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RESEARCH ARTICLE

Multivariate analyses of indigenous bread wheat (*Triticum aestivum* L.) landraces of Oman

Ali Hussain Al Lawati[1]*, Saleem Kaseemsaheb Nadaf[2], Nadiya Abubakar Al Saady[2], Saleh Ali Al Hinai[3], Almandhar Almamari[2], Abdulaziz Al Maawali[2]

[1]Assistant Professor, Plant Genetics, Natural and Medical Sciences Research Center, University of Nizwa, P.O. Box 33, PC 616, Birkat Al-Mauz, Nizwa, Sultanate of Oman, [2]Oman Animal & Plant Genetic Resources Center, Ministry of Higher Education, Research, and Innovation, SQU Campus, Al-Khod, PO Box 92, PC 123, Sultanate of Oman, [3]Jimah Agriculture Research Station, Directorate General of Agriculture & Livestock Research, Ministry of Agriculture & Fisheries, Jimah, Bahla, Al-Dakhiliya, Sultanate of Oman

ABSTRACT

Oman is endowed with enormous diversity of important food crops that have global significance for food security and has ancient history of cultivation of bread wheat (*Triticum aestivum* L.) with its divergent landraces, which are useful in crop improvement. 55 indigenous Omani accessions conserved at the USDA were evaluated in the winter season (November to April) of the years 2017-2018 and 2018-2019 on loamy soil under sprinklers in augmented design with 5 check varieties in 5 replications following crop husbandry practices as per national recommendations using 9 quantitative (descriptors) and 6 qualitative traits (anthocyanin pigmentation on plant parts). The data on traits were subjected not only for PC values and D values after varimax rotation through Kaiser normalization in Principal Component Analysis (PCA) but also for Agglomerative Hierarchical Clustering (AHC). The results indicated that indigenous bread wheat accessions were significantly different ($p>0.05$) for all the quantitative traits except number of tillers. The multivariate analyses led to formation of four diverse clusters from PCA analyses corresponding to four quadrants of bi-plot graphs and three clusters from AHC analysis corresponding to main clades of dendrogram. The parents were selected from common accessions of distinct clusters in all the multivariate analyses for hybridization for improving characters of growth for higher yield or productivity with pigmentation on one or two plant parts useful for DUS test of varieties. The indigenous bread wheat landraces/accessions were genetically diverse and have potential for use in national crop improvement programs for earliness and higher grain productivity with distinct identification markers.

Keywords: Accessions; Bread wheat; Clusters; Genetic diversity indigenous; Quantitative traits; Pigmentation

INTRODUCTION

Wheat is the most important food crop with a well-known global significance not only in terms of food security especially in developing countries after rice (an estimated 80 million farmers rely on wheat for their livelihoods) (Giraldo et al., 2019) but also in terms of climate change resilience because of its agronomic adaptability, ease of grain storage and multiple uses (Curtis, 2019; Giraldo et al., 2019). It is the most widely grown crop on the global level with more than 218 million ha cultivated and 734.74 million tons total production (Statistica, 2020), a world trade greater than all other crops combined (Curtis, 2019). Wheat, consumed as whole grains boiled or as bread from its flour in many ways, is not only a staple source of carbohydrates and nutrients for around 40% of the world's population providing 20% of the daily protein and food calories (Curtis, 2019).

Oman is endowed with rich diversity of food crops like wheat, which has been also nationally, regarded as the strategic food crop (MAF, 2005). It is grown in the country's diversified agro-ecological regions as indicated by large number of indigenous accessions collected during several FAO collaborated and national collecting missions undertaken since early 1980's (Guarino, 1990, MAF, 2012-2014). This is perhaps owing its strategic position in the middle east region and also its ancient trade relations with Iraq since before 3000 BCE in the *fertile crescent region* that covers Mesopotamia, the home of the earliest known human civilizations and origin of wheat species and landraces including allohexaploid bread wheat (6x=2n=42) around 4500 BCE (Zohary and Hoph, 2000; Gebauer et

Corresponding author:
Ali Hussain Al Lawati, Assistant Professor, Plant Genetics, Natural and Medical Sciences Research Center, University of Nizwa, P.O. Box 33, PC 616, Birkat Al-Mauz, Nizwa, Sultanate of Oman. **E-mail:** ali.allawati@unizwa.edu.om

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al., 2010; Zohary et al., 2012; Frenez (2018). Such landraces available with the farming community are the products of selections since centuries that resulted in resilience to different stress conditions such as extreme adverse edaphic, abiotic, biotic factors and climate change (Dwivedi et al., 2016; Azeez et al., 2018). In Oman, a wide array of variation has been recorded among different indigenous landraces of bread wheat in terms of quantitative characters that are related to yield and yield related traits as well as qualitative traits like pigmentation and other descriptors of wheat which are very important for crop improvement programs including breeding and selection (Al-Khanjari et al., 2008; Jaradat, 2013; Hammer et al., 2014; Jaradat and Shahid, 2014; McCouch, 2014). As they represent significantly broader genetic diversity, they are the best candidates as source of stress tolerance and some grain quality genes transferable to their relative commercial crops (Zeven, 2000; Almekinders and Elings, 2001(Maxted et al., 2010; Azeez et al., 2018).

The analysis and characterization of phenotypic diversity to identify phenotypic traits contributing to the total diversity in a germplasm collection and characterize the levels of similarity/dissimilarity among the cultivars depending on the position of accessions in the clusters formed through multivariate analysis have significance in crop improvement program (Deylong, 2011; Al-Khateeb, 2005; Rymuza et al., 2012; Baranwal et al., 2013; Mishra et al., 2015; Qaseem et al.,2018). Multivariate data analysis includes powerful statistical tools for simultaneously analyzing data with many characters/variables to resolve the patterns of diversity among the accessions and relationships between them in terms of affinity in terms of similarity. The most relevant multivariate analytical techniques for morphological characterization of genotypes are principal component analysis (PCA) with correlation matrix, PCA with Kaiser rule (varimax rotation) and agglomerative cluster analysis (AHC) (Mohammadi and Prasanna,2003; Walker, 2012). The combination of these statistical methods provides comprehensive information of the variables/characteristics contributing significantly to genetic diversity in plants (Khodadadi et al.,2011; Awan et al., 2015: Ebrahimnejad and Rameeh, 2016). Recently, Sant 'Anna et al. (2020) attempted to compare to compare different graphical dispersion analysis techniques such as principal component analysis (PCA), and principal coordinate analysis (PCoA) in two- or three-dimensional planes using the data from different published works of six different crop species for determination of the best methodology to analyze the genetic diversity in the germplasm. The efficiency was measured in terms of major components contributing to dispersion or diversity to the amount of total variation originally available and retained by the principal components. The authors concluded in favor of principal coordinate analysis as superior in terms of graphical dispersion efficiency in two-or three-dimension planes. The objectives of the present study were to i). evaluate the phenotypic diversity in 55 indigenous bread wheat (*Triticum aestivum* L.) landraces of Oman repatriated from USDA gene bank using three potential multivariate analytical techniques, ii). identify specific traits, iii). comprehend common relationships among the studied landraces and iv). select accessions for their use as parents for hybridization in national crop improvement programs. The use of three multivariate techniques is based on the assumption to identify common close relatives occurring in the same cluster across three techniques and select accessions with desirable traits in each cluster as parents.

MATERIALS AND METHODS

Material

Fifty-five bread wheat (*Triticum aestivum* L.) USDA accessions of landraces of Oman collected under FAO program in 1980's and 1990s and deposited by international FAO collectors in USDA gene bank, were repatriated by Oman Animal & Plant Genetic Resources Center (OAPGRC) of The Research Council in 2017 (Table 1; Fig. 1).

Experimental site, design, and cultural practices

These accessions were evaluated consecutively for two years 2017-2018 and 2018-2019 in winter season from November to March on loamy soil layouts under sprinkler irrigation at the Agricultural Research Station, Jimah (22.94006320N; 57.2738612E; 535 m above msl (mean sea level)), Al-Dakhliyah (Interior Oman) governorate. These bread wheat accessions were planted in 3-m three-row plots at spacing of 0.2 m between rows and 0.15 m between plants under augmented design with five check varieties viz. WQS-302; WQS-305; WQS-308; Jimah-1 and Jimah-110 replicated five times, randomized and distributed throughout the

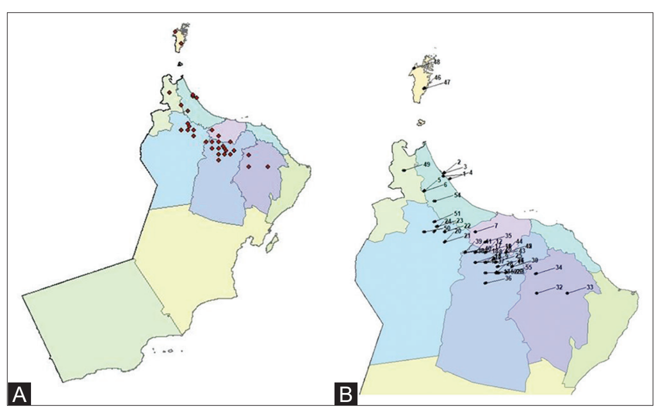

Fig 1. The distribution of locations in North Oman where indigenous bread wheat (*Triticum aestivum*) accessions were collected (A) and the number of accessions collected in respective locations (B).

Table 1: Fifty-five Indigenous Omani bread wheat (*Triticum aestivum L)* USDA accessions repatriated from USDA gene bank used in the study along with names of wilayats, governorates, latitude (N), longitude (E), and altitude of each location of their collection during 1990s by MAF-FAO joint collecting missions (Guarino, 1990)

Sl. No.	USDA Accession No.	Village	Wilayat	Governorate	Latitude (N)	Longitude(E)	Altitude(m)
1	PI 532236	12km NW of Sohar, N. Batinah Province.	Sohar	Batinah North	24.411	56.642	16
2	PI 532237	Majis, N. Batinah Province.	Sohar	Batinah North	24.456389	56.65361	16
3	PI 532238	Majis, N. Batinah Province.	Sohar	Batinah North	24.456389	56.65361	16
4	PI 532240	2km SE of Sohar, N. Batinah Province.	Sohar	Batinah North	24.366667	56.75	1
5	PI 532241	32km SW of Majis, W. Hajar Province.	Sohar	Batinah North	24.166667	56.33333	500
6	PI 532243	32km SW of Majis, W. Hajar Province.	Sohar	Batinah North	24.166667	56.33333	500
7	PI 532244	30km W of Rustaq, Western Hajar Province	Rustaq	Batinah South	23.500001	57.16667	450
8	PI 532245	2km E of Bahla, Interior Province.	Bahla	Al Dakhiliya	23.0001	57.33333	500
9	PI 532246	2km E of Bahla, Interior Province.	Bahla	Al Dakhiliya	23.0001	57.33333	500
10	PI 532247	2km NE of Al Hamra, Interior Province	Al Hamra	Al Dakhiliya	23.166667	57.33333	500
11	PI 532248	2km NE of Al Hamra, Interior Province	Al Hamra	Al Dakhiliya	23.166667	57.33333	500
12	PI 532249	1-2km from Al Hamra, Interior Province	Al Hamra	Al Dakhiliya	23.166667	57.33333	500
13	PI 532250	extensive wadi bed of plain, 10km SE of Jabrin, Interior Province	Bahla	Al Dakhiliya	22.833333	57.33333	400
14	PI 532251	6km N of Al Ayshi, Interior Province	Al Hamra	Al Dakhiliya	23.0001	57.16667	500
15	PI 532252	6km N of Al Ayshi, Interior Province	Al Hamra	Al Dakhiliya	23.0001	57.16667	500
16	PI 532253	6km N of Al Ayshi, Interior Province	Al Hamra	Al Dakhiliya	23.0001	57.16667	500
17	PI 532254	10km NNE of Al Ayshi, Interior Province	Al Hamra	Al Dakhiliya	23.166667	57.16667	500
18	PI 532255	10km NNE of Al Alshi, Interior Province	Al Hamra	Al Dakhiliya	23.166667	57.16667	500
19	PI 532256	20km SE of Nizwa, Interior Province	Manah	Al Dakhiliya	22.833333	57.66667	350
20	PI 532257	15km NE of Ibri, Dhahirah Province	Ibri	Al Dhahirah	23.333333	56.66667	300
21	PI 532258	15km NE of Ibri, Dhahirah Province.	Ibri	Al Dhahirah	23.333333	56.66667	300
22	PI 532259	30km NE of Ibri, Dhahirah Province	Ibri	Al Dhahirah	23.5	56.66667	400
23	PI 532260	Yankul, Dhahirah Province	Yankul	Al Dhahirah	23.585556	56.54083	500
24	PI 532261	19km SW of Yankul, Dhahirah Province	Dhank	Al Dhahirah	23.5	56.5	400

(*Contd*....)

Table 1: (*Continued*)

Sl. No.	USDA Accession No.	Village	Wilayat	Governorate	Latitude (N)	Longitude(E)	Altitude(m)
25	PI 532262	12km N of Nizwa, Interior Province	Nizwa	Al Dakhiliya	23.0001	57.5	450
26	PI 532263	Tanuf, Interior Province	Nizwa	Al Dakhiliya	23.055278	57.46833	500
27	PI 532264	Nizwa, Interior Province	Nizwa	Al Dakhiliya	22.933333	57.53333	450
28	PI 532265	5km N of Nizwa, Interior Province	Nizwa	Al Dakhiliya	22.833333	57.5	400
29	PI 532266	5km N of Nizwa, Interior Province	Nizwa	Al Dakhiliya	22.833333	57.5	400
30	PI 532267	Izki, Interior Province.	Izki	Al Dakhiliya	22.933333	57.76667	400
31	PI 532268	Nizwa, Interior Province	Nizwa	Al Dakhiliya	22.933333	57.53333	500
32	PI 532269	10km NW of Mudaybi, Sharqiya Province.	Mudaybi	Alsharqya North	22.5	58.16667	400
33	PI 532270	15km S of Ibra, Sharqiya Province.	Ibra	Alsharqya North	22.5	58.66667	400
34	PI 532271	Samad, Sharqiya Province	Mudaybi	Alsharqya North	22.817778	58.15583	600
35	PI 532272	30km W of Rustaq, Western Hajar	Rustaq	Batinah South	23.333333	57.33333	700
36	PI 532273	35km S of Jabrin, Interior Province	Bahla	Al Dakhiliya	22.666667	57.33333	400
37	PI 532274	3km SW of Bahla, Interior Province	Bahla	Al Dakhiliya	23.0001	57.33333	500
38	PI 532275	30km NW of Bahla, Interior Province	Ibri	Al Dhahirah	23.166667	57.0001	900
39	PI 532276	30km NW of Bahla, Interior Province	Ibri	Al Dhahirah	23.166667	57.0001	900
40	PI 532277	35km NW of Bahla, Interior Province	Ibri	Al Dhahirah	23.166667	57.0001	700
41	PI 532278	25km W of Al Hamra, Interior Province	Al Hamra	Al Dakhiliya	23.166667	57.16667	1100
42	PI 532280	20km N of Birkat al Mawz, Jebel Akhdar Province	Nizwa	Al Dakhiliya	23.166667	57.66667	1700
43	PI 532282	25km N of Birkat al Mawz, Jebel Akhdar Province	Nizwa	Al Dakhiliya	23.166667	57.66667	1800
44	PI 532283	25km N of Birkat al Mawz, Jebel Akhdar Province	Nizwa	Al Dakhiliya	23.166667	57.66667	1800
45	PI 532284	20km N of Birkat al Mawz, Jebel Akhdar Province	Nizwa	Al Dakhiliya	23.166667	57.66667	1600
46	PI 532285	25km N of Bayah, Musandam Province	Khasab	Musandam	25.833333	56.33333	300
47	PI 532286	50km N of Bayah, Musandam Province.	Khasab	Musandam	25.833333	56.33333	400
48	PI 532290	30km S of Khasab, Musandam Province	Khasab	Musandam	26.166667	56.16667	1200

(*Contd....*)

Table 1: (*Continued*)

Sl. No.	USDA Accession No.	Village	Wilayat	Governorate	Latitude (N)	Longitude(E)	Altitude(m)
49	PI 532293	45km NE of Buraimi, Jau and Buraimi Province	Buraimi	Al Buraimi	24.5001	56.0001	400
50	PI 532294	Wadi Qurayat Res. Stat., Dank, Dhahirah Province.	Dhank	Al Dhahirah	23.5001	56.33333	300
51	PI 532295	Wadi Qurayat Res. Stat., Dhahirah Province.	Yankul	Al Dhahirah	23.666667	56.5	300
52	PI 532296	Wadi Qurayat Res, Stat., Nizwa, Interior Province.	Nizwa	Al Dakhiliya	22.833333	57.5	400
53	PI 532297	Wadi Qurayat Res, Stat., Nizwa, Interior Province.	Nizwa	Al Dakhiliya	22.833333	57.5	400
54	PI 532298	50km SW of Sohar, Western Hajar Province	Sohar	Batinah North	24.0001	56.5	400
55	PI 532301	20km SE of Nizwa, Interior Province	Nizwa	Al Dakhiliya	22.833333	57.66667	350

experimental field. All the crop husbandry practices were practiced according to national recommendations of the Ministry of Agriculture & Fisheries (MAF), Oman (Akhtar and Nadaf, 2001) to raise a successful crop.

Data collection

The observations were recorded on pigmentation in various plant parts at respective growth stages when the pigmentation attained intense and clear and that on grain color were recorded at laboratory after harvest and threshing of spikes. The days to flowering and maturity were recorded as when each plot attained 50% flowering and 90% maturity of grains, respectively. The characters such as tiller number/plant, spike density, spikes/spike, grains/spike, grain length (mm), grain width (mm) and 1000-grain weight (g) were measured (IBPGR, 1995). The images of general view of the experiment and some selected studied quantitative traits related to spike and awned features of spikelets and qualitative traits like pigmentation on selected plant parts, are presented in Plate Box 1.

Statistical analyses of data

Analysis of variance, correlation analysis, principal component analysis (PCA) including Kaiser's varimax rotation, agglomerative hierarchical clustering (AHC) were performed by XLSTAT –software for Excel (XLSTAT, 2019). The combined analysis of variance of two-year data of check varieties, in the present study, revealed non significance of the effect of G (Check accessions) x E (environment/year) interaction ($p>0.05$) for each of the character. PCA was performed on the correlation matrix of two-year means of agro-morphological (quantitative) characters and scores of presences (1) and absence (0) of anthocyanin pigmentation on six plant parts (qualitative) in indigenous bread wheat accessions. The data on plant height, growth habit and awns were not used for statistical analysis as all the accessions were tall, erect and awned, respectively, in their morphological features. Similarly, grain color character was also not included in analysis owing to absence of appropriate measurement for distinctness although landraces had substantial variation in grain color from yellowish to dark brown. These landraces of bread wheat are all tall because of consistent overtime selection for tall types over centuries by the local famers traditionally for use of their straw after harvesting grains to feed on their livestock. (Table 2).

RESULTS

Variation in quantitative and qualitative characters among Omani bread wheat landraces

The grand-mean values over two cropping seasons for nine quantitative growth and yield attributes of Omani bread wheat landraces with USDA accession nos. are presented in Table 2. The accessions were found to be significantly ($p<0.05$) to highly significantly ($p<0.01$) different for all the quantitative characters except number of tillers and had higher magnitude of variation in respect of all the characters (Table 3). These landrace USDA accessions were similar ($p>0.05$) for plant stature (tall), erect growth habit and presence of awns (Table 2) and hence were not subjected to either correlation or multivariate analyses.


Plate 1. General view of the experiment (2018-19 season)


Plate 2. Awned spikelets


Plate 3. Dense awnleted spike


Plate 4. Lax spike without awns


Plate 5. Coleoptile purple

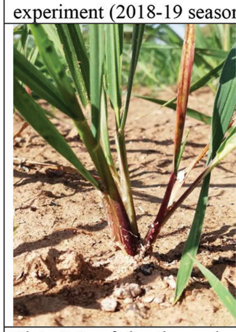
Plate 6. Leaf sheath purple


Plate 7. Both node & internode -green


Plate 8. Node green & internode purple


Plate 9. Both node & internode purple


Plate 10. Auricle purple

Plate Box 1. Images of general view of the experiment and some selected studied quantitative traits related to spike and awned features of spikelets and qualitative traits like pigmentation on selected plant parts observed in bread wheat landraces of Oman.

The accessions were the most diverse in respect of days to flowering from 60 days (PI 532293 and PI 532301) to 95 days (PI 532280) and for days to maturity from 101 days (PI 532301) to 132 days (PI 532251 and PI 532252) in comparison with other characters studied. The spike density ranged from score 5 (intermediate) to 7 (dense) of which majority were with dense spikes. The spikelets/spike varied from 38 (PI 532247) to 99 (PI 532252) whereas grains/spike ranged from 35 (PI 532247) to 98 (PI 532252). The accessions were also found to be diverse with respect to seed/grain associated traits especially with respect to grain width and 1000-grain weight. The accessions, PI 532259, PI 532260, PI 532274, and PI 532295 showed the lowest grain width with 2.1 mm whereas the accession, PI 532276 had the highest grain width. The highest 1000-grain weight of 44.5 g was found in the accession PI 532268 followed by two accessions, PI 532296 (42.8 g) and PI 532267 (42.6 g). The grain length, however, ranged from 4.25 mm (PI 532272) to 8 mm (PI 532295) (Tables 2 and 3). In respect of qualitative traits, as many as 44 accessions had cement leaf color vs parrot green followed by 35 accessions with coleoptile purple, 32 accessions with purple node, 31 accessions with internode purple and 8 accessions with purple sheath. Only two accessions viz. PI 532237 and PI 532301 had auricles purple. (Table 2).

Correlation among agro-morphological traits

Of 36 combinations of Pearson simple correlations among 9 quantitative characters studied, eleven correlations involving all the characters except grain length were found significant ($p<0.05$) (Table 4). Of these correlations, the correlation of days to flowering with days to maturity (0.489**), grains/spike (0.289*) and spike density (0.328*) were positive and significant ($p<0.05$). The spikelets/spike had significant and positive association with tiller no. (0.274*), grains/spike (0.958**) and spike density (0.293*) while the correlation between spikelets/spike and 1000-grain weight was significantly negative (-0.333*) ($p<0.05$). On the other hand, the association of grains/spike with spike density (0.312*) and tiller number (0.307*) was positive and significant ($p<0.05$) whereas its association with 1000-grain weight (-0.327*) was negative and significant ($p<0.05$). Similarly, the correlation between grain width and spike density was significantly negative (-0.296*; $p< 0.05$).

Multivariate analyses

Fifty-five bread wheat landrace USDA accessions were subjected to PCA with or without varimax rotation (Kaiser normalization) using correlation matrix of nine quantitative characters and the scores of six qualitative characters to measure the diversity in the form of clusters and evaluate the relative contributions of different characters to the total variability. Besides, the same data were subjected to AHC for the formation of clusters through dendrogram analysis.

The results of PCA indicated that first eight principal components/factors were accounted for 79.110% of

Table 2: Aggregate means of the agro-morphological quantitative characters over two cropping seasons (2017-2018 & 2018-2019) of 55 indigenous Omani bread wheat USDA accessions repatriated from USDA gene bank

Accession No.	Plant height	Days to flowering	Days to maturity	Spikelets/ spike	Grains/ spike	Grain Length (mm)	Grain width (mm)	1000 grain weight (g)	Growth Habit	Tiller No.	Awns	Spike density	Grain Color[1]	Coleoptile color	Node Color	Internode Color	Leaf Color	Leaf Sheath Color	Auricle Color
PI 532236	Tall	74	115	78	75	5.6	2.38	24.8	3	7	3	7	Y	1	1	1	1	0	0
PI 532237	Tall	63	112	77	76	6.93	2.91	32.4	3	4	7	7	LB	0	0	0	0	0	1
PI 532238	Tall	74	112	91	88	5.5	3.03	31.1	3	6	5	7	MB	1	0	0	1	0	0
PI 532240	Tall	72	112	71	68	6.79	2.95	27.8	3	7	2	7	DB	1	0	0	1	0	0
PI 532241	Tall	66	110	88	85	6.48	2.76	21.3	3	7	7	6	DB	0	0	0	1	0	0
PI 532243	Tall	74	115	71	67	6.02	3.4	30.5	7	8	2	7	MB	1	1	1	1	1	0
PI 532244	Tall	80	120	62	60	5.75	3.39	29.8	3	8	3	7	MB	0	1	1	1	1	0
PI 532245	Tall	82	127	66	64	5.8	3.81	28	7	7	3	7	Y	0	0	0	1	1	0
PI 532246	Tall	80	116	74	67	6.18	3.3	29.2	3	8	3	7	Y	1	1	1	1	0	0
PI 532247	Tall	60	112	38	35	5.94	2.94	39.9	3	3	7	6	Y	0	1	1	0	0	0
PI 532248	Tall	82	127	63	60	5.4	3.44	30.1	3	7	3	7	MB	1	0	0	1	0	0
PI 532249	Tall	76	116	47	45	6.39	3.56	39.8	3	4	3	7	LB	1	1	1	1	0	0
PI 532250	Tall	83	127	90	89	5.99	3.28	26.6	3	5	3	7	LB	0	1	1	1	0	0
PI 532251	Tall	81	132	64	61	5.63	2.73	23.8	3	3	3	7	LB	1	1	1	1	0	0
PI 532252	Tall	79	132	99	98	5.91	3.22	27.9	3	8	3	7	DB	1	1	1	1	0	0
PI 532253	Tall	74	127	81	79	7.44	3.11	34.1	3	8	3	7	Y	1	1	1	1	0	0
PI 532254	Tall	76	112	48	44	7.73	3.64	37.3	3	4	2	6	Y	0	0	0	0	0	0
PI 532255	Tall	76	110	73	67	7.42	3.29	25.4	3	8	7	7	Y	1	1	1	1	0	0
PI 532256	Tall	76	112	80	78	5.7	2.7	32.5	3	5	3	7	DB	1	1	1	1	0	0
PI 532257	Tall	79	112	85	82	6.2	2.2	31.9	3	7	3	7	Y	1	1	1	1	0	0
PI 532258	Tall	93	116	88	84	7.16	2.93	28.1	3	3	7	7	DB	1	1	1	1	1	0
PI 532259	Tall	81	112	79	75	5.33	2.1	33.1	3	4	3	7	DB	1	0	0	0	1	0
PI 532260	Tall	76	112	63	60	6.14	2.1	30.7	3	8	3	7	Y	1	0	0	0	1	0
PI 532261	Tall	74	115	55	51	5.4	2.4	27.5	3	7	7	7	Y	0	1	1	1	0	0
PI 532262	Tall	72	112	64	59	6.56	2.17	31.1	3	6	7	7	DB	0	1	0	1	0	0
PI 532263	Tall	72	116	65	64	5.4	2.8	34	3	5	7	7	Y	0	0	0	1	0	0
PI 532264	Tall	69	115	67	65	6.05	3.44	35.8	3	4	7	7	MB	0	0	1	1	0	0
PI 532265	Tall	74	112	61	55	6.7	3.5	38.3	3	4	7	7	MB	1	1	0	1	0	0
PI 532266	Tall	79	110	77	64	6.6	3.6	34.5	3	7	3	7	MB	1	1	1	1	0	0
PI 532267	Tall	62	108	56	51	6.34	2.65	42.6	3	3	7	7	MB	1	0	0	0	0	0
PI 532268	Tall	72	110	63	60	7.2	3	44.5	7	8	7	7	MB	1	1	1	1	0	0
PI 532269	Tall	74	112	71	66	6.08	3.52	36.6	3	7	2	7	MB	0	1	1	1	0	0
PI 532270	Tall	81	116	55	52	5.9	2.7	28.4	3	5	3	7	Y	0	1	1	1	0	0
PI 532271	Tall	82	112	85	82	6.83	3.32	38.7	3	7	3	7	DB	1	0	0	1	0	0
PI 532272	Tall	72	110	72	67	4.25	2.64	29	3	4	7	7	DB	1	1	1	1	0	0
PI 532273	Tall	72	112	66	64	6.92	2.92	32	3	6	2	7	Y	1	1	1	1	0	0
PI 532274	Tall	74	116	85	84	6.12	2.1	36.3	3	6	2	7	LB	1	1	1	1	0	0
PI 532275	Tall	76	118	93	88	6.33	2.11	39.2	3	8	7	7	MB	0	0	0	1	0	0
PI 532276	Tall	79	112	74	56	6.90	5.4	36.7	3	6	4	6	Y	1	1	1	1	0	0
PI 532277	Tall	62	110	79	51	6.65	3.48	28.7	3	4	3	7	LB	0	1	1	1	0	0
PI 532278	Tall	66	112	60	57	6.18	3.2	38.9	3	7	7	6	LB	1	0	0	0	0	0
PI 532280	Tall	95	118	77	76	5.1	3.1	36.8	3	8	7	7	Y	1	0	0	1	0	0
PI 532282	Tall	79	125	72	69	6.3	2.3	32.4	3	5	1	7	DB	1	1	1	1	0	0

(*Contd....*)

Table 2: (*Continued*)

Accession No.	Plant height	Days to flowering	Days to maturity	Spikelets/ spike	Grains/ spike	Grain Length (mm)	Grain width (mm)	1000 grain weight (g)	Growth Habit	Tiller No.	Awns	Spike density	Grain Color†	Coleoptile color	Node Color	Internode Color	Leaf Color	Leaf Sheath Color	Auricle Color
PI 532283	Tall	63	125	69	66	6.53	3	28.4	3	4	7	6	LB	0	1	0	0	0	0
PI 532284	Tall	85	128	46	43	6.93	2.73	36.8	3	4	7	6	LB	0	0	0	1	0	0
PI 532285	Tall	79	115	52	49	6.3	2.7	33.8	3	7	3	7	LB	0	0	0	0	0	0
PI 532286	Tall	68	110	57	53	6.41	3.3	27.8	3	6	7	5	LB	0	1	1	1	0	0
PI 532290	Tall	79	116	62	57	6.86	3.03	34.1	3	4	7	7	Y	1	0	0	1	0	0
PI 532293	Tall	60	110	44	39	6.73	3.63	34.4	3	4	7	6	DB	1	0	0	0	0	0
PI 532294	Tall	66	115	80	78	6.27	2.72	35.9	3	8	7	7	DB	1	1	1	1	0	0
PI 532295	Tall	81	120	38	37	8	2.1	32.6	3	7	7	7	DB	1	0	0	0	1	0
PI 532296	Tall	76	120	41	38	6.14	2.39	42.8	3	6	7	7	DB	1	1	1	1	0	0
PI 532297	Tall	82	125	79	75	6.29	3.1	37.1	3	6	1	7	DB	1	1	1	1	1	0
PI 532298	Tall	79	116	73	64	6.71	3.38	37.2	3	4	7	7	DB	0	0	1	1	0	0
PI 532301	Tall	60	101	42	39	6.89	2.87	37.7	3	6	7	7	LB	1	0	0	1	0	1
									3-upright 7-Prostrate		0-awnless 3-awnletted 7-awned	1-Very lax 2-Lax 5-Intermediate 7- Dense9-Very dense	LB-Light brown MB-Medium brown D-Dark brown Y-Yellowish	1-Purple 0- Green	1-Purple 0-Green	1- Purple 0- Green	1-Cement color 0-Green	1- Purple 0- Green	1-Purple 0-Green

*The accessions were all tall (plant height), erect in growth habit and awned in their morphological features; †-Grain color is not included in statistical analysis

the total variance (Table 5). In PCA without Kaiser normalization, the first principal component (PC1) or factor 1 (F1) accounted for approximately 23.826 % of the total variation (Table 5) which was influenced positively by three quantitative characters viz. spikelets/ spike (0.727), grains/spike (0.723) and days to flowering (0.587) and one qualitative character viz. leaf color (anthocyanin pigmentation) whereas it was negatively influenced by awns (-0.564) in terms of factor loadings (Table 5). This fact was corroborated by substantial contribution 47.661% of diversity by these four characters through PC 1 among the bread wheat germplasm tested (Table 6). In respect to the second principal component (PC2) or factor 2 (F2) accounted only 11.969% of the total variation (Table 5) which was largely influenced positively by only two pigmentation characters viz. node color (0.694) and internode color (0.691) in terms of factor loadings (Table 5). This fact was reflected by over 50% of the estimated contribution by these two qualitative traits through PC2 to the variation among the tested wheat accessions (Table 6).

In PCA with varimax rotation through Kaiser normalization, the variance % of PC1 called D1 was decreased to 20.574% from 23.826% of normal PC1 whereas that of PC2 called D2 was increased to 15.271% from 11.969% of normal PC2. However, influence of characters in terms of factor loadings (Table 7) and the contribution of characters to each factor (Table 8) were comparable to those of normal PCA.

In PCAs, the first two PCs or factors that contributed 35.795 % of the total variation present in the bread wheat accessions were used to draw a biplot graphs to know the pattern of distribution of accessions in the four quadrants of the graph with an assumption that two factors discriminate Omani bread wheat landraces into corresponding four clusters (Fig. 2 and 3). The graph also represents eigenvectors of the characters in each axis of the PC1 and PC2 in terms of their length proportional to its magnitude of influence on that axis.

In biplot graph of PCA, the quadrant I (+, +) consisting of 19 accessions formed the cluster 1, which were highly influenced by three pigmentation characters viz. node color, internode color and leaf color through accessions spread towards midway through X and Y-planes of quadrant-I. The cluster II corresponding to the quadrant II (-, +) contained 12 accessions, which were influenced by awns and 1000 grain weight. Similarly, the cluster III corresponding to quadrant III (-, -) consisted also of 12 accessions which were influenced by auricle color and grain length whereas the cluster IV corresponding to quadrant IV (+, -) also consisted of 12 accessions which were greatly

Table 3: Statistical parameters for the mean values of 9 quantitative characters of Indigenous Omani bread wheat (Triticum aestivum L) USDA accessions over two years along with standard error (S.E), coefficient of variation (CV%) for the analyses of five check varieties (r=5)

Sl. No.	Variables/ Characters	Minimum	Maximum	Mean	F-Test	Std. Error. (SE)	LSD (p=0.05)	CV (%)
1	Days to flowering	60.000	95.000	74.93	*	7.58	22.73	10.12
2	Days to maturity	101.000	132.000	115.82	*	6.49	19.46	5.61
3	Tiller No.	3.000	8.000	5.86	NS	1.66	4.98	28.35
4	Spike density	5.000	7.000	6.82	*	0.43	1.30	6.37
5	Spikelets/spike	38.000	99.000	68.29	*	14.83	44.46	21.72
6	Grains/spike	35.000	98.000	64.11	*	15.04	45.08	23.46
7	Grain Length (mm)	4.250	8.000	6.29	**	0.69	2.06	10.93
8	Grain width (mm)	2.100	5.400	2.99	*	0.58	1.73	19.26
9	1000 grain weight (g)	21.300	44.500	33.03	*	5.08	15.23	15.38

*Standard deviations and coefficient of variation (CV) was calculated based on ANOVA of mean data of two cropping seasons for checks (5 checks-WQS-305; WQS-308; Jimah-110; Jimah-125 and Jimah-132; Replications-5) for each quantitative character
* Significant at p<0.05; ** Significant at p<0.01; NS- Not significant

Table 4: Pearson Simple correlation coefficients among eight quantitative characters in 55 indigenous Omani bread wheat USDA accessions repatriated from USDA gene bank

Variables/ Characters	Days to flowering	Days to maturity	Spikelets/ spike	Grains/ spike	Grain Length (mm)	Grain width (mm)	1000 grain weight (g)	Tiller No.	Spike density
Days to flowering	1	0.489**	0.252ns	0.289*	-0.129ns	0.014ns	-0.120ns	0.189ns	0.328*
Days to maturity		1	0.149ns	0.227ns	-0.115ns	-0.022ns	-0.227ns	0.040ns	0.113ns
Spikelets/spike			1	0.958***	-0.208ns	0.000ns	-0.333*	0.274*	0.293*
Grains/spike				1	-0.215ns	-0.126ns	-0.327*	0.307*	0.312*
Grain Length (mm)					1	0.010ns	0.187ns	0.010ns	-0.116ns
Grain width (mm)						1	0.079ns	-0.035ns	-0.296*
1000 grain weight (g)							1	-0.108ns	0.008ns
Tiller No.								1	0.194ns

Significant correlation coefficient (r) at p <0.05 =0.273 and p<0.01= 0.354 at 50 df

influenced by spikelets/spike, grains/spike, spike density, days to flowering and leaf sheath color (Fig. 2).

In biplot graph of PCA with varimax rotation, the quadrant I (+, +) consisting of 17 accessions formed the cluster 1, was highly influenced by spikelets/spike, grains/spike and days to flowering in distribution towards X-plane and node and internode color towards Y-plane whereas leaf color towards midway through X and Y-planes of quadrant-I. The cluster II corresponding to the quadrant II (-, +) contained 15 accessions, which were influenced by grain width. Similarly, the cluster III corresponding to quadrant III (-, -) consists of 13 accessions which were influenced by grain length and the cluster IV corresponding to quadrant IV (+,-) consists of 10 accessions which were greatly influenced by leaf sheath color (Fig. 3).

In addition to two variants of PCA, the AHC analysis was also applied to explain the relationship among the indigenous bread wheat landraces and clustering pattern through dendrogram (Fig. 4) analysis. It indicated the formation of three clusters with 71.17 % similarity index based Euclidean distances. The cluster I contained as many as 18 accessions whereas cluster 2, which consisted of 24 accessions, formed the largest cluster. The cluster-3, however, had only 13 accessions.

The results of three multivariate analyses indicated both similarity and dissimilarity in pattern of clustering showing certain accessions their affinity in grouping in accordance with their distinct expressions of characters studied (Table 9). In respect of clusters of two PCA versions, I clusters had 13 accessions in common whereas their respective II, III and IV clusters had 9, 9 and 8 accessions in common. On the contrary, the compositions of first three clusters of three multivariate analyses indicated the occurrence of as many as five accessions in respective clusters in common (Table 9). Accordingly, five accessions namely PI 532250, PI

Table 5 (a): Factor loadings in respect of 16 variables (10 quantitative characters and 6 qualitative traits' scores) and eigen values and variability as explained by the first eight principal components (PC) in 55 indigenous Omani bread wheat (*Triticum aestivum*) accessions repatriated from USDA gene bank

Variables/ Characters	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
				Factor loadings				
Days to flowering	0.587	-0.299	0.472	0.048	0.177	-0.267	0.200	-0.006
Days to maturity	0.452	-0.114	0.509	-0.292	-0.052	-0.188	0.330	0.052
Spikelets/spike	0.727	-0.205	-0.467	-0.244	0.164	0.061	-0.060	-0.030
Grains/spike	0.723	-0.312	-0.446	-0.243	0.099	0.023	-0.044	0.024
Grain Length (mm)	-0.346	-0.073	0.036	0.265	0.189	0.416	0.518	0.403
Grain width (mm)	-0.010	0.426	0.137	-0.098	0.738	0.146	0.056	-0.390
1000 grain weight (g)	-0.414	0.045	0.018	0.553	0.280	-0.399	0.019	0.005
Tiller No.	0.408	-0.230	-0.132	0.195	0.305	0.267	-0.109	0.454
Awns	-0.564	0.016	-0.279	-0.145	-0.067	-0.346	0.067	0.309
Spike density	0.481	-0.354	-0.148	0.472	-0.280	-0.193	0.245	-0.200
Coleoptile color	0.267	-0.141	-0.063	0.680	0.132	-0.042	-0.342	-0.049
Node Color	0.499	0.694	0.028	0.175	-0.288	0.173	-0.012	0.108
Internode Color	0.544	0.691	0.025	0.201	-0.213	0.110	0.043	0.002
Leaf Color	0.649	0.313	-0.210	0.059	0.145	-0.247	0.315	0.052
Leaf Sheath Color	0.173	-0.450	0.513	0.121	-0.153	0.398	-0.102	-0.135
Auricle color	-0.371	-0.168	-0.486	0.132	-0.127	0.255	0.411	-0.418
Eigenvalue	3.812	1.915	1.586	1.442	1.112	1.021	0.900	0.870
Percentage of variance in normal PCA (without varimax rotation)								
Variability (%)	23.826	11.969	9.912	9.010	6.948	6.383	5.622	5.440
Cumulative %	23.826	35.795	45.707	54.716	61.664	68.048	73.670	79.110
Percentage of variance after varimax rotation (Kaiser Normalization)								
	D1	**D2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**
Variability (%)	20.574	15.221	9.912	9.010	6.948	6.383	5.622	5.440
Cumulative %	20.574	35.795	45.707	54.716	61.664	68.048	73.670	79.110

Table 6: Contribution of 15 variables/ characters (%) studied to each of the first eight principal components (PC) in 55 indigenous Omani bread wheat (*Triticum aestivum*) accessions repatriated from USDA gene bank

Variables / Characters	F1	F2	F3	F4	F5	F6	F7	F8
Days to flowering	9.032	4.657	14.063	0.157	2.803	6.970	4.444	0.005
Days to maturity	5.358	0.676	16.357	5.914	0.246	3.466	12.110	0.316
Spikelets/spike	13.873	2.190	13.744	4.135	2.428	0.360	0.404	0.100
Grains/spike	13.717	5.070	12.542	4.082	0.875	0.052	0.213	0.069
Grain Length (mm)	3.143	0.280	0.079	4.872	3.211	16.968	29.798	18.682
Grain width (mm)	0.003	9.464	1.180	0.662	49.019	2.100	0.346	17.512
1000 grain weight (g)	4.504	0.108	0.020	21.178	7.066	15.625	0.038	0.002
Tiller No.	4.361	2.755	1.093	2.648	8.356	6.958	1.317	23.673
Awns	8.355	0.013	4.914	1.468	0.403	11.730	0.498	10.987
Spike density	6.066	6.546	1.375	15.437	7.030	3.631	6.673	4.596
Coleoptiles color	1.864	1.042	0.247	32.053	1.575	0.173	12.984	0.273
Node Color	6.545	25.137	0.049	2.123	7.470	2.944	0.016	1.331
Internode Color	7.752	24.909	0.038	2.790	4.064	1.191	0.208	0.000
Leaf Color	11.039	5.108	2.789	0.244	1.901	5.980	11.035	0.308
Leaf Sheath Color	0.785	10.574	16.626	1.024	2.095	15.504	1.155	2.088
Auricle color	3.604	1.472	14.883	1.213	1.458	6.347	18.760	20.057

532253, PI 532256, PI 532274 and PI 532294 were included in one group (cluster 1), the accessions PI 532264, PI 532265, PI 532268, PI 532277 and PI 532298 were included in second group (cluster-2) whereas the accessions, PI 532267, PI 532284, PI 532285, PI 532295 and PI 532301 were included in third group (cluster 3) (Table 9).

DISCUSSION

Bread wheat (*Triticum aestivum* L.) has been under cultivation in Oman adapted to its location on the east of Arabian Peninsula and its trade relationships with MENA (Middle East and North Africa) countries around Fertile Crescent where wheat was originated 10000 years BP (Rufo et al.,

Table 7: Factor loadings in respect of 15 variables (9 agro-morphological characters and presence/absence of pigmentation in six plant parts) and variability as explained by the first two factors (D1 and D2) after varimax rotation (Kaiser normalization) in 55 indigenous Omani bread wheat (*Trticum aestivum*) accessions repatriated from USDA gene bank

Characters/ Variables	D1	D2
Days to flowering	0.656	0.053
Days to maturity	0.445	0.140
Spikelets/spike	0.727	0.206
Grains/spike	0.779	0.113
Grain Length (mm)	-0.257	-0.244
Grain width (mm)	-0.232	0.357
1000 grain weight (g)	-0.377	-0.178
Tiller No.	0.468	0.018
Awns	-0.489	-0.282
Spike density	0.595	-0.050
Coleoptile color	0.301	0.019
Node Color	0.062	0.853
Internode Color	0.101	0.873
Leaf Color	0.389	0.606
Leaf Sheath Color	0.383	-0.293
Auricle	-0.228	-0.337

Table 8: Contribution of 15 variables/ characters (%) studied to the first two factors D1 and D2 after varimax rotation (Kaiser Normalization) in 55 indigenous Omani bread wheat (*Trticum aestivum*) accessions repatriated from USDA gene bank

Characters/ Variables	D1	D2
Days to flowering	13.084	0.115
Days to maturity	6.004	0.802
Spikelets/spike	16.046	1.749
Grains/spike	18.445	0.527
Grain Length (mm)	1.999	2.438
Grain width (mm)	1.633	5.239
1000 grain weight (g)	4.312	1.306
Tiller No.	6.643	0.013
Awns	7.267	3.266
Spike density	10.757	0.102
Coleoptile color	2.754	0.015
Node Color	0.117	29.853
Internode Color	0.312	31.300
Leaf Color	4.593	15.088
Leaf Sheath Color	4.456	3.520
Auricle colour	1.577	4.667

2019). This has resulted in several land races including bread wheat in these countries including Oman due to consistent domestication and selection over the years (Guarino, 1990; Alkhanjari et al., 2005; Jaradat, 2006; Gebauer et al., 2007; Hammer et al., 2009; Filatenko and Hammer, 2014). These indigenous landraces are important to conserve for their utilization in crop improvement programs (Rufo et al., 2019). Oman's participation in worldwide activities for the collection of plant genetic resources under FAO program led to the collection of a large number of wheat landraces during 1980s and 1990s (Gaurino, 1990). The bread wheat accessions sourced from the USDA are used in the present study in particular the ones collected during 1990's (Guarino, 1990). These landraces form an important group because of their documented resilience to abiotic and their tolerance to biotic stresses like pests and diseases (Alkhanjari et al., 2007; Soriano et al., 2016; Rufo et al., 2019). The morphological variation, tolerance to biotic and abiotic stresses, and bread quality characters of landraces have not been fully exploited in wheat germplasm (Jaradat and Shahid, 2014; Ahmad et al., 2014). The results of the present investigations clearly revealed that 55 indigenous landrace accessions differed significantly ($p<0.05$) from one another with respect to the most of agro-morphological and pigmentation characters studied and showed a substantial level of phenotypic variation in terms of diversity (Tables 2-8; Figs. 1-3). In the present study, the pigmentation on six different parts of the plant as presence (score 1) or absence (score 0) has been used in the analyses of diversity (Basnet et al., 2014) because of their significance as genetic identification markers in DUS tests of varieties (Wang et al., 2015; Kumar et al., 2015; CPVO, 2019) with due consideration of using new traits in breeding procedures and statistical methods for integration of disciplinary investigation (Ahmadizadeh et al., 2011). Our results are in line with those of previous studies indicating considerable and significant ($p<0.05$) variation among bread wheat landraces investigated in terms of agro-morphological characters like days to flowering/maturity (Baranwal et al., 2013; Amin et al., 2014; Sheykhi et al., 2014; Qaseem et al., 2017; Singh et al., 2018), spikelets/spike (Atta et al., 2008; Baranwal et al., 2013; Ahmad et al., 2014; Amin et al., 2014; Ebrahimnejad and Rameeh, 2016; Qaseem et al., 2017; Singh et al., 2018), grains/spike (Atta et al., 2008; Khodadadi et al., 2011; Baranwal et al., 2013; Sheykhi et al., 2014; Amin et al., 2014; Ebrahimnejad and Rameeh, 2016; Singh et al., 2018) and 1000 grain weight (Atta et al., 2008; Baranwal et al., 2013; Ahmad et al., 2014; Amin et al., 2014; Qaseem et al., 2017). On the other hand, the variability on grain length and width existing among the bread wheat land races has been reported for thefirst time in the present study.

Pearson correlation coefficients for the agro-morphological characters were examined for potential associations that determine possible influence of one trait in selection on the stability in other characters of growth of the crop. In the present study as many as eight of eleven significant correlations were found positive among different agro-morphological characters in bread wheat indigenous landrace accessions, studied (Table 4). These positive associations among the characters indicated that an improvement of one trait could simultaneously improve the other desired traits (Ebrahimnejad and Rameeh,

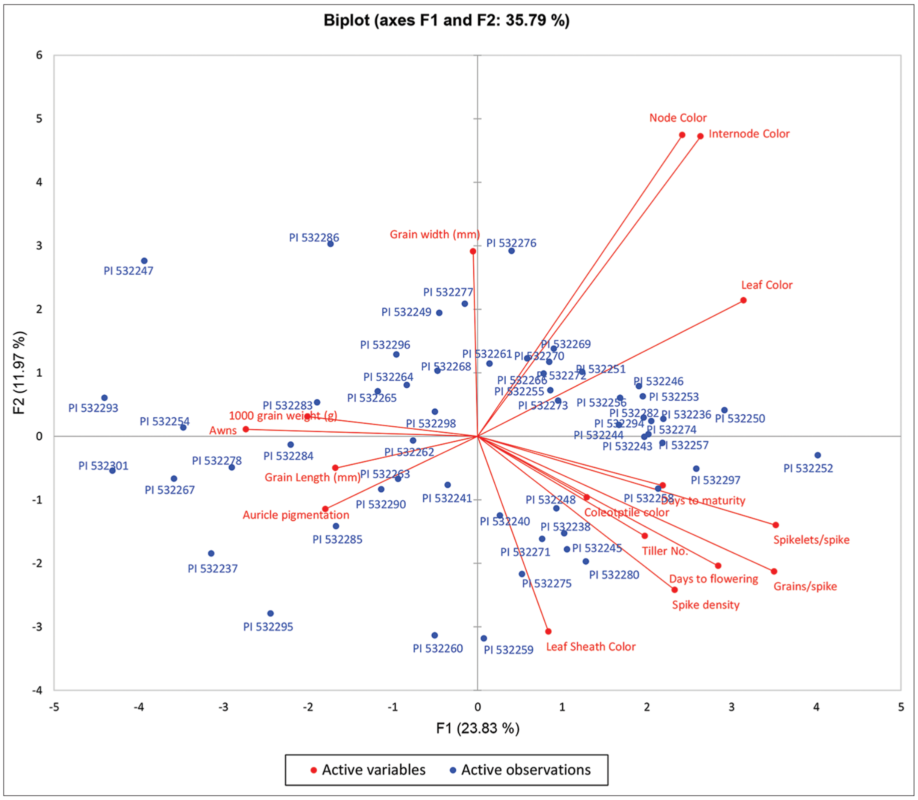

Fig 2. Biplot graph of Factor 1 and Factor 2 of PCA showing distribution of 55 Bread wheat (*Triticum aestivum*) USDA accessions in to its four quadrants as clusters along with eigenvectors of the characters that most influence on corresponding axis.

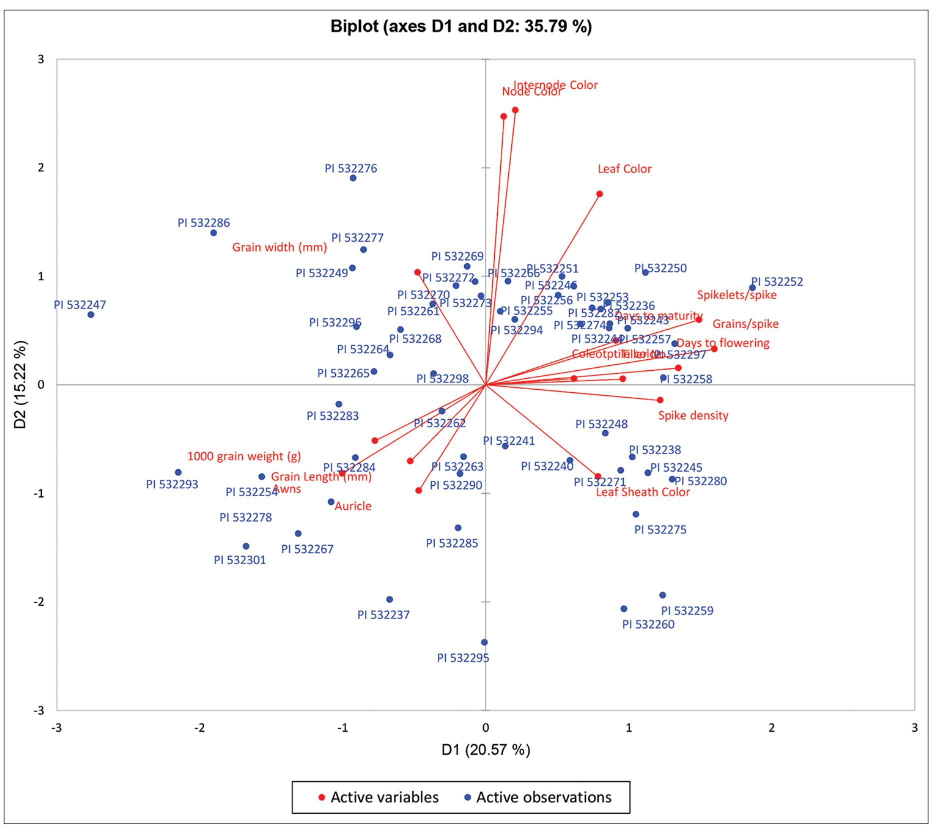

Fig 3. Biplot graph of D 1 and D2 after Kaiser Normalization (Varimax Rotation) showing distribution of 55 Bread wheat (*Triticum aestivum*) USDA accessions in to its four quadrants as clusters along with eigenvectors of the characters that most influence on corresponding axis.

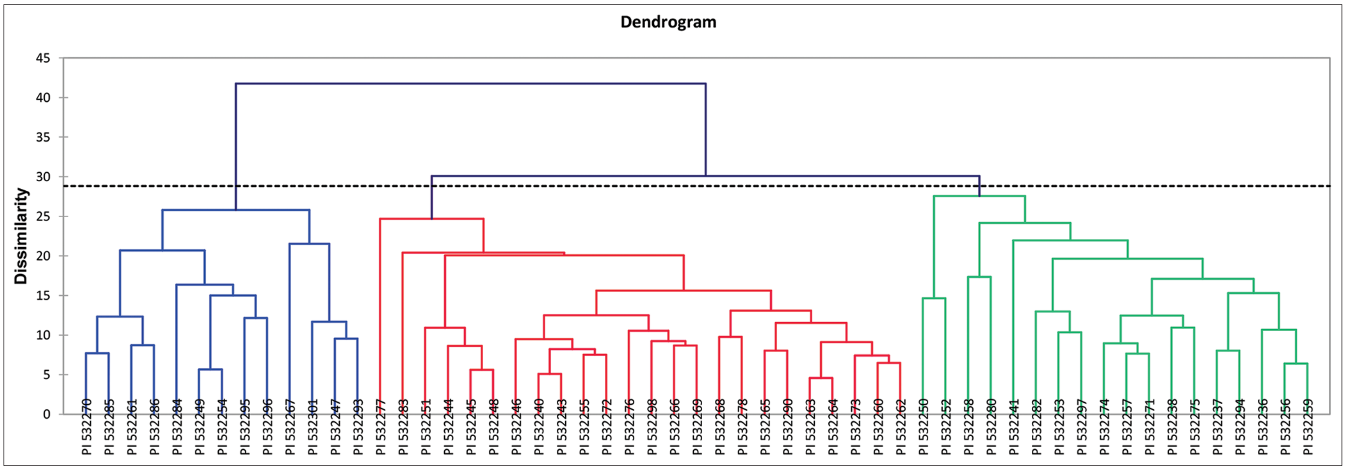

Fig 4. Dendrogram of cluster analysis of 55 indigenous aestivum wheat accessions using Wards' method.

2016; Qaseem et al., 2017). In the present study, tiller number should be increased correspondingly to maximize number of spikelets and grains per spike which finally determine total grain yield. On the other hand, negative associations between the growth and yield attributes would help in optimizing the extent of the characters in attaining maximum yield. For instance, spikelets/spike or grains/spike could be optimized to achieve highest test weight of the grains, which directly contribute to the yield (Table 4). Similar observations were reported by other researchers in their bread wheat germplasm (Atta et al., 2008; Ebrahimnejad and Rameeh, 2016; Khalil and Naghavi, 2017).

The genetic diversity among 55 indigenous bread wheat landrace USDA accessions representing seven out of ten governorates of Oman in northern part of the country was assessed by three methods of multivariate analyses viz. PCA with and without varimax rotation through Kaiser normalization and AHC based on grand means of nine agro-morphological characters (quantitative) and pigmentation scores on six plant parts (qualitative) over two cropping seasons. The similarities and differences between various PC (principal component) and factor analyses in decomposing the correlation matrix of the characters/variables to ultimately synthesizing a new set of unmeasurable variables and methods of clustering, have been explained by Walker (2014).

In the present study using a PCA based on the correlation matrix with or without varimax rotation, it has been revealed that the first eight principal components accounted for 79.1% of the total variance of which first two components contributed 35.795%. The percent contribution of the first factor was decreased by 13.65% while that of second factor was increased by 27.17% because of varimax rotation. This was considered substantial to scatter the positions of accessions over the four quadrants of the biplot graphs differentially due to changes in the factor scores as D1 and D2 from PC1 and PC2 (Figs. 2 and 3). Such magnitude of contribution of the first two PCs was in line with results of Pasandi et al., 2014 (41%), Janmohammadi et al. (40.87%) and Aharizad et al. (42.31%). In both versions of PCs, the factor 1 (PC1) influenced days to flowering, spikelets/spike, grains/spike and leaf color and were effective sources of variation, whereas the factor 2 (PC2) affected discrimination of accessions pigmentation on three plant parts viz. anthocyanin pigmentation on nodes, internodes, and leaves. This is due to effective differentiation of accessions into different clusters through relatively higher contribution of few characters rather than small contribution from each character (Chahal and Gosal, 2002 and Yan and Tincker, 2005).

In respect of cluster analysis, the results of multivariate analyses viz. PCA and AHC based on Euclidian distances showed differential nature of clustering and did not endorse each other. However, critical examination of composition of accessions in four clusters of PCAs and three clusters illustrated by dendrogram in the present study clearly depicted the fact that the discriminatory factors involved in three multivariate were helpful in screening the common accessions gradually to reduce their number to a minimum for ultimate selection of parents for use in crop improvement programs (Walker, 2014; Sant'Anna et al., 2020). In this sense, comparison of each of the respective four clusters of PCA without and with varimax rotation indicated that cluster nos. 1, 2, 3 and 4 of these two PCA analyses had 10, 9, 9 and 8 accessions were respectively common (Table 9). Further, comparison of three clusters formed by AHC through dendrogram with the first three clusters of two PCAs indicated interestingly 5 accessions to be in common (Table 9), the information of which was used for selection of parents for crossing program through

Table 9: Comparative analyses of common accessions from the clusters of three multivariate analyses applied in the study

*Multivariate Analysis	Cluster-1	No.	Cluster 2	No.	Cluster-3	No.	Cluster-4	No.
PCA	PI 532236, PI 532243, PI 532244, PI 532246, PI 532250, PI 532251, PI 532253, PI 532255, PI 532256, PI 532261, PI 532266, PI 532269, PI 532270, PI 532272, PI 532273, PI 532274, PI 532276, PI 532282, PI 532294, PI 532244, PI 532246	19	PI 532247, PI 532249, PI 532254, PI 532264, PI 532265, PI 532268, PI 532277, PI 532283, PI 532286, PI 532293, PI 532296, PI 532298	12	PI 532237, PI 532241, PI 532260, PI 532262, PI 532263, PI 532267, PI 532278, PI 532284, PI 532285, PI 532290, PI 532295, PI 532301	12	PI 532238, PI 532240, PI 532245, PI 532248, PI 532252, PI 532257, PI 532258, PI 532259, PI 532271, PI 532275, PI 532280, PI 532297	12
PCA after Kaiser Normalizaton	PI 532224, PI 532228, PI 532236, PI 532243, PI 532246, PI 532250, PI 532251, PI 532252, PI 532253, PI 532255, PI 532256, PI 532257, PI 532258, PI 532266, PI 532274, PI 532294, PI 532297	17	PI 532247, PI 532249, PI 532261, PI 532264, PI 532265, PI 532268, PI 532269, PI 532270, PI 532272, PI 532273, PI 532276, PI 532277, PI 532286, PI 532296, PI 532298	15	PI 532237, PI 532254, PI 532261, PI 532263, PI 532267, PI 532278, PI 532283, PI 532284, PI 532289, PI 532290, PI 532293, PI 532295, PI 532301	13	PI 532238, PI 532240, PI 532241, PI 532245, PI 532248, PI 532259, PI 532260, PI 532271, PI 532275, PI 532280	10
Common Accessions from two PCA analyses	PI 532236, PI 532243, PI 532246, PI 532250, PI 532251, PI 532253, PI 532255, PI 532256, PI 532266, PI 532274, PI 532294,	11	PI 532247, PI 532249, PI 532264, PI 532265, PI 532268, PI 532277, PI 532286, PI 532296, PI 532298	9	PI 532237, PI 532263, PI 532267, PI 532278, PI 532284, PI 532285, PI 532290, PI 532295, PI 532301	9	PI 532238, PI 532240, PI 532245, PI 532248, PI 532259. PI 532271, PI 532275, PI 532280	8
AHC	PI 532236, PI 532237, PI 532238, PI 532241, PI 532250, PI 532252, PI 532253, PI 532256, PI 532257, PI 532258, PI 532259, PI 532271, PI 532274, PI 532275, PI 532280, PI 532282, PI 532294, PI 532297	18	PI 532240, PI 532243, PI 532244, PI 532245, PI 532246, PI 532248, PI 532250, PI 532255, PI 532260, PI 532262, PI 532263, PI 532264, PI 532265, PI 532266, PI 532268, PI 532269, PI 532272, PI 532273,	24	PI 532247, PI 532249, PI 532254, PI 532261, PI 532267, PI 532270, PI 532284, PI 532285, PI 532286, PI 532293, PI 532295, PI 532296, PI 532301	13	-	

(*Contd....*)

Table 9: (*Continued*)

*Multivariate Analysis	Cluster-1	No.	Cluster 2	No.	Cluster-3	No.	Cluster-4	No.
AHC			PI 532276, PI 532277, PI 532278, PI 532283, PI 532290, PI 532298					
Common Accessions from all three multivariate analyses	PI 532250, PI 532253, PI 532256, PI 532274, PI 532294	5	PI 532264, PI 532265, PI 532268, PI 532277, PI 532298,	5	PI 532267, PI 532284, PI 532285, PI 532295, PI 532301	5		

*PCA-Principal Component Analysis (Biplot graph); AHC- Agglomerative Hierarchical Clustering (Dendrograms)

hybridization. The common accessions from cluster 1 of three multivariate analyses included four accessions from the locations of Al-Dakhliyah governorate from at altitudes 350 to 500 m viz. PI 532250 and PI 532274 from Bahla, PI 532253 (Al-Hamra) and PI 532256 (Manah) and one accession viz. PI 532294 from a location Dhank (300 m) of Al-Dhahirah governorate. On the other hand, five common accessions from cluster 2 included three accessions viz, PI 532264, PI 532265 and PI 532268 from three locations at altitudes ranging from 400 to 500 m in wilayat Nizwa of Al-Dakhliyah governorate, one accession PI 532277 from Ibri (600 m) of Al-Dhahirah governorate and one accession PI 532398 from a location at Western Hajar mountains in Sohar (400 m) of Al-Batinah North governorate. Similarly, five common accessions from cluster 3 included three accessions viz, PI 532267 from wilayat Izki at 400 m, PI 532284 from a high mountainous location at 1600 m in wilayat Nizwa and PI 532301 at 350 m in wilayat Nizwa of Al-Dakhliyah governorate and one accession PI 532285 from Khasab (500 m) of Musandam governorate and one accession PI 532395 from a location from Yankul (300m) in Sohar of Al-Batinah North governorate. Further, it is interesting to note that the cluster 4 of PCAs that contained 8 common accessions did not appear in any of the common accessions from three multivariate analyses providing scope of their selection as parents. These eight included three accessions viz. PI 532245 from Bahla and PI 532248 from Al-Hamra at 500 m whereas PI 532280 from Nizwa at the high altitude of 1700m from Al-Dakhliya governorate, two accessions PI 532238 and PI 232240 from the plains (1-16 m) of Sohar of Batinah North, two accessions from the mountains (400-900m) of Al-Dhahirah governorate viz. PI 532259 and PI 5322751in wilayat Ibri and one accession (PI 532271 from mountains of wilayat Mudaybi of North Al-Sharqiya governorate (Table 9).

The compositions of common accessions in the clusters of three multivariate analyses and that of the fourth cluster of two PCAs (Table 9) revealed the fact that there is no clear relationship existed between accessions and geographical diversity as these common accessions were from wilayats of different governorates. However, a few of the accessions varying from 2-3, yet along belonged to wilayats of different governorates were inclusions of same clusters due to their affinity based on agro-morphological characters. This indicates that selection of accessions as parents must be undertaken on landraces *per se* along with the factors associated with geographical location as a source of diversity in the germplasm under study. Our results involving three methods of multivariate analysis clearly brought genuine closest/related accessions into the same clusters thus providing opportunity to plant breeders to select parents from different clusters based on characters to be improved, as parents for producing transgressive segregants in F_2 (Dotlacil et al., 2000; Nimbalkar et al., 2012; Wani et al., 2018)). Accordingly, the accession PI 532250 from Bahla of Al Dakhiliya governorate and/ or PI 532294 from Dhank of Al-Dhahirah governorate could be selected from the cluster-I as one of the parents for manipulating days to flowering and grains/spike with anthocyanin pigmentation on node and internode and leaf color (cement green) as identification markers; Similarly, PI 532265 from Nizwa of Al-Dakhliyah governorate and/or PI 532 298 from Sohar of South Batinah governorate can be chosen from cluster-II for improving grain characters with awns as marker trait; PI 532284 from high Jabel Al-Akhdar mountains (wilayat Nizwa) of Al-Dakhliyah governorate and/or PI 532285 from Khasab of Musandam governorate from cluster-III for improving grain length and 1000-grain weight with awns as marker trait and PI 532238 from plains of Sohar of South Batinah governorate and/or PI 532271 of AlSharqiya governorate from cluster-IV for manipulating days to maturity, spikelet/spike and spike density along with coleoptile color (anthocyanin pigmentation) and awns as marker traits (Table 9). These bread wheat accessions of the present study are the landraces of Oman which are known for their desirable bread making quality for the local culinary preparations besides their adaptive characters to survive abiotic stresses like heat, drought and/salinity (Al-Maskri et al., 2003; AlKhanjari et al., 2005; Jaradat and Shahid, 2014).

CONCLUSIONS

Fifty-five indigenous bread wheat landraces/accessions were significantly different ($p<0.05$) with respect to all nine agro-morpho quantitative characters but of number of tillers and had a higher magnitude of variation for most quantitative characters. Only eleven correlations involving nine characters were significant ($p<0.05$). Three multivariate analytical methods were found assisting in discerning diversity with each forming distinct diverse clusters with common accessions occurring in different compositions of clusters. The common accessions occurring in the same clusters of three multivariate analyses were the means of selection of parents for hybridization for improving traits of growth and productivity with one or two identifying markers of pigmentation on plant parts.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

The authors declare that there are no conflicts of interest.

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Author contributions

Ali Hussain Al Lawati repatriated Oman bread wheat accessions from USDA gene bank and formulated morphological characterization activities, contributed to the conduct of the experiments, and revised/edited the draft of the paper. Saleem Kaseemsaheb Nadaf contributed to conducting experiments with special reference to recording pigmentation traits and prepared the original draft of the paper. Nadiya Abubakar AlSaady successfully directed the conduct of experiments by providing logistic supports as the Director of the institution. Saleh Ali Al Hinai supervised the conduct of the experiments by following up all the crop husbandry practices and supervising in recording the observations. Almandhar Almamari and Abdulaziz Almaawali contributed to recording the observations, statistical analyses of the data and tabulation of the final results.

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