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Genetic Diversity Assessment of Moroccan Sesame (*Sesamum indicum* L.) Populations Using Agro-morphological Traits

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Abstract: Genetic diversity of Moroccan sesame (*Sesamum indicum* L.) was analyzed for the first time using agro-morphological traits. Thirty-three sesame populations collected from Tadla region in Morocco were evaluated for 13 parameters in three contrasted environments, Afr-13, Afr-14 and Atj-14. Broad and significant variation among populations was observed only for three agro-morphologic traits, namely first capsule height (FCH), number of seeds per capsule (NSC) and thousand seeds weight (TSW). The respective overall averages were 71.82 cm (ranging from 65 cm to 77 cm), 61.39 (varying from 57 to 65) and 3.20 g (ranging from 3.0 g to 3.4 g). Environment had a highly significant effect on all studied parameters, except capsule size and oil content. The obtained mean values of parameters studied showed that environment Afr-14 was the most favorable for most of them, particularly seed yield (1.32 t/ha) and TSW (3.57 g). Significant and interesting correlations were observed between seed yield per plant (SYP) and other parameters. As relevant implication of this finding, number of capsules per plant (NCP) and NSC could be used as valuable selection criteria in sesame breeding program. However, limited and non-significant variation among sesame populations for most of parameters studied suggests that they are genetically very close and may be derived from a single cultivar or germplasm. Molecular characterization is needed to confirm or refute this hypothesis. Besides, when compared with sesame grown throughout the world, Moroccan sesame was found to be very promising, which open up the possibility to develop this crop in this country.

Key words: Sesame (*Sesamum indicum* L.), Morocco, Tadla region, variability, environment.

1. Introduction

Sesame (*Sesamum indicum* L.) is an annual plant belonging to the family of Pedaliaceae (order of Lamiales). It is an important oilseed crop and perhaps the oldest crop cultivated for its high quality oil [1]. Its domestication dates back to 3050-3500 BC [2]. The species has a long cultivation history, but with time it has been neglected, except in some developing and emerging countries. Nowadays, the most important producers of sesame are India, Myanmar, China, Sudan, Uganda, Ethiopia and Nigeria. However, the species can be considered suitable for different farming systems either as a main or secondary crop under low input cropping conditions.

Sesame has lots of global demand, as an important source of oil (44%-58%), protein (18%-25%), carbohydrate (~13.5%) and ash (~5%), mainly in Asia, Europe and North America [3]. Sesame oil contains a high level of polyunsaturated fatty acids [4] and is more stable than other cooking oils due to the presence of some antioxidants [2, 5]. Moreover, sesame oil is characterized by its high quality and resistance to rancidity due to the presence of the

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endogenous antioxidants, namely sesamol and sesaminol, in combination with tocopherols [6] and thus is often referred to as queen of vegetable oils. Sesame seeds are used as a source of food or as blended oil in the form of different sweets. Currently, sesame is mainly intended for industrial, medicinal, nutraceutical and pharmaceutical purposes. It is also utilized in production of biodiesel [7]. Besides, sesame plants have also been used to successfully remove organochlorine pesticides from soils [8].

To sustain a level of high productivity and to face future climatic challenges, sesame breeding programs strongly depends upon availability of genetic diversity. Especially, traditional landraces and related wild species serve as important and valuable resources which are the backbone of agricultural production. Thus, exploring and characterizing the existing variation, in all its aspects, among those resources is of crucial importance not only for breeding, but also for germplasm collection and conservation activities. In this regard, agro-morphological evaluation is the primary step to be taken for the categorization of different crop germplasms [9]. Many researchers have recognized the value of characterizing and preserving natural variation in sesame [10-12]. However, there are still many heterogeneous landraces in various growing areas [13] that need to be explored. Among these areas, Tadla zone in Morocco is actually the most important area of sesame production in this country. However, plant material cultivated in Morocco has never been characterized and genetic diversity remains unknown and unexplored. Furthermore, it is assumed that all landraces cultivated in this country might be derived from a same cultivar. Thus, the present study aimed at investigating and checking, for the first time, the genetic variability of Moroccan sesame populations collected from different locations in Tadla area, using some agro-morphological traits.

2. Materials and Methods

2.1 Plant Material

A total of 33 cultivated sesame populations were collected from various locations in sesame growing area of Tadla in Morocco during 2012. Locations and names given to collected populations are shown in Table 1. Seeds of this plant material are maintained in Regional Agricultural Research Center of Meknes, INRA Morocco.

2.2 Study Environments

The 33 populations were evaluated in three different environments. The first environment was the

Table 1 Collection locations and codes of the 33 sesame populations collected.

Locations	Population codes
Bni Ayat	BA
Taghazirt	TG2, TG1, TG3, TG4, TG7, TG5, TG6
Krakeb	KR1, KR2, KR3, KR4
Ouled Zian	OZ2, OZ1
Ouled Yaich	OY1, OY2
Had Boumoussa	HBl, HB2, HB3, HB4
Ouled Barkat	OBl, OB2
Souk Elhad	SE
Ibazaza	IZl, IZ2, IZ3, IZ4
Krifat	KF
Sidi Jaber	SJ
Ouled Ayad	OA
Souk Sebt	SS1, SS2
Ouled Mbarek	OM

experimental station of Afourar at INRA-Beni Mellal during 2013 and it will be indicated as Afr-13. The second environment was the same experimental station of Afourar during 2014 and will be mentioned as Afr-14. Finally, the third environment was the experimental station of Ain Taoujdate at INRA-Meknes during 2014 and it will be named Atj-14.

Afourar station is located 19 km far from Beni-Mellal city, in Tadla plain of the Khenifra-Beni-Mellal region (32°12′ N, 6°30′ W, 446 m above sea level). This experimental station is characterized by a chromic luvisol soil [14] and an arid to semi-arid climate with a wet season from November to March and a dry one from April to October. In 2013, annual rainfall was around 84 mm, while average annual temperature was 19.5 °C, with a maximum of 45.8 °C in July and a minimum of -2.4 °C in January. On the other hand, the year 2014 was characterized by an annual rainfall around 367 mm and an average temperature of 19.1 °C, with a maximum of 43.7 °C in August and a minimum 0.6 °C in January.

Ain Taoujdate station is 30 km far from Meknes city in the province of El Hajeb (33°56′ N, 5°13′ W and 550 m above sea level). The experimental station is characterized by a silty clay loam soil and during 2014, rainfall was 470 mm and average temperature was 17.5 °C, with a maximum of 37 °C in July and a minimum of 2.8 °C in January.

2.3 Experimentation

The experiment was carried out, under a full irrigation regime, on a plot of 600 m² (20 m × 30 m) according to a complete randomized blocks design with two replications. Each population was planted in two continuous 4 m-length rows. Inter row spacing was 60 cm. Planting was lately done on June 17, 2013 for Afr-13, whilst it was done on May 26, 2014 for Afr-14 and on April 28, 2014 for Atj-14.

In each replication, evaluation of the studied material was achieved on a randomized sample of five plants per population. Data were gathered on agronomic and morphological traits, namely growth rate (GR, cm/d), plant height (PH, cm), number of branches per plant (NBP), first branch height (FBH, cm), first capsule height (FCH, cm), number of capsules per plant (NCP), capsule width (CW, cm), capsule length (CL, cm), number of seeds per capsule (NSC), thousand seeds weight (TSW, g), seed yield per plant (SYP, g), total seed yield (TSY, t/ha) and seed oil content (SOC, %).

2.4 Statistical Analysis

Data collected were statistically analyzed using univariate general linear model procedure of SAS statistical package (SAS Institute, 2001). Analysis of variance was performed considering population as fixed factor and environment as random factor. Correlation procedure was also used to find out relationship and correlation coefficients between the parameters studied.

3. Results and Discussion

3.1 Effect of the Population, the Environment and Their Interaction on the Characters Studied

According to results of analysis of variance, there was no significant difference among Moroccan populations for studied traits except FCH, NSC and TSW (Table 2). This indicates there is a narrow genetic diversity between the tested populations of Moroccan sesame. The GR ranged from 0.95 cm/d to 1.63 cm/d (Table 3) and these respective values were noticed in populations KR4 and SE. This non-significant variation is almost similar to that found by Haruna [15] for Nigerian sesame (from 0.77 cm/d to 1.48 cm/d). Maximum and minimum PH were observed in TG2 (118 cm) and TG3 (133.87 cm), respectively, with an average value of 125.6 cm (Table 3). This range is smaller than that found by Abdou *et al*. [16] for Nigerian sesame cultivars and

Table 2 Results of analysis of variance (mean square and level of significance) of 33 sesame populations evaluated in three different environments.

Source of variation	PH (cm)	NBP	FBH (cm)	FCH (cm)	NCP	CW (cm)	CL (cm)	NSC	GR (cm/d)	TSW (g)	TSY (t/ha)	SYP (g)	SOC (%)
Environment	349,971.06 ***	472.25 ***	18,472.84 ***	124,789.87 ***	222,487 ***	4.52 ns	2,048,167 ns	5,696.27 ***	4.20 **	29.70 ***	96.15 ***	6,620.80 ***	63.16 ns
Population	783.09 ns	31.47 ns	141.31 ns	358.22 **	3,110.75 ns	1.76 ns	1,372,132.60 ns	183.13 **	0.88 ns	0.19 *	2.59 ns	135.62 ns	226.81 ns
Environment × population	617.01 ***	15.93 *	78.46 *	152.47 ns	6,963.82 ***	3.98 ns	2,021,099 ns	64.32 ns	0.69 *	0.09 ns	2.994 ns	275.76 ***	139.66 ***
Plants/population	339.79 ***	16.46 **	71.33 *	128.66 ns	1,860.81 ns	3.78 ns	1,722,080.8 ns	94.85 **	0.4 ns	0.08 ns	2.25 ns	87.75 ns	29.68 ***

PH: plant height; NBP: number of branches per plant; FBH: first branch height; FCH: first capsule height; NCP: number of capsules per plant; CW: capsule width; CL: capsule length; NSC: number of seeds per capsule; GR: growth rate; TSW: thousand seeds weight; SYP: seed yield per plant; TSY: total seed yield; SOC: seed oil content.
*, ** and ***means significant effect at 5%, 1% and 1‰, respectively; ns: non-significant.

Table 3 Mean values of agro-morphological traits of 33 Moroccan sesame populations evaluated in three environments.

	Afr-13		Afr-14		Atj-14		Overall environments	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
GR (cm/d)	1.39 ± 0.18	0.85-1.85	1.28 ± 0.27	0.88-2.68	1.16 ± 0.21	0.67-1.72	1.28 ± 0.14	0.95-1.63
PH (cm)	114.92 ± 8.65	92.45-128.5	165.72 ± 6.55	151.88-181.33	98.19 ± 8.79	82.12-120.42	126.25 ± 3.70	118.76-133.87
NBP	10.96 ± 0.91	9.60-14.27	10.41 ± 0.79	8.88-12.20	12.97 ± 2.30	10-18.85	11.46 ± 0.83	9.86-13.09
FBH (cm)	27.68 ± 2.82	17.40-31.80	31.85 ± 3.82	21.37-41.10	15.58 ± 2.72	11.02-26	25.05 ± 1.81	21.26-28.5
FCH (cm)	67.74 ± 3.37	62.66-77.60	94.90 ± 4.33	87.88-105.33	52.83 ± 6.04	40.87-66.71	71.82 ± 2.78	65.43-77.30
NCP	65.17 ± 10.05	49.40-88.60	83.42 ± 24.26	55.75-163.37	122.83 ± 38.55	66.83-228.75	90.47 ± 10.91	65.25-113.38
CW (cm)	0.63 ± 0.034	0.61-0.81	0.65 ± 0.013	0.60-0.67	0.59 ± 0.015	0.56-0.63	0.62 ± 0.012	0.61-0.68
CL (cm)	2.31 ± 0.21	2.12-3.33	2.59 ± 0.12	2.39-3	2.03 ± 0.10	1.82-2.88	2.31 ± 0.08	2.16-2.66
NSC	62 ± 2.92	54.42-67	65.72 ± 3.78	56.19-73.70	56.47 ± 2.45	53-60.86	61.39 ± 2.06	56.75-64.78
TSW (g)	3.09 ± 0.058	2.92-3.21	3.57 ± 0.16	3.23-3.80	2.95 ± 0.10	2.64-3.14	3.20 ± 0.075	3.01-3.36
TSY (t/ha)	0.76 ± 0.15	0.40-1.15	1.32 ± 0.28	0.72-1.88	0.39 ± 0.18	0.05-0.68	0.82 ± 0.11	0.63-1.02
SYP (g)	12.73 ± 2.01	9.66-16.35	20.76 ± 6.03	12.85-39.81	20.61 ± 6.03	10.98-38.19	18.03 ± 2.03	14.29-21.47
SOC (%)	53.21 ± 2.27	47.83-57.92	51.08 ± 2.78	42.22-55	51.78 ± 1.97	47.78-56.95	52.02 ± 1.33	48.48-54.50

GR: growth rate; PH: plant height; NBP: number of branches per plant; FBH: first branch height; FCH: first capsule height; NCP: number of capsules per plant; CW: capsule width; CL: capsule length; NSC: number of seeds per capsule; TSW: thousand seeds weight; SYP: seed yield per plant; TSY: total seed yield; SOC: seed oil content.

which was between 78 cm and 180 cm. However, the values of the present study were comparable to those reported by Furat and Uzun [17] in Turkey (117.7 cm to 158.3 cm) and by Akbar *et al.* [18] (121.7 cm to 150.2 cm) in Pakistan. FBH varied between 21.26 cm in population OA to 28.5 cm in population SS2, with a mean value of 25.05 cm (Table 3). This average FBH was found to be higher than that reported by Ali [19] for Sudanese sesame (19.2 cm) and too much lower than that found by Olowe [20] for Nigerian sesame (54 cm) and by Noorka *et al.* [21] for Egyptian sesame (36 cm). These large differences could be due to the genetic material or cultivars experimented in each country and to the environmental conditions in which those cultivars were evaluated. NBP ranged from 9.9 to 13.10 for populations TG3 and BA, respectively. Average NBP was 11.5 (Table 3), which was higher than that of local Turkish populations (3.7) [17], that of Nigerian sesame (6.7) [16] and that of Indian populations (7) [22]. On the other hand, this average value was comparable to that of Pakistani sesame (10.6) [18]. Regarding NCP, the mean value was 90, ranging from 65 in population OZ1 to 113 in population OZ2 (113). In previous studies, average NCP was 85.70 in Turkish sesame [17], 77 in sesame germplasm from Vietnam and Cambodia [23], 81.1 in Nigerian sesame [16], 72.30 in Indian sesame [24] and 44.50 in Iranian sesame [25]. Moroccan sesame populations were characterized by two capsules per insertion and dehiscent mode. Average CW and CL were, respectively, 0.62 cm and 2.31 cm (Table 3). This latter is comparable with average CL reported by Akbar *et al.* [18] (2.59 cm) and Pham *et al.* [26] (2.60 cm). However, average CW of Moroccan populations was larger than that of Pakistani sesame (0.49 cm) [18] and smaller than that observed in 17 different sesame varieties from India, Vietnam, Kenya, Salvador and Tanzania (0.94-1.23 cm, with an average of 1.03 cm) [26]. Again, these variations could be explained by the simultaneous effect of sesame genotype and environmental conditions on this trait.

There were highly significant differences among the 33 populations for FCH, NSC and TSW. Overall average FCH was 71.82 cm, with a variation from 65.43 cm to 77.30 cm (Table 3) in populations KR3 and OB1, respectively. Lower FCH mean values were found in Turkish sesame landraces (42.8 cm) [17], Ghanaian sesame (43 cm) [27] and Iranian sesame populations (49 cm) [25]. With regard to NSC, population SJ was the most performant, producing 65 seeds per capsule, whilst BA was the least productive, having 57 seeds per capsule. Overall average NSC was 61 seeds per capsule, being very comparable with average NSC found in a sesame collection from Iran, India, Pakistan, Iraq, China and the Mediterranean area (61.93) [25]. However, that was lower than NSC in Turkish sesame (75.3) [17] and in sesame from Vietnam and Cambodia (86) [23]. Probably, in these last three countries, the cultivars used might be more productive than Moroccan ones or grain filling would have occurred under environmental conditions more favorable than those of this experiment. For TSW, population SJ had the highest TSW (3.36 g), while population TG7 had the lowest one (3.01 g). This finding may be due to the genotypic variation between these populations as they originated from different locations. Average TSW was 3.20 g (Table 3), which is in perfect agreement with that of Iranian sesame (3.20 g) [25]. However, TSW of Moroccan sesame populations was higher than average TSW in sesame from Vietnam and Cambodia (2.84 g) [23] and sesame from Pakistan (2.60 g) [18]. On the other hand, it was lower than that of Turkish sesame (3.70 g) [17], which confirms either the superiority of Turkish cultivars or the more favorable growing conditions for this crop in that country.

Even though, statistically, there was no significant difference among populations for SYP, one could observe a variation from 14.26 g to 21.47 g (Table 3). These plant yields were recorded in populations TG3 and OZ2, respectively. Overall average SYP was

18.03 g, which was in consistence with that reported in sesame from Vietnam and Cambodia (18.96 g) [26]. These findings were more interesting than those reported in Indian sesame (5.63 g) [24] and in sesame from some regions of the world (8.78 g) [25], as the observed values in the present study were much higher for this trait being one of most important TSY components.

Average TSY was 0.82 t/ha, with a variation from 0.63 t/ha to 1.02 t/ha for populations TG2 and SS, respectively. Average seed yield of Moroccan sesame populations was higher than that of Nigerian sesame (0.52 t/ha) [16], Turkish sesame (0.65 t/ha) [17] and Ghanaian sesame (0.68 t/ha) [27]. On the other hand, it was lower than 1.87 t/ha, as average recorded for a sesame collection from Iran, Pakistan, Mediterranean area, India, China and Iraq [25] and 2.7 t/ha, as average seed yield of local Italian varieties and improved varieties grown in the Mediterranean area [28]. Like as any crop, sesame seed yield is a complex quantitative character, which is the final result of interrelated traits and is very influenced by environmental conditions. It was reported that total sesame seed yield (per hectare) was affected significantly by planting method and plant density [29], irrigation [30], sowing date [31] and row spacing [32].

Effect of population on SOC was not significant. However, there was a variation from 48.48% to 54.5% in HB4 and OA, respectively, with an overall mean value of 52.02% (Table 3). In other studies carried out in various locations in the world, different ranges were found: from 34% to 60% [13], from 42% to 62% [33], from 43% to 54% [34] and from 52% to 63% [35]. The highest oil content ever reported was 63.25% observed in Turkish sesame germplasm [35, 36]. Among the 33 populations evaluated in this research, 31 had a SOC higher than 50%. This indicates that sesame seeds of Moroccan populations are an excellent source of oil and can be useful for nutritional and industrial purposes in Morocco as well as in other regions of the world with similar environmental conditions.

These findings revealed populations were comparable for most of the studied traits, exhibiting limited and non-significant variation among them. This may suggest they are genetically very close and may be derived from a single cultivar or original germplasm. Additional molecular characterization of those populations should be carried out to confirm or refute this hypothesis. However, when compared with sesame grown throughout the world, Moroccan sesame was found to be very promising because of their NBP, NCP, NSC, SOC, TSW and TSY, which open up the possibility to develop this crop in this country.

Unlike population, environment factor had a highly significant effect on all studied traits, except CW, CL and SOC ($p < 0.01$) (Table 2). Likewise, environment × population interaction had a highly significant effect ($p < 0.01$) on PH, NCP, SYP and SOC and significant effect ($p < 0.05$) on NBP, FBH and GR (Table 2). This indicated that the studied populations were unstable and their performance fluctuated through environments, with a change in their ranking. This could be attributed to the effect of environmental on the expression and function of genes controlling those traits. Also, significant differences were observed between plants by population for PH, SOC, NBP, NSC and FBH (Table 2), suggesting that populations showed some heterogeneity for those traits. These findings are in agreement with those of Kangbo *et al.* [37] who reported that environment had strongest effect on the studied parameters, followed by genotype × environment interaction and then genotype. Similarly, in a previous study, it was shown that genotype, environment and genotype × environment had highly significant effect on morphological and agronomic traits in sesame [38].

Analyzing average values of the studied traits through the three environments, one could observe that Afr-14 was the most favorable for TSY and some related attributes like as NSC and TSW (Table 3). In fact, sesame populations exhibited, in this environment, highest average TSY (1.32 t/ha), NSC (65.72) and TSW (3.57 g). This might be due to the environmental conditions of Afr-14 that should be more suitable for sesame growth than those of the other environments, Afr-13 and Atj-14. The most plausible discriminant factors between those environments should be planting date, water supply and temperature throughout crop cycle, particularly during flowering, grain filling and maturity. First, regarding the Afourer station during two years (2013-2014), planting was earlier in Afr-14 than in Afr-13 (May 26 vs June 17). The others factors were almost similar. As a result, seed yield and all the parameters studied were more interesting under Afr-14 conditions. Actually, it was demonstrated that sowing date had a significant effect on NCP [32], NBP [39] and PH [39-41] and these decreased consistently with delay in planting date [39-42]. Early sowing enables crop to take advantage of a prolonged photoperiod for better vegetative growth and development, which often results in better performance. Second, in comparison between Afourar station and Ain Taoujdate station for 2014, even though planting date was later in Afr-14 (May 26 vs April 28), irrigation system applied in this latter (regular drip irrigation) was more efficient than that adopted in the former (irregular tank irrigation) where germination and emergence were seriously affected. Thus, under Atj-14 conditions, there was a drastic decrease in plant density of about 35%, compared to Afr-14 environment (data not shown). Nevertheless, lower plant density in Atj-14 enabled higher branching and number of capsules per plant (Table 3). A previous study did show significant effect of irrigation regime on safflower growth and productivity [31]. Third, Afr-14 was characterized by higher average and maximum temperatures, during cropping cycle, in comparison with Atj-14, which could be beneficial for better crop performance in the former. It is well known that sesame, as a crop of warm tropical and subtropical regions, requires fairly hot (27-35 °C) conditions for its optimum growth and yield production [13, 43, 44].

However, in Afr-13, overall SOC was 53.21%, slightly higher than that of Atj-14 (51.08%) and that of Afr-14 (51.78%). Temperature during maturity was more favorable for seed oil production in Afr-13 than the two other environments, Afr-14 and Atj-14. Compared with Afr-14 and Atj-14, planting was later in Afr-13 and subsequently, seed oil biosynthesis coincided with higher temperature. In their study of effect of planting date on protein and oil contents in soybean, Khan *et al.* [45], showed that oil content was higher in seed matured under high temperature, compared to seed matured under low temperature.

3.2 Relationship between the Studied Parameters

Table 4 shows correlation coefficients between studied parameters. The strongest relationship was observed between SYP and NCP (0.89, $p < 0.001$), indicating that the higher NCP, the higher SYP, which might suggest that NCP is the most important component contributing in the determination of seed yield. The PH was correlated significantly and positively with FCH (0.807, $p < 0.001$) and TSW (0.64, $p < 0.001$). These results could mean that high populations were also characterized by high FCH and TWS. Similarly, there was a significant and positive correlation between FBH and FCH (0.55, $p < 0.001$) and between FCH and TSW (0.51, $p < 0.001$), suggesting that populations with higher FCH had higher FBH and higher TSW. NSC was positively and significantly correlated with TSW (0.51, $p < 0.001$), which might mean that populations having higher NSC would also have high TSW. Accordingly, strong and positive correlations were found between SYP and NCP (0.98) in sesame from Ghana [27] and between PH and FCH (0.776) in a collection of local Turkish sesame populations [46]. Other researches evidenced significant and positive correlation between

Table 4 Correlation coefficients between the studied agro-morphological traits.

	PH	NBP	FBH	FCH	NCP	CW	CL	NSC	GR	TSW	TSY	SYP	SOC
PH													
NBP	-0.14***												
FBH	0.46***	-0.218***											
FCH	0.807***	0.01	0.55***										
NCP	0.04	0.29***	-0.36***	-0.106**									
CW	-0.03	-0.02	0.003	-0.04	-0.03								
CL	0.094*	-0.01	0.05	0.05	0.02	0.0005							
NSC	0.37***	-0.23***	0.18***	0.28***	-0.113**	-0.04	-0.22***						
GR	0.098*	0.01	0.07	0.09	0.02	-0.02	0.117**	-0.112**					
TSW	0.64***	-0.28***	0.33***	0.518***	-0.09	-0.02	-0.128***	0.513***	-0.06				
TSY	0.25***	-0.01	0.12**	0.216***	0.01	0	0.202***	-0.13***	0.133***	0.01			
SYP	0.27***	0.21***	-0.18***	0.08	0.89***	-0.03	0.104*	0.0002	0.07	0.09	0.14***		
SOC	-0.02	-0.09	-0.07	-0.04	-0.07	0.002	-0.316***	0.38***	-0.13***	0.24***	-0.39***	-0.25***	

PH: plant height; NBP: number of branches per plant; FBH: first branch height; FCH: first capsule height; NCP: number of capsules per plant; CW: capsule width; CL: capsule length; NSC: number of seeds per capsule; GR: growth rate; TSW: thousand seeds weight; SYP: seed yield per plant; TSY: total seed yield; SOC: seed oil content.
*, ** and *** means significant effect at 5%, 1% and 1‰, respectively.

TSY and NBP (0.414) and between TSY and NCP (0.468) [47]. It could be assumed that best yield may be obtained in highly branched plants with increased capsules number. Similar findings were reported for sesame collections from Asia [23], Ethiopia [48] and Niger [16]. Based on these findings, which were in line with those of previous studies, one could consider NCP and NSC as selection criteria for seed yield and oil content breeding in sesame.

4. Conclusions

Results of this study showed there was a low genetic diversity among 33 Moroccan sesame populations with regard to agro-morphological characters except for FCH, NSC and TSW, suggesting a narrow genetic distance among the populations that might have a common origin. Therefore, additional molecular characterization of these populations should be achieved to thoroughly analyze their genetic diversity. Nevertheless, environment had a highly significant effect on all studied parameters except capsule size and SOC. Among the three environments, Afr-14 was found to be most favorable for the majority of evaluated characters. Besides, due to their strong correlation with seed yield, NCP and NSC could be used as valuable selection criteria in sesame breeding programs in Morocco and other areas of the world.

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