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Evaluation of Agronomic Traits of Wheat Genotypes under Different Irrigation Regimes

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ABSTRACT

Wheat is one of the important cereal crops in the world and is the main staple food for many. Among the different environmental stresses, drought is the most critical threatening wheat productivity worldwide. This study evaluated and classified morphological and physiological characteristics of wheat genotypes in two non-stress and drought-stress conditions. A field study was conducted at the Research Station of Agricultural Faculty of Islamic Azad University of Tabriz, Iran between 2012 and 2013. Thirty wheat genotypes with six replications were sown in a randomised complete block design. As indicated in the results analysis of variance, the studied genotypes were genetically different in all characteristics. The grain yield had positive correlation with straw yield, harvest index, and biological yield Based on factor analysis, in the non-stressed condition, the first factor was referred to as yield, and in the stressed condition, the first factor was called yield components. To classify genotypes, cluster analysis was performed on the Ward method. The results of the analysis were divided into three groups in non-stressed experiment genotypes while in stress experiment genotypes, they were divided into four groups. Considering the cluster analysis, the first group was presented as the optimal one in the non-stress condition. The results indicated that in order to obtain the desirable grain yield, we can increase most of the traits with positive and significant correlations with the yield.

Keywords: Cluster analysis, water regimes, wheat genotypes, yield

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INTRODUCTION

Cereals are considered the most significant source of calories for human beings (Daryanto, 2016). Although cereals are considered a staple food for many, drought reduces more than 50% of the crop (Amiri et al., 2014). It is also used as a main source of straw for animal nourishment (Salwa & Osama, 2014). The global wheat production was about 735.23 million tonnes in 2016 (FAO, 2016). In many semi-arid environments, the relative humidity at the beginning of growing season is at the highest level and with increasing temperature, the amount of rainfall decreases. In these regions, wheat grain filling duration is simultaneous with water shortage and increased evaporation of soil surface; Thus, the yield is reduced (Heyne, 1987). Iran, with an annual average precipitation of 240 mm, is located in the semi-arid and arid areas of the world. In Iran, most farmers do not get a desirable result from planting water-expecting cultivars due to inadequate water in terms of assigning late-season irrigation to summer farming. Consequently, wheat farming results in the late-season drought stress. Therefore, to obtain and introduce cultivars capable of producing greater and reliable yields, managing normal and late-season drought stress is important (Koocheki et al., 2014). In arid and semi-arid regions, drought stress is one of the most important factors limiting agricultural production (Mollasadeghi et al., 2011).

Drought stress in different stages of wheat growth reduces grain yield, harvest index, biological yield, and grain yield components (Araus et al., 2003). A marked effect of humidity stress is shorter plants, which occurs as the result of a decrease in distances between internodes. Decrease in the height of plants and internodes occur due to drought stress usually before the emergence of spikes but would rarely be affected after that (Annicchiarico et al., 2000).

Zaefyzadeh et al. (2009) classified 13 wheat genotypes into three clusters using the Ward method in drought stress. Poudel et al. (2017) were categorised the clusters in into two groups in stress environment: Group A and Group B. Cluster 1, Cluster 2, Cluster 3 and Cluster 4 are included in Group A, while Group B consists of only one cluster, Cluster 5. Grain yield is a complex multi-component property which undergoes different environmental conditions. Different morphological and physiological characters contribute to grain yield (Naghavi & Khalili, 2017). Zi-Zhenali et al. (2004) indicated the number of spikes per unit area along with the number of grains per spike was considered as the main determining factor. However, the number of spikes per unit area has a negative influence on the number of grains per spike. Samarah (2005) had reported decreased grain yield under the drought stress condition as a result of decreased 1000-grain weight, the number of tillers, and the number of spikes and grains in the plant. He reported drought stress reduces grain yield by decreasing the number of grains per spike. Intense drought in pre-pollination stages decreases the number of spikes and spikelets, making the remaining spikelets fertile. In addition, the duration of this stage and acceleration of aging, as well as the period of grain filling in the later development stages are reduced by the drought stress in the flowering stage (Shepherd et al., 2002).

Slafer and Araus (1998) showed that if the late-season drought threatened crop growth, cultivars and lines capable of turning the vegetative to the generative stage—when more usable moisture is available in soil—led to a higher harvest index and grain yield, because they had more opportunity to use moisture stored in the soil prior to the late-season drought. By analysing wheat resistance to drought, it was found under adequate moisture conditions in the soil, the number of grains in spike and 1000-grain weight were among the influential factors. It was suggested that these two traits should be underlined in selecting cultivars for cropping in regions with limited water. In a study on wheat, Sio-Se Mardeh et al. (2006) indicated that grain yield under non-stress conditions was inversely correlated with that under stress conditions. On that basis, it was concluded that high yield in desirable irrigation conditions did not necessarily result in improved yield under stress conditions. They also expressed that under stress conditions, the potential gene expression is decreased. Thus, the genetic progress rate becomes higher in the non-stress than the stress condition. Therefore, that selection based on genotype yields in the stress condition is only suitable for that, but selection based on genotype yields in the non-stressed condition may be adopted to either condition. This study aims to investigate the relationships between different traits in non-stressed and drought-stressed conditions and to identify the effective factors in the genetic improvement of yield.

MATERIALS AND METHODS

This research was conducted between 2012 and 2013 at the Research Station of Agricultural Faculty of Islamic Azad University of Tabriz, Iran (longitude 46°17′ east, latitude 38°5′ north, and altitude 1364 m above sea level). In this study, 30 wheat genotypes were tested. The cultivars were provided by the Corn Research Department, Centre for Agricultural and Natural Resources, East Azerbaijan Province (Table 1).

The experiment was conducted in a randomised complete block with six replications, three for non-stressed and three for drought-stressed conditions, separately and simultaneously. Surface irrigation was performed. That is, the usual irrigation treatment was performed until the late-season growing based on the water needs of plants. Irrigational stress treatment was performed until the early heading stage as necessary. Then, stress irrigation was performed in three stages. The first irrigation of the stress treatment was performed after the stem elongation stage and the plants were under stress in the heading stage. Twenty days after the first irrigation, the second irrigation of the stress treatment was conducted while the third irrigation was performed 34 days after the second

Table 1
Wheat genotypes used in this study

Number	Pedigree	Origin
1	Seri/Avd/3/Rsh/Afn/4/jup/Bjy/Kauz	Iran
2	Yan 7578. 128//Chill/2*Star	Iran
3	Shi# 4414/Crow"s"//Kvz	Iran
4	Merual/4/Bloudan/3/Bb/7c*2/Y50E/Kal*3/5/shiroodi	Iran
5	Bloudan/3/Bb/7C*2//Y50e/3*Kal/4/MV 17	Iran
6	Gaspard/Attila	Iran
7	Tbs/Flt/3/Evwy2/Azd/Rsh*2/10120/4/M-75-7	Iran
8	1-66-22/5/1-66-31/4/Anza/3/Pi/Nar/Hyz/6/M-75-7	Iran
9	Alvand//Aldan/las58	Iran
10	Attila (CM85836-50Y-0M-0Y-3M-0Y)	Iran
11	Sha/Chil	Iran
12	Hereward/Siren/5/Gov/Az/Mus/3/DoDo/4/Bow	Iran
13	Owl*2/Shiroodi	Iran
14	Alondra"s"	Iran
15	Bilinmiyan96.40	Iran
16	Fr3*/MM/Mt-Y50//Rsh	Iran
17	200H/Vfn//Rsh	Iran
18	Kal/Bb//Cj"s"/3/Hork"s"/4/Gascogne	Iran
19	Bhr*5/Aga//Sni/3/Trk13/4/Drc	Iran
20	Gascogne/3/Nai60/Hn7//sy	Iran
21	Emu"s"/Tjb84-1543//1-27-7876/Cndr/3/ Azd//Tob/Chb	Iran
22	Dove"s"/Buc"s"//2*Darab	Iran
23	Maya"s"/Nac	Iran
24	Ghk"s"/Bow"s"//90Zhong87/3/Shiroodi	Iran
25	Choti/Lerma	Iran
26	Alvd/Aldan”s”/las58/4/Kal/Bb/Cj”s”/3/Hork”s”	Iran
27	Mv22-77Stepphon/3/mon"s"/Imu"s"//Falka/4/Zarrin	Iran
28	Appolo/4/Seri/Avd/3/Rsh//Ska/Afn/5/Pyn/Bau	Iran
29	4820/1-32-15409//Mexp	Iran
30	Omid/H7/4/839/3/Omid/Tdo/5/Kal/Bb/Cj”s”/Hork”s”	Iran

irrigation. Starting from mid-April 2013, drought stress was applied to encourage natal growth. The land preparation operation included single ploughing with mouldboard ploughshare and a single use of a disk and a trowel. Seeds of each genotype were sown in two-metre lines with 20 cm line distances. Planting and weeding were done mechanically. Since the studied genotypes were taken from wheat planted during winter, mid-October was considered as the planting date. Information related to temperature and rainfall was obtained from the Iran Meteorology Organization, Tabriz (Table 2).

Table 2
Meteorological statistics during 2010-2013 in Tabriz, Iran

	Total monthly rainfall				Mean monthly temperature			
	2010	2011	2012	2013	2010	2011	2012	2013
Jan	11.9	8.5	25.1	36.7	3.7	-1.2	-0.5	0.4
Feb	35.1	19.3	6.4	43.8	4.5	1.1	-0.3	3.8
Mar	20.4	41.9	20	9.6	8.8	5.9	2.8	8
Arp	51.2	83.2	35.6	47.3	12.2	12.3	13.6	13.3
May	38.5	50.3	22.2	39.5	17	17.2	19.1	16.6
Jun	6.9	0.7	15.8	7.8	25.3	23.8	23.8	23
Jul	0.4	11.4	14.9	4.5	28.1	28	25.8	26.4
Aug	10	4.5	0	0	26.7	25.6	28.3	25.3
Sep	2.4	16.1	5.1	0.4	23.8	21.3	21.7	21.8
Oct	6.9	15	9.2	7.6	16.6	13.2	16	13.2
Nov	0	23.8	20.2	47.4	8.2	1.8	8.8	8.3
Dec	0.3	7.6	42.8	18	3.7	-1.3	2	-5.8

In each row, 10 plants were randomly labelled and each studied for the number of grains per spike, straw yield, grain-filling duration, harvest index, 1000-grain weight, peduncle length, and days to physiological maturity, biological yield, and the number of fertile spikelets per spike, spike length, plant height, and grain yield were noted. In order to understand the relationship between the traits better, the correlation coefficients between all traits were measured and their significance at 5 and 1 percent probability levels was studied in each test. Factor analysis was done based on the analysis method for main components and varimax rotation on the data in either condition. The analysis method for the main components was used to extract load factor matrices, as well as estimate the number of factors. On that basis, the factors with characteristic root>1 were selected, and factor coefficients were employed for matrix formation. In this study, the cluster analysis with the Ward method was also used to classify genotypes. Data was subjected to statistical analysis using SAS and SPSS software. Analysis of variance and correlation coefficient were performed using SAS software and factor analysis and cluster analysis using SPSS software.

RESULTS AND DISCUSSION

Based on the results shown in Table 3, there was a significant difference between two non-stressed and drought stressed experimental conditions in terms of all the measured traits at 1% probability level, indicating the changed value of the studied traits and the effect they have received from the environmental test results.

Table 3
Analysis of variance of measured traits

S.O.V	df	GS	SY	GFD	HI	TKW	PL	PM	BY	FSS	SL	PH	GY
Stress	1	33121**	437**	14622**	1510**	13364**	396.06**	359**	1600**	67**	85**	54**	11939**
Error1	4	1.69	2.5	1.1	0.06	0.82	0.048	0.032	2.72	0.063	1.05	0.38	9.87
Genotype	29	60.9**	105.2**	130.6**	20.6**	33**	10.672**	2.86**	180.1**	5.42**	9.881**	8.1**	56.8**
Genotype × Stress	29	50.7**	4.035**	50.7**	12.2**	21**	5.788**	2.74**	23.58**	0.47**	7.14**	0.91 **	19.8**
Error2	116	0.585	0.965	0.924	0.039	0.696	0.027	0.011	2.720	0.053	0.923	0.172	0.435
CV (%)		2.38	2.69	3.25	1.75	2.69	2.18	2.86	4.58	2.80	8.22	2.84	0.25

GS: Grain per spike, SY: Straw yield, GFD: Grain filling duration, HI: Harvest index, TKW:1000 grain weight, PL: Peduncle length, PM: Physiological maturity, BY: Biological yield, FSS: Fertile spikelets per spike, SL: Spike length, PH: Plant height, GY: Grain yield. * and **significant at 5% &1% respectively

Table 4
Correlation coefficients between different agronomic characteristics of wheat genotypes drought under stressed condition

	GS	SY	GFD	HI	TKW	PL	PM	BY	FSS	SL	PH
SY	0.29										
GFD	0.16	-0.09									
HI	-0.3	0.58*	0.24								
TKW	-0.55*	-0.11	0.31	0.3							
PL	0.08	0.61*	-0.17	-0.67**	0.19						
PM	0.016	-0.1	0.67**	-0.08	-0.14	-0.02					
BY	0.21	0.96**	-0.01	-0.16	-0.01	0.49*	-0.14				
FSS	0.83**	0.04	-0.26	-0.49*	0.56*	0.1	0.17	-0.01			
SL	0.80**	0.29	0.02	-0.51*	-0.12	0.18	0.14	0.2	0.74**		
PH	0.51*	0.69**	-0.17	-0.80**	-0.49*	0.85**	0.11	0.54*	0.53*	0.60*	
GY	-0.21	0.69**	0.16	0.62**	0.19	-0.07	0.18	0.65**	-0.25	0.03	-0.05

GS: Grain per spike, SY: Straw yield, GFD: Grain filling duration, HI: Harvest index, TKW: 1000 grain weight, PL: Peduncle length, PM: Physiological maturity, BY: Biological yield, FSS: Fertile spikelets per spike, SL: Spike length, PH: Plant height, GY: Grain yield. *and **: Significant at 5% and 1% probability levels respectively.

There was a positive and significant correlation between the number of fertile spikelets per spike and grains per spike (Table 4).

The correlation between the number of fertile spikelets per spike and 1000-grain weight was positive and significant. There is a positive and significant correlation between plant height and biological yield. In this study, it was observed that, there was a positive and significant correlation between grain yield and the harvest index. Ali et al. (2008) reported similar results for the correlation between the number of fertile spikelets per spike and grains per spike. The flowering stage is one of the most drought-stress-sensitive stages of wheat life. At this time, water deficit causes a lack of insemination and infertility of flower spikes. Also, some of the vaccinated ovules are stillborn as a result of drought stress, and consequently, the number of grains per spike decreases. In the pollination stage, stress causes infertile pollen grains, disrupted current photosynthesis, and transmission of stored materials to grains, which is a reason for a reduced number of grains per spike (Wang et al., 2001). While studying 25 local wheat varieties, Nawaz et al. (2013) observed a positive correlation between the number of fertile spikelets per spike and 1000-grain weight. Marc et al. (1985) reported that drought stress after the flowering stage reduces the number of grain endosperm cells in the base, and finally reduced grain weight. Drought stress after flowering reduces grain weight, which shortens the duration of grain filling. In order to deal with drought stress and to prevent excessive wastage of water, the plant closes the stomata to reduce photosynthesis and assimilates for grain-filling. This, in turn, reduces the mean weight per grain. Mursalova et al. (2015) indicated a positive significant correlation between plant height and biological yield. In cultivars with greater plant height, the amount of production, especially in the later growing stages, depended on the transmission power of assimilates. Genotypes with greater plant height show increased biological yield (Nasri et al., 2014). Bisht et al. (2017) reported a non-correlation between grain yield and harvest index. Increasing the harvest index in case of sufficient photosynthetic organs led to increased grain yield, because at the end of the plant growth period, a large amount of photosynthetic material produced during the growth period entered the seeds. Duggan and Fowler (2006) observed in a study that in a drought-stress condition, two factors—the number of grains per spike and grain weight—played a significant role in the formation of grain yield. But in a favourable moisture condition, grain weight did not significantly influence grain yield. When 50% of the spikelets in a spike were removed artificially, the grain weight increased under humid stress, finally resulting in increased grain yield. But under non-stress conditions, these were not observed. That is, in stress and complete irrigation conditions, there were source and sink limitations respectively.

In factor analysis, considering that Eigen values were higher than 1, and factor coefficients were higher than 67%, four factors were identified for non-stressed and drought-stressed conditions (Table 5).

Table 5
Factor analysis for different agronomic characteristics of wheat genotypes in non-stressed and drought stressed conditions

	Non-stress				Drought stress			
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 1	Factor 2	Factor 3	Factor 4
Grain per spike	0.20	0.87	0.13	0.10	0.91	0.07	0.16	-0.01
Straw yield	0.92	0.06	-0.28	0.22	0.17	0.38	0.83	-0.07
Grain filling duration	0.04	-0.01	0.97	-0.13	-0.24	-0.19	0.11	0.89
Harvest index	-0.18	0.40	0.86	0.01	-0.30	-0.34	0.12	0.04
1000 grain weight	-0.17	-0.33	0.77	0.14	-0.31	-0.30	0.15	0.21
Peduncle length	0.15	0.18	0.03	0.94	-0.01	0.85	0.19	-0.08
Physiological maturity	0.35	0.24	0.40	-0.02	0.24	0.10	-0.23	0.83
Biological yield	0.93	0.21	-0.01	0.26	0.08	0.27	0.94	-0.06
Fertile spikelets per spike	0.20	0.86	-0.2	0.08	0.88	0.13	0.15	-0.05
Spike length	0.07	0.72	0.22	0.31	0.74	0.21	0.19	0.25
Plant height	0.35	0.16	-0.10	0.87	0.34	0.82	0.20	0.04
Grain yield	0.88	0.31	0.43	0.24	-0.15	-0.30	0.91	0.01
Eigen value	2.70	2.60	2.50	1.90	2.80	2.70	2.70	1.60
Variance	22.11	21.65	21	16.24	23.31	22.47	22.20	13.39
Component variance	22.11	43.76	64.76	81	23.31	45.78	67.97	81.36

Felenji et al. (2011) identified three factors through factorial analysis based on the main components, which explained that 80.01% of the total data variants of the whole, at the first factor (yield), had contributed most to this explanation (33.3%). In non-stressed conditions, four factors explained 81% of the total data variants. The first factor, showing the greatest contribution (22.1%) of data variants, has significant positive coefficients for biological yield, straw yield, and grain yield. With respect to the existing traits in this group, this factor can be called the yield factor. Since this factor involves yield, it can be considered as the most important and valuable factor. The second factor explains 21.7% of data variants, which have higher coefficients for factors such as spike length, the number of fertile spikelets per spike, and the number of grains per spike, which can be called the grain yield component factor. The third factor, with an explanation for 21% of the total variance, has a positive significant factor coefficient for traits, such as grain-filling duration, 1000-grain weight, and harvest index. It was named as a factor affecting grain weight and harvest index. In the fourth factor which involves 16.2% of the variants, the coefficients for plant height and peduncle length is high. Thus, it can be called an effective factor for height. The choice of every factor would lead to the selection of studied lines and cultivars on the basis of critical sub-traits in every trait. Under limited irrigation conditions, four main factors extracted from factor analysis explained 81.4% of all variants (Table 4). In the drought-stress experiment, the first factor that involves the biggest part (23.3%) of data variants has positive and greater coefficients for the following traits: spike length, the number of fertile spikelets per spike, and the number of grains per spike. Therefore, this factor can be represented as the components of grain yield. The second factor, involving 22.5% of variations, had great coefficients for traits, such as plant height and peduncle length. So, it can be called the influential factor for height. Thus, selecting and breeding based on these factors increase plant height, and as a result, leads to resistance to drought and earliness. By explaining 22.2% of the total variance, the third factor was affected by positive biological yield, straw yield, and grain yield, and it was introduced as an effective factor on yield. Traits such as the days to physiological maturity and grain-filling duration also had positive and significant load factors in the fourth factor, which explained 13.4% of the total variations. The fourth factor was related to plant phenology. Hence, these factors can be a good means of classification between lines and cultivars. With respect to the results from factor analysis under both non-stressed and stressed conditions, it can be seen the arrangement manner of traits in any factor is highly similar to each other. For example, in either conditions, traits such as plant height, peduncle height, biological yield, straw yield, and grain yield were located in the same factor, implying a significant correlation between these traits. This was also true for most traits within the same factor.

The results obtained from cluster analysis were used as a criterion for similarity through the Ward method using the Euclidean distance. They were divided into three groups in non-stressed drought experiments of genotypes (Figure 1).

As shown, peduncle length and plant height in the first group were greater than other groups (Table 6).

Slafer and Savin (1994) reported the influential role of peduncle length in improving yield, as cultivars with a taller peduncle length had greater stored and grain-transferable carbohydrates than those with a shorter length. The genotypes of this group had a good yield due to the maximal value for traits, such as straw, biological, and grain yields. The second group showed the earliest maturing genotypes due to the least number of days for physiological maturity, which was very important in breeding investigations. The results of cluster analysis in drought-stressed experiments divided the genotypes into four groups (Figure 2).

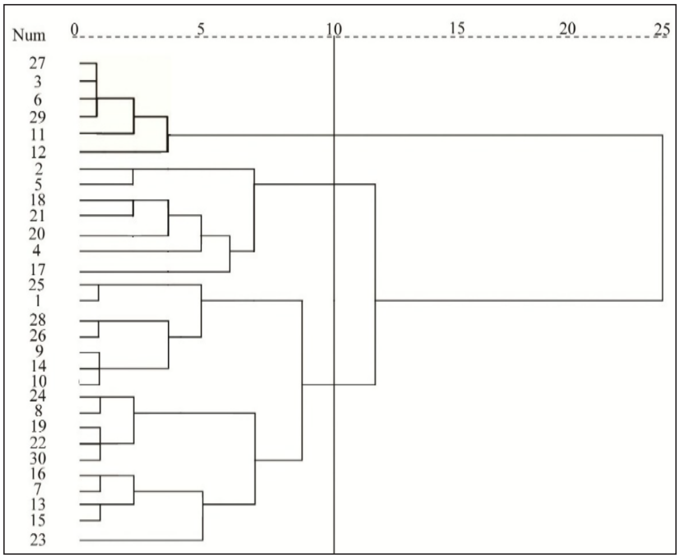

Figure 1. Grouping wheat genotypes based on all characteristics obtained from cluster analysis in non-stressed condition

Table 6
Comparison of groups between cluster analysis of wheat genotypes in non-stressed condition

	Cluster 1	Cluster 2	Cluster 3	Total average
Grain per spike	50.47	38.97	38.79	42.74
Straw yield	12.33	11.31	9.17	10.94
Grain filling duration	44.23	38.3	42.75	41.76
Harvest index	42.84	33.72	39.26	38.61
1000 grain weight	40.95	35.58	43.47	36.99
Peduncle length	44.25	41.79	38.95	41.66
Physiological maturity	275.71	268.81	272.79	272.44
Biological yield	18.23	15.95	13.9	16.03
Fertile spikelets per spike	17.37	16.99	15.7	16.69
Spike length	12.02	9.97	9.66	10.55
Plant height	110.03	106.27	96.68	104.33
Grain yield	8.02	5.72	5.82	6.52

Considering the genotypes in the first group, the values of these cultivars are the highest in terms of traits, such as peduncle length and plant height (Table 7).

In this group, straw yield, biological yield, and grain yield have the maximum values. This group is superior to other groups in terms of yield. On the other hand, the first group showed the lowest value among all groups in terms of the number of days to physiological maturity. Hence, the genotypes in this group are among the earliest maturing ones. Therefore, this group is introduced as the best of all groups

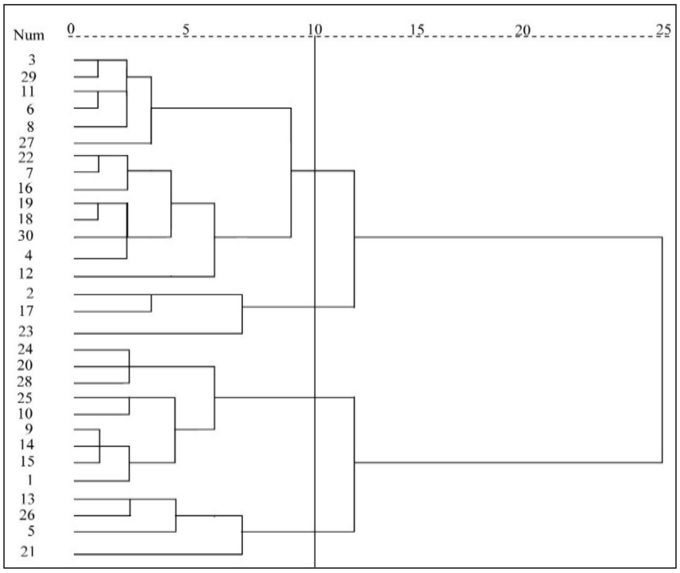

Figure 2. Grouping wheat genotypes based on characteristics obtained from cluster analysis in a drought-stressed condition

Table 7
Comparison of groups between cluster analysis of wheat genotypes in drought stressed condition

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total average
Grain per spike	37.81	34.21	31.61	34.93	34.64
Straw yield	8.59	7.62	6.68	5.16	7.01
Grain filling duration	23.28	25.73	27.29	23.65	24.99
Harvest index	28.26	27.01	33.26	31.8	30.08
1000 grain weight	21.56	20.22	26.51	22.96	22.81
Peduncle length	42.71	39.25	35.24	32.92	37.53
Physiological maturity	248.55	259.54	256.8	257.52	255.6
Biological yield	10.28	9.81	9.19	6.85	9.03
Fertile spikelets per spike	15.69	15.63	14.02	16.11	15.36
Spike length	9.23	8.81	8.47	8.7	8.8
Plant height	104.34	94.05	85.24	84.97	92.15
Grain yield	4.49	3.28	3.61	2.79	3.54

because of the genotypes' greater peduncle length, plant height, and higher yield as well as their earliness, and not facing late-season drought stress, which Mitra (2001) termed 'drought escape'. Since early-maturity cultivars enter the generative stage in more favourable conditions, they could avoid warming and late-season moisture tensions, and thus, had more yield resistance, while late-maturing cultivars suffered severe damages during water shortage due to late-season warming with much more need for water consumption.

CONCLUSION

The results of analysis of variance for the evaluated genotypes was highly varied in terms of their significance. The analysis of correlation coefficients proved that increased biological yield, straw yield, and harvest index culminated in genetic improvement of plant grain. Regarding factor analysis under two irrigation regimes, it can be concluded four factors are responsible for most variations in this study. In cluster analysis through the Ward method, genotypes were divided into four and three groups in and drought-stress and non-stress conditions, respectively. In non-stress conditions, the current superior traits could be used in group 1 and 2, and the first group can be introduced as the superior group in stress conditions because of its high yield and grain earliness.

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