0	**40/0	**37/0	20/0	*30/0	22/0	20/0
YP	01/0	*25/0	06/0	10/0	**35/0	**38/0	18/0	10/0	11/0	15/0
YS	11/0	06/0-	18/0	04/0-	**36/0	**32/0	18/0	**37/0	*24/0	20/0
Days to flowering 50%	**47/0	03/0-	**62/0	**41/0-	08/0	07/0	**46/0	**76/0	**43/0	11/0
Days to maturity	**46/0	04/0-	**58/0	**38/0-	09/0	11/0	**49/0	**77/0	*40/0	11/0
Plant height	**51/0	09/0	**46/0	20/0-	21/0	07/0-	**31/0	**62/0	**45/0	08/0
Number of filled pod in plant	22/0	17/0-	**65/0	**65/0-	09/0	*29/0	**44/0	**59/0	**35/0	17/0

**and * ns represent the significance level at the level of 1 and 5%, respectively.

Table 8 : Simple correlation coefficients between stress tolerance index and stress-related traits

	STI	SSI	TOL	MP	GMP	HARM	YP	YS	Days to flowering 50%	Days to maturity	Plant height	filled pod in plant
Number of empty pod in plant	-0.06	-0/07	09-0/	07/0	08/0	09/0	0/01	0/11	**47/0	**46/0	**51/0	22/0
Number of primary branch	02/0	*25/0	*35/0	0/12	0/09	0/06	**25/0	06/0-	-0/03	-0/04	09/0	17/0-
Number of secondary branch	08/0	04/0-	11/0-	0/13	0/14	0/15	0/06	0/18	**62/0	**58/0	**46/0	**64/0
Weight of 100 seeds	11/0	08/0	15/0	03/0	0/02	0/01	0/10	04/0-	**41/0-	**38/0-	20/0-	**65/0-
Yield in hectare	**40/0	01/0-	03/0	**39/0	**40/0	**40/0	**34/0	**36/0	08/0	-0/09	21/0	09/0
Harvest index	*26/0	08/0	10/0	*39/0	**38/0	**37/0	**38/0	**32/0	07/0	11/0	06/0-	*29/0
RWC	03/0	12/0	01/0	20/0	20/0	20/0	18/0	0/18	**46/0	**49/0	**30/0	**44/0
Seed protein content	18/0	04/0-	*24/0-	*26/0	*28/0	*30/0	10/0	**37/0	**76/0	**76/0	**61/0	**59/0
Protein accumulation	160	04/0-	10/0-	19/0	21/0	22/0	11/0	*24/0	**43/0	**40/0	**44/0	**34/0
Soluble sugars	11/0	14/0-	03/0-	19/0	20/0	20/0	15/0	20/0	11/0	11/0	08/0	17/0

**and * ns represent the significance level at the level of 1 and 5%, respectively.

Table 9 : Simple correlation coefficients between stress tolerance index and stress-related traits

	Number of empty podin plant	Number of primary branch	Number of secondary branch	Weight of 100 seeds	Yield in hectare	Harvest index	RWC	Seed protein content	Proline accumulation	Soluble sugars
Number of empty pod in plant	1									
Number of primary branch	15/0	1								
Number of secondary branch	**38/0	16/0-	1							
Weight of 100 seeds	12/0	**36/0	**52/0-	1						
Yield in hectare	01/0-	0/20	0/02	05/0	1					
Harvest index	**34/0-	20/0-	19/0-	14/0-	12/0	1				
RWC	12/0	-0/21	**30/0	17/0-	03/0	*27/0	1			
Seed protein content	**42/0	-0/10	**58/0	**38/0-	05/0	-0/18	**33/0	1		
Proline accumulation	*25/0	0/16	**41/0	*28/0-	07/0	**44/0-	0.02	**62/0	1	
Soluble sugars	03/0-	0.04-	0/22	10/0-	14/0	0/17	*29/0	04/0	12/0-	1

**and * ns represent the significance level at the level of 1 and 5%, respectively.

Table 10 : Lentil genotypes

Genotype	Genotype number
ILL-2126	1
ILL-9893	2
Bila Savar (control)	3
FILIP-2007-11L	4
ILL-2580	5
ILL-10023	6
LOCAL CHECK	7
ILL-10315	8
ILL-10277	9
ILL-465	10
ILL-10721	11
ILL-10837	12

Table 11: Causality analysis of traits affecting stress tolerance index (STI)

Traits	Direct effects	Indirect effects through							Linear correlation coefficient STI
		Number of days to maturity	Plant height	Number of empty pods	Secondary branch	Weight of 100 seeds	Harvest index	Protein content	
Number of days to maturity	-0/89	--------	0/69	-0/15	0/22	-0/18	0/06	0/43	0/18
Plant height	0/84	-0/74	--------	0/17	0/17	-0/09	-0/03	0/35	0/33
Number of empty pods	-0/32	-0/42	0/44	--------	0/14	0/06	-0/20	0/23	-0/07
Secondary branch	0/37	-0/52	0/39	-0/12	---------	-0/25	-0/11	0/32	0/08
Weight of 100 seeds	0/47	0/35	-0/17	-0/04	-0/20	---------	-0/08	-0/21	0/12
Harvest index	0/56	-0/11	-0/06	0/11	-0/07	-0/06	--------	-0/10	0/27
Protein content	0/56	-0/68	0/52	-0/13	0/21	-0/18	-0/10	---------	0/20

Table 12 : Factor coefficient of common rate of traits studied in factor analysis in the lentil genotypes study

Traits studied	Mean traits	Common rate	Factor		
			1	2	3
50% flowering (day)	114.6	.922	.939	.192	-
Maturity time (day)	145.3	.923	.930	.237	-
Plant height (cm)	29.6	.776	.862	-	.161
Number of filled pod in plant	37.4	.826	.842	-.148	-.168
Number of empty pod in plant	4.8	.622	.757	.279	-.417
Number of primary branches	2.9	.500	.712	-	-.350
Number of secondary branch	10.1	.637	.618	-.148	.467
Weight of 100 seed (kg)	4.6	.818	.601	-.581	-.106
Harvest index (%)	46.7	.721	-.142	.803	-.239
RWC (%)	57.1	.548	.440	.590	-
Seed protein (%)	21.1	.758	.115	.508	-
Proline (μmol g^{-1} FW)	14.9	.710	-.379	-	.821
Soluble sugars (mg / ml)	345.1	.272	-	-.184	.681
Eigen values			5.567	2.139	1.328
Relative variance %			42.824	16.457	10.213
Accumulative variance%			42.824	59.281	69.494

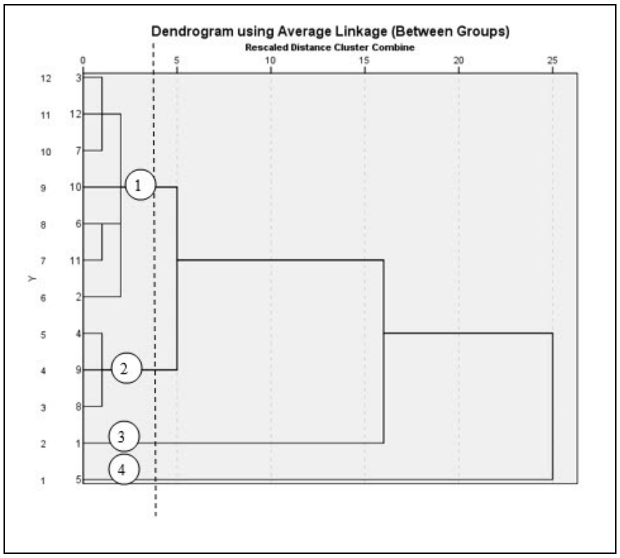

Fig. 1 : Dendrogram of lentil genotypes based on GMP, MP, STI and HARM indices

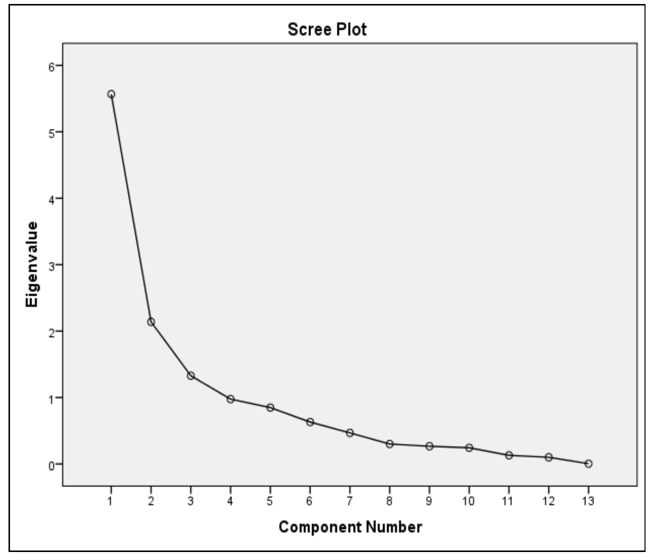

Diagram 1: scree graph for determining the number of factors

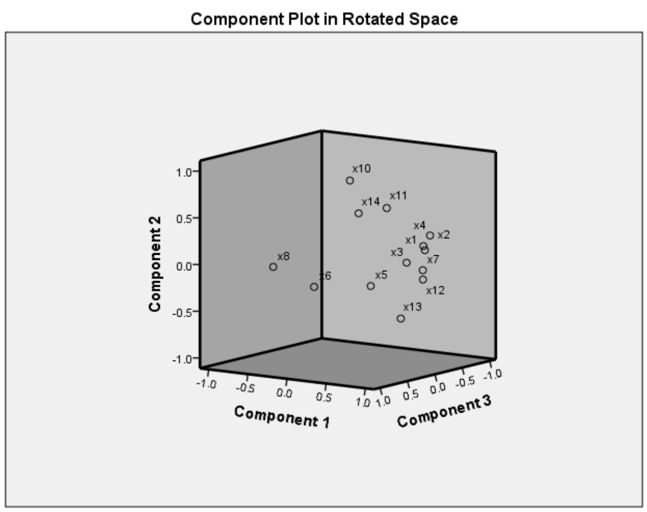

Diagram 2- Three-dimensional diagram of variables dispersion relative to extracted factors

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