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RESEARCH PAPER

Exploiting the morphological and phenological diversity in barley landraces of Iran

Shakiba Shahmoradi*

Department Seed and Plant Improvement Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran

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Abstract
Barley is one of the most widely cultivated crops in marginal lands, which is often exposed to abiotic stresses. It seems that genetic diversity is the key factor for adaptation to diverse environments. In this research, a diversity of 500 landraces of *Hordeum vulgare* in barley germplasm collection of National Plant Gene Bank of Iran (NPGBI) was collected from various climatic zones and evaluated for morphological and phenological traits. The experiment was held in the research field of Seed and Plant Improvement Institute, Karaj, Iran. The traits were measured based on the guidelines of Bioversity International. One-way analysis of variance indicated a significant difference between winter, facultative, and spring growth types concerning the traits. Based on the mean comparison, winter-type landraces had a longer growth phase (higher values in days to spike emergence and flowering). Winter and facultative landraces had more values in plant height (88.92 and 86.76 cm respectively) and grain yield was higher in winter barley landraces. The results of the multivariate analysis indicated that two-row landraces had higher kernel weight and spike length compared to six-row landraces, which seems to be a moderator of adverse environmental factors on yield production. The grain yield in two-row and six-row barley was not significantly different. The obtained results in this study revealed that two-row barley landraces were generally spring-type while six-row landraces were typically winter-type. Xerothermic coefficient of two-row barley landraces was significantly lower than that of six-row types; therefore, it could be assumed that six-row landraces were mostly originated from hot and dry areas.

Key words: *Hordeum vulgare*, Morphological traits, Phenological traits, Climate

Introduction

Barley is one of the most widely cultivated crops in marginal environments, which is often exposed and well adapted to abiotic stresses (Baum et al., 2007). Genetic diversity is the key factor for adaptation to diverse environments. Cultivated barley (*Hordeum vulgare*) is classified based on ear structure to two-row and six-row types. In six-row barley, the three spikelets at each node on the rachis are fertile whereas, in two-row barley, only the central spikelets are fertile. Researchers have suggested that six-row barley has the potential to outyield two-row barley, particularly under high-input conditions; meanwhile, the two-row type usually has higher tillering capacity and 1000 grain weight (Le Gouis, 1992; Maidl et al., 1996; Le Gouis et al., 1999). There is increasing interest in winter barley and the cultivation of six-row types between farmers. A study of yield components of two-row and six-row barley under terminal drought stress in different years has indicated that drought tolerance is higher in two-row barley while six-row genotypes exhibited higher stability in different years (Dodig, et al., 2018).

Based on the response to day length and temperature, barley varieties can be divided into winter, facultative, and spring growth types. Winter barley has prostrate growth habit and

* Corresponding author e-mail: shahmoradi@spii.ir

narrow leaves and because of vernalization requirement, it will not start shooting in spring cultivation. Researches have indicated that wild relatives of barley, especially *Hordeum spontaneum*, have a winter growth type and it has been assumed that the early varieties of cultivated barley have winter growth type (Takahashi et al., 1963; Saisho et al., 2011).

Breeding crops for early maturity along with yield stability are the main goals for breeders. Early maturity seems to be a key factor for drought stress adaptation (Escape mechanism). Vernalization requirement, photoperiod, and termoperiod responses are the main factors determining early maturity (Stefani 1993). Shahmoradi and Mozafari (2017) evaluated the growth type and drought stress adaptation in *H. spontaneum* L. ecotypes of Iran and reported a significant correlation between stress tolerance index and growth type. They concluded that ecotypes with lower vernalization requirements have better adaptability to drought stress conditions.

High genetic diversity has been reported in barley (*Hordeum vulgare* L.) landraces of National plant Gene Bank of Iran (Shahmoradi et al., 2011), which, in certain circumstances, was related to eco-geographic distributions of accessions origin (Shahmoradi et al., 2013; Shahmoradi and Mozafari, 2015; Shahmoradi and Zahravi 2016). Landraces are characterized by high yield stability although they often exhibit intermediate yield levels under low input agriculture (Pswarayi et al., 2008). Spike architecture and growth type seem to be the basic footprints of barley domestication; thus, they would be related to adaptation to different environments. This research was conducted in order to investigate the relationship between the morphological and phenological traits, in addition to the climatic conditions of collecting sites in barley landraces of Iran.

Materials and Methods

Assessment of qualitative and quantitative traits

In the 2014-15 cropping season, 500 landraces of *Hordeum vulgare* were collected from various regions of Iran, including desert to cool steppe regions (Table 1). They were evaluated in the research field of the National Plant Gene Bank of Iran-Seed and Plant Improvement Institute, in Karaj. Karaj is a city located at 50°59′E and 35°52′N. The vast plain of Karaj is an average of 1320 meters above the sea level and Alborz heights are the most important factors in shaping the climate of Karaj province (Figure 1). The rainfall in this region begins from November and December and lasts until mid-May. The experiment included an augmented design with 500 barley landraces and three commercial cultivars (Nosrat, Afzal and Yousef) as the control, cultivated in 1-meter-long plots and 50 plots in each block. There was a control cultivar after every 10 landraces to determine non-uniformity in the blocks. Table 1 depicts the geographic and climatic information of the collecting sites of the landraces. The genotypes were grouped according to the xerothermic coefficient (the number of dry days per year) of the collection sites (Sabeti, 1969).

Quantitative traits were also recorded, including days to spike emergence, days to flowering, plant height, grain yield, and the number of spikelets per spike, spike length, spike row number, and 1000 kernel weight. Qualitative traits, namely stem pigmentation, awn pigmentation, growth habit, glume color, lemma color, and auricle pigmentation, were measured based on the guidelines of Bioversity International (IPGRI) Institute (Table2). In order to have a perspective of the overall genetic diversity in the evaluated landraces, descriptive statistics were estimated and diversity indices were determined based on the coefficient of variation and Shannon index (Shannon and Weaver, 1949) in quantitative and qualitative traits, respectively.

Table 1. Climate of the collection sites for 500 barley landraces based on Gousan climatic zones (Sabeti, 1969)

	Climate	Province	Latitude	Longitude	landraces
1	Desert				59
	300<X*<350	Kerman**	31° 3′ N	57° 26′ E	3
		Sistan Baluchestan**	28° 43′ N	60° 51′ E	7
		Yazd	31° 53′ N	54° 21′ E	49
2	Severe Semi Desert				14
	250<X<300	Sistan Baluchestan	25° 26′ N	61° 10′ E	5
		Hormozgan	27° 11′ N	56° 16′ E	9
3	Mild Semi Desert				99
	200<X<250	Kerman	29° 14′ N	56° 36′ E	12
		Boshehr	28° 55′ N	50° 49′ E	67
		Esfahan	32° 39′ N	51° 40′ E	8
		Khorasan Shomali	37° 27′ N	57° 19′ E	6
		Khozestan	31° 31′ N	49° 52′ E	3
		Semnan	35° 34′ N	53° 23′ E	3
4	Hot Dry Mediterranean				160
	150<X<200	Khorasan Razavi	36° 18′ N	59° 36′ E	26
		Markazi	34° 4′ N	49° 40′ E	50
		Kermanshah	34° 20′ N	46° 25′ E	23
		Fars	29° 38′ N	52° 30′ E	2
		Ghazvin	36° 16′ N	50° 0′ E	7
		Ilam	33° 38′ N	46° 25′ E	13
		Lorestan**	33° 9' N	47° 43' E	37
		Tehran	35° 41′ N	51° 20′ E	2
5	Hot Mediterranean				13
	100<X<150	Lorestan	35° 53′ N	52° 11′ E	4
		Mazandaran**	36° 33′ N	53° 3′ E	9
6	Semi Mediterranean				9
	0<X<40	Mazandaran	36° 37′ N	52° 48′ E	8
		Gilan	37° 13′ N	49° 38′ E	1
7	Cool Xeric				29
	X=0	Kohkiloyeh Boyerahmad	30° 39′ N	51° 36′ E	29
8	Cool Steppe				111
	5 to 9 months Freezing	Azarbaijan Garbi	38° 3′ N	46° 17′ E	11
		Azarbaijan Sharghi	37° 31′ N	45° 2′ E	35
		Chaharmohale Bakhtiari	32° 21′ N	50° 49′ E	4
		Hamedan	34° 48′ N	48° 30′ E	5
		Kordestan	35° 18′ N	47° 0′ E	23
		Zanjan	36° 40′ N	48° 29′ E	33
-	Unknown				6
					500

*Xerothermic coefficient

** These provinces include two different climates (based on geographic informations)

Assessment of growth type

In order to determine the growth type in barley landraces of Iran and investigate its relationship with the agro-morphological and phenological traits, the landraces were cultivated in late-May 2015 after the end of winter cold (Figure 1). The experimental design was completely similar to the first experiment (an augmented design with 500 barley landraces and three commercial cultivars (Nosrat, Afzal and Yousef) as the control). The vernalization requirement and growth type were determined based on the heading percentage in each landrace (Mohammadi et al., 2013). The landraces were scored as winter type when less than 40% of tillers started heading (flowering) in spring cultivation, as facultative type when 50±10% of the tillers started heading, and spring type when more than 60% tillers flowered by the end of summer.

Descriptive statistics and correlation coefficients (Spearman method) for qualitative and quantitative traits was performed through SPSS 16.0 software. Analysis of variance based on one-way ANOVA was performed to compare the quantitative traits of landraces via Kruskal Wallis method (Steel and Torrie, 1980). In order to more accurately assess the data, principal component analysis was performed using Stat Graphics plus2.1 software.

Table 2. Bioversity International descriptor for qualitative traits in barley

Traits	Descriptions			
Growth Type (GRT)	3. Spring type	5. Facultative	7. Winter type	
Growth Habit (GRH)	3. Erect	5. Intermediate	7. Prostrate	
Row Number (RN)	2. Two row	6. Six row		
Stem Pigmentation (STP)	1. Green	2. Purple (basal only)	3. Purple (half or more)	
Auricle Pigmentation (AUP)	1. Green	2. Pale Purple	3. Purple	4. Dark Purple
Glume Color (GLC)	1. White	2. Yellow	3. Brown	4. Black
Awn Color (AWC)	1. Amber white 5. Black	2. Yellow 6. Other	3. Brown	4. Reddish
Lemma Color (LEC)	1. Amber (=normal) 5. Other	2. Tan/red	3. Purple	4. Black/grey
Grain (Pericap) Color (GRC)	1. White 5. Other	2. Tan/red	3. Purple	4. Black

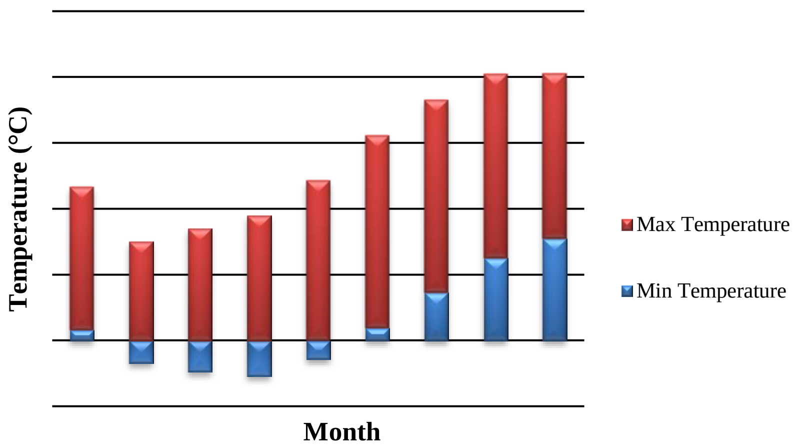

Figure 1. Rate of the temperature changes in 2014-2015 at the experimental field in SPII-Karaj

Results

Based on descriptive statistics in quantitative traits (Table 3a), with respect to the coefficient of variation parameter, the highest variation belonged to grain yield (53.28%), followed by spike length and number of spikelet groups (respectively 21.26 and 20.47%). Therefore, the landraces exhibited a high diversity in yield and yield components. The lowest and highest level of grain yield in barley landraces was 25 and 513 (g Plot^{-1}), respectively, which indicated a high variation. Spike length also exhibited a wide range from 2.5 to 10.9 cm. The number of spikelet groups ranged from 6 to 30 spikelets. Phenological traits, including days to spike emergence and days to flowering, had a relatively low coefficient of variation.

In qualitative traits (Table 3b), based on Shannon index, the highest genetic diversity was observed in row number in spike (0.96) and the most frequent landraces were six-row. Afterwards, the range of growth type and growth habit showed a high diversity based on Shannon index (0.89 and 0.83 respectively); this indicated different growth behaviors in these landraces, which was predictable due to the climatic diversity of the collection sites (Table1).

Table 3. Descriptive statistics parameters for quantitative (a) and qualitative (b) traits in 500 landraces of barley

(a) Traits	Range	Minimum	Maximum	Mean	Coefficient of Variance (%)
Days to Spike Emergence	30	155	185	162.49	4.69
Days to Flowering	21	168	189	173.35	3.94
Plant Height (cm)	70	55	125	87.46	14.34
Spike Length (cm)	8.4	2.5	10.9	5.782	20.47
Number of Spikelet Groups	24	6	30	16.32	21.62
Kernel Weight (g)	31. 7	28. 4	60.1	45.3	12.51
Grain Yield (g $Plot^{-1}$)	488	25	513	161.81	53.28
(b) Traits	Range	Minimum	Maximum	Mode	Shannon Index
Growth Type	4	3	7	3	0.89
Growth Habit	4	3	7	3	0.83
Spike Row Number	4	2	6	6	0.96
Stem Pigmentation	3	1	4	1	0.17
Auricle Pigmentation	3	1	4	1	0.23
Glume Color	2	2	4	2	0.18
Awn Color	2	2	4	2	0.19
Lemma Color	2	2	4	2	0.21
Grain Color	3	1	4	2	0.50

Correlation analysis for qualitative and quantitative traits focusing on spike row number, growth type, and climatic conditions of collecting sites (Table 4) indicated the highest correlation coefficients with a negative sign between kernel weight and spike row number (r=-0.54) and spike length and spike row number (r=-0.53). This suggested that further rows per spike were associated with a reduction in 1000-kernel weight and spike length. Thus, two-row landraces had higher kernel weight and spike length compared with six-row landraces. Correlation coefficients for growth type (Table 4) indicated a significant negative correlation between growth type and phenological traits in barley landraces. Since the winter growth type code, based on descriptor (IPGRI, 1994), was lower (3) and higher values were related to facultative and spring types (5 and 7, respectively), it could be concluded that winter type landraces had longer phenological periods. The spikes row number in barley landraces showed a significant negative correlation with growth type; accordingly, the landraces with two-row spikes were generally spring type and most of the six-row landraces were winter type. Xerothermic coefficient of the collecting site was also negatively correlated with phenological traits (days to spike emergence and days to flowering).

Table 4. Spearman Correlation Coefficients between the qualitative and quantitative traits and spike row number, growth type, and xerothermic coefficient of origin in 500 landraces of barley

Traits	Spike row Number	Growth Type	Xerothermic Coefficient
Days to Spike emergence	0.31**	-0.44**	-0.33**
Days to Flowering	0.28**	-0.41**	-0.33**
Plant Height	0.19**	-0.23**	-0.06
Spike Length	-0.45**	0.02	-0.25**
Number of Spikelet Groups	-0.53**	0.04	-0.15**
Kernel Weight	-0.54**	-0.04	-0.20**
Grain Yield	0.06	-0.19**	-0.09*
Growth Habit	0.29**	-0.23**	-0.14**
Auricle Pigmentation	-0.13**	-0.14**	-0.13**
Stem Pigmentation	-0.17**	-0.14*	-0.08
Awn Color	-0.14**	-0.10	-0.06
Lemma Color	-0.14**	-0.09	-0.02
Grain Color	-0.12**	0.02	0.13**
Glume Color	-0.16**	-0.09	-0.06
Spike Row Number	1	-0.22**	0.13**
Growth Type		1	0.23**

**and* significant at the 1% and 5% probability levels respectively.

The one-way analysis of variance for quantitative traits based on growth type of barley landraces confirmed a significant difference between winter, facultative, and spring growth types concerning certain traits (Table not shown). Based on the mean comparison, winter growth type landraces had a longer growth phase (higher values in days to spike emergence and flowering) while spring and facultative landraces were at the same level of significance for phenological traits (Table 5). There was also a significant difference between barley growth types in plant height. Winter and facultative landraces had more values in plant height (88.92 and 86.76 cm, respectively) in comparison with spring landraces (79.55cm). Grain yield was higher in winter barley landraces (175g). Xerothermic coefficient of winter barley landraces was significantly lower than facultative and spring types; therefore, according to Table1, spring landraces were mostly originated from dry climates.

The mean comparison according to one-way analysis of variance based on spike row number in barley landraces indicated that phenological traits were significantly higher in six-row landraces (Table 6) while two-row landraces had a shorter growth phase (lower values in days to spike emergence and flowering). Six-row landraces had significantly higher plant height. Meanwhile, spike length and the number of spikelets per spike was significantly higher in two-row landraces (Table 6). Kernel weight was also higher in two-row barley (49.1 g) than that in six-row types (42.8 g). However, in the end, grain yield did not show any significant differences between the two landraces.

Xerothermic coefficient of origins for two-row barley landraces was significantly lower than that for six-row types (Table 6); hence, it could be assumed that six-row landraces were mostly from hot and dry areas.

Table 5. The mean comparison of the traits in winter, facultative, and spring type landraces of barley

Growth Type	N	Days to spike emergence	Days to flowering	Plant Height (cm)	Grain yield (g $Plot^{-1}$)	Xerothermic Coefficient
Winter	197	165.69 a	176.10 a	88.92 a	175.3 a	113.9 b
Facultative	88	159.03 b	170.24 b	86.76 a	146.7 b	161.2 a
Spring	40	157.10 b	169.38 b	79.55 b	133.5 b	192.1 a

Means followed by similar letters are not significantly different (based on One way ANOVA analysis)

Table 6. The mean comparison of the traits in two-row and six-row landraces of barley

Spike Row Number	N	Days to Spike Emergence	Days to Flowering	Plant Height (cm)	Spike Length	Number of Spikelet	Kernel Weight(g)	Grain Yield ($gPlot^{-1}$)	Xerothermic Coefficient
2 Row	211	159.46 b	170.96 b	84.42 b	6.44 a	18.65 a	49.1 a	154.6 a	121.01 b
6 Row	289	165.06 a	175.33 a	89.9 a	5.44 b	14.92 b	42.8 b	166.3 a	141.15 a

Means followed by similar letters are not significantly different (based on One way ANOVA analysis)

In principle component analysis of quantitative traits, considering Eigen values greater or equal to 1.0, three principle components were identified, which accounted for 66.41% of the variability (Table 7). The highest variation was explained by the first component (30.03% of total variance) in which the phenological traits, including days to spike emergence and days to flowering (with positive coefficient) followed by growth type (with negative coefficient), had the largest values. The second component explained 25.53% of variation due to variation in yield components, number of spikelet groups per spike, and spike length. The third component (10.84% of total variance) was explained by the diversity in grain yield.

Table 7. Eigen values, relative variance, and coefficients of principle components in the quantitative traits of barley landraces

Traits	1	2	3
Xerothermic Coefficient	-0.13	-0.37	-0.03
Days to Spike Emergence	0.48	0.25	0.15
Days to Flowering	0.47	0.24	0.19
100 Kernel Weight	-0.26	0.35	-0.32
Number of Spikelet Groups	-0.27	0.42	0.22
Plant Height	0.19	0.22	-0.08
Spike Row Number	0.43	-0.28	0.05
Spike Length	-0.20	0.44	0.34
Grain Yield	0.07	0.18	-0.76
Growth Type	-0.31	-0.23	0.24
Eigen Value	3.01	2.55	1.08
Variance Percentage of	30.03	25.53	10.84
Cumulative Percentage	30.03	55.57	66.41

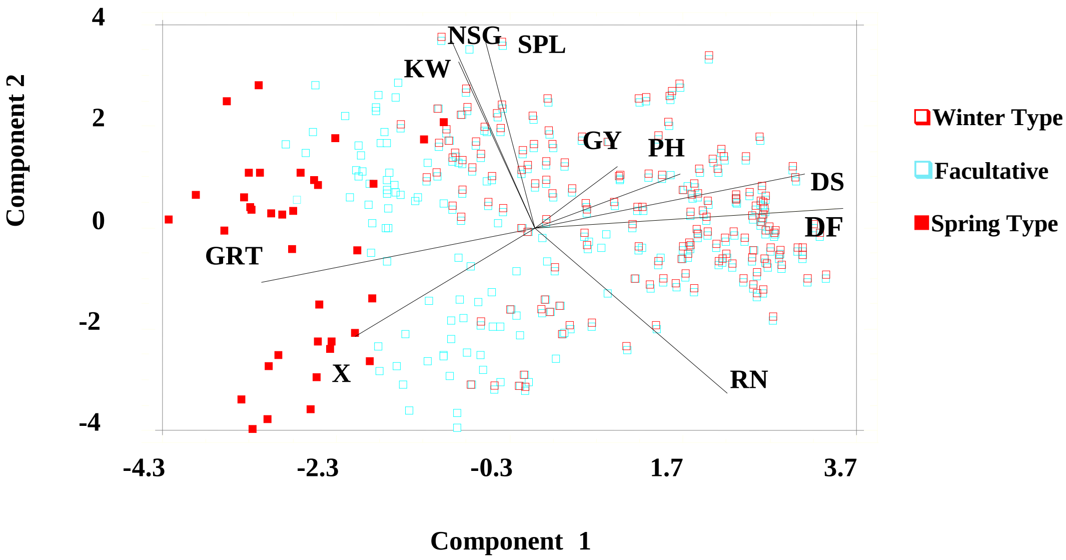

Figure 2. Bi-plot of the first two principal components for the quantitative traits in 500 *H. vulgare* landraces of Iran (DF: Days to Flowering; DS: Days to Spike Emergence; NSG: Number of Spikelet Groups; SPL: Spike Length; KW: 100 Kernel Weight; GY: Grain yield; X: Xerotermic Coefficient; GRT: Growth Type; PH: Plant Height)

The first and second components accounted for 55.57% of the total variability. The relation between the traits and growth type was displayed in principle components bi-plot (Figure 2). The first component successfully distinguished these growth types. Therefore, based on the first component, the landraces were divided into three main groups: group I (right side) was winter type, group II (central) was facultative, group III (left side landraces) was spring type. Phenological traits vectors were found to be in the opposite direction with growth type, which indicated the inverse relationship between them. Thus, it can be concluded that higher values in phenological traits (late maturity) is related to winter types. Xerothermic coefficient vector was located on the left side of plot, suggesting that the landraces from higher xerothermic coefficient were spring type. These results were in line with those found via One-Way ANOVA.

Principle component analysis based on the quantitative and qualitative traits of barley landraces identified five components, which accounted for 72.96% of the total variability (Table

8). The highest variation was explained by the first component (26.75% of total variance) in which glum color, awn color, lemma color, and stem pigmentation had the highest values. The second component explained 19.15% of variation on account of the variation in the phenological traits. In the third and forth components, spike length and plant height were the most effective traits (0.42 and 0.52, respectively) while in the fifth component, the grain yield had the largest value (0.74).

Table 8. Eigen values, relative variance, and coefficients of principle components in the quantitative and qualitative traits of the barley landraces

Traits	Components				
	1	**2**	**3**	**4**	**5**
Xerothermic Coefficient	-0.10	-0.14	-0.38	0.11	-0.01
Days to Spike Emergence	0.08	0.47	0.20	0.02	0.13
Days to Flowering	0.07	0.46	0.21	0.01	0.17
Glum Color	0.41	-0.004	-0.19	-0.05	-0.04
Grain Color	0.22	-0.04	-0.17	0.55	0.15
100 Kernel Weight	0.08	-0.23	0.39	0.01	-0.27
Lemma Color	0.39	-0.01	-0.22	-0.03	-0.05
Number of Spikelet Groups	0.24	-0.23	0.32	-0.02	0.24
Plant Height	0.11	0.16	0.14	0.62	-0.01
Spike Row Number	-0.14	0.40	-0.26	0.11	0.03
Spike Length	0.15	-0.17	0.42	0.02	0.38
Auricle Pigmentation	0.37	0.01	-0.06	-0.13	-0.05
Awn Color	0.40	0.01	-0.19	-0.02	-0.006
Stem Pigmentation	0.38	0.01	-0.07	-0.16	-0.06
Grain Yield	0.05	0.06	0.19	0.05	-0.74
Growth Habit	0.04	0.32	-0.009	-0.45	0.12
Growth Type	-0.11	-0.31	-0.18	-0.06	0.26
Eigen Value	4.54	3.25	2.24	1.26	1.10
Variance Percentage of	26.75	19.15	13.18	7.38	6.51
Cumulative Percentage	26.75	45.89	59.08	66.47	72.96

The relation between the quantitative and qualitative traits in the studied barley landraces is displayed based on the first and second components, which accounted for 45.89% of the total variability (Figure 3). The first component was the most effected one by the traits of glume color, lemma color, and stem color and the two-row landraces were located around the vectors of these traits; therefore, the two-row barley landraces had more pigments in glume, lemma, and stem. The second component successfully distinguished spike row number in the barley landraces; accordingly, the six-row barley landraces were mostly in the upper half of the chart and in the lower half, the two-row barley landraces were located. Assessing the placement of the vectors of spike length, the number of spikelet groups, and kernel weight (Figure 3), which were surrounded by two-row landraces, indicated that the two-row landraces had higher values in these traits in comparison with the six-row landraces. These results are in line with those obtained through One-Way ANOVA. The growth type vector was also located among the two-row barley landraces; as a result, it seems as though most of the two-row barley had spring growth type. These results were in line with the findings of correlation coefficients evaluation.

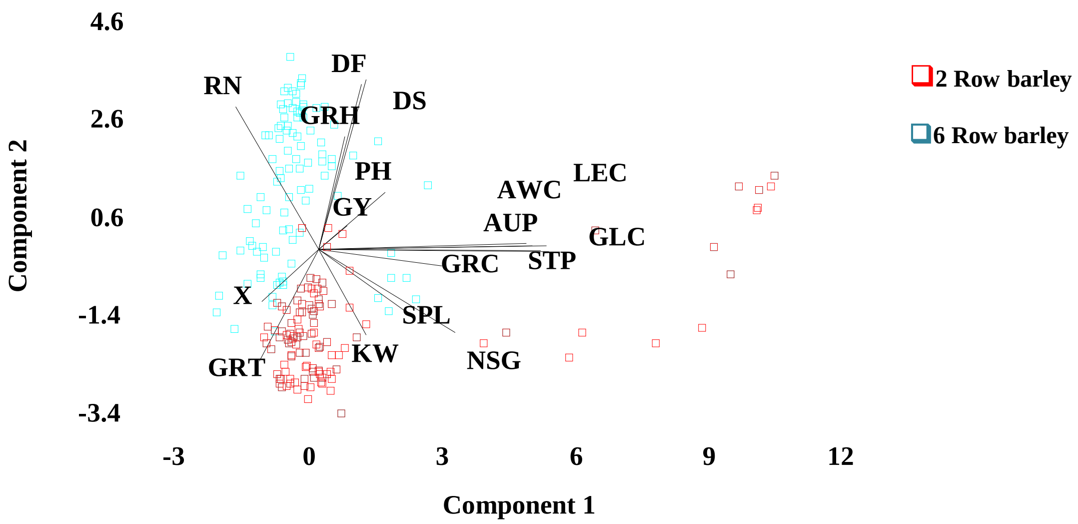

Figure 3. Bi-plot of the first two principal components for the qualitative and qualitative traits in 500 *H. vulgare* landraces of Iran (DF: Days to Flowering; DS: Days to Spike Emergence; RN: Spike Row Number; GRH: Growth Habit; AWC: Awn Color; LEC: Lemma Color; AUP: Auricle Pigmentation; GLC: Glum Color; STP: Stem Pigmentation; GRC: Grain Color; NSG: Number of Spikelet Groups; SPL: Spike Length; PH: Plant Height; KW: 100 Kernel Weight; GY: Grain Yield; X: Xerotermic Coefficient; GRT: Growth Type)

Discussion

In order to understand the complexity and structure of a population, analyzing the genetic diversity in that population could be of particular help (Pritchard et al., 2000). Recent research on barley germplasm has indicated that cultivated barley population structure contains clear levels with sub populations based on ear type and seasonal growth type (Rostoks et al., 2006; Hamblinet et al., 2010; Rajala et al., 2016).

Natural variations in flowering time could be an important factor in agro-ecological adaptation of barley (Casas et al., 2011). Therefore, it seems as if flowering time and agro-ecological adaptations are the impressive traits in cultivated barley. Evaluation of growth type in barley landraces in Iran and their eco-geographical distribution has indicated that barley growth types are significantly related to eco-geographic distribution of their origins. Based on our results, winter landraces were mostly originated from cooler climates and landraces from hot and dry climates were facultative or spring type. This conclusion is consistent with the results of previous researchers (Rao and Witcombe 1977; Saisho et al., 2011).

The two-row and six-row barley types have different sets of genes involved in their developmental processes (Kirby and Riggs, 1978). This affects most of their quantitative traits (Powell, 1990) and leads to differences in dry matter allocation in two-row and six-row barley. Therefore, the flexibility of yield components in response to changes in the environmental conditions is greater in two-row barley rather than six-row barley (Le Gouis, 1992). Multivariate analysis indicated that two-row landraces had higher kernel weight and spike length, which seems to be a moderator of adverse environmental factors on yield production. Although the grain yield in the six-row type was slightly higher than that in the two-row type, it was not significantly different.

Two-row barley usually has a smaller number of seeds per spike, which is adjusted with more tillering ability and a higher weight of 100 seeds. Six-row barley has a higher yield potential than two-row barley, specifically in full input conditions. Seed weight is less uniform in six-row barley since lateral florets produce smaller seeds in spikelets than middle florets (Maidl et al., 1996; Le

Gouis et al., 1999). The results of multivariate analysis in this study suggested that the two-row barley landraces were generally spring type and the six-row ones were often winter type.

Based on the results of principle component analysis and the one-way analysis of variance, winter growth type landraces had a longer growth phase (higher values in days to spike emergence and flowering) while spring and facultative landraces were at the same level of significance for phenological traits.

Plant height was significantly different between barley growth types. Winter and facultative landraces had higher values in plant height. Grain yield was significantly higher in winter barley landraces. It seems as if longer vegetative phase in these landraces resulted in higher grain yield potential. In addition, lower grain yield in spring types of barley was found to be related to lower tillering capacity (Garcíadel Moral and Garcíadel Moral 1995). Additionally, based on the results, the climatic condition of origin was significantly related to growth type, phenological characters, and grain yield in barley landraces. These results could be conducive to future genetic studies regarding flowering time, yield, and yield components and to the production of barley for cultivation adapted to different agricultural conditions.

Crop breeding for adaptive traits and at the same time maintaining yield sustainability is one of the most important breeders' objectives . The vernalization, photoperiod, and thermoperoid response are the most important determinants of early maturity in crop plants (Stephanie 1993). *VRN-H1* expression is activated after being exposed to cold temperature and seems to be involved in cold acclimation pathway resulting in frost tolerance (Oliver et al., 2013). On the other hand, studies have indicated that early flowering is a drought escape mechanism allowing the plant to reproduce before overcoming the dry season (Francia et al., 2011; Comadran et al., 2011). Hence, this character is the most important factor for adaptation to climatic conditions with late-season heat or severely cold winters (Kato and Yamashita, 1991; Penrose et al., 1991), which should be considered in the breeding programs and introducing cultivars for different regions and climates.

Conclusion

Evaluation of barley landraces from different regions of Iran indicated that barley growth type is significantly related to eco-geographic distribution of their origins. Winter type landraces were mostly originated from cooler climates and landraces from hot and dry climates were often facultative or spring type. Phenological traits were affected by growth type of barley. Moreover, the xerothermic coefficient of the collection site was significantly related to growth type of the barley landraces. The landraces from higher xerothermic coefficients (arid climates) were spring type and xerothermic coefficient of winter barley landraces was significantly lower. These findings revealed that growth type of barley landraces is a climate-adapted strategy. The studied two-row landraces were mostly spring type and had higher kernel weight and spike length compared to the six-row landraces, which seems to be a moderator of adverse environmental factors on their performance.

According to these results, further genetic investigation on morphological and phonological traits could be conducive to devising breeding programs for selecting proper genotypes of barley for cultivation in different environmental conditions**.**

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