DESERT

Desert
Online at http://desert.ut.ac.ir

Desert 25-2 (2020) 139-146

The most effective yield-components associated with increasing yield of wheat (*Triticum aestivum* L.) under terminal drought stress conditions

S.S. Moosavi[a*], M. Nazari[a], M. Chaichi[b], K. Jamshidi Goharrizi[c]

[a] *Department of Agronomy and Plant Breeding, Faculty of Agriculture, Bu-Ali Sina University, Hamedan, Iran*
[b] *Seed and Plant Improvement Research Department, Hamedan Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization, Hamedan, Iran*
[c] *Department of Plant Breeding, Yazd Branch, Islamic Azad University, Yazd, Iran*

Received: 21 June 2019; Received in revised form: 11 February 2020; Accepted: 15 February 2020

Abstract

Due to the rising drought-severity all around the world, one of the most important goals of arid agricultural systems is to increase wheat yield as a strategic crops in these areas. Improving the yield components is believed to be an efficient and vonventional strategy for increasing wheat yield. This study was carried out on 61 advanced lines and five Iranian commercial cultivars in order to identify the most effective components of grain yield (GY) under late-season drought stress conditions. The experiment was carried out based on an augment design during 2013-14 and 2014-15 growing seasons. Fertile spikes number m^{-2} (FSN), spike weight m^{-2} (SPW), grain number per spike (GNS) and plant harvest index, as the most effective variables, explained 94.06% of GY variance. FSN and SPW revealed the maximum direct and positive effect on GY enhancement. The first and second factors, as “yield and yield-components” and “vegetative growth” factors, respectively, explained 76.4% of the data on the total variance. The highest alignment with GY belonged to SPW and FSN . The genotypes were grouped in four different clusters. Bi-plot and cluster results revealed a remarkable genetic diversity among the genotypes; therefore, these results might be helpful to identify donor parents in wheat breeding crosses for yield increscent. Finally, FSN and SPW, the main indicators for increasing grain weight m^{-2}, were proposed as the most important grain yield-components under terminal drought stress conditions.

***Keywords*:** Bread wheat, Cluster analysis; Factor analysis; Genetic diversity; Harvest index, Path analysis; Stepwise regression

1. Introduction

According to the United Nations Population Outlook, the world's population will increase by nearly 2 billion over the next 26 years. So, it is predicted to increase to over 9.7 billion by 2050, resulting into the most severe food inequality in arid developing countries (Ashraf and Harris, 2005). In these countries, despite the fact that wheat plays an important role in food security, unfortunately, water deficiency is the most serious problem for its production (Farooq *et al.,* 2015). Selection of drought-tolerant genotypes with favorite yield related traits is a permanent solution for solving the problem. Yield-related traits with high heritability have been proposed to assist the selection of genotypes for grain yield under drought conditions (Quarrie *et al.,* 1999; McIntyre *et al.,* 2010).

In previous studies, complex statistical methods have been used in modeling crop yield, including stepwise regression, path analysis, factor analysis, cluster analysis and discriminate function analysis for simplifying complex data sets (Lee and Kaltsikes 1973; Protić *et al.,* 2009; Janmohammadi *et al.,* 2014).

* Corresponding author. Tel.: +98 918 8526940
Fax: +98 81 34425402
E-mail address: s.moosavi@basu.ac.ir

Leilah and Al-Khateeb (2005) reported that spikes number m^{-2} (SPN), 1000-grain weight (TGW), grain weight per spike (GWS) and biological yield (BY) were the most effective traits for the improvement of grain yield (GY). In a research, Uddin *et al.* (1997) suggested that grain number per spike (GNS) and TGW had the strongest association with GY. In addition, Janmohammadi *et al.* (2014) introduced SPN, GNS and TGW, as the routine yield components. Grain yield of wheat is the integration of several traits affecting plant growth throughout the growing period (Protić *et al.*, 2009). Brdar and colleagues (2008) suggested that GY of wheat depends on GWS, GNS and SPN. In addition, each trait changes to a different extent and direction under the influence of environmental factors. Arduini *et al.* (2006) demonstrated that biomass, harvest index and plant height explained 95.2% of data variance. Bhatt (1973) reported that the traits of the FSN and GWS had the maximum direct effect and days to flowering had the maximum indirect effect on GY. Certain researchers have suggested that high wheat grain yield could be obtained by selecting high FSN, TGW, GWS and BY (Leilah and Al-Khateeb, 2005). According to Rymuza *et al.*, (2012) TGW was reported to be most closely related to GY and was often utilized in selecting high yielding wheat cultivars.

Factor analysis is a useful statistical method of explaining the inter-correlations among a set of selected variables (Walton, 1971; Bhatt, 1973). It has been employed to identify growth and plant characters associated with wheat grain yield (Leilah and Al-Khateeb, 2005). Attempts to develop ideal plant architecture of wheat have rarely been made. Previous researches (Briggs and Shebeski, 1972; Mohamed, 1999; Leilah and Al-Khateeb, 2005) reported that the first three factors explained about 70% of the total variation. In another research (van Beuningen and Busch, 1997), different wheat genotypes were grouped into 20 clusters.

This research was carried out (i) to identify the most important effective yield-related traits in 61 advanced lines along with five Iranian commercial cultivars, and (ii) to evaluate genetic diversity of the plant materials using different statistical methods under terminal drought stress conditions.

2. Materials and Methods

2.1. Plant materials

Sixty-six bread wheat genotypes, including 61 F_8 advanced lines (developed by crops adaptation Department, CSIRO, Canberra, Australia) and five Iranian commercial cultivars (Table 1), were assessed during 2013–14 and 2014–15 growing seasons.

Table 1. The studied plant materials during 2013–14 and 2014–15 growing seasons

Genotype No.	Cultivar name	Release year	Explanations
1	F_8 line	-	The lines were created by crossing Vig18 (drought tolerant) × Cm18 (drought susceptible). It was developed by crops adaptation Dep., CSIRO, Canberra, Australia.
60	…..	…..	…..
61	"	"	"
62	Shahryar	2002	Susceptible to drought, resistant to cold, brown rust, and yellow rust.
63	Pishgam	2008	Resistant to cold, terminal drought, brown rust, and yellow rust.
64	Mihan	2010	Resistant to cold, drought and yellow rust and semi-susceptible to brown rust.
65	Zare	2010	Resistant to cold, drought, yellow rust, and brown rust.
66	Oroum	2011	Resistant to cold, drought, yellow rust and brown rust.

2.2. Experimental design and location

The field experiments were carried out at Hamedan Agricultural and Natural Resources Research and Education Center (at 34◦ 52' N latitude, 48◦ 32' E longitude and an altitude of 1730 meters above the sea level with about 250 mm annual average rainfall), Iran. The experiments were performed based on an augment design with seven incomplete blocks. The research field was prepared by a deep plowing, two inverse disks and leveling. Nitrogen, phosphor and potassium fertilizers were added to the land, according to results of the soil nutrient test.

Shahryar cultivar was cultured to avoid all the edge effects, including shading. The distance of rows was 20 cm and the seed density was considered to be 400 seeds per square meter. The plants were watered until the flowering time, and after that, the seasonal rainfall was employed. The plants were harvested following the physiological maturity on July 10-13th and July 15-18th in 2013-14 and 2014-15, respectively.

2.3. The traits measurement

During the growing season and after harvesting the plants, we measured the traits of fertile spike number m^{-2} (FSN), biomass or biological yield m^{-2} (BY), plant height (PH), spike length (SPL), peduncle length (PL), spikelet number per spike (SNS), stem weight m^{-2} (STW), peduncle weight m^{-2} (PW), spike weight m^{-2} (SPW), grain number per spike (GNS), 1000-grain weight (TGW), stem harvest index (STHI), spike harvest index (SPHI), plant harvest index (PHI) and grain yield m^{-2} (GY). The plants were harvested when the shrubs were completely yellow for all the bushes in the plots.

2.4. Statistical analysis

The datasets were analyzed for different statistical techniques, includingPearson's correlation, forward stepwise regression, path analysis, factor analysis (based on principal component method by varimax orthogonal rotation), Ward's cluster analysis (by the square of Pearson's distance) and discriminant function analysis.

The data were analyzed utilizing the software of SPSS version 19.0 (SPSS Inc., Chicago, IL, USA), SAS version 9.2 (SAS Institute Inc., Cary, NC, USA). MINITAB version 16 (Minitab Inc., Harrisburg, PA, USA) and Path-2 (for path analysis).

3. Results

3.1. Correlation

The results showed that fertile spike number m^{-2} (FSN), biological yield m^{-2} (BY), spike weight m^{-2} (SPW), grain number per spike (GNS), spike length (SPL) ,1000-grain weight (TGW), spikelet number per spike (SNS), plant harvest index (PHI), spike harvest index (SHI) and plant height (PH) were of the maximum and significant ($p<0.05$) correlation with grain yield m^{-2} (GY) (Table 2).

Table 2. Correlation coefficients between grain yield and fourteen different characters in 66 bread wheat genotypes

Traits	FSN	BY	PH	SPL	PL	SNS	STW	PW	SPW	GNS	TGW	STHI	SPHI	PHI
BY	0.89^{**}	-	-	-	-	-	-	-	-	-	-	-	-	-
PH	0.51^{*}	0.50^{*}	-	-	-	-	-	-	-	-	-	-	-	-
SPL	0.61^{**}	0.62^{**}	0.64^{**}	-	-	-	-	-	-	-	-	-	-	-
PL	0.31^{ns}	0.33^{ns}	0.73^{**}	0.51^{*}	-	-	-	-	-	-	-	-	-	-
SNS	0.57^{*}	0.59^{*}	0.62^{**}	0.89^{**}	0.52^{*}	-	-	-	-	-	-	-	-	-
STW	0.33^{ns}	0.38^{ns}	0.80^{**}	0.48^{*}	0.48^{*}	0.55^{*}	-	-	-	-	-	-	-	-
PW	0.30^{ns}	0.35^{ns}	0.72^{**}	0.49^{*}	0.84^{**}	0.55^{*}	0.77^{**}	-	-	-	-	-	-	-
SPW	0.56^{*}	0.59^{*}	0.43^{ns}	0.51^{*}	0.31^{ns}	0.58^{*}	0.46^{*}	0.39^{ns}	-	-	-	-	-	-
GNS	0.50^{*}	0.50^{*}	0.40^{ns}	0.45^{ns}	0.32^{ns}	0.52^{*}	0.38^{ns}	0.35^{ns}	0.92^{**}	-	-	-	-	-
TGW	0.45^{ns}	0.52^{*}	0.32^{ns}	0.35^{ns}	0.19^{ns}	0.41^{ns}	0.30^{ns}	0.26^{ns}	0.65^{**}	0.39^{ns}	-	-	-	-
STHI	0.30^{ns}	0.27^{ns}	-0.15^{ns}	0.14^{ns}	0.02^{ns}	0.17^{ns}	-0.34^{ns}	-0.18^{ns}	0.60^{**}	0.60^{**}	0.47^{*}	-	-	-
SPHI	0.41^{ns}	0.39^{ns}	0.31^{ns}	0.23^{ns}	0.38^{ns}	0.26^{ns}	0.06^{ns}	0.23^{ns}	0.57^{*}	0.62^{**}	0.63^{**}	0.68^{**}	-	-
PHI	0.38^{ns}	0.20^{ns}	0.21^{ns}	0.23^{ns}	0.27^{ns}	0.29^{ns}	0.01^{ns}	0.17^{ns}	0.67^{**}	0.72^{**}	0.39^{ns}	0.65^{**}	0.74^{**}	-
GY	0.93^{**}	0.86^{**}	0.48^{*}	0.61^{*}	0.35^{ns}	0.59^{*}	0.37^{ns}	0.35^{ns}	0.74^{**}	0.64^{**}	0.62^{**}	0.44^{ns}	0.49^{*}	0.52^{*}

ns,* and ** indicate non-significant, and significant at 5% and % probability levels respectively

3.2. Stepwise regression

Stepwise regression indicated that the traits of FSN, SPW, GNS (with a negative regression coefficient) and PHI, as the most effective traits, entered into the regression model. They explained 94.06% of grain yield variance (Table 3). Only FSN explained 85.82% of yield variance.

Table 3. Stepwise regrssion for grain yield, as dependent variabl, and fourteen diffrent characters in 66 bread wheat genotypes

Regression steps	Constant	Regression coeficient for different traits				Cumulative R^2
		Fertile spike number m^{-2}	Spike weight m^{-2}	Grain number per spike	Plant harvest index	
1	-14.87	3.25	-	-	-	85.82^{**}
2	-37.27	2.62	11.00	-	-	93.03^{**}
3	-34.69	2.60	18.8	-0.49	-	93.82^{**}
4	-36.79	2.60	18.7	-0.61	13.30	94.06^{*}

* and ** indicate significant at 5%,1 % probability levels, respectively

3.3. Path analysis

Path analysis confirmed the results of stepwise regression. The findings (Table 4) implied that the traits of FSN and SPW had the maximum direct positive effect on GY. Despite the negative direct effect of GNS on GY (-0.30), this trait had the most indirect effect on grain yield (0.506) by increasing SPW (Table 4). In addition, in spite of the insignificant direct effect of PHI (0.082), its indirect effect was remarkable by increasing FSN and SPW.

Table 4. The results of path analysis in 66 bread wheat genotypes

Traits	Direct effect	Indirect effect of a trait on grain yield by below traits				Correlation with grain yield
		FSN	SPW	GNS	PHI	
FSN	0.741	-	0.304	-0.015	0.031	0.93^{**}
SPW	0.548	0.412	-	-0.277	0.055	0.74^{**}
GNS	-0.30	0.369	0.506	-	0.059	0.64^{**}
PHI	0.082	0.281	0.367	-0.217	-	0.52^{*}

The direct and indirect effect of the traits of fertile spike number m^{-2} (FSN), spike weight m^{-2} (SPW), grain number per spike (GNS) and plant harvest index (PHI) were investigated on grain yield as dependent variable.* and ** indicate significant at 5%, 1% probability levels respectively. Residual effect=0.234

3.4. Factor analysis

The two first-factors accounted for 76.4% of the total variation of the data. The first and second factors explained about 53.2% and 23.2% of the total variation of the data, respectively. According to the results (Fig 1), line 9, 16 and cultivars Mihan (64) and Oroum (66) were the best genotypes, and line 48, 27 and 58 were found to be the worst genotypes.

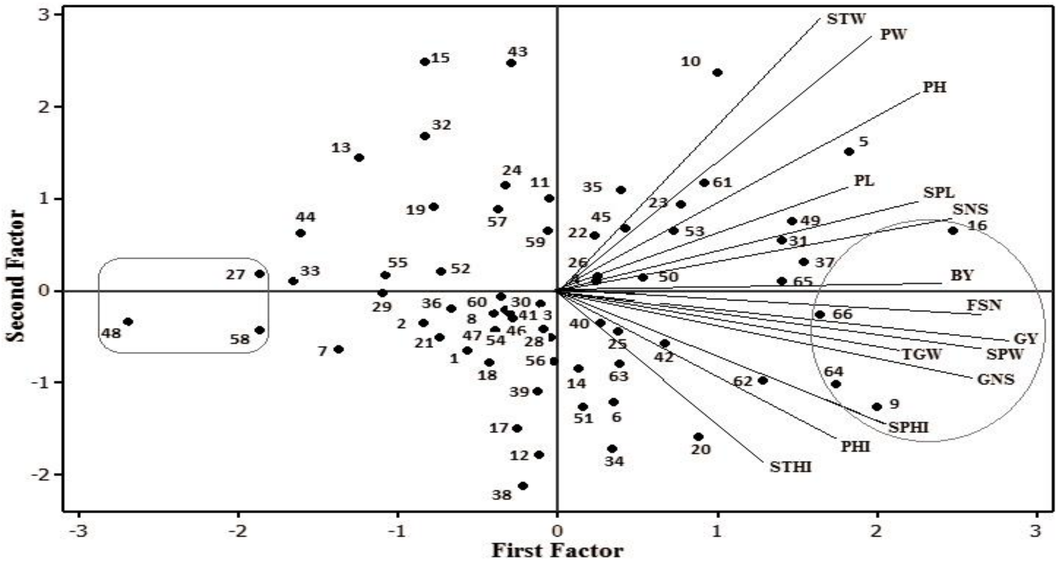

Fig. 1. Bi-plot graph of the two first factors for 15 characters in 66 bread wheat genotypes.
The mesured traits, including fertile spike number m^{-2} (FSN), biomass or biological yield m^{-2} (BY), plant height (PH), spike length (SPL), peduncle length (PL), spikelet number per spike (SNS), stem weight m^{-2} (STW), peduncle weight m^{-2} (PW), spike weight m^{-2} (SPW), grain number per spike (GNS), 1000-grain weight (TGW), stems harvest index (STHI), spike harvest index (SPHI), plant harvest index (PHI) and grain yield m^{-2} (GY).

3.5. Cluster and discriminant function analyses

The cluster analysis was done after deleting spike harvest index (SPHI) according to 14 remained characters. The results (Fig 2) revealed that the 66 wheat genotypes were categorized into four separate groups. The first, second, third and fourth clusters containing 31, 10, 11 and 14 members, respectively. The above-mentioned result indicated high genetic diversity of the germplasm.

4. Discussion

According to the correlation results, any attempt for increasing FSN, BY, SPW, GNS, SPL, TGW, SNS, PHI, SHI and PH lead to GY improvement. In confirmation of these results, stepwise regression also showed that FSN could be a significant attribute for the indirect improvement of GY under drought stress conditions. In general, FSN and SPW are suggested as two major-components of GY with high and significant correlation ($r=0.93^{**}$ and

0.74**respectively) with grain yield. Although the increase of the above two traits has led to an increase in grain yield in new wheat cultivars, but the factor in improving grain yield in old cultivars has been an increase in single spike weight. In fact, several studies (Austin *et al.*, 1989; Slafer and Andrade, 1989; Slafer, 1994) have previously revealed a positive and significant correlation between grain number m^{-2} and grain yield. All above-mentioned researchers suggested that grain number m^{-2} in new wheat cultivars was significantly greater than old varieties, and this trait was identified as the basic component for grain yield potential. Moreover, two valuable traits of FSN and GNS are the most important components of grain number m^{-2}. Therefore, increasing FSN will result in increasing GY. Meanwhile, SPW is a valuable index of PHI in the unit area. As a result, owing to the correlation between SPW and harvest index, which is in accordance with previous studies (Richards and Townley-Smith, 1987; Sadras, 1990), with the increase in spike weight per unit area, GY will increase. Increasing fertile spike number per unit area will lead to increased plant density and plant biomass per unit area. Thus, increasing biomass would be obtained by increasing solar use and absorption per unit area (Slafer, 1994).

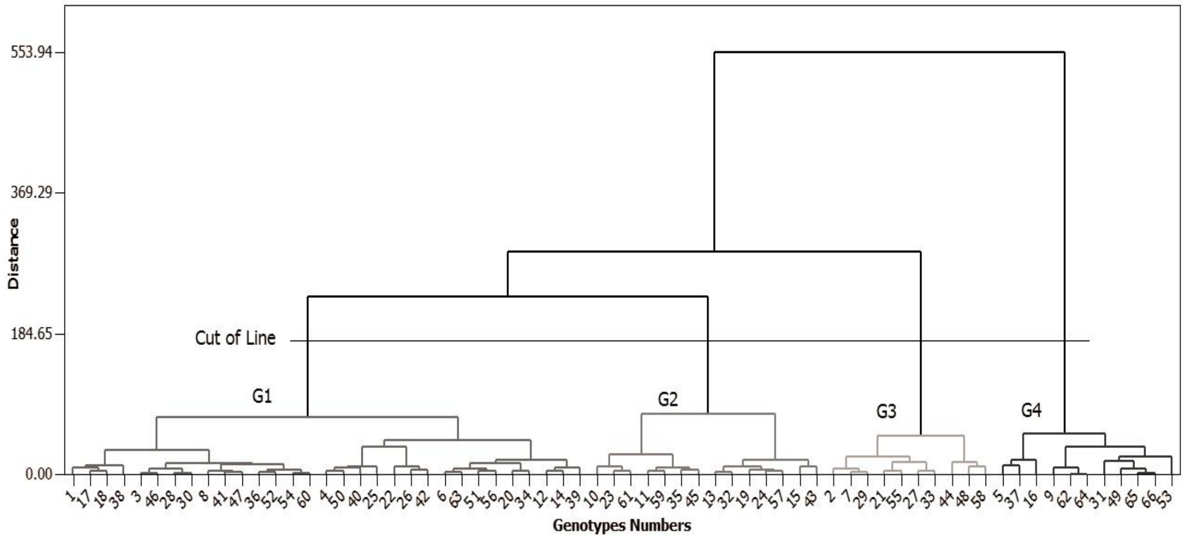

Fig. 2. Dendrogram of diffrent characters by Ward's method in 66 bread wheat genotypes

In other words, the genotypes with the greater FSN, have better exploitation in limited environmental resources and therefore, they will improve their yield. Munir *et al.* (2007) reported that tillers number $plant^{-1}$, grains number $plant^{-1}$, grain weight $plant^{-1}$ and TGW had a positive and significant correlation with GY. Additionally, Brdar *et al.* (2008) reported that GY was positively correlated with both grain filling duration and rate, and it was also negatively correlated with GNS, and the number of spikes per m^2. They reported a significant and positive correlation between GY and the number of tillers, spike length, plant height, awn length, and fertile tillers per plant, 1000 kernel weight, harvest index and biological yield. In addition, in regression analysis, BY, PHI, GNS and TGW remained in the final model. In a research (De Vita *et al.*, 2007), FSN, GNS and TGW were suggested as the most effective traits for grain yield improvement. Slafer (1994) suggested that PHI and BY are two main-components of GY. Despite the fact that the harvest index trait has always improved during wheat breeding programs, it can still be maximized (62%) by focusing on the harvest index. So that, this strategy may be able to improve GY in the future. In this regard, there is a positive and significant correlation between water use efficiency and PHI (Richards and Townley-Smith, 1987; Sadras, 1990). In a research, Arduini *et al.* (2006) reported that BY, PHI, FSN, grain number m^{-2} and day to grain filling had been significantly correlated with GY. Mollasadeghi and Shahryari (2011) suggested that GY was significantly correlated with BY, PHI, TGW and grain filling rate, while Ranjbar *et al.* (2015), reveled a negative and significant correlation (r= -0.478) between TGW and GY. They attributed it to the opposed behavior and ontogeny relationships between seed number and TGW. The results (Table 2) showed a positive and significant correlation between TGW and GY ($r=0.62^{**}$). In other words, the majority of genotypes with a greater TGW, showed a higher GY. The new improved cultivars with increasing WUE in their terminal growing period, can improve TGW and GY. Slafer (1994) reported that new wheat cultivars had more assimilate transfer rate from sink to source about 1 month before flowering time, which leads to increasing TGW in them. Our results (Table 2) indicated that PH had a positive and significant ($p<0.05$) correlation with GY. Law and Worland (1978) reported a direct and significant correlation between PH and GY. A better solar distribution in the plant canopy leads to the above-mentioned relationship. However, increasing PH is not always favorable (Slafer, 1994). In other words, increasing plant height, as an indicator of increased vegetative growth, does not always improve harvest index and grain yield. The results of an experiment revealed that PHI, BY and FSN involved in regression model as the most effective traits with maximum direct effect on GY (De Vita *et al.*, 2007). Moosavi *et al.* (2013) reported that PHI, BY and RWC were the most important traits for indirect GY selection. Hohan *et al.* (1993) indicated that filling period, GNS, FSN, PH and PHI included into regression model. Ranjbar *et al.* (2015), revealed that the traits of spike length, FSN, GNS and PHI showed positive effects on GY and other traits, such as TGW, and grain weight per spike, and infertile-tiller number per plant, showed negative effects on GY under rain-fed conditions. Leilah and Al-khateeb (2005), explained that spike length, FSN, GWS, PHI and BY were the most important traits.

Even though GNS had positive and significant correlation with GY, its direct effect was negative on GY (Table 4). However, the indirect effect of this trait on the grain yield was positive and significant. Therefore, increasing SPW, GNS had the maximum indirect positive effect on GY. The direct effects of FSN and SPW, were equal to their correlation coefficient with the GY. Accordingly, it seems that the improvement of the two traits will result in the improvement of GY; increasing BY and PHI or both of them are the efficient methods for indirect yield increscent (Slafer, 1994). In the other hand, FSN and SPW are two main important components of PHI, whose changes will result in the improvement of PHI and GY. The results of previous studies indicated that PHI, BY and FSN had the maximum direct effect on GY (Hohan *et al.*, 1993). Ranjbare *et al.* (2015) and Leilah and Al-khateeb (2005) demonstrated that BY and PHI had the greatest positive and direct effect on yield. In a research under terminal drought stress, Moosavi *et al.* (2013) reported that PHI and BY had the maximum direct and indirect effect on GY, respectively. Despite the negative direct effect of GNS on GY, this trait had the most indirect effect on grain yield by increasing SPW. Due to the existence of a threshold for potential yield in any environmental conditions, increasing the number of grains may lead to a decrease in TGW and a decrease in GY (Neyestani *et al.*, 2005). Meanwhile, it results in indirect increscent of GY by increasing SPW (Zafarnaderi *et al.*, 2013). In addition, in spite of the little direct effect of PHI, its indirect effect was remarkable by increasing FSN and SPW. Although BY had a significant and a remarkable correlation ($r=0.866$) with GY, it could not enter into regression model. The results (Table 4) indicated that the BY had a great positive indirect effect on GY by increasing FSN and SPW. Accordingly, we observed a positive significant correlation among BY, FSN and SPW (Table 2). Aycicek and Yildirim (2006) reported that PHI had positive direct and negative indirect effect on GY. Therefore, according to direct and indirect effect of the traits, the selection could be done in future breeding programs.

The traits, contributed more remarkably to the first factor, were GY, SPW, FSN, SNS, GNS, SPL and BY (Fig 1), suggesting that these components reflected the yield potential of each genotype, which is known as “yield and yield-components factor”. The second factor is related to stem weight m^{-2}, peduncle weight m^{-2}, plant height and peduncle length. Therefore, it was known as “vegetative growth or plant vigor factor”. In spite of the high amount of the first factor, the medium or low amount of the second factor could be suggested under terminal drought stress. Moreover, excessive increscent of the second factor is not suitable under limited drought stress conditions, because in that case, some parts of assimilates transfer to vegetative growth instead of grain yield. Consequently, the part between area I and area IV was found to be the best area and the part between area II and area III was the worst part in bi-plot graph (Fig 1). The suitable traits of SPW, FSN, TGW, GNS, spike harvest index, PHI and stem harvest index were placed in area IV. Rahman *et al.* (2016) reported a significant negative correlation of plant height with grain yield. In a research on rapeseed, Majidi *et al.* (2015) reported that three independent factors explained 71% of the total variance; the first factor was named 'productivity factor'. Mohamed (1999) classified the ten wheat variables into two main-factors, which accounted for 80.79% of the total variance.

Cluster IV with the maximum distance to cluster III, contained the highest amount of yield and yield components, known as "grain yield cluster" (Fig 2). The perfect genotypes 9, 16, 64 and 66 were grouped in cluster IV while imperfect lines 48, 27 and 58 were categorized in cluster III. Cluster III and IV are the best groups for creation of the maximum diversity for yield and yield components and these two clusters had the maximum distance together. In an experiment, 64 wheat genotypes were grouped into five clusters, and landrace genotypes were placed in a cluster (Rashidi *et al.*, 2007).

In addition, the discriminant function analysis confirmed 98.5% of the categorization results of the cluster analysis averagely. The result obtained of discriminat function indicated that the cluster analysis was correctly done. Moosavi et al. (2013) and Rashidi et al. (2007) used discriminant function analysis to confirm the results of their cluster analysis.

5. Conclusion

According to the obtained results, i)- Indirect selection of grain yield through selection to improve FSN, SPW, GNS and PHI will lead to improved wheat GY under terminal drought stress conditions. , ii)-there was a considerable variation and a high level of genetic diversity among genotypes, which could be implicated in the selection of wheat for the development of commercial cultivars, iii)- lines 9 and 16 were the suitable lines and lines 48, 27 and 58 were the unsuitable lines, and iv)- there was maximum distance between cluster iii and iv, which makes them the best groups to create the maximum diversity in future breeding programs.

Acknowledgments

The grant for academic staff of Bu-Ali Sina University, Hamedan, Iran, supported this research. We also thank CSIRO for providing a part of the plant materials.

References

Arduini, I., A. Masoni, L. Ercoli, M. Mariotti, 2006. Grain yield, and dry matter and nitrogen accumulation and remobilization in durum wheat as affected by variety and seeding rate. European Journal of Agronomy, 25; 309-318.

Ashraf, M. P. Harris, 2005. Abiotic stresses: plant resistance through breeding and molecular approaches: CRC Press.

Austin, R., M.A. Ford, C. Morgan, 1989. Genetic improvement in the yield of winter wheat: a further evaluation. The Journal of Agricultural Science, 112; 295-301.

Aycicek, M., T.Yildirim, 2006. Path coefficient analysis of yield and yield components in bread wheat (*Triticum aestivum* L.) genotypes. Pakistan Journal of Botany, 38; 417-426.

Bhatt, G.M., 1973. Significance of path coefficient analysis in determining the nature of character association. Euphytica, 22; 338-343.

Brdar, M.D., M.M. Kraljević-Balalić, B.Đ. Kobiljski, 2008. The parameters of grain filling and yield components in common wheat (Triticum aestivum L.) and durum wheat (*Triticum turgidum* L. var. durum). Central European Journal of Biology, 3; 75-82.

Briggs, K. L. Shebeski, 1972. An Application of Factor Analysis to Some Breadmaking Quality Data 1. Crop Science, 12; 44-46.

De Vita, P., O.L.D. Nicosia, F., Nigro, C., Platani, C., Riefolo, N. Di Fonzo, L. Cattivelli, 2007. Breeding progress in morpho-physiological, agronomical and qualitative traits of durum wheat cultivars released in Italy during the 20th century. European Journal of Agronomy, 26; 39-53.

Farooq, S., M., Shahid, M., Khan, M. Hussain, M. Farooq, 2015. Improving the productivity of bread wheat by good management practices under terminal drought. Journal of Agronomy and Crop Science, 201; 173-188.

Hohan, D., S.Harbir, O. Khola, H. Singh, 1993. Correlation and path analysis is late sown bread wheat (*Triticum aestivum* L.) cv WH 291. Crop Research, 10; 72-77.

Janmohammadi, M., Z. Movahedi, N. Sabaghnia, 2014. Multivariate statistical analysis of some traits of bread wheat for breeding under rainfed conditions. Journal of Agricultural Sciences 59, 1-14.

Law, C.N., J.W. Snape, A.J. Worland, 1978. The genetical relationship between height and yield in wheat. Heredity, 40; 133-144.

Lee, J. P.J. Kaltsikes, 1973. Multivariate statistical analysis of grain yield and agronomic characters in Durum wheat. Theoretical and Applied Genetics, 43; 226-231.

Leilah, A., S. Al-Khateeb, 2005. Statistical analysis of wheat yield under drought conditions. Journal of Arid environments, 61; 483-496.

Majidi, M., Y. Sharafi, M. Jafarzadeh, A. Mirlohi, 2015. Multivariate analysis of genetic variation in winter rapeseed (*Brassica napus* L.) cultivars. Journal of Agricultural Science and Technology, 17; 1319-1331.

McIntyre, C.L., K.L. Mathews, A. Rattey, S.C. Chapman, J. Drenth, M. Ghaderi, M. Reynolds, R. Shorter, 2010. Molecular detection of genomic regions associated with grain yield and yield-related components in an elite bread wheat cross evaluated under irrigated and rainfed conditions. Theoretical and Applied Genetics, 120; 527-541.

Mohamed, N. 1999. Some statistical procedures for evaluation of the relative contribution for yield components in wheat. Zagazig Journal of Agricultural Research, 26; 281-290.

Mollasadeghi, V. R. Shahryari, 2011. Important morphological markers for improvement of yield in bread wheat. Advances in Environmental Biology, 538-543.

Moosavi, S.S., F.Kian Ersi, M.R. Abdollahi, 2013. Application of multivariate statistical methods in detection of effective traits on bread wheat (*Triticum aestivum* L.) yield under drought stress condition. Cereal Researches, 3; 119-130.

Munir, M., M. Chowdhry, T. Malik, 2007. Correlation studies among yield and its components in bread wheat under drought conditions. International Journal of Agriculture and Biology, 2; 287-290.

Neyestani, E., A. Mahmoudi, F. Rahimnia, 2005. Path analysis of grain yield and its components and estimation of heritability in barley. Journal of Agriculture, 7; 55-64.

Protić, R., G. Todorović, N. Protić, 2009. Correlations of yield and grain yield components of winter wheat varieties. Journal of Agricultural Sciences, 54; 213-221.

Quarrie, S., J. Stojanović, S. Pekić, 1999. Improving drought resistance in small-grained cereals: A case study, progress and prospects. Plant Growth Regulation, 29; 1-21.

Rahman, M., N. Barma, B.Biswas, A. Khan, J. Rahman, 2016. Study on morpho-physiological traits in spring wheat (*Triticum aestivum* L.) Under rainfed condition. Bangladesh Journal of Agricultural Research, 41; 235-250.

Ranjbar, A., A. Sepaskhah, S. Emadi, 2015. Relationships between wheat yield, yield components and physico-chemical properties of soil under rain-fed conditions. International Journal of Plant Production, 9; 433-466.

Rashidi, V., H.E. Majidi, S.G. Mohammadi, V.M. Moghadam, 2007. Determine of genetic relationship in durum wheat lines by cluster analysis and identity of morphological main characters in each gropes. Journal of Agricultural Sciences, 13; 439-449.

Richards, R., T. Townley-Smith, 1987. Variation in leaf area development and its effect on water use, yield and harvest index of droughted wheat. Australian Journal of Agricultural Research, 38; 983-992.

Rymuza, K., E.Turska, G.Wielogórska, A. Bombik, 2012. Use of principal component analysis for the assessment of spring wheat characteristics. Acta Scientiarum Polonorum Agricultura, 11; 79-90.

Sadras, V.O. 1990. Transpiration, transpiration efficiency and harvest index in sunflower (*Helianthus annuus* L.). Irrigation Science, 12; 87-91.

Slafer, G.A. 1994. Genetic improvement of field crops. CRC Press, AP - Technology and, Engineering, 488 pages.

Slafer, G.A., F.H. Andrade, 1989. Genetic improvement in bread wheat (*Triticum aestivum*) yield in Argentina. Field Crops Research, 21; 289-296.

Uddin, M., B. Mitra, M. Chowdhury, 1997. Genetic parameters, correlation, path coefficient analysis and selection indices in wheat. Bangladesh Journal of Scientific and Industrial Research, 32; 523-528.

van Beuningen, L.T. R.H. Busch, 1997. Genetic Diversity among North American Spring Wheat Cultivars: I. Analysis of the Coeffecient of Parentage Matrix. Crop Science, 37; 570-579.

Walton, P.D. 1971. The use of factor analysis in determining characters for yield selection in wheat. Euphytica, 20; 416-421.

Zafarnaderi, N., S. Aharizad, S. Mohammadi, 2013. Relationship between grain yield and related agronomic traits in bread wheat recombinant inbred lines under water deficit condition. Annals of Biological Research, 4; 7-11.