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Genetic diversity of Algerian sorghum (*Sorghum bicolor (L.)* Moench) landraces by using agro-morphological markers

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Abstract
The present study was performed to assess the native Algerian sorghum germplasm,19 accessions originating from the South of Algeria and one introduced commercial hybrid were evaluated for 12quantitative agro-morphological markers. Analysis of variance revealed significant differences ($p < 0.05$) between accessions for all characters. Comparison of means by Duncan's least significant test separate accessions into several homogeneous groups. It was found that sorghum landrace Ai19 showed the highest scores of final height (317 cm) and biomass dry yield (38 tons), Ai13 showed shortest vegetative cycles by 75 days to 50% flowering and the highest exploration of water to accumulate dry matter. The first two-principle component showed together more than 76% of the total variation. Clustering analysis showed that the 20 accessions were divided into four groups, mainly differentiated by forage production, days to 50% of flowering, final height, tillering capacity and leaf characteristics. The current study demonstrates that the characterization of the entire collection revealed a great phenotypic variability within the accessions and showed those that have markers of agronomic interest. Agro-morphological traits were very practical in detecting variation between local and commercial hybrid sorghum. Landraces Ai19, Ai13 and Fr1, through their valuable agro-morphological markers, could be used in sorghum genetic breeding programs.
Keywords: *Sorghum bicolor* (L) Moench, landrace, agro-morphological markers, phenotypic variability, diversity.

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important cereal after maize, rice, wheat, and barley. It is grown for different purposes, such as grain, forage, sugar syrup, biofuel, and various medicinal uses(Bantilan et al., 2004; Tonapi et al., 2011; Dahlberg et al., 2011; Teshome et al., 2015; Upadhyaya et al.,2016). It was a staple food crop of millions of populations throughout the world and helped poor farmers to survive during difficult times. It is still an integral part of the livelihood of African and Asian farmers (Tonapi et al., 2011; Rakshit et al., 2014).Sorghum plays a major role in the semi-arid regions where drought, heat and poor soil conditions made the production of other cereals difficult (House, 1985; Ayana and Bekele, 2000). Sorghum adaptation to biotic and abiotic stress made it an important major cereal in the worldwide (Almodares et al.,2013; Hadebe et al., 2019), which could be also a useful model for identifying genes related to stress tolerance (Raoet al., 2013).Information of genetic diversity is important for improvement, conservation, and survival of sorghum (Gerrano et al., 2014). Agronomic and morphological characterization and evaluation have long been, over the years, used to study genetic diversity within and among the accessions in different crops. The best use of the information contained in the data for morphological characterization is an important issue in plant breeding (Al-Naggar et al., 2020).Agro-morphological traits in sorghum were associated with important economical traits and helpful in selecting the high yielding sorghum genotypes (Mohammed et al., 2015).There were several scientific reports on agro-morphological diversity, genetic variability, adaptation to environmental conditions, nutritional, and biological properties of sorghum. However, in Algeria, most of the studies on sorghum focused on grain quality (Boudries et al.,2009; Belhadi et al.,2013; Souilah et al.,2014), protein fractions (Mokrane et al.,2009, 2010), their benefit characteristics for food and non-food uses (Mokrane et al.,2009, 2010; Souilah et al.,2014), and antioxidant activity (Hadbaoui et al., 2010). To the best of our knowledge, no study reported genetic and morphological variability of sorghum cultivated in Algeria and on its potential uses in breeding plant programs. Thus, the main objectives of this study were to estimate the level of phenotypic variability and genetic diversity among local sorghum landraces and the commercial hybrid according to agro-morphological markers and promising accessions for different traits that could be used in sorghum breeding programs.

Materials and methods

Experimental site and materials

Table 1. List of common name sorghum accessions, origin and their status.

Accession code	Common name	Origin and status
Ai08	*Tafsoutbeid*	In salah-SalahTouil/ Landrace
Ai09	*Tafsoutbeid*	ElMaleh - Elham.Plur/ Landrace
Ai10	*Tafsoutbeid*	ElMaleh - Elham.Khort/ Pop
Ai12	*Tafsoutbeid*	In salah - Salah20 / Landrace
Ai13	*Tafsouthamr*	In salah - Salah21 / Landrace
Ai14	*Tafsouthamr*	ElMaleh - DaiesTouil/ Landrace
Ai16	*Tafsouthamr*	ElMaleh - DaiesHab/ Landrace
Ai18	*Tafsouthamr*	ElMaleh - 17BTouil / Landrace
Ai19	*Tafsoutbeid*	ElMaleh - Elham.Touil/ Landrace
Ai24	*Tafsoutbeid*	FogEzz-Bakad2II / Landrace
Ai29	*Tafsoutbeid*	FogEzz- BakadIII6 / Landrace
Ai30	*Tafsoutbeid*	FogEzz-BakadIV2 / Landrace
Ai33	*Tafsoutmouch*	ElMaleh-DaiesHab/ Landrace
Ai34	*Tafsoutbeid*	ElBarka-DahriHab/ Landrace
Ai35	*Tafsoutbeid*	ElBarka-DahriTouil/ Landrace
Ai36	*Tafsouthamr*	ElBarka-HamraniTouil/ Landrace
Ai39	*Tafsouthamr*	ElBarka-HamraniHab/ Landrace
Ai40	*Tafsoutbeid*	ElBarka-HamraniHab/ Landrace
Ai42	*Tafsoutbeid*	FogEzz-BakadTouil/ Landrace
F01	*Lussi*	French - CAUSSADE/ *commercial hybrid*

The study was carried out during 2014, from April to September in sub-humid stage at the experimental station of high national agronomic school (ENSA Algiers, Algeria, 36°43'10.59″N–3°09'01.58″E, altitude: 39m).Nineteen landraces from south Algeria (Aïn Salah) and one hybrid variety from France (i.e. 20 accessions) were grown under rain-fed conditions (irrigations were applied when needed). The environmental conditions at the experiment site are illustrated in Figure 1.The ombrothermic diagram showed that April, July and August was marked by a very low quantities of rainfall contrary to other months particularly before the sowing or in the middle of vegetation cycle. A moderate temperature was recorded during all the cycle. The information related to the description of the studied sorghum accessions including common name, status, and origin were given in Table 1.The accessions were raised in four randomized complete blocks design with four replicates. The experiment site dimension was 30,5m length and 9m width (274.5m^2 in total) with 0.5m spacing between micro-plots and 1m between blocks. Micro-plot area was 1.575m^2 (1.5m x 1.05m), row and plant spacing were 35 and 30 cm respectively (Figure 2, 3 and 4).Spacing between plants was adopted to accommodate 8 plants per micro-plot surrounded by 16 plants to eliminate edge effects. All micro-plots were tilled to depth of 30cm. A pre-plant NPK fertilizer (15-15-15) was applied at a rate of 400kg.ha^{-1} with additional 150kg.ha^{-1} of urea (46-0-0) (divided in two intakes).A foliar fertilizer (N) (70-0-0) was applied after planting. Fungicide and insecticide were used when necessary. Sowing was done, on April 17th 2014. Uniform crop management practices were applied to all entries during the trial. Materials used in the experiment consisted of a tape measure, decameter, calipers, stapler, hoe, paper bags, plastic bags, twine, reed, backpack fertilizer, gloves, knife, digital camera, labels, cans.

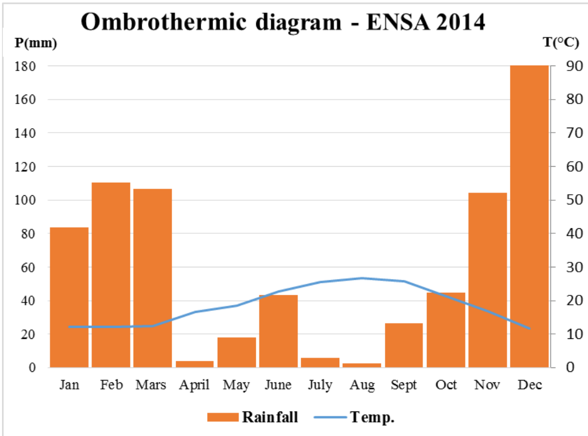

Figure 1. Ombrothermic diagram for the experimental site. P: precipitation, T: Temperature. (The study period limited between April and September 2014).

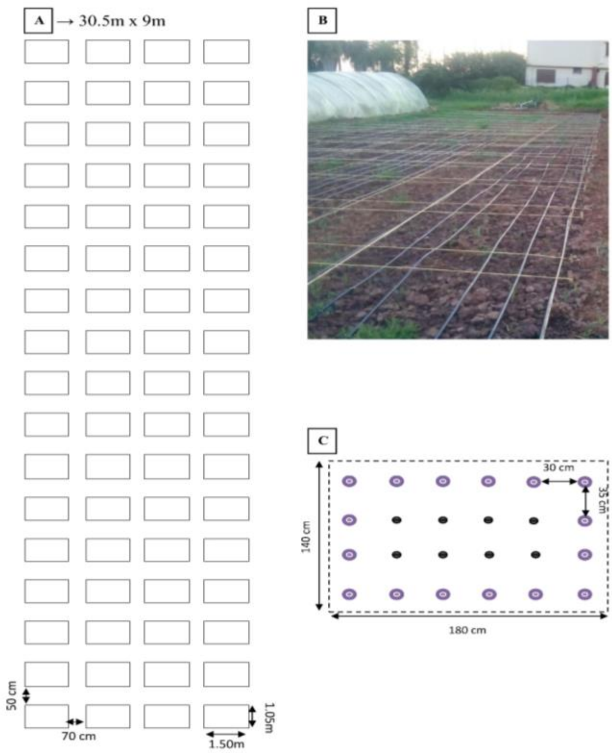

Figure 2. Experimental site (A and B) and microplot(C) dimensions.

Figure 3. Experimental site 120 days after sawing

Figure 4. Landrace Ai19 at right and the hybrid Fr1 at left

Data collection and trait measurements

The collected data including twelve traits related to vegetative growth and flowering time were presented in Table 2. For each micro-plot, eight selected individual plants were used for estimating different quantitative traits. Data was recorded as per trait descriptors for sorghum (IBPGR/ICRISAT, 1993).

Table 2. Codes and description for measured traits.

	Trait	Description
01	Leaf width (*Lwid*, cm)	Measured at the widest point of the penultimate leaf;
02	Leaf area (*Larea*, cm^2)	Computed as leaf length x leaf width x 0.747 suggested by Stickler *et al.* (1961);
03	Leaf dry matter (*DryMatL* %)	Calculated as the ratio between dry weight and fresh weight of the second leaf multiplied by 100;
04	Biomass fresh yield (*BioFrY, Tonne*)	Estimated by weighing the aboveground biomass fresh yield for three plants and then converting into tons at a density of 95,000 plants per hectare;
05	Biomass dry yield (*BioDryY*, *Ton*)	Estimated by weighing the aboveground biomass dry yield for three plants and then converting into tons at a density of 95,000 plants per hectare;
06	Forage index (*ForInd*)	Measured by dividing the rate of the dry matter of the aboveground biomass over the volume of water (precipitation and irrigation - 140.94mm at 80 days date of harvest);
07	Tillers number (*TillNb*)	Computing the number of tillers per plant;
08	Stem diameter (*StDiam*, mm)	Measured in mm using a caliper between third and fourth nodes of the main stem;
09	Emergence (*Emerg*, %)	Percentage of seeds germinated in each microplot at 11 days after sowing;
10	Final plant height (*FHeig*, cm)	Measured from soil surface to the tip of the main inflorescence (Rooney *et al.*, 2013);
11	Growth rate (*GrRate*, cm)	Comparing between two measurements of plants height, during growth stage (comparisons heights between 58 and 66 days after sowing);
12	Days to 50% flowering (*Flow*)	The date which 50% of heads of the same micro-plot were starting flowering.

Data analysis

To test the differences significance among twenty genotypes, the data for each trait were subjected to one way ANOVA using Statistica software v 8. The comparison of means was performed using the Duncan's multiple range test at 5%.The correlations coefficients between pairs of traits were calculated using the Spearman rank correlation option included in XLSTAT software v 14 at 1%. The principal component analysis (PCA) has been used in order to figure out the grouping of genotypes based on twelve traits related to vegetative growth and flowering time. To estimate similarities of individuals, a hierarchical clustering analysis (HCA) was done to describe origin of accessions, based on dissimilarity matrix using Euclidean distances, with the Ward's method included in XLSTAT software v 14, Addinsoft, USA.

Results

Table 3. Means of the studied agro-morphologic measured markers for the 20 accessions studied and Duncan's multiple range test.

Gen	Lwid (cm)	Larea (cm²)	DryMatL (%)	BioFrY (t/ha)	BioDryY (t/ha)	ForInd	TillNb	StDiam (mm)	Emerg (%)	FHeig (cm)	GrRate	Flow (day)
Ai8	9,43^{bcd}	514,17^{de}	36,2^{cde}	76,85^{ef}	13,65^{fghi}	0,39^{cdef}	2b^{c}	13,38^{cdef}	96,88^{ab}	166^{efg}	4,32^{bcdef}	85,5^{efgh}
Ai9	12,18^{a}	909^{a}	34,61^{cde}	188,43^{b}	30,49^{b}	0,35^{fg}	1,25^{c}	16,9^{bcd}	83,33^{bc}	218,5^{c}	2,19^{fgh}	113,5^{abc}
Ai10	6,6^{hi}	283,29^{ij}	36,26^{cde}	51,58^{fg}	10,63^{ghi}	0,45^{bc}	2,75^{bc}	9,42^{f}	78,13^{c}	149,5^{fgh}	4,06^{bcdefg}	78,5^{ghi}
Ai12	7,6^{fghi}	414,61^{efgh}	38,95^{cde}	68,44^{efg}	12,94^{fghi}	0,42^{cde}	3,25^{b}	11,97^{def}	94,79^{ab}	161,75^{efg}	6,59^{a}	77^{hi}
Ai13	6,18^{i}	267,37^{j}	42,59^{bcde}	34,27^{g}	8,8^{hi}	0,56^{a}	2,25^{bc}	9,98^{f}	94,79^{ab}	146,75^{fgh}	5,41^{abcd}	75^{i}
Ai14	8,25^{defg}	433,84^{defg}	43,25^{bcd}	73,86^{efg}	12,4^{fghi}	0,37^{defg}	2,75^{bc}	12,32^{def}	95,83^{ab}	172,5^{def}	5,16^{abcde}	85^{efgh}
Ai16	8,2^{defg}	447,47^{defg}	46,52^{abc}	73,15^{efg}	15,83^{efg}	0,46^{bc}	2^{bc}	12,34^{def}	91,67^{ab}	190,25^{cdef}	5,5^{abc}	85,75^{efgh}
Ai18	7,75^{efgh}	387,96^{efghij}	42,2^{bcde}	49,82^{fg}	10,38^{ghi}	0,46^{bc}	1,75^{bc}	13,84^{cdef}	86,46^{abc}	166,25^{efg}	3,81^{bcdefgh}	79,25^{ghi}
Ai19	10,15^{bc}	877,94^{ab}	31,05^{e}	260,61^{a}	38,38^{a}	0,31^{g}	1,5^{bc}	24,17^{a}	96,88^{ab}	317^{a}	1,88^{gh}	120,5^{a}
Ai24	7,1^{ghi}	396,73^{efghi}	43,03^{bcde}	85,69^{ef}	14,63^{fgh}	0,37^{defg}	2,33^{bc}	12,77^{cdef}	91,67^{ab}	191,33^{cdef}	5,5^{abc}	81^{ghi}
Ai29	9,08^{cde}	552,20^{d}	36,36^{cde}	166,58^{b}	27,38^{bc}	0,36^{efg}	1,5^{bc}	16,35^{bcde}	90,63^{abc}	259^{b}	3,09^{defgh}	115,75^{ab}
Ai30	10,73^{b}	755,33^{c}	39,32^{cde}	161,27^{bc}	26,8^{bc}	0,36^{efg}	1^{c}	19,03^{b}	51,04^{d}	180,25^{cdef}	1,63^{h}	109,75^{bc}
Ai33	8,3^{defg}	462,98^{def}	44,32^{bcd}	50,23^{fg}	8,45^{i}	0,37^{defg}	2,5^{bc}	13,8^{cdef}	91,67^{ab}	115,5^{h}	2,72^{fgh}	82,75^{fghi}
Ai34	8,58^{def}	417,32^{efgh}	37,30^{cde}	62,36^{fg}	12,43^{fghi}	0,44^{bcd}	2,5^{bc}	14,25^{cdef}	91,67^{ab}	123^{gh}	3,66^{bcdefgh}	87,25^{defg}
Ai35	7,13^{fghi}	299,11^{hij}	41,60^{bcde}	89,46^{ef}	15,07^{efg}	0,36^{defg}	1,67^{bc}	12,16^{def}	94,44^{ab}	190,33^{cdef}	3,13^{bcdefgh}	93,33^{de}
Ai36	7,33^{fghi}	367,13^{fghij}	56,51^{a}	75,04^{ef}	14,08^{fghi}	0,41^{cdef}	2,75^{bc}	12,85^{cdef}	88,54^{abc}	204^{cde}	3,78^{bcdefgh}	89,75^{def}
Ai39	9,15^{cde}	511,02^{de}	40,99^{bcde}	105,87^{de}	20,23^{de}	0,41^{cdef}	2^{bc}	11,92^{ef}	97,92^{a}	217^{cd}	2,88^{efgh}	94,25^{d}
Ai40	12,03^{a}	778,27^{bd}	33,97^{de}	127,85^{cd}	24,41^{cd}	0,41^{cdef}	1,5^{bc}	17,56^{bc}	94,79^{ab}	164,25^{efg}	1,78^{gh}	106^{c}
Ai42	6,5^{hi}	321,14^{ghij}	46,16^{abcd}	60,94^{fg}	11,69^{fghi}	0,41^{cdef}	3,25^{b}	11,48^{ef}	85,42^{abc}	184,5^{cdef}	3,19^{bcdefgh}	87^{defg}
Fr1	6,33^{hi}	303,72^{hij}	51,5^{ab}	73,06^{efg}	17,12^{ef}	0,5^{ab}	5,5^{a}	11,3^{f}	92,72^{ab}	292^{ab}	7,28^{a}	78,5^{ghi}
Means	*8,43*	*485,08*	*41,13*	*96,77*	*17,29*	*0,41*	*2,30*	*13,89*	*89,46*	*190,48*	*3,88*	*91,27*

Trait and accession abbreviations as given in tables 1 and 2.Lwid: Leaf width,Larea: Leaf area, DryMatL: Leaf dry matter,BioFrY: Biomass fresh yield, BioDryY: Biomass dry yield, ForInd: Forage index, TillNb: Tillers number, StDiam: Stem diameter, Emerg: Emergence, FHeig: Final plant height, GrRate: Growth rate, Flow: Days to 50% flowering.

The results of the ANOVA showed highly significant differences for all studied markers. Ai19 showed very high scores of biomass fresh yield (*BioFrY*)by more than 260 tons, biomass dry yield (*BioDryY*) with more than 38 tons, stem diameter (*StDiam*)with approximately 24 mm and final height (*FHeig*) with 317cm.Howeverlow values of dry matter of leaves (*DryMatL*, 31%), biomass accumulation (*ForInd*, 0.31)and growth rate (GrRate, 1,88) were recorded. Ai9 have also presented very wide leaves (*Lwid*) and leaf area (*Larea*) with Ai19, Ai40 and Ai30 but with low scores of tillers number (*TillNb*). The hybrid variety Fr1 showed high scores of growth rate (*GrRate*)with 7.28cm per one day and *TillNb*by 5.5 tillerswith good *FHeig* and *ForInd* against low scores of *Lwid*, *Larea*, *StDiam* and *Flow*.Ai13 landrace showed the highest *ForInd* with 0.56 and the shortest cycle with 75 dates to *Flow*(Table 3).

A long vegetative cycle was observed in some landraces such as Ai9, Ai19, Ai29, Ai30 and Ai40 corresponding of 113, 120, 115, 109 and 106 days, a moderate vegetative cycle was found in many landraces namely Ai24, Ai33, Ai14, Ai8, Ai16, Ai42, Ai34 and Ai36with an interval between 81 and 87 days.Fr1 the hybrid variety withAi12, Ai13, Ai18 have presented the short vegetative cycles (*Flow*)with values less than 80 days after sowing.

All phenotypic markers were much correlated between them ($r>0.1$, $P<0.0001$). Among 66 correlations found between quantitative traits, 52 correlations were significant and 24 of them were positives (Table 4). *Flow* was highly and positively correlated with *BioFrY*,*BioDrY*, *Larea*, *Lwid*,*StDiam* and negatively with *GrRate* and *ForInd*.*St Diam*was also highly and positively correlated with *Larea*,*BioFrY* and*BioDrY*. *FHeig* was highly correlated with *BioFrY* and *BioDrY*.

Table 4. Pairwisecorrelation analysis among measured traits (*Pearson*)

	Lwid	**Larea**	**DryMatL**	**BioFrY**	**BioDryY**	**ForInd**	**TillNb**	**StDiam**	**Emerg**	**FHeig**	**GrRate**
Larea	**0,92**										
DryMatL	**-0,47**	**-0,47**									
BioFrY	**0,65**	**0,81**	**-0,35**								
BioDryY	**0,67**	**0,80**	**-0,33**	**0,97**							
ForInd	**-0,47**	**-0,53**	**0,18**	**-0,63**	**-0,49**						
TillNb	**-0,43**	**-0,41**	**0,37**	**-0,36**	**-0,32**	**0,34**					
StDiam	**0,58**	**0,69**	**-0,32**	**0,64**	**0,61**	**-0,45**	**-0,35**				
Emerg	-0,17	-0,21	0,09	-0,12	-0,11	0,14	0,19	**-0,24**			
FHeig	0,13	**0,32**	0,00	**0,64**	**0,66**	**-0,26**	0,01	**0,31**	0,14		
GrRate	**-0,45**	**-0,46**	**0,25**	**-0,40**	**-0,35**	**0,39**	**0,38**	**-0,38**	0,17	0,06	
Flow	**0,67**	**0,77**	**-0,33**	**0,84**	**0,83**	**-0,57**	**-0,45**	**0,61**	-0,14	**0,46**	**-0,61**

In bold*: moderate significance;* ***In blue****: high significance;*Significant at* α = 0.01*; Trait abbreviations as given in tables 2.Lwid*: Leaf width,*Larea*: Leaf area, *DryMatL*: Leaf dry matter,*BioFrY*: Biomass fresh yield, *BioDryY*: Biomass dry yield, *ForInd*: Forage index, *TillNb*: Tillers number, *StDiam*: Stem diameter, *Emerg*: Emergence, *FHeig*: Final plant height, *GrRate*: Growth rate, *Flow*: Days to 50% flowering

A principal component analysis was performed from 12 traits; the first two components had better summarize the information provided by all variables, and theyshowed together over than 76% of the information contained in the data set. The first principal component alone explained more than 61% of the variation, mainly due to variation positively in *Flow*, *StDiam*,*BioFrY*, *Larea*, *BioDryY*, *Lwid*, and negatively in *GrRate*. Both *Flow-StDiam*and*BioFrY-BioDrY* were strongly and positively correlated. Markers that contributed more to the second principal component explained up to 14% of the total variation and were mainly dominated by *FHeig* (Figure 5, Table 5).

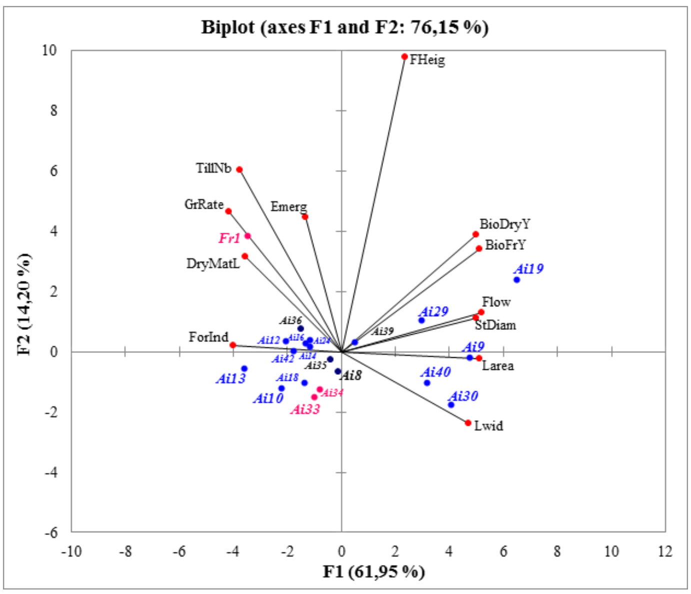

Figure 5. Genotype by marker biplot illustrating the relationship between PC1 and PC2 for 20 accessions and 12 traits of sorghum. PC (F): principal component.

In bold: significant at α *= 0,01.Lwid: Leaf width,Larea: Leaf area, DryMatL: Leaf dry matter,BioFrY: Biomass fresh yield, BioDryY: Biomass dry yield, ForInd: Forage index, TillNb: Tillers number, StDiam: Stem diameter, Emerg: Emergence, FHeig: Final plant height, GrRate: Growth rate, Flow: Days to 50% flowering*

The distribution of the studied varieties according to the parameters analyzed in the present work indicated that the studied accessions were grouped over four quadrants showing a large genetic variability. On the positive side of PC1, the genotypes Ai19, Ai9, Ai30, Ai40 and Ai29 characterized by an excellent fodder yielding (*BioFrY* and *BioDryY*), a high score of leaf traits and *StDiam*,. The same axis but on the negative side, the accessions Ai13 and Fr1 characterized by a high values of *ForInd*, *TillNb* and *GrRate* (Figure 5).

Table 5. Projection of the different traits studied on the three axes of the principal components analysis

Markers	Components		
	PC1	PC2	PC3
Lwid	**0,754**	0,044	0,017
Larea	**0,886**	0,000	0,002
DryMatL	**0,426**	0,078	0,217
BioFrY	**0,889**	0,091	0,001
BioDryY	**0,849**	0,117	0,003
HarvInd	**0,539**	0,000	0,000
TillNb	**0,483**	0,284	0,014
StDiam	**0,845**	0,010	0,001
Emerg	0,062	0,154	**0,694**
FHeig	0,189	**0,746**	0,016
GrRate	**0,593**	0,166	0,012
Flow	**0,919**	0,013	0,007

Lwid: Leaf width,Larea: Leaf area, DryMatL: Leaf dry matter,BioFrY: Biomass fresh yield, BioDryY: Biomass dry yield, ForInd: Forage index, TillNb: Tillers number, StDiam: Stem diameter, Emerg: Emergence, FHeig: Final plant height, GrRate: Growth rate, Flow: Days to 50% flowering.

Based on the 12 quantitative markers, the relationship among accessions was assessed using hierarchical clustering analysis (Figure 6). At a genetic distance of 0.2, the dendrogram showed that the 20 accessions were easily discriminated and clustered into four groups. The first group assembledAi19, Ai9, Ai29, Ai13 and Ai40. Cluster I was characterized by the widest leaf, highest leaf area, most productive of fresh and dry forage and longest days to 50% of flowering. The second group constituted Ai30, Ai12, Ai42, Ai14, Ai16, Ai24, Ai10 and Ai18. These accessions had the smallest leaves width and area, highest leaf dry matter, least productive of fresh and dry forage, most productive of tillers, thickest stem and shortest days to 50% of flowering. The third group assembled the hybrid variety Fr1 with Ai33 and Ai34. This cluster grouped the accessions with smallest leaves width and area, least productive of fresh and dry forage, most productive of tillers, shortest days to 50% of flowering. Fr1 was separated within the third cluster indicating the highest Growth rate and tallest plant. Ai8, Ai35, Ai36 and Ai39 which form the last group characterized by the highest leaf dry matter and a medium values for all others traits.

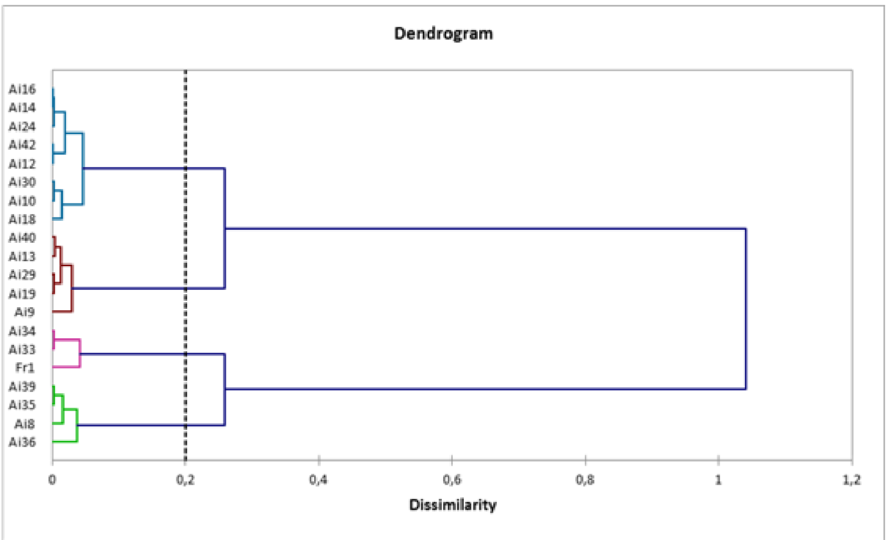

Figure 6. Dendrogram of 20 accessions revealed by cluster analysis of genetic distance based on agronomical traits.

Discussion

Characterization of accessions on the basis of their morphological characters will aid to identify and choice the best parents for hybridization(Souza and Sorrells, 1991).According to the morphological aspect, landraces belong to Durra, Caudatum or intermediate races, while the hybrid variety from French seems like Guinea race (Harlan and De Wet, 1972; Stemler et al., 1977; Reddy and Patil, 2015). Stemler et al. (1975) and Doggett (1988) pointed out that Caudatum and Durra are races with great agronomic values and better adaptation to harsh conditions. In sorghum, flowering was considered as a crucial event because of its key role in the adaptation and geographical distribution (EL Mannai et al., 2011). Gebrekidan (1981) reported that early flowering and short plant height sorghum types are suitable for regions with limited amount of rainfall and short growing season. In other hand, the earliest accessions would provide breeders with a simple tool to escape water stress (Upadhiaya et al., 2016).Many accessions as the hybrid Fr1, Ai13, Ai12 and Ai10 could be selected for their earliness with a cap of 80 days. Other accessions like Ai9, Ai19, Ai29 and Ai30 characterized by their tardiness reaching 130 days. By average of all accessions, the mean value of the number of days to 50% flowering was 91.27, Our results were in agreement to those reported by Upadhyaya et al.(2009) who found 82 days of flowering among 242 accessions from India, but less than to that reported by Bello et al.(2007) and Dossou-Aminon et al.(2015) who recorded 113 and 138 days, respectively. The obtained results are higher when compared to those reported by Abu Assar et al.(2009) who recorded 75 days among 40 sorghum accessions from Sudan.

The final plant height (*FHeig*) among the studied accessions showed a significant variation. Accessions as Ai19, Ai29 and Fr1 were the tallest plants, which exceeded 259 cm, could contribute significantly to increase the fresh and dry fodder yield; these kinds of genotypes are recommended to cover energy demand by livestock farming. On the other hand, accessions like Ai8, Ai12, Ai18, Ai10, Ai13 and Ai40 with a maximum of 166 cm were the shortest plants had the possibility to accumulate genes for the dwarf trait suitable in dry environmental conditions. The mean value of the final plant height was 190.48 cm which is approximately similar to that found by Grenier et al.(2004) and Abu Assar et al.(2009) with a mean value of 180 cm. Tariq et al.(2012) who recorded approximately 145 cm among 25 genotypes. Many studies reported that landraces were shorter than European or US varieties. In fact, farmers are looking for accessions with shorter plant height because the latter had sturdier stems, easier to harvest mechanically, and prevent damage and loss caused by wind or other environment conditions (Lin et al., 1995; Mutava et al., 2011).The number of tillers also revealed a significant variation ranging between 1 to 5.5 tillers per plant. Accessions with low tiller production capacity like the tallest ones require less water resources and are recommended in dry regions; by contrast, genotypes with high tiller production capacity as shortest ones are suitable in potential regions.

Fodder yield is crucial in crop improvement programs for the benefit of livestock farming, Ayubet al.(2012) found that landraces presented valuable leaf area, leaf fresh weight, leaf dry weight, and stem diameter and plant height that should be preferred over the tested varieties for green fodder purpose. In the present work, the accessions Ai9, Ai19 and Ai29 seem to be a good source of fresh or dry forage reaching 260t and 38t respectively, these genotypes had the highest values of leaf and stem characteristics. Leaf width presented a mean value of 8.43 cm in our study, and these results were similar to that recorded by Adugna (2014) and Dossou-Aminon et al.(2015) i.e. 8.2 cm and 7.52 cm, respectively.

The positive correlation between plant height and days to 50% flowering was reported previously (Zongo et al., 1993; Kebede et al. 2001). Leaf area was significantly and positively correlated with leaf length and width (Shegro et al., 2013). More than 75% of correlations were significant and we suggest that *BioFrY*, *BioDryY*, *Larea*, *Flow* and *StDiam* were strongly and positively correlated. They were worth exploiting directly for biomass production and/or integrating into breeding programmes (Habyarimana et al., 2004).

The present study showed an important contribution of the first principal component in total variability. This is in quite agreement to other previous studies (Mujaju and Chakuya, 2008; Jain and Patel, 2016). Moreover, Jain and Patel (2016) and Mulimaet al.(2018) recorded, like our study, that days to 50% flowering was the major character in first principal component while leaf traits were found among characters contributing to the first principal component. From Figure 5 and Table 6, the markers *Flow*, *Larea*, *StDiam*, *BioFrY*, *BioDryY* and *Lwid* showed a great influence on the distribution of data on the first two main components. However, some landraces such as Ai19, Ai9, Ai29, Ai30 and Ai40 had a positive factor loading value on the first major component. The hybrid Fr1, known by its high height, had a negative factor loading to the left of the first component but on the positive part of the second component, which represented more than 14% of the information. These results confirm the importance of certain Algerian local varieties compared to the hybrid for the markers mentioned. These results are in agreement with Kavithamani et al. (2019) who found that the important morphological traits of PC1 are due to variations between accessions and confirm that the Algerian landraces presented some good characters at the future breeding programs.

The dendrogram clearly defined differences in the distribution of the quantitative characters, which was reflected in the separation of the accessions. According to Dudhe et al. (2018) the genotypes within the same clusters may have originated from similar genetic backgrounds.

Conclusion

Landraces selections should be a good source of genetic diversity since they had high levels of variability for important agronomic traits of primary interest in sorghum breeding, such as days to 50% flowering, plant height, number of tillers, fresh or dry biomass yield. Results of particular interest from this present study were those concerning the short vegetative cycle for Ai13, Ai12 and Ai10 accessions. Highest values of biomass fresh and dry yield, leaf area and number of tillers for Ai19, Ai9, Ai29 and Ai30 landraces, which explain some fodder abilities. These accessions must be considered as sources of important genes/traits that plant breeders need to exploit in Algeria and should allow development of new genotypes of desired traits through characterization, evaluation, selection and crossing programs.

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Compliance with Ethical Standards Conflict of interest

The authors declare that there is no conflict of interest in this study.

References

Abu Assar AH. Uptmoor R. Abdelmula AA. Wagner C. Salih M. Ali AM. Ordon F. Friedt W. 2009. Assessment of sorghum genetic resources for genetic diversity and drought tolerance using molecular markers and agro-morphological traits. *U. K. J. Agric. Sci.*, 17, 1-22.

Adugna A. 2014. Analysis of in situ diversity and population structure in Ethiopian cultivated *Sorghum bicolor* (L.) landraces using phenotypic traits and SSR markers. *SpringerPlus*, 3(212), 2-14.

Almodares A. Hotjatabady RH. Mirniam E. 2013. Effects of drought stress on biomass and carbohydrate contents of two sweet sorghum cultivars. *J. Environ. Biol.*, 34, 585-589.

Al-Naggar AMM. Shafik MM. Musa RYM. Younis ASM. Anany AH. 2020. Genetic Variability of Maize Hybrids and Populations and Interrelationships among Grain Yield and Its Related Traits under Drought and Low N Using Multivariate Analysis. *AJBGMB* 4(2), 26-44.

Ayana A. Bekele E. 2000. Geographical patterns of morphological variation in sorghum (*Sorghum bicolor* L. Moench) germplasm from Ethiopia and Eritrea : Quantitative characters. *Euphytica*, 115, 91-104.

Ayub M. Khalid M. Tariq M. Elahi M. Nadeem MA. 2012. Comparison of sorghum genotypes for forage production and quality. *J. Anim. Plant Sci.*, 22, 733-737.

Bantilan M. Deb U. Gowda C. Reddy B. Obilana A. Evenson R. 2004. *Sorghum genetic enhancement: research process, dissemination and impacts*. Ed. ICRISAT (Patancheru 502 324, Andhra Pradesh). ISBN 92-9066-470-3, 320p.

Belhadi B. Djabali D. Souilah R. Yousfi M. Nadjemi B. 2013. Three small-scale laboratory steeping and wet-milling procedures for isolation of starch from sorghum grains cultivated in Sahara of Algeria. *Food Bioprod. Process.*, 91, 225-232.

Bello D. Kadams AM. Simon SY. Mashi DS. 2007. Studies on genetic variability in cultivated sorghum (*Sorghum bicolor* L . Moench) cultivars of adamawa state Nigeria. *Am. J. Agric. Environ. Sci.*, 2, 297-302.

Boudries N. Belhaneche N. Nadjemi B. Deroanne C. Mathlouthi M. Roger B. Sindic MP. 2009. hysicochemical and functional properties of starches from sorghum cultivated in the Sahara of Algeria. *Carbohydr.Polym.*, 78, 475-480.

Dahlberg J. Berenji J. Sikora V. Latkovic D. 2011. Assessing sorghum (*Sorghum bicolor* (L.)Moench) germplasm for new traits: food, fuelsand unique uses. *Maydica*, 56, 85-92.

Doggett H. 1988. *Sorghum*. Tropical agricultural series. Longman Scientific, Essex, 2ed éd. UK.

Dossou-Aminon I. Loko LY. Adjatin A. Ewédjè EEBK. Dansi A. Rakshit S. Cissé Patil NJV. Agbangla C. Sanni A. Akoègninou A. Akpagana K. 2015. Genetic divergence in northern benin sorghum (*Sorghum bicolor* L. Moench) landraces as revealed by agromorphological traits and selection of candidate genotypes. *Sci. World J.*, 2015, 1-10.

Dudhe MY. Rajguru AB. Bhoite KD. Kadam SM. Ranganatha ARG. Sujatha M. Reddy AV. 2018. Characterization, evaluation and multivariate analysis of sunflower germplasm under semi-arid environments of three locations in two sunflower growing states in India. *J. Environ. Biol.*, 39, 990-996.

El Mannai Y. Shehzad T. Okuno K. 2011. Variation in flowering time in sorghum core collection and mapping of QTLs controlling flowering time by association analysis. *Genet. Resour. Crop Evol.*, 58, 983-989.

Gebrekidan B. 1981. Salient features of the sorghum breeding strategies used in Ethiopia. Eth. J. Agri. Sci. **3**, 97-104.

Gerrano AS. Labuschagne MT. van Biljon A. Shargie NG. 2014. Genetic diversity assessment in sorghum accessions using qualitative morphological and amplified fragment length polymorphism markers. *Sci. Agri.*, 71, 394-401.

Grenier C. Bramel PJ. Dahlberg JA. EL-Ahmadi A. Mahmoud M. Peterson GC. Rosenow DT. Ejeta G. 2004. Sorghums of the Sudan: analysis of regional diversity and distribution. *Genet. Resour. Crop Evol.,* 51, 489-500.

Hadbaoui Z. Djeridane A. Yousfi M. Saidi M. Nadjemi B. 2010. Fatty acid, tocopherol composition and the antioxidant activity of the lipid extract from the sorghum grains growing in Algeria. *Med. J. Nutrition Metab.*, 3, 215-220.

Hadebe ST. Mabhaudhi T. Modi AT. 2019. Water Productivity of Selected Sorghum Genotypes Under Rainfed Conditions. *International Journal of Plant Production*, https://doi.org/10.1007/s42106-019-00082-4.

Harlan JR. De Wet JMJA. 1972. simplified classification of cultivated sorghum. *Crop Sci.*, 12, 172-176.

Habyarimana E. Laureti D., De Ninno M. Lorenzoni C. 2004. Performances of biomass sorghum [*Sorghum bicolor* (L.) Moench] under different water regimes in Mediterranean region. *Ind. Crops Prod.*, 20, 23-28.

House LRA. 1985. *Guide to Sorghum Breeding*. Tropics, ICRISAT, 2ed Ed., Andhra Pradesh 502 324, India.

IBPGR/ICRISAT. 1993. *Descriptor for Sorghum* (*Sorghum bicolor* (L) Moench), 44p.

Jain SK. Patel PR. 2016. Principal component and Cluster analysis in sorghum (*Sorghum bicolor* (L.) Moench). *Forage Res.*, 42(2), 90-95.

Kavithamani D. Yuvaraja A. Selvi B. 2019. Principal component analysis and grouping of sorghum(*Sorghum bicolor* L. Moench) gene pool for genetic diversity. *Electronic Journal of Plant Breeding*, 10 (4), 1426-1434.

Kebede H. Subudhi PK. Rosenow DT. Nguyen HT. 2001. Quantitative trait loci influencing drought tolerance in grain sorghum (*Sorghum bicolor* L. Moench). *Theor. Appl. Genet*. 103, 266-276.

Lin YR. Schertz KF. Paterson AH. 1995. Comparative analysis of QTLs affecting plant height and maturity across the poacea, in reference to an interespecific sorghum population. *Genetics*, 141, 391-411.

Mohammed R. Are AK. Bhavanasi R. Munghate RS. Kavi Kishor PB. Sharma HC. 2015. Quantitative genetic analysis of agronomic and morphological traits in sorghum, Sorghum bicolor. *Front. Plant Sci.*, 6, 1-17.

Mokrane H. Lagrain B. Gebruers K. Courtin CM. Brijs K. Proost P. Delcour JA. 2010. Assessment of Algerian sorghum protein quality. *Food chem.*, 121, 719-723.

Mokrane H. Amoura H. Belhaneche-Bensemra N. Christophe M. Delcour JA. Nadjemi B. 2009. Characterization of kafirins in Algerian sorghum cultivars. *Cereal Chem.*, 86, 487-491.

Mujaju C. Chakauya E. 2008. Morphological variation of sorghum landrace accessions on-farm in semi-arid areas of Zimbabwe. *Int. J. Bot.*, 4, 376-382.

Mulima E. Sibiya J. Musvosvi C. Nhamucho E. 2018. Identification of important morphological traits in Mozambican sorghum [*Sorghum bicolor* (L.) Moench] germplasm using multivariate analysis. *Afr. J. Agric. Res.*, 13(34), 1796-1810.

Mutava RN. Prasad PVV. Tuinstra MR. Kofoid KD. Yu J. 2011. Characterization of sorghum genotypes for traits related to drought tolerance. *F. Crop. Res.*, 123, 10-18.

Rakshit S. Hariprasanna K. Gomashe S. Ganapathy KN. Das IK. Ramana OV. Dhandapani A. Patil JV. 2014. Changes in area, yield gains, and yield stability of sorghum in major sorghum-producing countries, 1970 to 2009. *Crop Sci.*, 54, 1571-1584.

Rao PS. Kumar CG. Reddy BVS. 2013. *Characterization of improved sweet sorghum cultivars*. ISSN 2211-808X, 133p.

Reddy PS. Patil JV. 2015. *Genetic enhancement of rabi sorghum – adapting the Indian durras*. Elsevier, AP, 249p.

Shergo A. Labuschagne MT. Geleta N. Van Biljon A. 2013. Assessment of Genetic Diversity in Sorghum Using Phenotypic Markers. *Cereal Res Comm*. 41(4), 509-518.

Souilah R. Djabali D. Belhadi B. Mokrane H. Boudries N. Nadjemi B. 2014. In vitro starch digestion in sorghum flour from Algerian cultivars. *Food Sci. nturition*, 2(3), 251-259.

Souza E. Sorrells ME. 1991. Relationships among 70 American oat germplasms. I. Cluster analysis using quantitative characters. *Crop Sci*., 31, 599-605.

Stemler A. Harlan J. De Wet J. 1977. The sorghums of ethiopia. *Econ. Bot.*, 31, 446-460.

Stemler A. Harlan J. De Wet J. 1975. Caudatum sorghums and speakers of chari-nile languages in Africa. *J. Afr. Hist.*, 16, 161-183.

Tariq AS. Akram Z. Shabbir G. Gulfraz M. Khan KS. Iqbal MS. Mahmood T. 2012. Character association and inheritance studies of different sorghum genotypes for fodder yield and quality under irrigated and rainfed conditions. *African J. Biotechnol.*, 11, 9189-9195.

Teshome A. Patterson D. Asfaw Z. Dalle S. Torrance JK. 2015. Changes of sorghum bicolor landrace diversity and farmers' selection criteria over space and time, Ethiopia. *Genet. Resour. Crop Evol.*, 63, 55-77.

Tonapi VA. Patil JV. Dayakar RAO B. Elangovan M. Venkatesh Bhat B. Raghavendra Rao KV. 2011. *Sorghum:Vision 2030*. Directorate of sorghum research, Rajendranagar, Hyderabad 500 030 (AP), India, 38 pp.

Upadhyaya HD. Pundir RPS. Dwivedi SL. Gowda CLL. Reddy VG. Singh S. 2009. Developing a mini core collection of sorghum for diversified utilization of germplasm. *Crop Sci.*, 49, 1769-1780.

Upadhyaya HD. Dwivedi SL. Vetriventhan M. Krishnamurthy L. Singh SK. 2016. Post-flowering drought tolerance using managed stress trials, adjustment to flowering,and mini core collection in sorghum. *Crop Sci*. 57, 1-12.

Zongo JD. Gouyon PH. Sandmeier M. 1993. Genetic variability among sorghum accessions from the Sahelian agro-ecological region of Burkina Faso. *Biod. Cons*. 2, 627-636.