Original article

Assessment of genetic diversity of some Iran bread wheat (*Triticum aestivum* L.) landraces using multivariate statistical analysis

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Extended abstract

Introduction
It is expected that world wheat production would be about 761.5 million tons in 2020 while world demand would be doubled by 2025. Drought stress is one of the most important factors of yield loss that can decrease wheat production significantly. In the Middle East, drought stress usually happens at the end of the growing season and after the spike appearance. Late-season drought stress can slow down the seed development stage and decrease grain yield. In order to have stable food security one of the ways is to use the genetic diversity of germplasms.

Materials and methods
An association panel including 199 Iran bread wheat landraces was sown in Alborz and Zanjan provinces under late-season drought stress and normal irrigation conditions where climate zones are semi-arid. The experiments conducted using two alpha lattice designs with two replications for each of the conditions in each of the locations. The drip irrigation method was used for watering till spike appearance. Then, watering terminated for one of the designs whereas another design was normally irrigated for more three times in each location. Phenotypes measurements included days to heading, days to heading, duration of heading-to-maturity, plant height, grain yield/m2, thousand kernel weight, seed length, seed width, seed number per spike, spike length, spike weight, flag leaf length, flag leaf width, peduncle length, shoot diameter, and awn length.

Results and discussion
Agronomic traits varied lower under late-season drought stress conditions compared to normal irrigation conditions (except days to heading). Significant genetic effects observed for all of the traits under both irrigation systems. The genetic by environment effect was only significant for days to heading, days to heading, duration of heading-to-maturity, plant height, and grain yield. Heritability values were increased under normal irrigation conditions. Days to maturity and days to heading had

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lowest (0.35 and 0.47) and highest (0.85 and 0.86) heritability under both late-season drought stress and normal irrigation conditions, respectively. The highest correlation coefficients were achieved for the traits of days to heading and plant height (0.65) and grain yield/m2 with seed number per spike (0.60) under late-season drought stress conditions and the traits of days to heading and plant height (0.76) and spike weight with seed number per spike (0.64) under normal irrigation conditions. The first two components in principle components analyses were explained 0.40 of phenotypic variations under late-season drought stress conditions and 0.39 of phenotypic variations under normal irrigation conditions. A significant negative correlation was observed between days to heading and duration of heading-to-maturity under both late-season drought stress and normal irrigation conditions (-0.42 and -0.54, respectively). Using path analysis, thousand kernel weight (0.60) and seed number (0.79) under late-season drought stress conditions and days to heading (-0.57), days to maturity (0.40), duration of heading-to-maturity (-0.53), thousand kernel weight (0.52), and seed number per spike (0.81) under normal irrigation conditions had the highest direct effects on grain yield. The indirect effect of seed number through spike weight (0.51) on grain yield was highest under late-season drought stress conditions, and the indirect effect of days to heading through the duration of heading-to-maturity (0.42), as well as seed number through spike weight (0.52) on grain yield, were highest under normal irrigation conditions. The dendrograms obtained for grouping landraces showed a very good match with principal component analyses, while more landraces were placed in higher-yielding groups under normal irrigation conditions. The results showed that additional waterings increase grain yield in Iran bread wheat landraces. The landraces such as 57785, 57733, and 54502 are suggested to be used in applied breeding programs due to high yield performance under both late-season drought stress and normal irrigation conditions.

Conclusions
The results of this study suggest that the available genetic diversity of Iran bread wheat landraces be used in applied breeding programs.
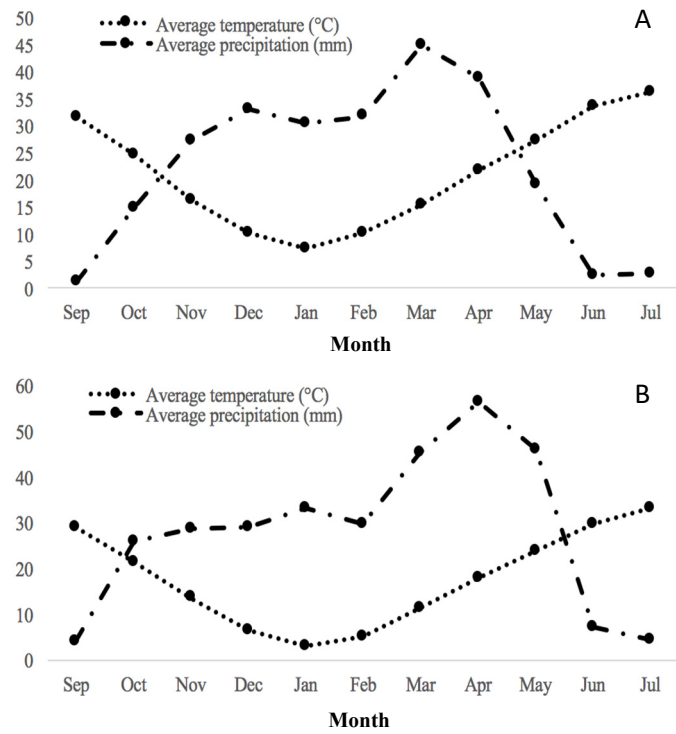
Fig. 1. Weather conditions at the research stations during 2017-2018 cropping season. A) Agricultural Research Farm of Karaj Islamic Azad University, Alborz province, and B) Kheirabad Agricultural Research Station located, Zanjan province. The average temperature (ºC) and precipitation (mm) are shown for the cropping season using the dotted and dashed lines, respectively.

Table 1. The name of 199 Iran bread wheat landraces used in the present study.

Row	Year of collection	Registered ID in UT	Row	Year of collection	Registered ID in UT	Row	Year of collection	Registered ID in UT
1	1940	2243-1	58	1959	6503-4	115	1959	6154-1
2	1957	5781-8	59	1957	5783-5	116	1959	6154-2
3	1959	6251-2	60	1957	5784-1	117	1959	6353-1
4	1964	7496-2	61	1957	5797-5	118	1966	7706-3
5	1964	7439-2	62	1958	5851-2	119	1966	7708-2
6	1961	7063-3	63	1959	6299-3	120	1966	7709-1
7	1961	7277-2	64	1959	6301-2	121	1966	7709-3
8	1961	6926-5	65	1959	6352-2	122	1940	2660-2
9	1964	7575-3	66	1959	6354-3	123	1959	6482-2
10	1961	7034-1	67	1961	6941-1	124	1959	6482-6
11	1960	6786-2	68	1959	6136-6	125	1959	6472-1
12	1961	6830-3	69	1959	6280-2	126	1940	2852-2
13	1961	6814-4	70	1959	6360-5	127	1968	8032-1
14	1961	6813-2	71	1959	6222-2	128	1957	5783-2
15	1941	3189-8	72	1959	6147-6	129	1959	6166-3
16	1961	6822-2	73	1959	6229-2	130	1959	6242-1
17	1941	3201-2	74	1958	5889-3	131	1959	6234-1
18	1961	7272-5	75	1959	6353-2	132	1931	382-2
19	1941	3227-6	76	1957	5781-1	133	1959	6326-4
20	1961	7280-3	77	1957	5781-4	134	1960	6717-5
21	1961	7280-2	78	1959	6354-2	135	1959	6345-1
22	1961	7149-2	79	1959	6351-1	136	1931	489-8
23	1961	6823-2	80	1959	6351-2	137	1948	5261-3
24	1961	6939-2	81	1959	6432-3	138	1959	6063-1
25	1964	7513-5	82	1961	7069-1	139	1940	2754-1
26	1959	6347-2	83	1939	1719-1	140	1959	6079-6
27	1961	6943-1	84	1950	5418-6	141	1959	5938-2
28	1961	6943-3	85	1950	5418-8	142	1947	5239-1
29	1960	6779-1	86	1956	5758-8	143	1948	5255-1
30	1960	6780-1	87	1966	7705-2	144	1961	6843-2
31	1961	7262-4	88	1959	6358-2	145	1961	6845-2
32	1959	6010-1	89	1966	7701-3	146	1961	6845-3
33	1960	6781-1	90	1961	7149-3	147	1966	7655-2
34	1961	7045-3	91	1966	7694-1	148	1939	2040-2
35	1961	7125-1	92	1964	7518-2	149	1959	5934-2
36	1964	7439-3	93	1964	7518-3	150	1959	6218-1
37	1961	7280-7	94	1964	7518-5	151	1960	6779-5
38	1959	6126-1	95	1957	5806-1	152	1956	5694-2
39	1959	6469-2	96	1961	7003-2	153	1962	7333-4
40	1959	6229-3	97	1964	7607-1	154	1959	6432-4
41	1959	6547-2	98	1939	2180-2	155	1961	7156-3
42	1963	7388-5	99	1960	6778-2	156	1964	7456-1
43	1959	6485-2	100	1960	6778-3	157	1964	7456-2
44	1959	5933-1	101	1959	6269-1	158	1964	7457-1
45	1959	6482-5	102	1959	6269-3	159	1964	7457-2
46	1959	6268-2	103	1961	6835-7	160	1961	7021-1
47	1947	5178-2	104	1939	1756-1	161	1964	7497-4
48	1959	5987-10	105	1960	6779-5	162	1961	6829-6
49	1959	6161-12	106	1961	7102-3	163	1953	5620-2
50	1959	6060-2	107	1959	6073-1	164	1957	5788-3
51	1959	6214-2	108	1957	5783-1	165	1959	6100-2
52	1959	6344-4	109	1961	7002-1	166	1959	6098-1
53	1964	7547-3	110	1964	7499-2	167	1956	5756-6
54	1959	6351-6	111	1966	7685-3	168	1950	5418-7
55	1939	2160-2	112	1961	7262-3	169	1956	5758-2
56	1940	2230-2	113	1961	6960-12	170	1956	5758-5
57	1968	8032-2	114	1957	5791-13	171	1940	2897-5

Table 1. Continued

Row	Year of collection	Registered ID in UT	Row	Year of collection	Registered ID in UT	Row	Year of collection	Registered ID in UT
172	1959	6043-3	182	1931	489-3	192	1959	6218-1
173	1966	7702-2	183	1931	500-9	193	1959	6218-2
174	1960	6717-6	184	1964	7556-3	194	1959	6267-4
175	1959	6282-2	185	1939	1761-2	195	1959	6291-1
176	1959	6282-3	186	1947	5208-3	196	1959	6301-1
177	1931	497-1	187	1948	5255-2	197	1959	6503-2
178	1931	484-1	188	1956	5747-3	198	1962	7333-1
179	1946	5164-2	189	1957	5778-5	199	1962	7335-1
180	1948	5251-3	190	1959	5938-7			
181	1931	489-2	191	1959	6070-1			

Table 2. Analysis of variance for 16 agronomic traits in a collection of 199 Iran bread wheat landraces under late-season drought stress

S.O.V	df	DTH	DTM	DHTM	PH	GY	TKW	SEL	SEW
Location	1	239558**	250576**	123.8**	86753**	3.17**	29367.73**	908.09**	198.8**
Replication/Location	2	11.72	0.08	9.95	0.59	0.00	0.00	0.03	0.03
Block (Replication/Location)	84	3.45	2.71	5.49	0.59	0.00	0.03	0.02	0.03
Genotype	198	174.5**	90.53**	133.16**	778**	0.02**	127.45**	1.92**	0.27**
Genotype × Location	198	25.9**	59.11**	68.19**	150**	0.00**	86.09	0.04	0.01
Error	312	3.31	2.88	6.27	0.81	0.00	0.03	0.02	0.02

Table 2. Continued

S.O.V	df	SN	SPL	SPW	FLL	FLW	PL	SHD	AWL
Location	1	15681**	239**	140**	5483.9**	1216.4**	10754.15**	30.85**	6.02**
Replication/Location	2	3.35	0.05	0.03	1.17	0.26	2.57	0.03	0.10
Block (Replication/Location)	84	2.73	0.11**	0.02	0.68	0.51	1.83	0.03*	0.33
Genotype	198	372.9**	10**	1.85**	37.78**	17.57**	430.54**	0.93**	23.1**
Genotype × Location	198	1.97	0.05	0.02	0.29	0.32	2.96	0.01	0.23
Error	312	3.24	0.07	0.03	0.67	0.44	1.80	0.02	0.28

Days to heading (DTH), Days to maturity (DTM), Duration of heading-to-maturity (DHTM), Plant height (PH), Grain yield/m^2 (GY), Thousand kernel weight (TKW), Seed length (SEL), Seed width (SEW), Seed number per spike (SN), Spike length (SPL), Spike weight (SPW), Flag leaf length (FLL), Flag leaf width (FLW), Peduncle length (PL), Shoot diameter (SHD), Awn length (AWL). ** and *: significant at 0.01 and 0.05 probability levels, respectively

Table 3. Analysis of variance for 16 agronomic traits in a collection of 199 Iran bread wheat landraces under normal irrigation conditions

S.O.V	df	DTH	DTM	DHTM	PH	GY	TKW	SEL	SEW
Location	1	234725**	272801**	1430**	68775**	5.6**	47470**	1019.8**	161.73**
Replication/Location	2	5.38	4.95	19.47	0.88	0.00	0.02	0.06	0.01
Block (Replication/Location)	84	2.75	1.78	4.68	1.06	0.00	0.02	0.03	0.03
Genotype	198	186.3**	90.61**	162**	725**	0.02**	128.8**	1.68**	0.27**
Genotype × Location	198	24.64**	43.89**	62**	139**	0.01**	87.73	0.02	0.01
Error	312	2.87	2.51	5.41	1.13	0.00	0.03	0.03	0.03

Table 3. Continued

S.O.V	df	SN	SPL	SPW	FLL	FLW	PL	SHD	AWL
Location	1	16182.06**	49.65**	756.23**	7285.1**	783**	12989**	18.9**	32.36**
Replication/Location	2	4.83	0.02	0.03	0.44	0.65	2.08	0.02	0.38
Block (Replication/Location)	84	6.21	0.10	0.04	0.83	0.28	5.30	0.03	0.19
Genotype	198	374.59**	10.16**	1.78**	38.52**	17.97**	423.03**	0.93**	21.67**
Genotype × Location	198	4.41	0.08	0.03	0.52	0.26	2.87	0.01	0.14
Error	312	6.29	0.11	0.03	0.85	0.41	4.22	0.03	0.23

Days to heading (DTH), Days to maturity (DTM), Duration of heading-to-maturity (DHTM), Plant height (PH), Grain yield/m² (GY), Thousand kernel weight (TKW), Seed length (SEL), Seed width (SEW), Seed number per spike (SN), Spike length (SPL), Spike weight (SPW), Flag leaf length (FLL), Flag leaf width (FLW), Peduncle length (PL), Shoot diameter (SHD), Awn length (AWL). ** and *: significant at 0.01 and 0.05 probability levels, respectively.

Table 4. Descriptive analysis and variance parameters for 16 agronomic traits in a collection of 199 Iran bread wheat landraces under late-season drought stress and normal irrigation conditions.

Irrigation conditions	Trait	Descriptive statistics			Variance parameters			
		Min	Mean	Max	σ_G^2	$\sigma_{(G \times E)}^2$	σ_E^2	H^2
Late-season drought stress	DTH	156	200.33	230	41.77	13.01	3.38	0.85
Normal irrigation		160	200.53	230	43.12	12.14	2.86	0.86
Late-season drought stress	DTM	192	246.54	276	8.84	31.46	2.83	0.35
Normal irrigation		210	252.3	280	11.46	25.13	2.37	0.47
Late-season drought stress	DHTM	5	46.21	79	19.53	35	6.12	0.51
Normal irrigation		22	51.76	116	24.61	33.34	5.33	0.58
Late-season drought stress	PH	49	105.57	151	173.24	86.23	0.76	0.80
Normal irrigation		64	110.86	157	158.06	79.26	1.11	0.81
Late-season drought stress	GY	0.03	0.22	0.51	0.12	0.12	0.04	0.63
Normal irrigation		0.05	0.29	0.69	0.16	0.09	0.07	0.72
Late-season drought stress	TKW	10.21	31.25	52	10.53	-	0.03	-
Normal irrigation		12.07	37.89	60.65	9.18	-	0.03	-
Late-season drought stress	SEL	3.3	6.51	9.7	0.51	-	0.02	-
Normal irrigation		3.4	6.68	9.9	0.46	-	0.03	-
Late-season drought stress	SEW	1.4	2.78	4	0.07	-	0.02	-
Normal irrigation		1.6	2.99	4.2	0.07	-	0.02	-
Late-season drought stress	SN	12	40.54	84	104.79	-	2.65	-
Normal irrigation		13	43.26	87	105.06	-	5.48	-
Late-season drought stress	SPL	4.2	10.12	15.7	2.8	-	0.07	-
Normal irrigation		5	10.61	15.9	2.79	-	0.1	-
Late-season drought stress	SPW	0.2	2.1	5.1	0.52	-	0.02	-
Normal irrigation		0.7	3.3	6.4	0.49	-	0.03	-
Late-season drought stress	FLL	9.5	22.35	37	10.52	-	0.53	-
Normal irrigation		13	26.3	41.6	10.91	-	0.71	-
Late-season drought stress	FLW	4	9.32	18.5	4.8	-	0.39	-
Normal irrigation		5	10.1	19	4.98	-	0.34	-
Late-season drought stress	PL	9.4	44.77	71.5	117.66	-	1.81	-
Normal irrigation		6.8	49.67	77.1	120.28	-	3.79	-
Late-season drought stress	SHD	2.1	3.37	5.2	0.26	-	0.02	-
Normal irrigation		2.3	3.53	5.3	0.26	-	0.02	-
Late-season drought stress	AWL	0.7	7.26	16.2	6.42	-	0.27	-
Normal irrigation		0.8	7.45	16.6	6.05	-	0.19	-

Genetic variance (σ_G^2), genotype by environment interaction variance ($\sigma_{(G \times E)}^2$), residual variance (σ_E^2), heritability (H^2), Days to heading (DTH), Days to maturity (DTM), Duration of heading-to-maturity (DHTM), Plant height (PH), Grain yield/m² (GY), Thousand kernel weight (TKW), Seed length (SEL), Seed width (SEW), Seed number per spike (SN), Spike length (SPL), Spike weight (SPW), Flag leaf length (FLL), Flag leaf width (FLW), Peduncle length (PL), Shoot diameter (SHD), Awn length (AWL).

Table 5. Pearson correlation coefficients for 16 agronomic traits in a collection of 199 Iran bread wheat landraces under late-season drought stress and normal irrigation conditions.

Trait صفت	DTH	DTM	DHTM	PH	GY	TKW	SEL	SEW
DTH		0.51**	-0.54**	0.76**	-0.16*	0.01	0.14*	-0.10
DTM	0.46**		0.27**	0.44**	-0.02	0.12	0.18**	-0.06
DHTM	-0.42**	0.24**		-0.40**	0.16*	0.08	-0.01	0.06
PH	0.65**	0.45**	-0.36**		-0.15*	-0.03	0.10	-0.11
GY	-0.15*	0.08	0.24**	-0.10		0.48**	0.10	0.09
TKW	0.01	0.08	0.06	-0.01	0.44**		0.37**	0.22**
SEL	0.10	0.24**	0.08	0.14*	0.11	0.36**		0.28**
SEW	-0.12	0.04	0.17*	-0.09	0.10	0.19**	0.29**	
SN	-0.19**	0.02	0.23**	-0.14*	0.60**	-0.09	-0.16*	-0.05
SPL	0.28**	0.27**	-0.10	0.32**	0.27**	-0.06	0.19**	-0.09
SPW	-0.06	0.20**	0.23**	0.04	0.58**	0.16*	0.30**	0.22**
FLL	0.00	0.12	0.10	0.12	0.26**	-0.02	0.04	0.01
FLW	-0.07	0.13	0.18**	-0.05	0.37**	0.02	0.05	0.08
PL	0.23**	0.17*	-0.12	0.28**	0.10	-0.02	0.13	0.05
SHD	-0.12	0.01	0.14*	-0.02	0.36**	0.01	-0.10	0.12
AWL	-0.21**	-0.17*	0.10	-0.23**	0.07	-0.04	0.06	-0.06

Table 5. Continued

Trait صفت	SN	SPL	SPW	FLL	FLW	PL	SHD	AWL
DTH	-0.20**	0.26**	-0.03	0.02	-0.06	0.24**	-0.13	-0.17*
DTM	-0.10	0.13	0.10	-0.02	0.03	0.13	-0.08	-0.10
DHTM	0.13	-0.18**	0.11	-0.04	0.08	-0.16*	0.08	0.11
PH	-0.16*	0.27**	0.00	0.08	-0.01	0.23**	-0.03	-0.27**
GY	0.62**	0.30**	0.61**	0.29**	0.38**	0.10	0.36**	0.04
TKW	-0.07	-0.06	0.18**	-0.02	0.01	-0.02	0.01	-0.05
SEL	-0.14*	0.20**	0.30**	0.05	0.01	0.14*	-0.10	0.02
SEW	-0.05	-0.06	0.23**	0.00	0.09	0.08	0.10	-0.06
SN		0.39**	0.64**	0.32**	0.42**	0.14*	0.39**	0.09
SPL	0.37**		0.41**	0.26**	0.19**	0.15*	0.23**	-0.12
SPW	0.60**	0.39**		0.34**	0.41**	0.16*	0.42**	0.10
FLL	0.30**	0.26**	0.30**		0.23**	0.25**	0.34**	0.04
FLW	0.40**	0.18**	0.42**	0.23**		0.25**	0.29**	0.08
PL	0.14*	0.15*	0.15*	0.23**	0.29**		-0.03	-0.01
SHD	0.40**	0.22**	0.43**	0.33**	0.28**	-0.04		-0.01
AWL	0.11	-0.12	0.13	0.05	0.13	0.02	-0.02	

Pearson correlation coefficients below the diagonal are under late-season drought stress conditions and upper the diagonal under normal irrigation conditions. Days to heading (DTH), Days to maturity (DTM), Duration of heading-to-maturity (DHTM), Plant height (PH), Grain yield/m² (GY), Thousand kernel weight (TKW), Seed length (SEL), Seed width (SEW), Seed number per spike (SN), Spike length (SPL), Spike weight (SPW), Flag leaf length (FLL), Flag leaf width (FLW), Peduncle length (PL), Shoot diameter (SHD), Awn length (AWL). ** and *: significant at 0.01 and 0.05 probability levels, respectively

Table 6. Path analysis for 16 agronomic traits in a collection of 199 Iran bread wheat landraces under late-season drought stress conditions.

Trait	Direct effect	Indirect effect						
		DTH	DTM	DHTM	PH	TKW	SEL	SEW
DTH	-0.16		0.06	0.10	0.02	0.01	0.00	0.00
DTM	0.11	-0.08		-0.03	0.02	0.05	0.00	0.00
DHTM	-0.13	0.12	0.03		-0.01	0.04	0.00	0.00
PH	0.04	-0.11	0.05	0.05		-0.01	0.00	0.00
TKW	0.60	0.00	0.01	-0.01	0.00		0.00	0.00
SEL	0.01	-0.02	0.03	-0.01	0.00	0.22		0.00
SEW	0.01	0.02	0.00	-0.02	0.00	0.11	0.00	
SN	0.79	0.03	0.00	-0.03	0.00	-0.05	0.00	0.00
SPL	-0.02	-0.05	0.03	0.01	0.01	-0.04	0.00	0.00
SPW	0.04	0.01	0.02	-0.03	0.00	0.10	0.00	0.00
FLL	0.01	0.00	0.01	-0.01	0.00	-0.01	0.00	0.00
FLW	0.03	0.01	0.01	-0.02	0.00	0.01	0.00	0.00
PL	-0.02	-0.04	0.02	0.02	0.01	-0.01	0.00	0.00
SHD	0.01	0.02	0.00	-0.02	0.00	0.01	0.00	0.00
AWL	0.00	0.03	-0.02	-0.01	-0.01	-0.02	0.00	0.00

Table 6. Continued

Trait	Direct effect	Indirect effect						
		SN	SPL	SPW	FLL	FLW	PL	SHD	AWL
DTH	-0.16	-0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DTM	0.11	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00
DHTM	-0.13	0.18	0.00	0.01	0.00	0.01	0.00	0.00	0.00
PH	0.04	-0.11	-0.01	0.00	0.00	0.00	-0.01	0.00	0.00
TKW	0.60	-0.07	0.00	0.01	0.00	0.00	0.00	0.00	0.00
SEL	0.01	-0.13	0.00	0.01	0.00	0.00	0.00	0.00	0.00
SEW	0.01	-0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.00
SN	0.79		-0.01	0.02	0.00	0.01	0.00	0.00	0.00
SPL	-0.02	0.29		0.01	0.00	0.01	0.00	0.00	0.00
SPW	0.04	0.51	-0.01		0.00	0.01	0.00	0.00	0.00
FLL	0.01	0.24	0.00	0.01		0.01	0.00	0.00	0.00
FLW	0.03	0.32	0.00	0.02	0.00		-0.01	0.00	0.00
PL	-0.02	0.11	0.00	0.01	0.00	0.01		0.00	0.00
SHD	0.01	0.32	0.00	0.02	0.00	0.01	0.00		0.00
AWL	0.00	0.09	0.00	0.01	0.00	0.00	0.00	0.00	

Days to heading (DTH), Days to maturity (DTM), Duration of heading-to-maturity (DHTM), Plant height (PH), Grain yield/m² (GY), Thousand kernel weight (TKW), Seed length (SEL), Seed width (SEW), Seed number per spike (SN), Spike length (SPL), Spike weight (SPW), Flag leaf length (FLL), Flag leaf width (FLW), Peduncle length (PL), Shoot diameter (SHD), Awn length (AWL). Residual effect² = 0.03.

Table 7. Path analysis for 16 agronomic traits in a collection of 199 Iran bread wheat landraces under normal irrigation conditions.

Trait	Direct effect	Indirect effect						
		DTH	DTM	DHTM	PH	TKW	SEL	SEW
DTH	-0.57		0.19	0.39	-0.01	0.01	0.00	0.00
DTM	0.40	-0.26		-0.4	-0.01	0.06	0.00	0.00
DHTM	-0.53	0.42	0.11		0.01	0.04	0.00	0.00
PH	-0.02	-0.38	0.18	0.21		-0.02	0.00	0.00
TKW	0.52	-0.01	0.05	-0.04	0.00		0.00	0.00
SEL	0.01	-0.08	0.07	0.01	0.00	0.19		0.00
SEW	-0.01	0.06	-0.02	-0.03	0.00	0.11	0.00	
SN	0.81	0.11	-0.04	-0.07	0.00	-0.04	0.00	0.00
SPL	-0.02	-0.15	0.05	0.10	0.00	-0.03	0.00	0.00
SPW	0.07	0.02	0.04	-0.06	0.00	0.09	0.00	0.00
FLL	0.02	-0.01	-0.01	0.02	0.00	-0.01	0.00	0.00
FLW	0.01	0.03	0.01	-0.04	0.00	0.01	0.00	0.00
PL	-0.02	-0.14	0.05	0.08	0.00	-0.01	0.00	0.00
SHD	0.01	0.07	-0.03	-0.04	0.00	0.01	0.00	0.00
AWL	-0.02	0.10	-0.04	-0.06	0.00	-0.03	0.00	0.00

Table 7. Continued

Trait	Direct effect	Indirect effect						
		SN	SPL	SPW	FLL	FLW	PL	SHD	AWL
DTH	-0.57	-0.16	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
DTM	0.40	-0.08	0.00	0.01	0.00	0.00	0.00	0.00	0.00
DHTM	-0.53	0.10	0.00	0.01	0.00	0.00	0.00	0.00	0.00
PH	-0.02	-0.13	-0.01	0.00	0.00	0.00	0.00	0.00	0.01
TKW	0.52	-0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.00
SEL	0.01	-0.11	0.00	0.02	0.00	0.00	0.00	0.00	0.00
SEW	-0.01	-0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00
SN	0.81		-0.01	0.05	0.01	0.00	0.00	0.00	0.00
SPL	-0.02	0.31		0.03	0.00	0.00	0.00	0.00	0.00
SPW	0.07	0.52	-0.01		0.01	0.00	0.00	0.00	0.00
FLL	0.02	0.26	-0.01	0.02		0.00	0.00	0.00	0.00
FLW	0.01	0.34	0.00	0.03	0.00		0.00	0.00	0.00
PL	-0.02	0.11	0.00	0.01	0.00	0.00		0.00	0.00
SHD	0.01	0.31	0.00	0.03	0.01	0.00	0.00		0.00
AWL	-0.02	0.07	0.00	0.01	0.00	0.00	0.00	0.00	

Days to heading (DTH), Days to maturity (DTM), Duration of heading-to-maturity (DHTM), Plant height (PH), Grain yield/m^2 (GY), Thousand kernel weight (TKW), Seed length (SEL), Seed width (SEW), Seed number per spike (SN), Spike length (SPL), Spike weight (SPW), Flag leaf length (FLL), Flag leaf width (FLW), Peduncle length (PL), Shoot diameter (SHD), Awn length (AWL). Residual effect^2 = 0.04

Table 8. Principle component analysis for 16 agronomic traits in a collection of 199 Iran bread wheat landraces under late-season drought stress and normal irrigation conditions.

Trait	Late-season drought stress			Normal irrigation		
	PC1	PC2	PC3	PC1	PC2	PC3
DTH	-0.10	0.54	-0.04	-0.10	0.55	0.04
DTM	0.12	0.36	0.19	0.00	0.29	-0.26
DHTM	0.20	-0.32	0.20	0.11	-0.37	-0.24
PH	-0.02	0.50	-0.01	-0.06	0.50	0.04
GY	0.44	-0.05	0.09	0.46	-0.03	-0.10
TKW	0.13	0.01	0.52	0.12	0.03	-0.55
SEL	0.11	0.15	0.53	0.09	0.17	-0.52
SEW	0.10	-0.05	0.42	0.10	-0.04	-0.38
SN	0.42	-0.07	-0.29	0.44	-0.06	0.24
SPL	0.24	0.30	-0.16	0.25	0.29	0.13
SPW	0.45	0.05	0.05	0.45	0.08	-0.10
FLL	0.26	0.09	-0.17	0.27	0.11	0.18
FLW	0.31	0.01	-0.09	0.31	0.03	0.09
PL	0.13	0.25	-0.04	0.12	0.25	0.02
SHD	0.30	-0.04	-0.19	0.31	-0.03	0.18
AWL	0.07	-0.19	-0.04	0.05	-0.19	0.03
Eigenvalue	3.61	2.77	1.76	3.57	2.75	1.77
Proportion	0.23	0.17	0.11	0.22	0.17	0.11
Cumulative	0.23	0.40	0.51	0.22	0.39	0.50

The results of first three principle components (PCs) are given. Days to heading (DTH), Days to maturity (DTM), Duration of heading-to-maturity (DHTM), Plant height (PH), Grain yield/m^2 (GY), Thousand kernel weight (TKW), Seed length (SEL), Seed width (SEW), Seed number per spike (SN), Spike length (SPL), Spike weight (SPW), Flag leaf length (FLL), Flag leaf width (FLW), Peduncle length (PL), Shoot diameter (SHD), Awn length (AWL).
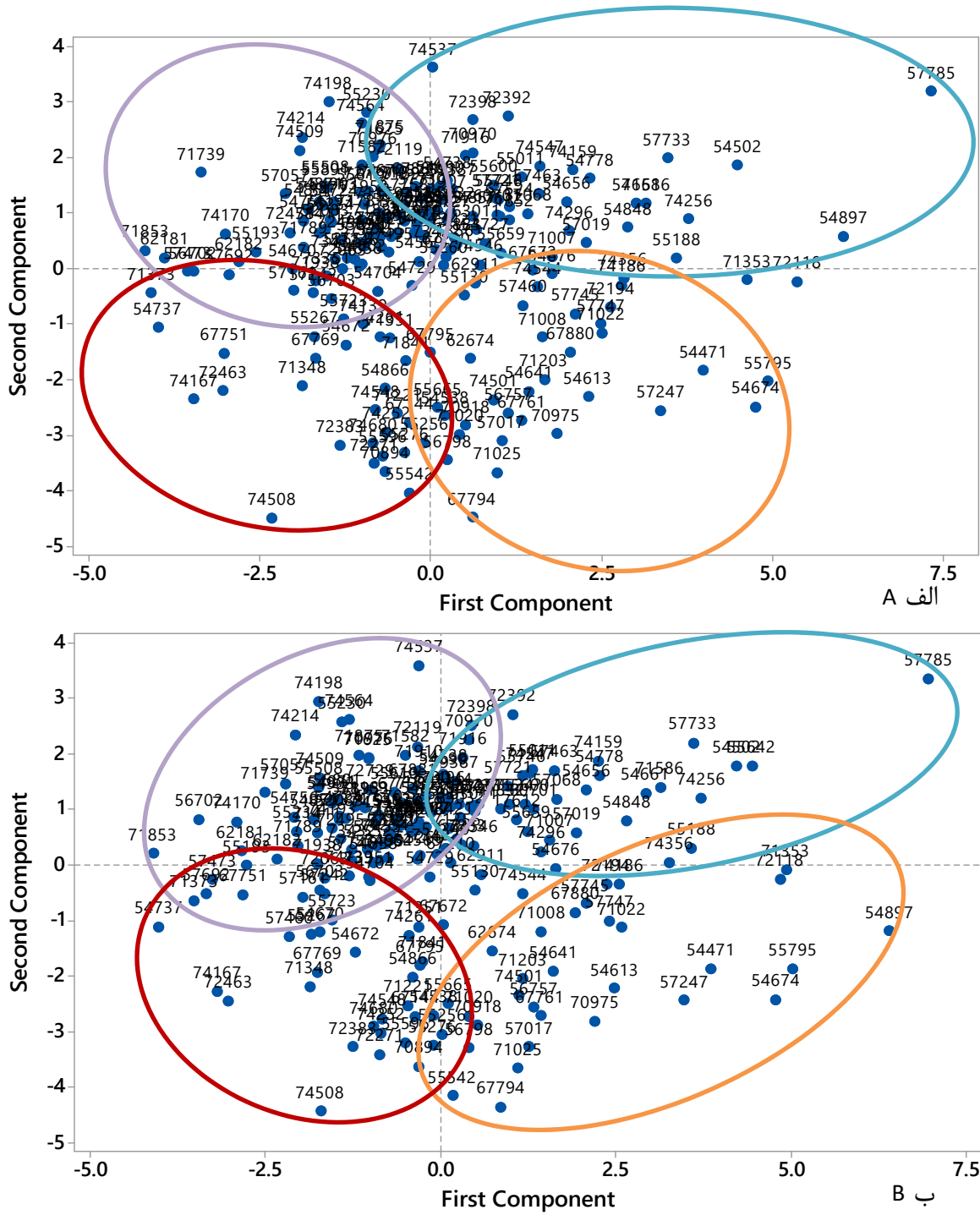
Fig. 2. Bi-plot of the principal component analysis using the first two components for the 199 Iran bread wheat landraces under (A) late-season drought stress and (B) normal irrigation conditions.
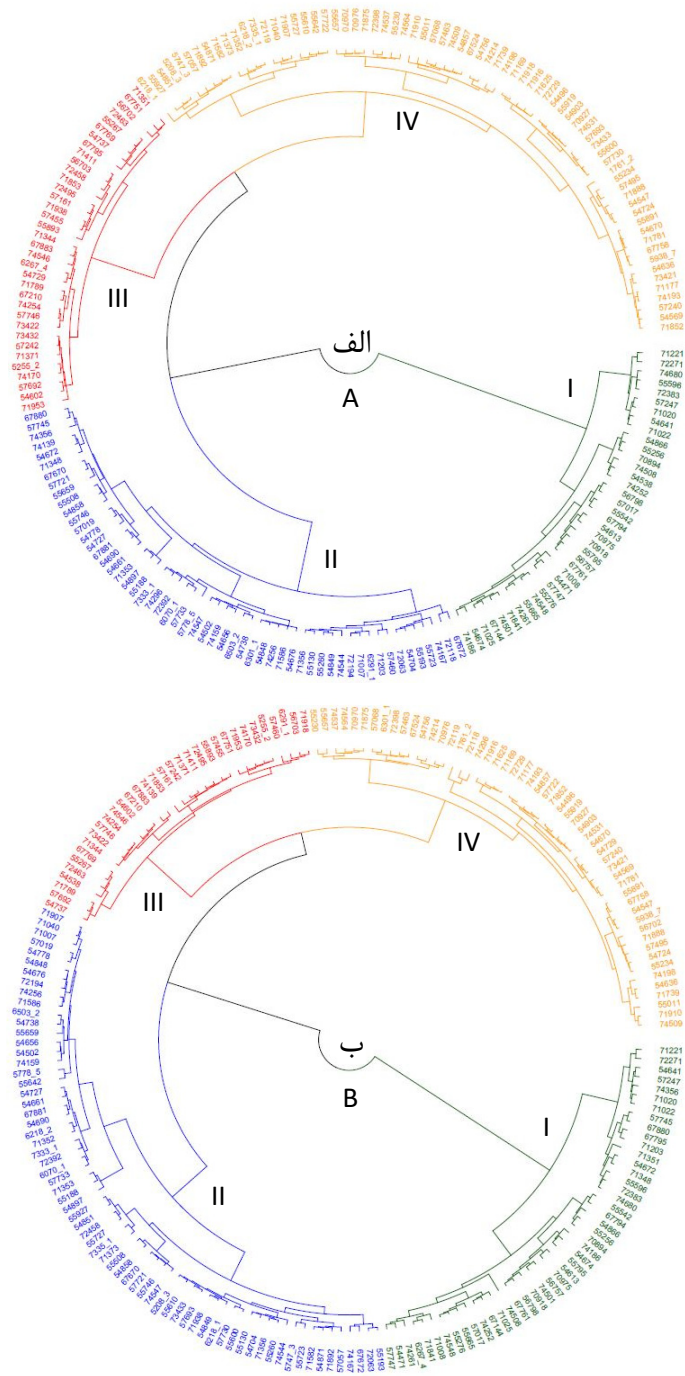
Fig. 3. Dendrogram of the 199 Iran bread wheat landraces using 16 agronomic traits under (A) late-season drought stress and (B) normal irrigation conditions.