RESEARCH ARTICLE

Genetic Diversity of Omani Durum Wheat (Triticum turgidum sub sp. durum) Landraces

Ali H. Al Lawati1*, Saleem K Nadaf1, Nadiya A. AlSaady1, Saleh A. Al Hinaï2, Almandhar Almamari1, Masoud H. Al Adawi2, Rashid S. Al Hinaï2 and Abdulaziz Al Maawali1

1University of Nizwa, Birkat Al Mouz, Nizwa, Sultanate of Oman
2Jimah Agriculture Research Station, Directorate General of Agriculture & Livestock Research, Ministry of Agriculture & Fisheries, Jimah, Bahla, Al-Dakhiliya, Oman

Abstract:

Introduction: The Sultanate of Oman is rich in diversity of the most important crops like wheat, which not only has a global significance but is also regarded as one of the strategic crops in the country. The country has an ancient cultivation history of both bread wheat (Triticum aestivum L.s.l.) and durum wheat (Triticum turgidum sub sp. durum) because of its characteristic location on the eastern edge of the Arabian Peninsula. Wheat landraces constitute the prime genetic resources of cultivated wheat not only in Oman but also in several MENA (the Middle East and North Africa) countries. Indigenous landraces have paramount significance for their potential utilization in crop improvement and conservation programs. Hence, the present study was undertaken to subject 17 indigenous durum wheat accessions for analyses of diversity to select parents for hybridization in national crop improvement programs.

Materials and Methods: The trial was conducted consecutively for two cropping seasons (2017-2018 and 2018-2019) during winter from November to March on the layouts of a loamy soil site under sprinkler irrigation system in Augmented Design with five check varieties replicated five times randomized and distributed throughout the experimental area under spacing and crop husbandry practices as per national recommendations. The data on 9 quantitative (Plant descriptors) and 6 qualitative traits on the presence (score 1) or absence (score 0) of pigmentation on 6 plant parts were collected. These traits were subjected to both Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) to comprehend the contribution of these characters towards diversity and form prime diverse clusters from 17 indigenous durum wheat landraces to select appropriate parents for crossing.

Results: The results indicated that indigenous durum wheat accessions were significantly different (p>0.05) with respect to all the quantitative characters except the number of tillers. Of 36 combinations of associations among 9 agro-morphological characters’ studied, only six correlations involving four characters viz. tiller no., spikelets/ spike, grains/spike, and grain length were found significant (p<0.05). The results of two multivariate analyses indicated the formation of four diverse clusters with different compositions of accessions, thus not supporting each other in discerning diversity. The parents were selected for hybridization for improving characters of growth for higher yield or productivity with one or two identifying markers of pigmentation on plant parts.

Conclusion: The indigenous durum wheat landraces / accessions were found to be more diverse and potential for use in the national crop improvement programs for higher productivity.

Keywords: Characters, clusters, diversity, landraces, pigmentation, variability, wheat (Durum).

1. INTRODUCTION

Wheat (Triticum sp.) is one of the most important food crops of the world, which is known to provide nearly 44% of the total edible dry matter and 40% of food crop energy consumed by the most developing countries of the world [1]. Of the seventeen different wheat species, only three species, namely allohexaploid Triticum aestivum, known as bread wheat, whereas other two allotetraploid species, Triticum durum (Triticum turgidum ssp. durum) and Triticum dicoccum, known internationally for pasta making and locally in specific

Article History

Received: May 17, 2020 | Revised: October 13, 2020 | Accepted: November 20, 2020

DOI: 10.2174/1874331502115010021, 2021, J5, 21-32
food preparations, are cultivated in the world. Of the world wheat cultivated area, *Triticum aestivum* occupies 90%, whereas of the remaining two species, *Triticum durum* contributes 9-10% and *Triticum dicoccum* contributes to a negligible extent [2, 3]. As for the production at a global level, the production of wheat was estimated to be 735 million tons in 2018 to 2019, of which bread wheat accounted for about 94%. In 2017-2018, the production of durum wheat *Triticum turgidum ssp. durum* was recorded 37.5 million tons with more than a 5% share of the global wheat production [4 - 6]. Countries in the Mediterranean and Southern Europe, the Balkans, North Africa, and southwest Asia, where initial wheat domestication and cultivation are observed, the durum wheat cultivars are still predominant [7 - 11]. These indigenous durum wheat cultivars form an important source of genetic materials due to their ease in adapting to adverseiotic and abiotic stresses and grain quality. These could be the products of natural selection through domestication performed by the farmers through ages [4].

The Sultanate of Oman is rich in diversity of the most important crops like wheat, which not only has a global significance but is also regarded as one of the strategic crops in the country [12]. It is grown in diversified environments, as evidenced by the number of indigenous accessions collected during several collecting missions undertaken in Oman involving international organizations like the Food & Agriculture Organization (FAO) of the United Nations (UN) [13 - 16]. This is because of its position in the Middle East and its ancient trade relations tracing back to 3000 BCE with Iraq in the fertile crescent region that covers Mesopotamia, the home to the earliest known human civilizations and origin of several wheat species, including allohexaploid bread wheat (6x=2n=42) around 4500 BCE [17 - 19]. Durum wheat (*Triticum turgidum* sub sp. *durum* (4x=2n=28) having two genomes, A and B twice in its somatic cells (AABB), was domesticated at the same time [20, 21].

There exists enormous variation among different indigenous accessions of durum wheat in terms of quantitative characters that are directly related to yield and yield-related traits or qualitative traits like pigmentation and other descriptors of wheat, which are very important for crop improvement programs through breeding and selection [22 - 26]. Among the yield-related traits, number of tillers, number of grains/ spike, and test weight are known to influence directly and positively to the grain yield [25, 27 - 29]. Several approaches and analyses like those of principal components, clusters, and factors have been suggested by many researchers for estimation of genetic diversity or distances among and between groups of cultivars studied based on not only morphological and growth attributes [29 - 34] but also molecular markers [4, 35, 36]. Most of these authors have used Hierarchical Cluster Analysis (HCA) to estimate genetic dissimilarity and similarity, and Factor Analysis (FA)/Principal Component Analysis (PCA) to determine the factors that contribute to the variation of quantitative characters in durum wheat. There have been no studies conducted so far on understanding the genetic diversity among the available indigenous durum landraces of Oman. Hence, in the present study, indigenous durum wheat landrace accessions repatriated from the USDA gene bank were investigated to estimate the potentiality of genetic diversity using both HCA and FA/PCA for the selection of appropriate parents for hybridization programs to improve the productivity of durum wheat.

2. MATERIALS AND METHODS

2.1. Material and Details of Conducting Experiments

Seventeen indigenous durum wheat (*Triticum turgidum ssp. durum*) landraces of the USDA accessions, repatriated by the Oman Animal & Plant Genetic Resources Center (OAPGRC) of the Research Council from USDA gene bank, where these accessions were deposited by international FAO collectors during their joint MAF-FAO collecting missions during the 1990s from different governorates of Oman, were studied (Table 1). The trial was conducted consecutively for two cropping seasons (2017-2018 and 2018-2019) during winter from November to March on a loamy soil site under sprinkler irrigation system at Agriculture Research Station, Jimah in Al Bahla wilayat of Al-Dakhiliyah (Interior Oman) governorate. These durum wheat accessions were planted in the plots of 3-m three rows at a spacing of 0.2 m between rows and 0.15 m between plants under Augmented Design with five check varieties (WQS-302; WQS-305; WQS-308; Jimah-1 and Jimah-110) replicated five times. All the crop husbandry practices were followed according to the national recommendations of the Ministry of Agriculture & Fisheries (MAF), Oman [37], to raise a successful crop. The qualitative traits of pigmentation were recorded at the respective growth stage of the plants in each plot when the pigmentation on the plant parts was observed as intense and clear. The days to flowering and maturity were recorded when each plot attained about 50% flowering and 90% maturity of grains. The characters viz. tiller number/plant, spike density, spikes/spike, grains/spike, grain length (mm), grain width (mm), and 1000-grain weight (g) were measured based on the guidelines in Descriptors of Wheat (revised) (IBPGR) [38].

Table 1. Indigenous *Triticum turgidum* sp. *durum* accessions with their USDA accession numbers and wilayats, governorates, latitude (N), longitude (E), and altitude of each location of the collection during the 1990s by MAF-FAO joint collecting missions

| S. No. | USDA Accession No. | Village | Wilayat | Governorate | Latitude (N) | Longitude (E) | Altitude (m) |
|--------|-------------------|---------|---------|-------------|-------------|--------------|--------------|
| 1      | PI 532239         | 2km SE of Sohar, N. Batinah Province. | Sohar | Batinah North | 24.36667 | 56.75 | 1 |
| 2      | PI 532242         | 32km SW of Majis, W. Hajar Province. | Sohar | Batinah North | 24.16667 | 56.333333 | 500 |
| 3      | PI 532279         | 20km N of Birkat al Mawz, Jebel Akhdar Province. | Nizwa | Al Dakhiliya | 23.16667 | 57.666667 | 1700 |
2.2. Statistical Analyses

Analysis of variance, correlation analysis, HCA through agglomerative hierarchical clustering (AHC) and FA/PCA were performed by applying XLSTAT-software for Excel [39]. Factor analysis aimed for the estimation of commonality from the quantum of variance by the highest correlation coefficient in each array [40] and adopted Euclidian distance as a measure of dissimilarity and the unweighted pair-group average method as the clustering algorithm, whereas PCA estimated the number of factors. The software adapted varimax or orthogonal rotation to define each factor as a distinct cluster of correlated variables and determined factor loadings of the rotated matrix, percent of variability contributed by each factor, and communalities of each variable. In the present study, a combined analysis of variance of two-year data of check varieties indicated an insignificant effect of GxE (genotype and environment/year) interaction (p>0.05) for each quantitative character. PCA was performed on the correlation matrix between two-year means of agro-morphological characters and scores of presence (1) and absence (0) of anthocyanin pigmentation on six plant parts in indigenous durum accessions. The data on plant height, growth habit, and awns were not included in statistical analysis as all the accessions were tall, erect, and awned, respectively, in their morphological features. Similarly, grain color was not included in the analysis because of the absence of appropriate measurement for distinctness, although landraces had variation in grain color. Landraces of wheat are all tall as they were constantly selected for a long time by the local farmers for straw traditionally to feed their livestock (Table 2).

Table 2. Aggregate means of the agro-morphological quantitative characters of two cropping seasons and 17 Oman accessions repatriated from USDA gene bank

| Accession | Plant Height | Days to Flower | Days to Maturity | Spikelet/spike | Grains/spike | Grain Length (mm) | Grain Width (mm) | 1000 Grains Weight (g) | Growth Habit | Tillers No. | Awns | Spike density | Grain Color | Coleoptile Color | Nodal Color | Internode Color | Leaf Color | Leaf Sheath Color | Awns
|-----------|-------------|----------------|------------------|----------------|--------------|------------------|------------------|---------------------|-------------|-----------|------|---------------|------------|-----------------|------------|-----------------|-----------|------------------|------
| PI 532239 | Tall        | 72             | 112              | 66             | 66           | 6.6             | 3.58             | 25.5                | 3           | 4         | 7    | M Brown       | 1          | 0               | 0           | 1               | 0         | 0               | 0
| PI 532242 | Tall        | 74             | 112              | 64             | 59           | 7.5             | 3.31             | 33.5                | 3           | 8         | 7    | M Brown       | 0          | 0               | 0           | 1               | 0         | 0               | 0
| PI 532279 | Tall        | 68             | 115              | 92             | 87           | 7.1             | 2.80             | 37.1                | 3           | 4         | 7    | M Brown       | 0          | 0               | 0           | 1               | 0         | 0               | 0
| PI 532281 | Tall        | 70             | 118              | 87             | 85           | 5.4             | 2.40             | 35.7                | 3           | 5         | 7    | L Brown       | 1          | 0               | 0           | 1               | 0         | 0               | 0
| PI 532287 | Tall        | 70             | 112              | 60             | 57           | 7.7             | 2.40             | 40.3                | 3           | 7         | 7    | L Brown       | 1          | 0               | 0           | 1               | 0         | 0               | 0
| PI 532289 | Tall        | 70             | 115              | 68             | 71           | 7.41            | 3.17             | 39.5                | 3           | 4         | 7    | L Brown       | 1          | 0               | 0           | 1               | 0         | 0               | 0
| PI 532291 | Tall        | 70             | 116              | 71             | 68           | 7.3             | 2.97             | 39.2                | 3           | 4         | 7    | L Brown       | 0          | 0               | 0           | 1               | 0         | 0               | 0
| PI 532292 | Tall        | 68             | 118              | 53             | 48           | 6.3             | 2.10             | 42.6                | 3           | 4         | 7    | L Brown       | 0          | 0               | 0           | 1               | 0         | 0               | 0
| PI 532303 | Tall        | 74             | 112              | 36             | 33           | 9.8             | 2.34             | 32.9                | 3           | 9         | 7    | L Brown       | 1          | 0               | 1           | 1               | 0         | 1               | 0
| PI 532342 | Tall        | 70             | 115              | 52             | 52           | 7.7             | 3.31             | 40.3                | 3           | 4         | 7    | L Brown       | 1          | 0               | 0           | 1               | 0         | 1               | 0
| PI 532344 | Tall        | 74             | 115              | 44             | 44           | 8.8             | 2.43             | 30.9                | 3           | 8         | 7    | L Brown       | 1          | 0               | 0           | 1               | 0         | 1               | 0
| PI 532345 | Tall        | 76             | 115              | 45             | 43           | 9.2             | 2.72             | 37.9                | 3           | 9         | 7    | L Brown       | 1          | 0               | 0           | 1               | 0         | 1               | 0
| PI 532346 | Tall        | 95             | 127              | 45             | 42           | 8.2             | 2.17             | 35.4                | 3           | 8         | 7    | L Brown       | 0          | 0               | 0           | 1               | 0         | 1               | 0
| PI 532367 | Tall        | 85             | 120              | 56             | 54           | 8.9             | 2.45             | 30.0                | 3           | 8         | 7    | L Brown       | 0          | 0               | 0           | 1               | 0         | 1               | 0
3. RESULTS

3.1. Variation in Agro-morphological and Qualitative Traits among Oman Landraces

The aggregate mean values over two cropping seasons for all agro-morphological characteristics of Oman landraces with USDA accession nos. are presented in Table 2. The accessions were found to be significantly different (p<0.05) in respect of all the quantitative characters except the number of tillers, and had a higher degree of variation in respect of most of the studied quantitative characters (Table 3). These accessions were similar with respect to plant stature (tall), erect growth habit, and presence of awns (Table 2). The accessions were the most diverse in respect of spikelets/spike and grains/spike, respectively, from 32 and 29 (PI 532302) to 92 and 87 (PI 532279) in comparison with other characters studied.

There existed variation also for seed characteristics and seed dimensions among the durum accessions, studied especially with respect to test weight and seed length besides grain color. The accession, PI 532239 showed the lowest 1000-grain weight with 25.5 g, whereas the highest 1000-grain weight was found in the accession PI 532302 (44.7 g), followed by two accessions, PI 532292 and PI 532300 with 42.6 g and another two accessions PI 532287 and PI 532288 with 40.3 g. The grain length, however, varied from 5.4 mm (PI 532281) to 9.8 mm (PI 532303), whereas grain width varied from the lowest of 2.02 mm as in the case of PI 602425 to the highest of 3.80 mm for PI 532302 (Tables 1 and 2). In respect of grain color, 11 accessions had light yellow brown grain color followed by three accessions with yellow, 2 accessions with internode purple, and one accession, each with node and auricle pigmentation (Table 2).

3.2. Correlation among Agro-morphological Traits

Phenotypic characters played a significant role during the introduction of crop plants as traits such as plant height, days to flowering and maturity, spike, and seed characters were selection criteria during domestication. In this respect, an overview based on the association between characters could have a strong connection with the introduction of the crop species. Statistical comparisons of relationships among nine agronomical and morphological traits for 17 indigenous durum landraces are shown in Table 4.

Of 36 combinations of associations among 9 agro-morphological characters studied, only six correlations involving four characters viz. tiller no., spikelets/spike, grains/spike, and grain length, were found significant (p<0.05) (Table 4). The correlations of taller no. with spikelets/spike (-0.537*) and grains/spike (-0.508*) were negative and significant, whereas those with grain length was positive (+0.833**) and highly significant. Similarly, grains/spike was positively, highly, and significantly correlated with spikelets/spike (+0.998**), whereas the associations of grain length with spikelets/spike (-0.581*) and grains/spike (-0.556*) were negative and significant (p<0.05).

Table 3. Statistical parameters for the mean values of characters of durum wheat over two years along with standard error (S.E), coefficient of variation (CV%) for the analyses of five check varieties (r=5).

| SL. No. | Characters | Minimum | Maximum | Mean | F-Test | Std. Error. (SE) (16 d.f.) | LSD (p=0.05) | CV (%) |
|---------|------------|---------|---------|------|--------|---------------------------|-------------|--------|
| 1       | Days to flowering | 66      | 95      | 75.12 | *      | 7.49                      | 18.53       | 6.37   |
| 2       | Days to maturity   | 112     | 127     | 117.59 | *      | 5.03                      | 12.44       | 4.47   |
| 3       | Tiller No.         | 3       | 9       | 6.00  | NS     | 2.09                      | -           | 34.87  |
| 4       | Spike density      | 6       | 7       | 6.94  | *      | 0.24                      | 0.59        | 3.50   |
| 5       | Spikelets/spike    | 32      | 92      | 58.18 | *      | 16.65                     | 41.19       | 28.62  |
| 6       | Grains/spike       | 29      | 87      | 54.82 | *      | 16.54                     | 40.92       | 30.16  |
| 7       | Grain length (mm)  | 5.4     | 9.8     | 7.57  | *      | 1.16                      | 2.86        | 15.30  |
| 8       | Grain width (mm)   | 2.02    | 7.80    | 2.72  | *      | 1.33                      | 3.29        | 2.09   |
| 9       | 1000 grain weight (g) | 25.5    | 44.7    | 36.82 | *      | 5.05                      | 12.49       | 13.71  |

*Standard deviations and coefficient of variation (CV) was calculated based on ANOVA of mean data of two cropping seasons for checks (5 checks-WQS-302, WQS-305, WQS-308, Jimah-1 and Jimah-110; Replications-5) for each quantitative character.
Table 4. Simple correlation coefficients among agro morphological characters

| Variables/Characters | Days to flowering | Spikelets/spike | Grains/spike | Grain Length (mm) | Grain width (mm) | 1000 grain weight (g) | Tiller No. | Spike density |
|----------------------|------------------|-----------------|--------------|-------------------|-----------------|----------------------|------------|--------------|
| Days to flowering    | 0.460**          | -0.462          | -0.455       | 0.283**           | -0.098**        | -0.209**             | 0.295**    | 0.038**      |
| Days to maturity     | 1                | -0.181          | -0.189       | -0.188            | -0.008          | 0.392                | -0.137**   | 0.287**      |
| Spikelets/spike      | -1               | 0.998**         | -0.581*      | -0.251            | -0.107**        | -0.537*              | -0.090**   |              |
| Grains/spike         | -                | 1               | -0.556*      | -0.248*           | -0.130*         | -0.508*              | -0.065**   |              |
| Grain Length (mm)    | -                | -               | -1           | 0.044**           | -0.261**        | 0.833**              | 0.004**    |              |
| Grain width (mm)     | -                | -               | -            | 1                 | 0.281**         | 0.087**              | -0.069**   |              |
| 1000 grain weight (g)| -                | -               | -            | -                 | 1               | -0.267**             | 0.169**    |              |
| Tiller No.           | -                | -               | -            | -                 | -               | 1                    | -0.246**   |              |

* Significant at p<.05 ; ** Significant at p<.01; ns- p>0.05

3.3. Multivariate Analyses

Multivariate analyses have been applied to measure the diversity in durum wheat germplasm accessions and evaluate the relative contributions of different characters to the total variability in a crop germplasm collection. These analyses enable germplasm accessions to be classified into groups/clusters with similar characters. In this study, the principal component analysis (PCA) based on 9 agro-morphological traits and presence or absence of pigmentation on six plant parts was used to discern the patterns of variation within 17 traits and presence/absence of pigmentation in six plant parts as explained by the first eight principal components (PC) in 17 indigenous durum wheat accessions repatriated from USDA gene bank.

The first principal component (PC1) accounted for approximately 30.127% of the total phenotypic variation (Table 5) which was influenced to the extent of 76.839% by four quantitative characters and one qualitative character viz. grain length (16.943%), spikelets/spike (15.455%), tiller no. (15.271%), grains/spike (14.598%), and leaf sheath color (14.572%) (Table 6). PC2 accounted for 16.579% (Table 5) phenotypic variability, which was contributed mainly by days to maturity (26.565%), days to flowering (13.348%), and internode color (13.086%) to the extent of 52.999% (Table 6). However, PC3, which accounted for 12.370%, was built from coleoptile pigmentation (33.057%), spike density (19.197%), 1000-grain weight (17.601%), and days to flowering (11.594%), contributing in total 81.449% (Table 6).

Table 5. Eigenvectors and eigenvalues associated with each character with respect to 9 agro-morphological characters and presence/absence of pigmentation in six plant parts as explained by the first eight principal components (PC) in 17 indigenous Durum wheat accessions repatriated from USDA gene bank

|                | PC1    | PC2    | PC3    | PC4    | PC5    | PC6    | PC7     | PC8     |
|----------------|--------|--------|--------|--------|--------|--------|---------|---------|
| Days to flowering | 0.205  | 0.365  | -0.340 | 0.180  | 0.032  | -0.173 | -0.291  | -0.227  |
| Days to maturity  | -0.003 | 0.515  | 0.053  | 0.340  | 0.010  | -0.048 | 0.102   | 0.337   |
| Spikelets/spike   | -0.393 | -0.208 | -0.128 | 0.067  | 0.204  | 0.048  | -0.103  | 0.389   |
| Grains/spike      | -0.382 | -0.216 | -0.126 | 0.076  | 0.228  | 0.056  | -0.132  | 0.409   |
| Grain Length (mm) | 0.412  | -0.106 | -0.063 | -0.127 | 0.136  | -0.034 | -0.076  | 0.215   |
| Grain width (mm)  | 0.042  | 0.169  | 0.271  | -0.345 | -0.342 | 0.409  | -0.472  | 0.108   |
| 1000 grain weight (g) | -0.098 | 0.316  | 0.420  | -0.200 | -0.114 | -0.090 | 0.566   | 0.246   |
| Tiller No.        | 0.391  | -0.075 | -0.165 | -0.239 | 0.100  | 0.040  | -0.004  | 0.355   |
| Spike density     | 0.028  | 0.086  | 0.438  | 0.423  | 0.264  | -0.251 | -0.305  | -0.034  |
| Coleoptile color  | 0.001  | -0.218 | 0.575  | 0.078  | 0.150  | 0.120  | -0.218  | -0.117  |
| Nodal Color       | 0.191  | -0.252 | -0.004 | 0.447  | -0.109 | 0.434  | 0.332   | -0.046  |
| Internode Color   | 0.307  | -0.362 | 0.066  | 0.275  | -0.189 | 0.010  | 0.137   | 0.041   |
| Leaf Color        | -0.162 | 0.302  | -0.180 | 0.207  | 0.165  | 0.630  | 0.054   | -0.138  |
| Leaf Sheath Color | 0.382  | 0.153  | 0.049  | 0.140  | 0.158  | 0.115  | -0.108  | 0.417   |
| Auricle           | 0.143  | 0.041  | 0.084  | -0.293 | 0.745  | 0.161  | 0.210   | -0.244  |
| Eigen value       | 4.519  | 2.487  | 1.855  | 1.513  | 1.186  | 1.147  | 0.675   | 0.586   |
| Variability (%)   | 30.127 | 16.579 | 12.370 | 10.088 | 7.905  | 7.648  | 4.502   | 3.904   |
| Cumulative %      | 30.127 | 46.705 | 59.075 | 69.163 | 77.068 | 84.715 | 89.218  | 93.122  |
Fig. (1). Scree plot showing eigenvalues in response to the principal components (factors, Fs) for the quantitative and qualitative traits of indigenous durum wheat accession.

Table 6. Contribution of 9 agro-morphological characters and presence/absence of pigmentation in six plant parts in percent to the first eight principal components in 17 indigenous Durum wheat accessions repatriated from USDA gene bank.

| Character                        | PC1   | PC2   | PC3   | PC4   | PC5   | PC6   | PC7   | PC8   |
|----------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Days to flowering                | 4.205 | 13.348| 11.594| 3.253 | 0.101 | 3.000 | 8.452 | 5.162 |
| Days to maturity                 | 0.001 | 26.565| 0.277 | 11.581| 0.009 | 0.232 | 1.037 | 11.379|
| Spikelets/spike                  | 15.455| 4.326 | 1.636 | 0.443 | 4.147 | 0.229 | 1.053 | 15.102|
| Grains/spike                     | 14.598| 4.679 | 1.578 | 0.573 | 5.203 | 0.313 | 1.731 | 16.767|
| Grain Length (mm)                | 16.943| 1.120 | 0.393 | 1.625 | 1.853 | 0.115 | 0.576 | 4.629 |
| Grain width (mm)                 | 0.754 | 2.856 | 7.339 | 11.911| 11.686| 24.907| 22.290| 1.174 |
| 1000 grain weight (g)            | 0.954 | 9.978 | 17.601| 4.008 | 1.290 | 0.811 | 32.041| 6.076 |
| Tiller No.                       | 15.271| 0.558 | 2.730 | 5.715 | 1.007 | 0.159 | 0.001 | 12.590|
| Spike density                    | 0.076 | 0.743 | 19.197| 17.896| 6.993 | 6.293 | 9.325 | 0.117 |
| Coleoptile color                 | 0.000 | 4.773 | 33.057| 0.610 | 2.236 | 1.436 | 4.763 | 1.362 |
| Nodal Color                      | 3.652 | 6.350 | 0.002 | 19.975| 1.187 | 18.831| 11.021| 0.212 |
| Internal Color                   | 9.436 | 13.086| 0.429 | 7.578 | 3.583 | 0.010 | 1.865 | 0.165 |
| Leaf Color                       | 2.611 | 9.093 | 3.226 | 4.296 | 2.725 | 39.749| 0.288 | 1.911 |
| Leaf Sheath Color                | 14.572| 2.355 | 0.237 | 1.959 | 2.481 | 1.329 | 1.158 | 17.378|
| Auricle                          | 2.052 | 0.170 | 0.703 | 8.578 | 55.500| 2.585 | 4.398 | 5.977 |

The first two PCAs that contributed 46.705% of the total variation present in the accessions were used to draw a biplot graph to understand the pattern of distribution of accessions in the four quadrants of the graph. Thus, PCA discriminates all the Oman durum wheat landraces into four clusters scattered respectively over four quadrants of the biplot graph (Fig. 2). The graph also represents eigenvectors of the characters that greatly influence each axis of the PC1 and PC2 in terms of length that is proportional to its magnitude of influence on that axis [29, 41, 42]. Accordingly, quadrant I (+,+) consisting of four accessions viz. PI 532302, PI 532305, PI 532306, and PI 532307 formed cluster I, which was highly influenced by days to flowering and leaf sheath color. The quadrant II (-,+) consisting of five accessions viz. PI 532288, PI 532291, PI 532292, PI 532300, and PI 602425 formed cluster II, which was highly influenced by days to maturity and leaf color. The quadrant III (-,-) consisting of six accessions viz. PI 532239, PI 532242, PI 532279, PI 532281, PI 532287, and PI 532289 formed cluster II, which was highly influenced by spikelets/spike and grains/spike whereas cluster IV was formed of only two accessions located in quadrant IV (+,-) which were greatly influenced by internode color and grain length.
The cluster analysis has been applied to explain the relationship among the indigenous durum wheat landraces, as different accessions within a cluster were presumed to be more closely related to each other in terms of the characters under investigation than those accessions of other clusters. The nature of association among 17 indigenous durum wheat landraces signifying diversity was revealed by Wards’ method of cluster analyses on the basis of Euclidian distance coefficients (Fig. 3) for 9 agro-morphological and 6 pigmentation traits (Table 5). As against the classificatory pattern indicated by the PCA, the HCA of Wards’ method showed the different composition of four classes (clusters) of indigenous durum wheat accessions as A, B, C, and D. (Fig. 3).

Cluster A contained only two landraces (PI 532279 and PI 532281); cluster B consisted highest of nine accessions, viz. PI 532242, PI 532287, PI 532239, PI 532289, PI 532291, PI 532307, PI 532300, PI 532288, and PI 532292. Cluster C was formed of only one accession, PI 532202, whereas cluster D consisted of five accessions viz. PI 602425, PI 532306, PI 532303, PI 532304, and PI 532305.

In both the pattern of clustering, it was observed that the landraces collected from different governorates of Oman were distributed over all clusters, indicating the existence of more diversity.

4. DISCUSSION

The Sultanate of Oman has an ancient cultivation history of both bread wheat (*Triticum aestivum* L.s.l.) and durum wheat (*Triticum turgidum* ssp. *durum*) because of its characteristic location on the eastern edge of the Arabian Peninsula [13, 43 - 45]. Wheat landraces constitute the prime genetic resources of cultivated wheat not only in Oman but also in several MENA (the Middle East and North Africa) [42, 46 - 52]. Indigenous landraces have paramount significance for their potential utilization in crop improvement and conservation programs. A large number of wheat landraces have been collected from different parts of Oman during collecting missions during the 1980s and 1990s after Oman’s inclusion in worldwide activities for the collection of plant genetic resources under the FAO program [13]. The *T. turgidum* USDA accessions used in the present investigation were part of the collected genetic material during the 1990s [13]. Although the wealth of the Omani landraces has been emphasized [53], the morphological variation, tolerance to biotic and abiotic stresses, and their quality characters have not been significantly exploited in crops like wheat [52, 54]. Besides, information on the extent and pattern of genetic diversity in these durum wheat accessions is not available.
The results of the present investigations clearly revealed that 17 indigenous accessions differed significantly from one another with respect to all morpho-agronomic and pigmentation characters and showed a considerable level of phenotypic variation in terms of diversity (Tables 2-6; Figs. 1-3). In view of the requirement to use new traits in breeding procedures and statistical methods for integration of disciplinary investigation [49], in the present study, the pigmentation on different parts of the plant as presence (score 1) or absence (score 0) has been considered in the analyses of diversity [55] for their potential use as genetic identification markers in DUS tests of varieties [56 - 58]. Our results are in agreement with those of previous studies underlining the existence of genetic variability or diversity among durum wheat accessions studied not only in terms of agro-morphological characters like tiller number, spikelets/spike, grains/spike, 1000 grain weight [3, 25, 29, 59 - 62] but also for days to flowering and maturity [3, 25].

Correlation coefficients for the agro-morphological and qualitative characters were examined for potential correlations to determine whether the selection for stability in one character might influence the stability in other characters of growth of the crop. In this study, only two of the six significant correlations were found positive among the different agro-morphological and quality traits in durum wheat indigenous accessions investigated (Table 4). Accordingly, a positive association among the characters indicated that improvement of one character might simultaneously improve the other desired trait [29, 63]. For example, a positive correlation among the traits related to inflorescence, such as spikelets/spike and grains/spike showed that an improvement in physical properties of the inflorescence also results in an improvement in the number of grains that contribute to yield. Conversely, negative associations between the growth and yield attributes would help in maintaining the magnitude of the characters in balance for achieving optimum yield. For instance, spikelets/ spike or grains/ spike could be balanced to achieve the required grain length as correlations between spikelets/grains and grain length are negative and significant. Similarly, the tiller number should be optimum to get maximum spikelets and grains (Table 4). Similar observations were done by other researchers in their durum wheat germplasm [64].

The structure of the genetic diversity among the set of 17 indigenous durum wheat accessions representing six governorates of Oman extending from north of the country to its south, was assessed by multivariate analyses such as PCA and CA based on aggregate phenotypic means over two cropping seasons. Using a PCA based on the correlation matrix, it appeared that the first eight principal components...
accounted for over 90% of the total variance of which the first two components contributed 46.705%, which was considered to be substantial to scatter the positions of accessions over the four quadrants of the biplot graph (Fig. 2). Such a magnitude of the contribution of each of the first three PCs rightly agreed with the results of research conducted in 2014 [65], which indicated the contribution of the PC1, PC2, and PC3 as 25.9%, 17.1%, and 13.3%, respectively and that in 2018 [42] which found PC1, PC2 and PC3 contributing 45.13%, 17.85%, and 14.71%, respectively in wheat germplasm studied. Similar results were also obtained by other researchers [66 - 71]. In PC1, tiller number, grain length, spikelets/spike, grains/spike, and leaf sheath color were effective main sources of variation, whereas, in PC2, accessions were discriminated mainly through days to flowering, days to maturity and internode pigmentation. This is because, in PCA, differentiation of accessions into different clusters was ensured with a relatively high contribution of few characters rather than a small contribution from each character [72, 73].

In the present investigation, the results of two multivariate analyses viz. PCA and CA based on Euclidian distances showed different patterns of clustering, and they did not appear to support each other. PCA analysis formed four clusters viz. cluster I of 4 accessions, cluster II of 5 accessions, cluster III of 6 accessions, and cluster IV of 2 accessions (Fig. 2) while a dendrogram of cluster analysis (Fig. 3) revealed the formation of four clusters viz. cluster A of 2 accessions, cluster B of 9 accessions, cluster C of only one accession and cluster D of 5 accessions based on the principle of discrimination each one adapted. Further, these results revealed that accessions within each cluster might belong to the same or different governorates (Figs. 2 and 3), thus suggesting the fact that there existed no clear relationship between accessions and geographical diversity. For instance, in the composition of clusters from PCA, the accessions of each of all the four clusters were found to be from different governorates. Cluster IV consisted of two accessions, namely PI 532303 and PI 532304, which belonged to Al Batinah South (Rustaq) and Dhofar (Salalah) governorates, which are about 1000 km distant. Similarly, all the four accessions of cluster I were the ones collected from the four different governorates viz. PI 532 302 (Dhofar), PI 532305 (Al-Dhahiriya), PI 532306 (Al-Dakhiliya), and PI 532307 (Alsharqiya South). A similar trend of clustering was observed in cluster II and cluster-III. This might be due to the exchange or two identifying markers of pigmentation on plant parts. characters of growth for higher yield or productivity with one to the selection of parents for hybridization to improve the diversity, with each forming four diverse clusters with different compositions of accessions. However, their overall results led to the selection of parents for hybridization to improve the characters of growth for higher yield or productivity with one or two identifying markers of pigmentation on plant parts.

CONCLUSION

Seventeen indigenous durum wheat landraces/ accessions were significantly different (p<0.05) with respect to nine quantitative characters except in respect of a number of tillers and had a higher degree of variation in respect of most of these quantitative characters. Only six correlations involving four characters viz. tiller no., spikelets/ spike, grains/spike, and grain length were significant (p<0.05). Two multivariate analyses were found not supporting each other in discerning diversity, with each forming four diverse clusters with different compositions of accessions. However, their overall results led to the selection of parents for hybridization to improve the characters of growth for higher yield or productivity with one or two identifying markers of pigmentation on plant parts.

LIST OF ABBREVIATIONS

| AHC     | = Agglomerative Hierarchical Clustering |
| BI      | = Bioversity International |
| CA      | = Cluster Analysis |
| FAO     | = Food and Agriculture Organization of the United Nations |
| HCA     | = Hierarchical Cluster Analysis |
| IBPGR   | = International Bureeu of Plant Genetic Resources |
| (Now, BI) | |

Genetic Diversity of Omani Durum Wheat The Open Agriculture Journal, 2021, Volume 15
ACKNOWLEDGEMENTS

The authors gratefully acknowledge OAPGRC, TRC of Oman, for the financial support of the research.

REFERENCES

[1] Lantican MA, Dubin HJ, Morris NL. Impacts of international wheat breeding research in developing world, 1988-2002. D.F., Mexico: CIMMYT 2016.
[2] Food FAO. Food and Agriculture Organization of the United Nation FAOSTAT, Italy [Accessed 2018]. [http://faostat.fao.org
[3] Devesh P, Moitra PK, Shukla RS, Pandey S. Genetic diversity and principal component analyses for yield, yield components and quality traits of advanced lines of wheat. Journal of Pharmacognomy and Phytochemistry 2019; 8(3): 4834-9.
[4] Ganeva G, Viktor K, Misheva S, Popova Z, Christov NK. Genetic diversity assessment of Bulgarian durum wheat (Triticum durum Desf.) landraces and modern cultivars using microsatellite markers. Genet Resour Crop Evol 2010; 57: 273-85. [http://dx.doi.org/10.1007/s10722-009-9468-5]
[5] Collejo MJ, Vargas-Kostiuk ME, Rodriguez-Quijano M. Selection, training and validation process of a sensory panel for bread analysis: Influence of cultivar on the quality of breads made from common wheat and spelt wheat. J Cereal Sci 2015; 61: 55-62. [http://dx.doi.org/10.1016/j.jcs.2014.09.008]
[6] Suchowiska E, Wiwat M, Krska R, Do Kandler W. Do Triticum aestivum L. and Triticum spelta L. Hybrids constitute a promising source material for quality breeding of new wheat varieties?. Agronomy 2020; 10:43: 16p.
[7] Ivanov IV, Hartweizen DB. T durum Desf. Jahrbuch der Universita's Sofia, Landwirtschaftliche Fakulta't 1927; Vol. V: pp. 1926-7.
[8] Zhukovsky PM. Cultivated plants and their relatives. Leningrad, USSR: Kolos 1964. (in Russian)
[9] Bozzi A. Origin, distribution, and production of durum wheat in the world.Durum wheat: chemistry and technology. St. Paul, MN: American Association of Cereal Chemistry 1988; pp. 1-16.
[10] Srivastava JP, Dumania AB, Pecceti L. Landraces, primitive forms and wild progenitors of macaroni wheat, Triticum durum: their use in dryland agriculture. In: Miller TE, Koebner RMD, Eds. Proc 7th Int Wheat Genet Symp. 153-9.
[11] Wang HY, Wei YM, Yan ZH, Zheng YL. EST-SSR DNA polymorphism in durum wheat (Triticum durum L.). collections. J Appl Genet 2007; 48(1): 35-42. [http://dx.doi.org/10.1007/FO03194655] [PMID: 17272859]
[12] MAF. Agriculture & Livestock Research - Five-Year Research Strategy 2011-2015. In: Directorate General of Agriculture & Livestock Research. Sultanate of Oman.: Ministry of Agriculture. 2011; p. 52p.
[13] Guarino L. Crop collecting in the Sultanate of Oman in the context of the Arabian Peninsula. IBPGR Plant Gen Res Newsletter 1990; 77: 23-33.
[14] Annual Report MAF. Sultanate of Oman.: Ministry of Agriculture & Fisheries. 2012. Directorate General Agriculture & Livestock Research.
[15] Annual Report MAF. Sultanate of Oman.: Ministry of Agriculture & Fisheries. 2013. Directorate General Agriculture & Livestock Research.
[16] Annual Report MAF. Sultanate of Oman.: Ministry of Agriculture & Fisheries. 2014. Directorate General Agriculture & Livestock Research.
[17] Frenez D. The Indus Civilization Trade with the Oman Peninsula.the Shadow of the Ancestors The Prehistoric Foundations of the Early Arabian Civilization in Oman. Second expanded edition.. Ministry of Heritage and Culture Sultanate of Oman. 2018.; pp. 385-96.
[18] Zohary D, Hopf M. Domestication of plants in the Old World. 2nd ed. Oxford, UK: Clarendon Press 2000.
[19] Gebauer J, Al Khmiri S, Khan IA, Buerkert A, Hammer K. Plant genetic resources in Oman – Evidence of millennia of cultural exchange in the Middle East.Oases of Oman. Muscat: Al Roya Press and Publishing House 2010; pp. 28-33.
[20] Zohary D, Hopf M, Weiss E. The domestication of the plants in the old world: the origin and spread of cultivated plants in West Asia, Europe and Nile Valley. Oxford: Oxford University Press 2012. [http://dx.doi.org/10.1003/acprof:osobl/978109594906.001.0001]
[21] Maccaferri M, Harris NS, Twardziok SO, et al. Durum wheat genome highlights past domestication signatures and future improvement targets. Nat Genet 2019; 51(5): 885-95. [http://dx.doi.org/10.1038/s41588-019-0381-3] [PMID: 30962619]
[22] Islam MR. Genetic diversity in irrigated rice. Pak J Biol Sci 2004; 2: 226-9. [http://dx.doi.org/10.3923/pjbs.2004.226.229]
[23] Khodadadi M, Fotokhan MH, Miransari M. Genetic diversity of wheat (Triticum aestivum L.) genotypes based on cluster and principal component analyses for breeding strategies. Aust J Crop Sci 2011; 5(1): 17.
[24] Mir RR, Zaman-Allah M, Sreenivasulu N, Trethowan R, Varshney RK. Integrated genomics, physiology and breeding approaches for improving drought tolerance in crops. Theor Appl Genet 2012; 125(4): 625-45. [http://dx.doi.org/10.1007/s00122-012-1904-9] [PMID: 22696006]
[25] Afroz G, Sahighnia N, Karimizadeh R, Shekari F. Analysis of some agronomic traits of durum wheat under dryland and supplemental irrigation conditions. Agriculture (Polnospodpardostva) 2014; 4: 149-58. [http://dx.doi.org/10.1015/agri-2013-0004]
[26] Desheva G, Kysyev B. Genetic diversity assessment of common winter wheat (Triticum aestivum L.) genotypes. Emir J Food Agric 2015; 27: 283-90. [http://dx.doi.org/10.9755/ejfa.v27i3.19799]
[27] Mohammadi M, Karimizadeh R, Shefazadeh MK, Sadeghzadeh B. Statistical analysis of durum wheat yield under semi-warm dryland condition. Aust J Agric Res 2011; 5: 1292-7.
[28] Karimizadeh R, Mohammadi M, Armon M, Shefazadeh MK, Chalajour H. Determining heritability, reliability and stability of grain...
yield and yield-related components in durum wheat (Triticum durum L.), J. Bot. Agric Sci 2012; 18(4): 595-607.

[29] Zarei L, Cheghamiriz K, Farshadfar E. Evaluation of grain yield and some agronomic characters in durum wheat (Triticum turgidum L.) under rainfed conditions. Aust J Agric Res 2013; 7: 699-17.

[30] Carver SM, Smith EL, England HO. Regression and cluster analysis of environmental responses of hybrid and pure line wheat cultivars. Crop Sci 1987; 27: 659-64. [http://dx.doi.org/10.2135/cropsci1987.0011183X002700040009x]

[31] Mohammadi SA, Prasanna BM. Analysis of genetic diversity in crop plants-salient statistical tools and considerations. Crop Sci 2003; 43: 1235-48. [http://dx.doi.org/10.2135/cropsci2003.1235]

[32] Eivazi AR, Naghavi MR, Hajheidari M, et al. Assessing wheat (Triticum aestivum L.) genetic diversity using quality traits, amplified fragment length polymorphisms, simple sequence repeats and proteome analysis. Ann Appl Biol 2007; 152: 81-91. [http://dx.doi.org/10.1111/j.1474-7748.2007.02001.x]

[33] Mengistu DK, Kiros AY, Pe ME. Phenotypic diversity in Ethiopian durum wheat (Triticum turgidum var.durum) landraces. Crop J 2015; 3: 190-9.

[34] Mengistu D, Yusuf G, Fadda C, et al. Genetic diversity in Ethiopian durum wheat (Triticum turgidum var.durum) from Ethiopia. Crop Sci 2015; 55: 997-1006. [http://dx.doi.org/10.2135/cropsci2014.02.0176]

[35] Al-Khanjari S, Hammer K, Buerkert A. Molecular diversity of Omani durum wheat (Triticum turgidum) landraces in northern Oman: An environment for evolution and in situ conservation of plant genetic resources. Genet Resour Crop Evol 2007; 54: 465-81. [http://dx.doi.org/10.1007/s10722-006-9205-2]

[36] Hammer K, Gebauer J, Kabil E, Buerkert A. Mountain oases in northern Oman: An environment for evolution and in situ conservation of plant genetic resources. Genet Resour Crop Evol 2007; 54: 465-81. [http://dx.doi.org/10.1007/s10722-006-9205-2]

[37] Al-Khanjari S, Kabil E, Buerkert A. Oman at the cross roads of inter-regional exchange of of cultivated plants. Crop Evol 2009; 56: 547-60. [http://dx.doi.org/10.1007/s10722-008-9385-4]

[38] Filatenko AA, Hammer K. Wheat landraces from Oman: A botanical analysis. Emer J Food Agric 2014; 26: 19-136. [http://dx.doi.org/10.9755/efja.v26i2.16760]

[39] Belay G, Tesemma T, Bechere E, Mitiku D. Natural and human selection for purplegrain tetraploid wheats in the Ethiopian highlands. Genet Resour Crop Evol 1995; 42: 87-91. [http://dx.doi.org/10.1007/BF02432143]

[40] Al-Khanjari S, Hammer K, Buerkert A, Khan I, Al-Maskri A. A survey of wheat landraces in Oman. FAO/IPGRI Plant Gen. Res Newsletter 2005; 141: 7-10.

[41] Jaradat AA. Phenotypic divergence in the meta-population of the Hourani wheat landrace. J Food Agric Environ 2006; 4: 186-91.

[42] Ahmadizadeh M, Shahbazi H, Valizadeh M, Zareifzadeh M. Genetic diversity of durum wheat landraces using multivariate analysis under normal irrigation and drought stress conditions. Afr J Agric Res 2011; 6(1): 2294-302. [http://dx.doi.org/10.5539/ajar.v6n1p2294]

[43] Al-Khanjari S, Hammer K, Buerkert A. Molecular diversity of Omani wheat revealed by microsatellites: I. Tetraploid landraces. Genet Resour Crop Evol 2007; 54: 1291-300. [http://dx.doi.org/10.1007/s10722-006-9110-8]

[44] Al-Khanjari S, Hammer K, Buerkert A. Six new botanical varieties of Triticum from Oman. Genet Resour Crop Evol 2010; 57: 135-1139. [http://dx.doi.org/10.1007/s10722-010-9610-4]

[45] Jaradat AA, Shahid M. How diverse a farmer-managed wheat landrace can be? Emer J Food Agric 2014; 26(2): 93-118. [http://dx.doi.org/10.9755/efja.v26i2.16753]

[46] Ahmadin NA, Ali MA. Multivariate analysis of some morpho-ecological traits in durum wheat (Triticum aestivum L.) germplasm. J Plant Resour 2018; 1: 22-6.

[47] Belay G, Tesemma T, Bechere E, Mitiku D. Genetic diversity analysis for morpho-physiologic traits, under timely and late sown condition in bread wheat (Triticum aestivum L.). J Wheat Res 2015; 7(1): 27-30.

[48] Wang LX, Qiu J, Chang LF, et al. Assessment of wheat variety distinctness using SSR markers. J Integr Agric 2015; 14(10): 1923-35. [http://dx.doi.org/10.1016/S2095-3119(15)61057-7]

[49] Garcia Del Moral LF, Raharbay, V., Villegas D. Royo C. Evaluation of grain yield and its components in durum wheat under Mediterranean conditions: an ontogenic approach. Agron J 2003; 95: 266-74.

[50] Zarkti H, Ouabbou H, Illial A, Udupa SM. Detection of genetic diversity in Moroccan durum wheat accessions using agromorphological traits and microsatellite markers. Afr J Agric Res 2010; 5: 1837-44.

[51] Khan MI, Shabbir G, Akram Z, et al. Character association studies of seedling traits in different wheat genotypes under moisture stress conditions. SABRAO J Breed Genet 2013; 45: 458-67.

[52] US National Plant Germplasm System. [https://npgsweb.ars-grin.gov/gringlobal/2020]

[53] Ayed-Slama O, Bouhaoel I, Chamakeh Z, et al. Genetic variation of salt-stressed durum wheat (Triticum turgidum subsp. durum Desf.) genotypes under field conditions and gynogenetic capacity. J Genet Eng Biotechnol 2018; 16(1): 161-7. [http://dx.doi.org/10.5513/JCEA01/12.2.922]

[54] Ali Y, Atta BM, Akhter J, Monneveux P, Lateef Z. Genetic variability, association and diversity studies in wheat (Triticum aestivum L.) germplasm. Pak J Bot 2011; 43(6): 2087-97.

[55] Bhanupriya B, Satyaranaraya N, Makherjee S, Sarkar K. Genetic diversity of wheat genotypes based on the principal component analysis in Gangetic alluvial soil of West Bengal. J Crop Weed 2014; 10: 104-7.

[56] Hailegiorgis D, Mesfin A, Genet T. Genetic divergence analysis in spring wheat (Triticum aestivum L.). Bangladesh J Agric
Nielsen NH, Backes G, Stougaard J, Andersen SU, Jahoor A. Genetic diversity and population structure analysis of European hexaploid bread wheat (Triticum aestivum L.) varieties. PLoS One 2014; 9(4):e94000
[http://dx.doi.org/10.1371/journal.pone.0094000] [PMID: 24718292]

Chahal GS, Gosal SS. Principles and Procedures of Plant Breeding: Biotechnology and Conventional Approaches. UK: Alpha Science International 2002; p. 664.

Yan W, Tinker NA. An integrated system of biplot analysis for displaying, interpreting, and exploring genotype-by-environment interactions. Crop Sci 2005; 45: 1004-16.
[http://dx.doi.org/10.2135/cropsci2004.0076]

Fayaz F, Aghaee Sarbarzeh M, Talebi R, Azadi A. Genetic Diversity and Molecular Characterization of Iranian Durum Wheat Landraces (Triticum turgidum durum (Desf.) Husn.) Using DArT Markers. Biochem Genet 2019; 57(1): 98-116.
[http://dx.doi.org/10.1007/s10528-018-9877-2] [PMID: 30051349]

Alemu YA, Anley AM, Abebe TD, Moral MT. Genetic variability and association of traits in Ethiopian durum wheat (Triticum turgidum L. var. durum) landraces at Dabat Research Station, North Gondar. Cogent Food Agric 2020; 6: 1.
[http://dx.doi.org/10.1080/23311932.2020.1778684]

Al-Maskri A, Nagieb M, Hammer K, Filatenko AA, Khan I, Buerkert A. A note about Triticum in Oman. Genet Resour Crop Evol 2003; 50: 83-7.
[http://dx.doi.org/10.1023/A:1022986113736]