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GENETIC DIVERSITY OF CHARACTERISTICS IN BARLEY CULTIVARS

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Knowledge of the genetic diversity is important to design appropriate selection criteria in the breeding programs. In this study, the genetic diversity of 42 Iranian and European barley cultivars was investigated with morpho-agronomic traits including phenological, physiological, morphological traits, grain yield and associated traits. Analysis of variance showed high variability among cultivars. The European cultivars Panaka, Aiace and Pariglia had the highest grain yield. The results of group comparisons indicated that the European cultivars produced higher grain yield (500.57 g/m^2) than the Iranian cultivars (445.50 g/m^2), but larger genetic diversity based on morpho-agronomic traits was observed among Iranian cultivars than European cultivars. Correlation analysis revealed the high significant correlations between grain yield with biological yield (0.92), straw yield (0.77), and number of spike per square meter (0.67). Based on the factor analysis, the six factors that justified 81.63 percent of the variations were identified. The first factor having the largest eigenvalue was identified as effective factor on the vegetative and reproductive growth. In path analysis, biological yield had the greatest effect on grain yield (0.906). Cluster analysis classified the cultivars in six groups and showed that genetic variation based on the all studied traits among the barley cultivars was not related to geographical location.

Keywords: Barley, genotype diversity, group comparisons, traits similarity.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the oldest domesticated crops. It was domesticated about 10,000 years ago from it's a two rowed wild progenitor (*H. vulgare* ssp. *spontaneum*) in the region of the Middle East known as the Fertile Crescent (BADR *et al.*, 2000). Barley belongs to the genus *Hordeum* in the family Poaceae and tribe Triticeae. The tribe Triticeae consists of approximately 350 species. Genus *Hordeum* consists of about 32 species including the wild and cultivated one. The cultivated barley (*Hordeum vulgare* ssp. *vulgare*) is a diploid with 2n=2X=14 chromosomes (KUMAR *et al.,* 2014). In terms of global acreage and production, it is after wheat,

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rice and corn the world's fourth major grain (FAO, 2013), and is second cereal after wheat in Iran (MOHTASHAMI, 2015). It has superior nutritional qualities due to presence of beta-glucan (anti-cholesterol substance), acetylcholine carbohydrate substance which nourishes our nervous system and recovers memory loss, easy digestibility due to low gluten content and high lysine, thiamin and riboflavin render cooling effect in the body (YADAV *et al.*, 2015). Barley is regarded as one of the most tolerant crops to drought and alkaline soils and it has the highest water-use efficiency compared to other cereal crops but it is less tolerant to acid soils (USUBALIEV, 2013). Diploid nature, short cell life, self-pollinating, exist of genetic variation among cultivated and related wild species and ease of hybridization are the factors that the barley has become a model experimental system for various researches (MATSUMOTO *et al.*, 2011; KUMAR *et al.*, 2014). Knowledge of the extent and nature of genetic variation within cultivars and relationships between cultivars is momentous for find out the genetic variability accessible and utilization in breeding programs. Study the genetic diversity is the process that analyzes the variation among genotypes by a specific method or a combination of methods (IBRAHIM *et al.*, 2011). Several approaches exist to assay genetic diversity. One of the used techniques for assessment linear relationship between two variables is correlation analysis. The coefficient of correlation shows the variations of common traits interactions under study and does not imply causation (MOHTASHAMI, 2015). Path analysis is one of the reliable statistical techniques which allow quantifying the interrelationships of different components and their direct and indirect effects on grain yield through correlation estimates (DRIKVAND *et al.*, 2011).

The aim of this study was to estimate and compare genetic variation among Iranian and European barley cultivars using morpho-agronomic traits.

MATERIALS AND METHODS

The investigation was done at the Research Station of Agricultural Faculty of Razi University, Kermanshah, Iran (latitude 34° 19′ N, longitude 47° 7′E, and altitude 1322 m) during 2013-2014 cropping season. Experiment field located in the west of Iran with moderate-cold and semi-arid climate and mean annual rainfall of 450-480 mm.

Plant material

In the current study, forty two Iranian and European barley cultivars were investigated. Sixteen barley cultivars were provided by Dryland Agricultural Research Institute (DARI) of Iran and twenty six barley cultivars were obtained from Genomics Research Centre (CRA-GPG) of Italy. Details of the 42 cultivars are presented in Table 1.

Table 1. Name and characteristics of 42 barley cultivars used in the current study

Cultivar No.	Cultivar name	Geographic location	Pedigree	Growth habit	Row type	Grain type	Time of sowing
1	Fajr 30	Iran	Lignee131/ Gerbet//Alger- Ceres/ jonoob	F	6	Hulled	Winter
2	Gorgan 4	Iran	Herta	F	2	Hulled	Winter
3	Aras	Iran	Arumir	S	2	Hulled	Winter
4	Makooei	Iran	Star	F	6	Hulled	Winter
5	Zarjo	Iran	1-28-9963	F	6	Hulled	Winter
6	Afzal	Iran	Chahafzal	F	6	Hulled	Winter

Table 1cont. Name and characteristics of 42 barley cultivars used in the current study

Cultivar No.	Cultivar name	Geographic location	Pedigree	Growth habit	Row type	Grain type	Time of sowing
7	Jonoob	Iran	Gloria" s"/ Copal"s"	F	6	Hulled	Winter
8	Karoon	Iran	Strain- 205	F	6	Hulled	Winter
9	Jo Danmark	Iran	Denmark55	W	2	Hulled	Winter
10	Sahra	Iran	L. B. LRAN/ Una8271// Giorias"s" Com	F	6	Hulled	Winter
11	Mahoor	Iran	Wi2291/Wi2269//Er/Amp	W	2	Hulled	Winter
12	Yoosef	Iran	Lignee527/chn-01//Gustoe/4/Rhn-08/3/Deir Alla 106//DI71/strain 205	S	6	Hulled	Winter
13	Nimrooz	Iran	Trompillo, CMB74A-432-25B-1Y-IB-IY-OB	F	2	Hulled	Winter
14	Reyhan	Iran	Rihane-03/4Alanda/lLignee527/Arar/3/Centinela/2*	S	6	Hulled	Winter
15	Sararood	Iran	Chicm/An57//Albert	W	2	Hulled	Winter
16	Nosrat	Iran	Karoon/Kavir	F	6	Hulled	Winter
17	Astartis	Europe	(IABO x Arda3) x Amillis	W	2	Naked	Winter
18	Cometa	Europe	PO202.169 x FO 3358	W	2	Hulled	Winter
19	Explora	Europe	[(Onice\Arma\\Onice\Mirco\\\Jaidor) x (Plaisant\Jaidor\Express)] x Gotic	W	6	Hulled	Winter
20	Rodorz	Europe	Baraka x Gotic	W	2	Hulled	Winter
21	Martino	Europe	FIOR 3007 x Federal	W	6	Hulled	Winter
22	Aqvirone	Europe	FIOR 5186 x Naturel	W	2	Hulled	Winter
23	Ponente	Europe	(Vetulio x Arma) x Express	W	6	Hulled	Winter
24	Alce	Europe	(Tipper x Igri3) x [(Tipper x Alpha)x(Sonja x Wb117/18)]	W	2	Hulled	Winter
25	Sirio	Europe	FIOR 2136 x Arco	W	2	Hulled	Winter
26	Panaka	Europe	Amillis x Diadem	W	2	Hulled	Winter
27	Pariglia	Europe	Airone x Arco	W	2	Hulled	Winter
28	Sfera	Europe	((Katy x HJ54/30) x Igri x Arda) x (Tipper x Sonja)) x Amillis	W	2	Hulled	Winter
29	Alimini	Europe	FIOR 2551 x Federal	W	6	Hulled	Winter
30	Aldebaran	Europe	Rebelle x Jaidor	W	6	Hulled	Winter
31	Vega	Europe	Rebelle x FIOR 1341	W	6	Hulled	Winter
32	Aliseo	Europe	(Plaisant x Gerbel) x Express	W	6	Hulled	Winter
33	Nure	Europe	(FIOR 40 x Alpha2) x Baraka	W	2	Hulled	Winter
34	Airone	Europe	Gitane x FIOR 763	W	2	Hulled	Winter
35	Aiace	Europe	FO 1078 x FO 1638	W	2	Hulled	Winter
36	Scirocco	Europe	FIOR 1000 x Express	W	6	Hulled	Winter
37	Trebbia	Europe	selection from Fior Synt 3	W	6	Hulled	Winter
38	Alfeo	Europe	Tipper x Igri	W	2	Hulled	Winter
39	Zacinto	Europe	IABO 329 x Arda	W	2	Naked	Winter
40	Arda	Europe	Igri x HJ 51-15-3	W	2	Hulled	Winter
41	Doria	Europe	(Nure x Zita)x(Nure x PO 202.169)	S	2	Hulled	Spring
42	Tidone	Europe	(Okos x 273 cat.) x Igri	S	2	Hulled	Spring

F: Facultative; **W**: Winter; **S**: Spring

Experimental design

Table 2. List of the evaluated traits and their method of measurement

No.	Trait	Abbreviation	Method of measurement
1	Flag Leaf Width	FLW	the width of the flag leaf from its base to tip in cm
2	Flag Leaf Length	FLL	the length of the flag leaf from its base to tip in cm
3	Flag Leaf Area	FLA	flag leaf width (FLW)× flag leaf length (FLL)× 0.7
4	Excised Leaf Water Retention	ELWR	1- [FW –DW / FW] ×100; FW: fresh weight, DW: dry weight
5	Relative Water Content	RWC	[(FW-DW) / (TW-DW)] × 100; FW: fresh weight, TW: , turgid weight, DW: dry weight
6	Stomatal Conductance	SC	using of leaf prometer model Li-1600; LI-COR Inc., Lincoln, NE
7	Maximum quantum yield of psII	F_V/F_M	using of chlorophyll fluorescence (model PSM, Hansantech, UK)
8	Soil and Plant Analyzer Division	SPAD	using of chlorophyll meter model SPAD-502
9	Days to Heading	DTH	the number of days from planting to 50% heading
10	Days to Anthesis	DTA	the number of days from planting to 50% anthesis
11	Days to Physiological Maturity	DTPM	the number of days from planting to 50% physiological maturity
12	Kernel Filling Period	KFP	the number of days from anthesis 50% to physiological maturity
13	Kernel Filling Rate	KFR	the ratio weight of grain to kernel filling period in mg/day
14	Weight of Kernels Per Spike	WKPS	the weight of grains per spike
15	Number of Kernel Per Spike	NKPS	the number of grain of the per spike
16	Spike Weight	SW	the weight of per spike in g
17	Spike Straw Yield	SSY	the weight of straw of per spike
18	Spike Yield Index	SYI	the weight of grains per spike to the weight of per spike
19	Spike Density	SD	the ratio number of grain to spike length
20	Number of Node	NN	the number of node per main tiller
21	Plant Height	Phe	the length from the ground level to the tip of the bottom of spike in cm of the main tiller
22	Peduncle Length	PL	the length from the flag leaf node to the bottom of spike
23	Spike Length	SL	distance from the bottom of the spike to the tip of topmost spikelet (excluding own) in cm
24	Awn Length	AL	distance from the tip of the centric spikelet to the apex of the awn
25	Peduncle Length/ Plant Height	PL/Phe	the ratio peduncle length (PL) to plant height (Phe)
26	Grain Length	GL	the length of the grain from its bottom to tip in mm
27	Grain Width	GW	the width of the grain from its bottom to tip in mm
28	Biological Yield	BY	the weight the biomass harvested from the $1m^2$ in g/ m^2
29	Grain Yield	GY	the weight of the grain yield harvested from the $1m^2$ in g/ m^2
30	Straw Yield	SY	the weight of the Straw harvested from the $1m^2$ in g/ m^2
31	Harvest Index	HI	ratio of grain Yield to weight of biological Yield from the $1m^2$ in percentage
32	Hectoliter Weight	HLW	weight of seeds in one liter volume in g/ L
33	Number of Spike Per m^2	$NSPm^2$	the number of the fertile tillers per $1m^2$
34	Thousand Kernel Weight	TKW	weight of 1000 seeds from each plot in g
35	Grain Length/ Grain Width	GL/GW	the ratio of grain length (GL) to grain width (GW)

This study was carried out as a randomized complete block design (RCBD) with three replications under rainfed condition. Each plot contained 5 rows with 22.5cm distance between rows and row length of 3m. Plant density was 350 seeds in square meter. Winter and spring sowing were carried out on November 6, 2013 and March 8, 2014, respectively. Five plants were randomly chosen from each plot to measure some of traits and also one m^2 of each plot was harvested on July 2014. The measured traits in barley involve morphological, physiological, phenological traits, grain yield and related characters. The investigated traits and their method of measurement are listed in Table 2.

Statistical analysis

Analysis of variance, specific group comparisons, the least significant difference (LSD) test for mean comparisons and correlation analysis were down using SAS (Ver. 9.1), MSTAT-C (Ver. 2.10) and SPSS (Ver. 16.0.1, SPSS Inc) software. Cultivars Scirocco, Doria and Tidone were planted in one replication due to limitation in the number of seeds. Therefore, these cultivars were excluded for analysis of variance and mean comparison. Path analysis was performed based on logical relationships between GY and other traits to identify direct and indirect path coefficients. Factor and cluster analyses were assessed based on only 25 directly measured traits including flag leaf width (FLW), flag leaf length (FLL), excised leaf water retention (ELWR), relative water content (RWC), stomatal conductance (SC), maximum quantum yield of psII (F_V/F_M), soil and plant analyzer division (SPAD), weight of kernels per spike (WKPS), number of kernel per spike (NKPS), spike weight (SW), number of node (NN), plant height (Phe), peduncle length (PL), spike length (SL), awn length (AL), grain length (GL), grain width (GW), days to heading (DTH), days to anthesis (DTA), days to physiological maturity (DTPM), biological yield (BY), grain yield (GY), hectoliter weight (HLW), number of spike per m^2 ($NSPm^2$) and thousand kernel weight (TKW). Cluster analysis and factor analysis were performed using SPSS software (Ver. 16.0.1, SPSS Inc).

RESULTS AND DISCUSSION

Differences among barley cultivars in most traits

At the analysis of variance (data not shown), high significant differences obtained between cultivars for all investigated traits, except relative water content, maximum quantum yield of psII, stomatal conductance and excised leaf water retention. Minimum, maximum and other statistics of mean comparison are presented in Table 3. Mean comparison indicated the European cultivars Panaka, Aiace and Pariglia had the highest yield (data not shown). Analysis of variance for specific group comparisons showed that significant differences were between Iranian and European cultivars for all measured traits except for harvest index, thousand kernel weight, spike yield index, stomatal conductance, days to anthesis, kernel filling period, kernel filling rate, peduncle length/ plant height and grain width. The mean of European cultivars was higher than the mean of Iranian cultivars for the traits such as biological yield, grain yield, straw yield, number of spike per m^2 and hectoliter weight (Table 4). While, the Iranian cultivars had larger mean for the weight of kernels per spike, number of kernel per spike, spike weight, number of node, plant height and peduncle length. The average of some traits in two-row cultivars was significantly more than average of same traits in six-row cultivars. These traits are including biological yield, straw yield, number of spike per m^2, kernel weight, hectoliter weight and kernel filling rate.

Table 3. Minimum, maximum, mean values, standard deviation and coefficient of variation for the estimated traits of 42 barley cultivars

Traits	Mean	Maximum	Minimum	Sdev.	Coefficient of variation
GY (g/m^2)	477.98	770.29	208.52	116.481	24.36
BY (g/m^2)	1224.75	2088.00	408.00	260.544	21.27
SY (g/m^2)	746.76	1337.45	199.46	160.089	21.43
HI (%)	39.25	51.63	28.30	4.142	10.55
$NSPm^2$	720.47	1540.33	222.33	143.279	19.88
WKPS (g)	1.48	2.46	0.83	0.184	12.42
NKPS	39.37	63.93	22.06	3.681	9.35
TKW (g)	31.32	40.76	23.73	2.566	8.19
SW (g)	1.73	2.81	1.03	0.207	11.94
SSY (g)	0.25	0.33	0.16	0.035	13.85
SYI	0.85	0.89	0.80	0.014	1.68
SD (%)	49.27	83.23	24.12	4.436	9.00
HLW (g/L)	590.02	960.86	508.83	36.856	6.24
FLW (cm)	1.02	1.40	0.63	0.129	12.65
FLL (cm)	11.46	17.03	8.29	1.738	15.15
FLA (cm)	8.44	17.01	3.77	2.763	32.73
ELWR (%)	51.08	62.62	41.81	6.340	12.41
RWC (%)	55.17	63.76	46.27	5.963	10.80
SC (mmol H_2O m^{-2} s^{-1})	16.85	25.44	11.58	6.365	37.78
F_V/F_M	0.77	0.80	0.73	3.030	3.94
SPAD	52.18	57.86	46.33	2.785	5.33
DTH (day)	164.86	171.33	151.33	1.606	0.97
DTA (day)	168.55	176.00	156.66	2.490	1.47
DTPM (day)	197.06	202.66	188.66	3.346	1.70
KFP (day)	28.51	34.33	19.66	3.579	12.55
KFR (mg/day)	1.21	1.48	0.69	0.158	14.16
NN	4.27	5.40	3.46	0.307	7.19
Phe (cm)	7.87	91.63	57.96	6.110	8.38
PL (cm)	20.38	33.59	14.80	1.946	9.52
SL (cm)	8.35	10.72	6.15	0.554	6.63
AL (cm)	12.51	15.48	9.36	0.882	7.05
PL/Phe	0.28	0.37	0.18	0.026	9.60
GL (mm)	10.19	11.32	8.38	0.464	4.55
GW (mm)	3.25	3.57	2.84	0.135	4.15
GL/GW (mm)	3.15	3.67	2.52	0.180	5.72

Sdev.: Standard Deviation**, FLW**: Flag Leaf Width, **FLL**: Flag Leaf Length, **ELWR**: Excised Leaf Water Retention, **RWC**: Relative Water Content, **SC**: Stomatal Conductance, **F_V/F_M**: Maximum quantum yield of psII, **SPAD**: Soil and Plant Analyzer Division, **WKPS**: Weight of Kernels Per Spike, **NKPS**: Number of Kernel Per Spike, **SW**: Spike Weight, **NN**: Number of Node, **Phe**: Plant Height, **PL**: Peduncle Length, **SL**: Spike Length, **AL**: Awn Length, **GL**: Grain Length, **GW**: Grain Width, **DTH**: Days to Heading, **DTA**: Days to Anthering, **DTPM**: Days to Physiological Maturity, **BY**: Biological Yield, **GY**: Grain Yield, **HLW**: Hectoliter Weight, **$NSPm^2$**: Number of Spike Per m^2, **TKW**: Thousand Kernel Weight.

Table 4. Mean values and standard deviation of the measured traits in the compared groups of 39 barely cultivars

	Comparison 1				Comparison 2			
	Iranian		European		2-row		6-row	
Traits	Mean	Sdev.	Mean	Sdev.	Mean	Sdev.	Mean	Sdev.
GY (g/m^2)	445.50*	139.863	500.57	110.064	493.70^{ns}	132.239	459.64	115.698
BY (g/m^2)	1155.39*	330.890	1273.00	273.412	1315.31**	290.733	1119.09	282.188
SY (g/m^2)	709.88*	207.448	772.42	176.564	821.61**	173.825	659.44	173.047
HI (%)	38.87^{ns}	5.345	39.52	3.325	37.47**	3.781	41.33	3.797
NSPm^2	610.29**	196.709	797.13	251.298	885.95**	204.432	527.42	113.090
WKPS (g)	1.67**	0.538	1.34	0.365	1.09**	0.098	1.93	0.254
NKPS	42.58**	14.197	37.14	15.560	25.91**	1.895	55.07	4.312
TKW (g)	31.63^{ns}	4.150	31.10	4.862	33.39**	4.155	28.90	3.760
SW (g)	1.95**	0.593	1.58	0.405	1.29**	0.115	2.24	0.278
SSY (g)	0.28**	0.063	0.23	0.048	0.20**	0.031	0.30	0.042
SYI	0.84^{ns}	0.024	0.85	0.019	0. 83**	0.019	0.86	0.017
SD (%)	57.70**	24.349	43.40	19.935	28.95**	1.948	72.97	6.458
HLW (g/L)	581.03*	50.340	596.28	49.937	617.48**	45.998	557.98	32.936
FLW (cm)	1.14**	0.199	0.94	0.138	0.91**	0.170	1.14	0.131
FLL (cm)	12.61**	2.041	10.67	1.140	11.02**	1.578	11.97	2.000
FLA (cm)	10.19**	3.176	7.22	1.621	7.42**	2.434	9.62	2.737
ELWR (%)	53.15**	4.191	49.65	3.798	50.48^{ns}	4.840	51.79	3.528
RWC (%)	57.11**	4.416	53.83	3.643	55.60^{ns}	4.196	54.68	4.380
SC (mmol H_2O m^{-2} s^{-1})	17.00^{ns}	3.464	16.75	3.655	15.74*	3.190	18.15	3.551
F_V/F_M	0.76**	0.022	0.78	0.012	0.77^{ns}	0.016	0.77	0.022
SPAD	50.26**	2.813	53.52	2.140	52.49^{ns}	3.059	51.82	2.748
DTH (day)	164.39*	4.680	165.18	2.245	164.74^{ns}	3.973	165.00	2.753
DTA (day)	168.02^{ns}	4.946	168.92	2.653	168.87^{ns}	3.899	168.18	3.605
DTPM (day)	196.29*	3.445	197.60	2.500	196.73^{ns}	3.576	197.46	2.042
KFP (day)	28.27^{ns}	3.656	28.68	2.506	27.85*	1.887	29.27	3.830
KFR (mg/day)	1.14^{ns}	0.186	1.10	0.197	1.21**	0.141	1.01	0.188
NN	4.47**	0.422	4.14	0.313	4.09**	0.305	4.49	0.384
Phe (cm)	74. 77**	8.618	71.54	4.170	71.14**	4.482	74.88	7.888
PL (cm)	21.15**	5.092	19.85	1.328	19.68**	1.752	21.21	4.601
SL (cm)	7.84**	1.415	8.71	0.663	8.98**	0.806	7.61	0.961
AL (cm)	11.95**	1.484	12.90	1.308	13.41**	1.168	11.46	0.939
PL/Phe	0.28^{ns}	0.050	0.27	0.021	0.27^{ns}	0.026	0.28	0.045
GL (mm)	10.58**	0.610	9.91	0.627	9.94**	0.745	10.47	0.519
GW (mm)	3.26^{ns}	0.214	3.24	0.216	3.38**	0.133	3.10	0.187
GL/GW (mm)	3.25**	0.216	3.08	0.348	2.94**	0.237	3.38	0.187

Sdev.: Standard Deviation, **GY:** Grain Yield**, BY:** Biological Yield, **SY:** Straw Yield, **HI:** Harvest Index **, NSPm^2:** Number of Spike Per m^2, **WKPS:** Weight of Kernels Per Spike, **NKPS:** Number of Kernel Per Spike, **TKW:** Thousand Kernel Weight, **SW:** Spike Weight, **SSY:** Spike Straw Yield, **SYI:** Spike Yield Index, **SD:** Spike Density, **HLW:** Hectoliter Weight, **FLW:** Flag Leaf Width, **FLL:** Flag Leaf Length, **FLA:** Flag leaf Area, **ELWR:** Excised Leaf Water Retention, **RWC:** Relative Water Content, **SC:** Stomatal Conductance, **F_V/F_M:** Maximum quantum yield of psII, **SPAD:** Soil and Plant Analyzer Division, **DTH:** Days to Heading, **DTA:** Days to Anthesis, **DTPM:** Days to Physiological Maturity, **KFP:** Kernel Filling Period, **KFR:** Kernel Filling Rate, **NN:** Number of Node, **Phe:** Plant Height, **PL:** Peduncle Length, **SL:** Spike Length, **AL:** Awn Length, **PL/Phe (cm):** Peduncle Length/ Plant Height, **GL:** Grain Length, **GW:** Grain Width, **GL/GW:** Grain Length/ Grain Width. ^{ns}, * and **: not significant, significant at $p< 0.05$ and $p<0.01$ respectively, for comparison 1 and 2, separately.

Relationships among analyzed traits

Awareness of the relationship between different traits in breeding programs to improve the yield is important, because the one way choice for agronomic traits, regardless of other attributes will cause adverse results (JOUYBAN *et al.*, 2015). Simple correlations of grain yield and biological yield with the measured traits were calculated to identify and understand the relationships between traits (Table 5). The correlation analysis showed that grain yield had a significant positive correlation with biological yield, straw yield, number of spike per m^2, days to anthesis, days to heading, days to physiological maturity, soil and plant analyzer division, harvest index, spike yield index, thousand kernel weight, peduncle length, plant height and peduncle length/ plant height. High correlation between grain yield and biological yield indicates that with increasing biomass grain yield was increased. The result of this research is consistent with SINEBO (2002) who reported that grain yield had the highest correlation with biological yield. Harvest index had a high significant positive correlation with grain yield and a non-significant positive correlation with biological yield. Grain yield had a highly significant positive correlation with the number of spike per m^2 that these results were also reported by MOHTASHAMI *et al.* (2015). The significant positive correlation between peduncle length and plant height with grain yield is indicating the positive effect of these variables on grain yield.

Table 5. Correlation coefficients of grain yield and biological yield with the measured traits in 42 barley cultivars

	FLW	FLL	FLA	ELWR	RWC	SC	FV/FM	SPAD	WKPS	NKPS	SW	SSY	SYI	SD	NN	Phe	PL	SL
GY	0.13	0.29	0.16	-0.12	-0.13	-0.03	0.23	0.47**	0.15	0.02	0.13	-0.02	0.41**	0.01	-0.04	0.33*	0.37*	0.15
BY	0.14	0.27	0.16	-0.09	-0.10	-0.00	0.12	0.44**	0.00	-0.13	-0.01	-0.09	0.23	-0.16	-0.01	0.21	0.22	0.25

	AL	PL/Phe	GL	GW	DTH	DTA	DTPM	KFP	KFR	BY	GY	SY	HI	HLW	$NSPm^2$	TKW	GL/GW
GY	0.19	0.31*	0.10	0.21	0.52**	0.52**	0.52**	0.18	0.10	0.92**	1.00	0.77**	0.45**	0.27	0.67**	0.37*	-0.06
BY	0.21	0.20	-0.02	0.29	0.45**	0.46**	0.44**	0.02	0.24	1.00	0.92**	0.96**	0.09	0.34*	0.73**	0.40**	-0.20

* and **: $p< 0.05$ and $p<0.01$ respectively.

FLW: Flag Leaf Width, **FLL**: Flag Leaf Length, **ELWR**: Excised Leaf Water Retention, **RWC**: Relative Water Content, **SC**: Stomatal Conductance, **F_V/F_M**: Maximum quantum yield of psII, **SPAD**: Soil and Plant Analyzer Division, **WKPS**: Weight of Kernels Per Spike, **NKPS**: Number of Kernel Per Spike, **SW**: Spike Weight, **NN**: Number of Node, **Phe**: Plant Height, **PL**: Peduncle Length, **SL**: Spike Length, **AL**: Awn Length, **GL**: Grain Length, **GW**: Grain Width, **DTH**: Days to Heading, **DTA**: Days to Anthesis, **DTPM**: Days to Physiological Maturity, **BY**: Biological Yield, **GY**: Grain Yield, **HLW**: Hectoliter Weight, **$NSPm^2$**: Number of Spike Per m^2, **TKW**: Thousand Kernel Weight.

Description of variability of measured barley traits

The factor analysis was performed based on principal component analysis and using varimax rotation with eigenvalues greater than one. Factor analysis is an effective multivariate statistical method in reducing the volume of the data and getting the certain results of the data which showed high correlation between the primary variables (COOPER, 1983). Six factors were account for 81.63 percent of the total variation (Table 6).

Table 6. Factor analysis by principal components using varimax rotation in 42 barley cultivars

	Factor					
Traits	1	2	3	4	5	6
FLW	0.390	0.626*	-0.045	0.051	0.134	0.535*
FLL	0.529*	0.393	0.182	0.100	0.171	0.535*
ELWR	-0.235	-0.012	-0.033	-0.009	0.108	0.708*
RWC	-0.618*	0.165	0.498	-0.014	-0.082	0.152
SC	0.200	0.641*	0.011	-0.099	-0.271	-0.234
F_V/F_M	0.550*	0.039	-0.094	0.093	0.105	-0.473
SPAD	0.569*	0.093	-0.094	0.412	-0.203	-0.437
WKPS	0.247	0.815*	-0.204	0.046	0.409	0.064
NKPS	0.203	0.752*	-0.508*	-0.012	0.290	0.011
SW	0.244	0.822*	-0.200	0.029	0.392	0.071
NN	0.315	0.570*	-0.221	-0.108	-0.113	0.471
Phe	0.808*	0.115	-0.092	0.066	0.370	0.046
PL	0.565*	0.082	0.024	0.129	0.681*	-0.180
SL	0.582*	-0.447	-0.031	0.054	-0.484	0.000
AL	0.272	-0.825*	0.137	0.064	0.023	-0.060
GL	0.140	0.146	-0.008	-0.061	0.799*	0.241
GW	0.062	-0.311	0.872*	0.050	0.090	0.020
DTH	0.920*	0.174	0.000	0.255	0.058	-0.006
DTA	0.918*	0.170	0.024	0.263	0.037	-0.005
DTPM	0.918*	0.168	0.006	0.249	0.101	-0.053
BY	0.262	-0.038	0.232	0.901*	-0.060	0.068
GY	0.294	0.014	0.170	0.907*	0.140	-0.030
HLW	-0.061	-0.225	0.782*	0.210	-0.201	-0.036
$NSPm^2$	0.300	-0.526*	0.240	0.646*	-0.127	-0.207
TKW	-0.060	-0.076	0.889*	0.216	0.104	-0.018
Eigenvalue	7.797	5.714	2.736	1.613	1.429	1.120
Proportion of variance	31.189	22.856	10.944	6.452	5.714	4.480
% of Cumulative variance	31.189	54.046	64.989	71.442	77.156	81.636

FLW: Flag Leaf Width, **FLL:** Flag Leaf Length, **ELWR:** Excised Leaf Water Retention, **RWC:** Relative Water Content, **SC:** Stomatal Conductance, **F_V/F_M:** Maximum quantum yield of psII, **SPAD:** Soil and Plant Analyzer Division, **WKPS:** Weight of Kernels Per Spike, **NKPS:** Number of Kernel Per Spike, **SW:** Spike Weight, **NN:** Number of Node, **Phe:** Plant Height, **PL:** Peduncle Length, **SL:** Spike Length, **AL:** Awn Length, **GL:** Grain Length, **GW:** Grain Width, **DTH:** Days to Heading, **DTA:** Days to Anthesis, **DTPM:** Days to Physiological Maturity, **BY:** Biological Yield, **GY:** Grain Yield**, HLW:** Hectoliter Weight, **$NSPm^2$:** Number of Spike Per m^2, **TKW:** Thousand Kernel Weight,
*: significant loading factor.

Kaiser-Meyer-Olkin (KMO) value and Sphericity Bartlett test was listed in Table 7. According to the formula F< (P+1)/2, (P and F represent the number of variables and factors, respectively), six selection factors correspond with the presented principles. Factor loadings greater than 0.5, regardless of the respective sign were considered as significant coefficients

(TADESSE and BEKELE, 2001). Factor analysis revealed that the first factor which described 31.18% of the total variation had significant correlation with the days to heading, days to physiological maturity, days to anthesis, plant height, relative water content, spike length, soil and plant analyzer division, peduncle length, maximum quantum yield of psII and flag leaf length (Table 6). This factor was named the factor affecting vegetative and reproductive growth. The second factor included awn length, spike weight, weight of kernels per spike, number of kernel per spike, stomatal conductance, flag leaf width, number of node and number of spike per m^2. The second factor which accounted for 22.85% of the total variation was named the factor affecting the properties of the spike and flag leaf. The third factor accounted for 10.94% of the total variance. This factor had a positive relationship with the thousand kernel weight, grain width and hectoliter weight and had a negative relationship with the number of kernel per spike. Accordingly, this factor named as a factor affecting the grain yield. The fourth factor which was named target factor, it explained 6.45% of the variations. This factor contained traits of grain yield, biological yield and number of spike per m^2. The positive signs of these indicate the positive direction of the relationship between the factor and the variables. The fifth factor that justified 5.71% of the variations, called as factor affecting length. This factor included the grain length and peduncle length. With considering that excised leaf water retention, flag leaf width and flag leaf length had the highest loading factors in final factor, thus sixth factor called as a factor affecting characteristics of flag leaf. This factor justified 4.48% of the variations.

Table 7. KMO and Spheericity Bartlett Test value

Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy	Bartlett's Test of Spheericity		
	Approx. Chi-Square	df	Sig.
0.649	1.410E3	300	0.000

Evaluation of causal relationships between the measured traits

Path analysis is a reliable statistical method, which provides tool to quantify the interrelationship of various grain yield components and indicates whether the influence is directly reflected in the grain yield or take some other path ways to produce an effect (SADEGHI *et al.*, 2011; JANMOHAMMADI *et al.*, 2014). For path analysis the traits were selected based on the correlation coefficient and route based on logical relationships between them (Figure 1). With respect to correlation coefficients and logical relationships, the traits were separated in two groups one including the traits with the primary effects on grain yield and the other traits with the secondary effects on GY via their effect on the primary traits. The results of path analysis were presented in Table 8. In the primary level of grain yield, GY was affected by number of spike per m^2, thousand kernel weight, and biological yield, each of them affected by another trait. Biological yield had the highest correlation coefficient and value of direct effect on GY, but its indirect effects through number of spikes per square meter and thousand kernel weight was negligible. Number of spikes per square meter had the highest positive indirect effect through biological yield. Similar results were reported by SEYED AGHAMIRI *et al.* (2012) who declared that the biological yield has the most direct and positive effect on grain yield.

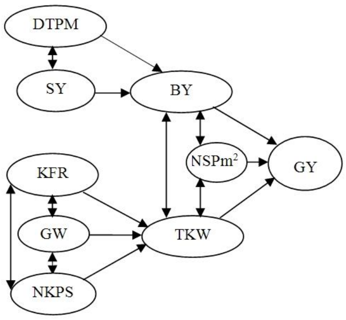

Figure 1. Path coefficient diagram showing the interrelation of traits in primary and secondary levels of grain yield. **GY**: Grain Yield, **BY**: Biological Yield, **TKW**: Thousand Kernel Weight, **NSPm²**: Number of Spike Per m², **DTPM**: Days to Physiological Maturity, **SY**: Straw Yield, **KFR**: Kernel Filling Period, **GW**: Grain Width, **NKPS**: Number of Kernel Per Spike.

Table 8. Path coefficient (direct and indirect effects) of the estimated yield attributes on grain yield variation in barley

Primary level of grain yield		Secondary level			
GY		BY		TKW	
BY		DTPM		KFR	
Direct effect	0.906**	Direct effect	0.129**	Direct effect	0.396**
Indirect effect via		Indirect effect via		Indirect effect via	
NSPm²	0.012	SY	0.308	GW	0.343
TKW	-0.002	Correlation	0.437**	NKPS	-0.041
Correlation	0.916**			Correlation	0.699**
NSPm²		SY		GW	
Direct effect	0.017	Direct effect	0.917**	Direct effect	0.556**
Indirect effect via		Indirect effect via		Indirect effect via	
BY	0.659	DTPM	0.043	KFR	0.244
TKW	-0.001	Correlation	0.960**	NKPS	-0.046
Correlation	0.673**			Correlation	0.754**
TKW				NKPS	
Direct effect	-0.004			Direct effect	0.073
Indirect effect via				Indirect effect via	
NSPm²	0.005			KFR	-0.223
BY	0.364			GW	-0.350
Correlation	0.365*			Correlation	-0.500**
R^2	0.84		0.93		0.66

GY: Grain Yield, **BY**: Biological Yield, **TKW**: Thousand Kernel Weight, **NSPm²**: Number of Spike Per m², **DTPM**: Days to Physiological Maturity, **SY**: Straw Yield, **KFR**: Kernel Filling Period, **GW**: Grain Width, **NKPS**: Number of Kernel Per Spike,* and **: $p < 0.05$ and $p<0.01$ respectively.

Thousand kernel weight had a low direct and negative effect on grain yield, but high and positive indirect effect through biological yield. The direct effect of biological yield and indirect effects through thousand kernel weight and number of spikes per square meter on grain yield caused an increase in grain yield. At the secondary level of grain yield, the direct effects of days to physiological maturity and straw yield on biological yield were investigated. The straw yield had the largest positive direct effect and days to physiological maturity through straw yield had the highest indirect effect on biological yield. So, the biological yield could be increased via straw yield and physiological maturity directly and indirectly. The path analysis at the secondary level of grain yield indicated grain width had the highest positive direct effect and kernel filling rate had the highest positive indirect effect through grain width on thousand kernel weight. The number of kernel per spike had negative and significant correlation with thousand kernel weight, while it had the negligible indirect effect on thousand kernel weight. This trait had the highest indirect negative effect through grain width on thousand kernel weight. It seems with regarding to constant other variables, with increase of this trait, thousand kernel weight has been decreased. In view of a significant positive correlation between grain width and thousand kernel weight and also positive direct and indirect effect, thousand kernel weights could be increased directly and indirectly through grain width.

Similarity of barley cultivars on the base of measured traits

Cluster analysis aims to detect homogeneous groups with large heterogeneity among them (GARCÍA-ESCUDERO *et al.*, 2010). Cluster analysis was performed on UPGMA method and based on square Euclidean distance matrix. According to the cluster analysis, 42 barley cultivars were classified into six separate classes (Figure 2). Means of the traits per cluster are listed in Table 9. Cluster 1 consisted of ten Iranian and four European cultivars which all of them were six-row cultivars expect cultivar Sirio. The first cluster was less than other clusters in terms of harvest index. Cluster 2 was the largest with eight Iranian and eleven European cultivars. All of them are six-row cultivars except cultivars Aras, Cometa and Airone. Cluster 2 had the highest number of kernel per spike, weight of kernels per spike, spike weight and plant height among the clusters. Cultivar Pariglia with the highest biological yield was alone in third cluster. Cluster 3 presented the high grain yield. Cluster 4 included two-row cultivars Panaka and Aiace that distinguished from other groups by having the highest grain yield, harvest index, thousand kernel weight, spike length, awn length, peduncle length and days to physiological maturity. Cluster 5 comprised the Iranian cultivars Fajr 30, Gorgan 4 and Afzal. These cultivars had the highest grain yield among Iranian cultivars. This cluster exhibited the high grain yield, biological yield, number of kernel per spike, weight of kernels per spike, harvest index and relative water content. Highest amount of excised leaf water retention, number of node and grain width were calculated in this cluster. Sixth cluster constituted European spring cultivars Doria and Tidone and Iranian winter cultivar Reyhan. This cluster had the lowest grain yield, biological yield, harvest index, number of spike per m^2, weight of kernels per spike, flag leaf length, flag leaf width, soil and plant analyzer division, spike weight, plant height, spike length, awn length, peduncle length, grain length, grain width, hectoliter weight and days to physiological maturity. Cultivar Reyhan had the lowest grain yield, biological yield, number of spike per m^2 between cultivars.

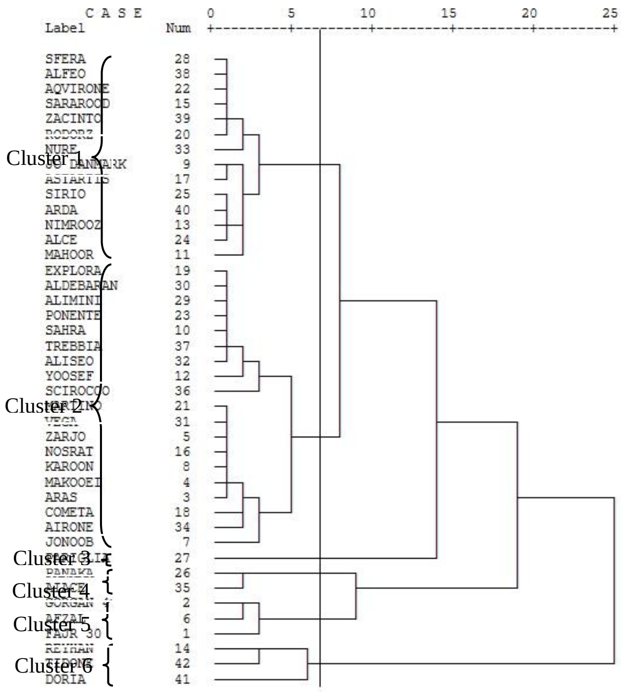

Figure 2. Dendrogram of cluster analysis of 42 barley cultivars using UPGMA method and based on square Euclidean distance matrix

Table 9. The clusters average of 42 barley cultivars and their deviation from total mean

	1		2		3		4		5		6	
	Mean	Sdev.	Mean	Sdev.	Mean	Sdev.	Mean	Sdev.	Mean	Sdev.	Mean	Sdev.
GY	454.14	58.780	428.72	63.403	750.55	0.000	765.19	7.224	671.99	47.670	151.41	50.179
BY	1228.07	91.160	1099.88	139.512	2088.00	0.000	1796.00	99.466	1671.56	122.866	505.33	174.684
NSPm2	871.17	96.990	539.77	87.864	1540.33	0.000	1091.83	1.650	702.44	18.869	243.28	24.353
WKPS	1.06	0.083	1.82	0.409	1.13	0.000	1.21	0.187	1.74	0.431	0.99	0.731
NKPS	25.85	1.978	51.27	11.870	25.43	0.000	26.80	2.074	40.83	13.132	29.93	23.675
TKW	32.11	3.821	29.36	4.134	33.23	0.000	39.14	2.293	34.94	4.018	30.67	1.825
SW	1.26	0.085	2.12	0.451	1.33	0.000	1.47	0.196	2.00	0.467	1.22	0.837
HLW	602.38	46.328	569.50	46.325	686.23	0.000	626.85	0.825	608.21	49.396	576.72	35.928
FLW	0.89	0.145	1.12	0.157	1.07	0.000	0.81	0.066	1.27	0.070	0.79	0.347
FLL	10.62	1.345	11.72	1.904	10.81	0.000	11.56	2.607	13.76	1.231	8.54	3.212
ELWR	50.67	5.397	50.89	3.315	46.09	0.000	48.72	2.211	56.70	0.739	53.59	7.769
RWC	55.36	4.789	54.19	3.844	54.90	0.000	54.25	0.101	60.74	2.105	63.12	9.065
SC	15.80	2.885	18.39	3.663	12.85	0.000	15.13	0.764	17.06	7.369	14.68	3.225
FV/FM	0.78	0.014	0.77	0.020	0.79	0.000	0.78	0.009	0.75	0.024	0.75	0.050

Table 9cont. The clusters average of 42 barley cultivars and their deviation from total mean

	1		2		3		4		5		6	
	Mean	Sdev.	Mean	Sdev.	Mean	Sdev.	Mean	Sdev.	Mean	Sdev.	Mean	Sdev.
SPAD	52.50	2.589	51.77	2.688	56.13	0.000	54.42	2.569	50.23	5.132	46.43	6.256
DTH	164.29	4.624	165.53	2.749	162.00	0.000	166.00	0.471	165.56	1.925	105.33	49.116
DTA	168.24	4.488	168.96	3.743	166.67	0.000	170.33	0.000	170.11	1.678	107.78	49.002
DTPM	196.00	3.836	198.00	2.264	194.33	0.000	199.50	2.593	196.67	1.528	133.11	55.654
NN	4.07	0.267	4.45	0.420	4.00	0.000	4.13	0.000	4.46	0.580	4.13	0.577
Phe	72.08	4.080	73.42	8.862	72.24	0.000	68.86	1.457	67.76	3.401	49.60	27.575
PL	19.85	1.763	20.68	4.216	19.32	0.000	21.25	1.556	19.21	5.847	12.87	8.598
SL	8.93	0.819	8.05	1.096	8.47	0.000	9.39	0.264	7.22	1.370	6.78	1.148
AL	13.15	1.179	11.85	1.209	12.83	0.000	15.15	0.471	11.60	1.938	11.59	1.069
GL	9.91	0.819	10.37	0.541	9.41	0.000	10.24	0.368	10.41	0.886	9.80	0.821
GW	3.36	0.148	3.15	0.209	3.45	0.000	3.43	0.082	3.27	0.264	3.13	0.128

Sdev.: standard Deviation, FLW: Flag Leaf Width, **FLL:** Flag Leaf Length, **ELWR:** Excised Leaf Water Retention, **RWC:** Relative Water Content, **SC:** Stomatal Conductance, **F_V/F_M:** Maximum quantum yield of psII, **SPAD:** Soil and Plant Analyzer Division, **WKPS:** Weight of Kernels Per Spike, **NKPS:** Number of Kernel Per Spike, **SW:** Spike Weight, **NN:** Number of Node, **Phe:** Plant Height, **PL:** Peduncle Length, **SL:** Spike Length, **AL:** Awn Length, **GL:** Grain Length, **GW:** Grain Width, **DTH:** Days to Heading, **DTA:** Days to Anthering, **DTPM:** Days to Physiological Maturity, **BY:** Biological Yield, **GY:** Grain Yield**, HLW:** Hectoliter Weight, **$NSPm^2$:** Number of Spike Per m^2, **TKW:** Thousand Kernel Weight.

CONCLUSION

Existence of significant differences in the most of the traits evaluated by analysis of variance revealed that these cultivars have the considerable potential to utilize in breeding programs. This result demonstrates that there was noticeable genetic diversity; therefore it could be used as suitable source for breeding programs. The results of the specific group comparisons showed that European cultivars had higher yield than Iranian cultivars, but larger genetic diversity among Iranian cultivars based on morpho-agronomic traits was observed than European cultivars.

The significant positive correlation between grain yield and the traits such as biological yield, straw yield and number of spike per m^2, indicates these traits can be considered to increase grain yield under reinfed. It could be concluded that indirect selection based on traits that have positive and significant correlation with grain yield can be used.

The results of factor analysis revealed that the traits of related to the first factor (the factor affecting vegetative and reproductive growth) give rise to the most differences among investigated cultivars. According to the obtained results, selection based on first factor could be considered as the desirable criteria for selecting superior barley cultivars under field conditions.

Path analysis corroborated the important role of biological yield on grain yield. It is concluded that, the direct selection for the maximum biological yield would enhance yield in barley. In totally, the results of this experiment revealed that the barley cultivars with high biological yield and number of spike per square meter are superior than other cultivars, and this should be considered in breeding programs.

In the current study, cluster analysis based on the assessed traits showed that cultivars were grouped in six clusters. According to the results of cluster analysis, genetic variation based on the all studied traits among the barley cultivars was not related to geographical location. The barley cultivars with same geographical location classified in the different groups according to grain yield. Every group could be represented by any individual belonging to that group; this will be useful in reducing the number of cultivars being tested in the next assessment.

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GENETIČKI DIVERZITET SORATA JEČMA

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Izvod

Poznavanje genetičkog diverziteta je od velikog značaja za dizajniranje odgovarajućih kriterijuma selekcije u oplemenjivačkim programima. U ovom radu, proučavan je genetički diverzitet sorata ječma (ukupno 42 iranske i evropske sorte), pomoću morfo-agronomskih svojstva, uključujući fenološka, fiziološka, morfološka svojstva, prinos zrna i druge povezane osobine. Analiza varijanse je pokazala visoku varijabilnost između sorata. Evropska sorte Panaka, Aiace i Pariglia imale su najviši prinos zrna. Rezultati grupnog poređenja ukazuju da su evropske sorte imale viši prinos zrna od iranskih, koje su pokazale veći diverzitet na osnovu morfo-agronomskih osobina. Korelaciona analiza je pokazala značajne korelacije između prinosa zrna i biološkog prinosa (0.92), prinosa slame (0.77), i broja klasova po kvadratu (0.67). Na osnovu faktorske analize, izdvojeno je šest faktora (sa 81.63% varijacije). Prvi factor sa najvećom eigen vrednošću je izdvojen kao značajan za vegetativan i reproduktivan porast. Path analiza je pokazala da je biološki prinos sa najvećim uticajem na prinos zrna (0.906)

Klaster analiza je grupisala sorte u šest grupa i pokazala da genetičke varijacije zasnovane na svim proučavanim svojstvima sorata ječma nisu povezane sa geografskim poreklom.

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