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Biodiversity of sorghum, *Sorghum bicolor* L. Moench (Poales Poaceae) in southern Algeria (Tidikelt region)

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ABSTRACT This study aims to identify the *Sorghum bicolor* (L.) Moench (Poales Poaceae) phenotypes grown in southern of Algeria (Tidikelt region). We organized several field visits to sorghum cultivation sites during the plant's maturity period to inventory and evaluate the phenotypes of this crop, based on the descriptive study of the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT). The results of plant parameters measurements demonstrated, that plant height (HP), the number of nodes (NN) and leaves (LN), and panicle color (PC) showed significant differences, while we recorded very slight differences for the dimensions of the third leaf: Length (L.3L) width (W.3L) and panicle (PL and PW). The results also showed that there is a phenotypic diversity of local white and red sorghum, in addition to mixed and domesticated sorghum, which are commonly used as fodder. On this basis, this type of cereal cultivation can play a leading role in promoting the cultivation of millet groups local to the region.

KEY WORDS Biodiversity; Character; Morphology; Panicle; Seed; Sorghum; Tidikelt.

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INTRODUCTION

The cultivation area of sorghum, *Sorghum bicolor* (L.) Moench) (Poales Poaceae) is about 40.5 million hectares. It is a plant well adapted to hot and dry climates, both in tropical and temperate zones. World sorghum production amounted to 60.1 million ton (USDA, 2021); this crop ranks fifth among the world's cereal crops and provides food for approximately 400 million people in the semi-arid regions of the world (Mwithiga et al., 2006; FAOSTAT, 2015). About 90% of the area cultivated with sorghum in the world, and 70% of world production is in developing countries; Africa and Asia account for over 95% of total sorghum food use where it comes second, after maize (USDA, 2021).

We distinguish two groups of producing countries, according to the way the crop is managed and the main uses. The first group, which applies an intensive cropping system using hybrid seeds, obtaining yields from 3 to 5 tons / hectare, to be used mainly for animal and poultry feed, and this is in all developed countries (United States of America, Australia, and Mediterranean Europe). It is also exploited for other industrial purposes such as the production and processing of ethanol and other artisanal products such as brooms (Smith & Frederickson, 2000).

The second group, which includes most of the developing countries (Africa, India and Central America), generally uses genetically pure sorghum, and practices traditional methods of cultivation, however the average yield remains very low, with a productivity of 0.6 to 1 ton / ha. The crop is mainly used as human food, like in Sudan and India. In addition to the harsh environmental and climatic conditions, pests and diseases affect crops and livestock in these countries (COHAB, 2010).

The southern regions of Algeria bordering the countries of the Sahel, are characterized by a biodiversity of varieties of sorghum and pearl millet, as these varieties have adapted to conditions of temperature and drought, in addition to groundwater irrigation of high salinity. The cultivation of these crops is limited to the regions of the far south (Tidikelt, Hoggar, and Adrar), with the aim of exploiting the crop for human (grain) and animal (leaves and stems) food (Djabali et al., 2005; lemgharbi et al., 2016, 2017).

In general, southern Algeria has a typical desert climate; hot and dry, with a scarcity of rain at an average of 1.20 mm, with dry and often salty soil, according to the National Weather Service (ONM, 2020). Despite these harsh local environmental and climatic conditions, sorghum and millet have adapted and maintained their original morphological diversity over the centuries, allowing for the genetic biodiversity of sorghum today.

Unfortunately, knowledge on the biodiversity of sorghum cultivated in the southern Algerian region is still very limited, although these regions are characterized by various pure and diverse native cultivars. They can be an important source of strategic materials and meet demand in the food and animal nutrition industries (Lemgharbi et al., 2016; 2017).

The purpose of this work is to identify and evaluate the biodiversity of sorghum cultivated in southern Algeria (Tidikelt region) for valuing and conserving the natural resources of the local grain.

MATERIAL AND METHODS

Study area

The Tidikelt region is located south of the Algerian capital, about 1274 km, with an area of approximately 100,000 km^2, between the 27°15' North 2°31' East. It includes the In Salah town and its surroundings: Zaouia, El Barka, Sahla, In Ghar and Fouggarat Ezzoua (Fig. 1).

This region is characterized by a flat topography with deposits of the Middle Cretaceous period (Alban-Permian) and a layer of sandy alluvial surface of the Quaternary period (Flamand, 1900).

The hydrographic and climatic analysis showed that the region depends on rain to refill the groundwater, as this water is collected in low areas or in hidden ponds locally called "Foggara"(Foggara: underground drainage galleries with wells, used for irrigation and drinking water flowing in Tidikelt region) (Ruffié et al., 1963).

Tidiklet ranks among the hottest deserts, with a very hot and dry desert climate, in addition, the rainfall is exceptional with an annual average of less than 1.18 mm, and the temperature is very high, averaging from 27 °C to 47 °C (min/max) per month during recent decades. The mean summer temperatures (June to August) is 45.2 °C with highs exceeding 52 °C (ONM, 2022), the region is classified as a very arid zone according to Köppen (1900). We excavated and identified the morphological characteristics of sorghum from northwest of In Saleh, Foggarat Ezzoua town, 45 Km from In Salah center

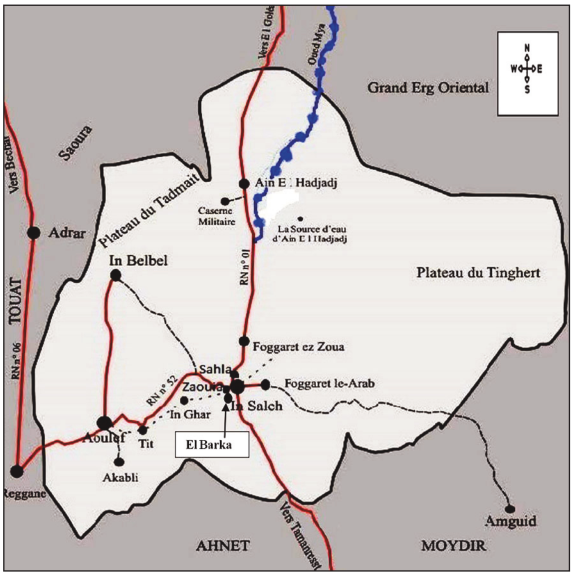


Figure 1. Tidikelt map (Ruffié et al., 1963 modified). Red = route (road), blue = Oued (valley), black = piste (track).

to the South of the region, to El Barka 5 km south of the In Salah area.

We organized several field visits to the sorghum cultivation sites in the region during the maturation of the plants and during four consecutive harvest seasons. These fields are classified as traditional (Zaouia), where the soil is very old and irrigated with the Foggara, and the new fields (El-Maleh, Javo situated in Sahlan), which consist of new fertile soil which depends on a modern irrigation system (drip system) (Table 1).

Data collection

We organized exploratory field visits to more than 45 agricultural fields of the sorghum agricultural sites in the region, during the maturity stage of the crop (panicles). We collected data on local methods and techniques for growing sorghum varieties (local and domesticated) in the region, using a different methodology to assess rural participation. This was done through discussions with farmers interested in this type of crop, and the use of questionnaires on traditional methods of growing and producing sorghum, and how to exploit it in the region (Lillo et al., 1995). In addition, we relied on the technique of collecting data and field observations of the sorghum phenotypes.

Sorghum morphological characters

We carried out a descriptive field plant study, based on quantitative and qualitative measures of morphological parameters of sorghum varieties at the plant maturity stage, according to millet descriptions (Andrews & Kumar, 1996; Christinck et al., 2000), for example: Plant Height (PH), Number of Nodes (NN), and Leafs Number (LN), the third leaf dimensions (L.3L, W.3L) and Panicle Color (PC) at maturation (Table 2).

Sites	Distance (km)	Latitude (N)	Longitude (E)	Altitude (m)	Site characteristics
Zaouia	3 km W	27°12'37	02°27'26	260 m	Traditional fields
El Barka 4	5 km S	27°12'06	02°22'22	277 m	New fields
El Barka 2	12 km N-E	27°11'53	02°26'37	267 m	New fields Ammar (115 ha)
Sahla	12 km N-E	27°19'33	02°49'17	873 m	New fields (El-Maleh, Javo)
Foggarat Ezzoua	45 km N-W	36°28'14	02°50'30	874 m	New fields (Emttiaze, 500 ha)

Table 1. Coordinates and distances of the study sites for the Tidikelt region.

Characters	Code	Description
Plant Height (cm)	PH	Height of the main stem from the ground to the tip of the main panicle
Number of Nodes	NN	Number of nodes on the main stem (Plant)
Leafs Number (count)	LN	Number of leafs on the main stem (Plant)
Stem Diameter (mm)	SD	Diameter measured on the third internodes from the ground surface
Panicle Length (cm)	PL	Length of the panicle from its base to tip
Panicle Width (mm)	PW	Width of panicle in natural position at the widest part
Leaf Length (cm)	L.3L	Length of the third leaf from the flag leaf
Leaf Width (mm	W.3L	Width of the third leaf
Panicle Color	PC	Color of panicle in maturity on the main stem (Plant)
Panicle Form	PF	Form of panicle in maturity
Panicle Setae	PS	Setae on the main panicle

Table 2. Morphological characters with their codes and descriptions. Source: IBPGR & ICRISAT descriptors, 1993.

We also descriptively studied the panicles and seeds in the laboratory, to determine some physical characteristics, based on the descriptive parameters of IBPGR & ICRISAT (1993) such as; Setae of Panicle (PS), Seed Envelop style (SE), Seed Form (SF) and Proportion of Floury Endosperm (PFE). The PFE was estimated using the percentage of corneous and floury endosperm, and was determined by the examination of seed sections using a stereomicroscope and was then compared to sorghum standards (Taylor & Taylor, 2008). On this basis, the various millet grain groups are classified into corneous, intermediate, or floury according to the International Association of Cereal Science and Technology (ICC, 2008). The moisture analysis content of seeds millet groups was carried out in the laboratory according to method 44 15 A of the American Association of Cereal Chemists (AACC) (2000) (Table 3).

The quantitative and qualitative data were organized into groups of four replicates (n = 4), then analyzed using the Analyze of Variance (ANOVA) and the Principal Component Analysis (PCA). As a result, we calculated the differences in mean values at the 0.05 probability level depending on the least significant difference (LSD) method SPSS. Statistic version 17.0 software.

Physical and cytological characteristics of sorghum grain Seed weight (SW)

One hundred grains of sorghum were weighed as they are variable in dimensions (Gomez et al., 1997). We cleaned the samples from impurities, then we weighed these 100 grains by analytical balance (Gallenkamp Matter H 31 AR) with an uncertainty of ±0.0001 g. We repeated the process three times and calculated the average.

Determination of grain moisture content

The moisture content of the grains was determined by oven method according to ASAE standard (1999). This was accomplished by putting 100 g of grains for each variety into three containers and then weighed using the sensitive scale. It was then oven dried at a temperature of 130 ˚C for 18 h. The average moisture content of three samples was calculated to obtain the moisture content for each of the samples using the following equation:

$$Mc\ \% = W^{W} - W^{d} / W^{W} \times 100$$

Where: Mc: the moisture content (%); W^{w} = weight of wet sample (g); W^{d}: weight of dried sample (g)

Determination of grain dimensions

The dimensions of sorghum grains were determined based on the method described by Jain & Bal (1997) and Mwithiga & Sifuna (2006). Dimensions of 50 grains of sorghum were measured with the method described by Jain & Bal (1997) with an accuracy of 0.01 mm (Fig. 2).

These dimensions allow the calculation of both the degree of sphericity (Ø), and the geometric di-

Qualitative characters	Code	Description
Grain moisture content	Mc%	The moisture content of the seed
Seed Color	SC	Color of seed in maturity
Hundred Seed Weight	TSW	Weight (g) of 100 seed of maturated panicle at 20 °C
Seed dimensions	L, W, T	Length, Width, and Thickness Seed
Geometric diameter	Dg	Diameter geometric of seed
Degree of sphericity	Ø	The degree of seed roundness
Seed surface area	S	The surface of grain (mm^2)
Proportion of the Floury Endosperm	PFE	Proportion(%) of floury Endosperm in seed (section)

Table 3. Grain sorghum characters recorded in the laboratory. Source: IBPGR & ICRISAT descriptors, 1993.

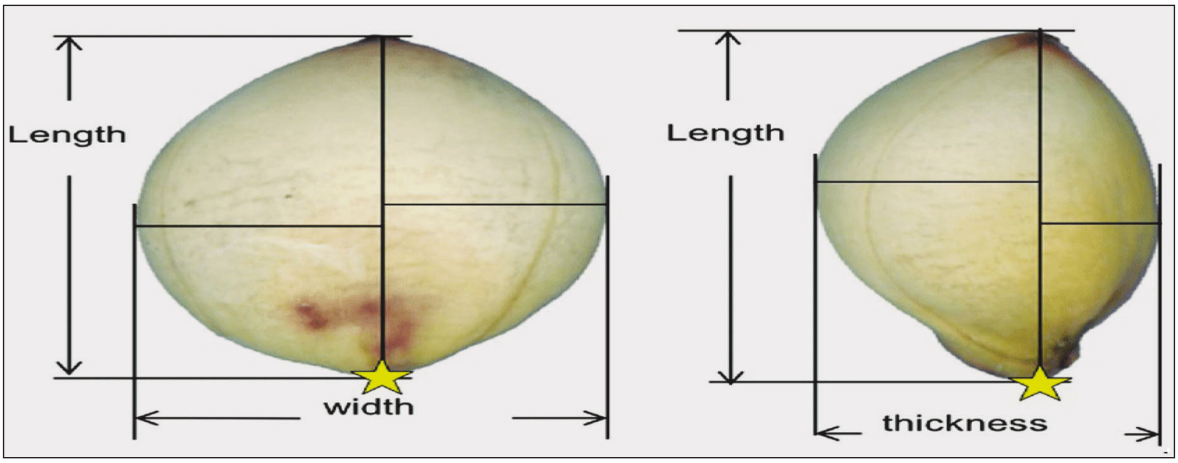


Figure 2. The three main dimensions of the sorghum grain (Jain & Bal, 1997).

ameter (Dg) of the grain, and grain surface area (S) according to the following relationships:

Dg (mm) = $(LWT)^{1/3}$; Ø = Dg / L; S = Π BL^2 /2L - B; B = $(WT)^{1/2}$.

Where, Dg: Geometric Diameter; L: Length; W: Width; T: Thickness; Ø: Degree of sphericity; S: Grain surface area.

Proportion of the floury endosperm

Endosperm texture was defined as the proportion of corneous structure relative to the floury one in the grain, which was determined subjectively by viewing sectioned kernels using a stereomicroscope, and comparing them to sorghum standards (Taylor & Taylor, 2008). The kernels were classified as corneous, intermediate, or floury (International Association for Cereal Science and Technology, ICC, 2008).

RESULTS AND DISCUSSION

Field visit data

Based on repeated field visits and morphological measurements coinciding with the maturity of the crop (panicles), in addition to field observations and discussions with those interested by sorghum cultivation planting, we can illustrate the following results regarding the phenotypic variation and diversity of sorghum in the region.

From the results recorded in Table 4, it became clear that there are ten sorghum phenotypes planted in the fields of the TidiKelt region, based on the morphology of the plant, and their panicle shape and color of the mature panicle, where we distinguish four main groups of sorghum namely: the local white, red, and mixed sorghum, in addition to the domesticated, have been erroneously named locally "Khartal"(annual herbaceous Poaceae plant) both wild and cultivated, Provides fodder for animals and birds) (Table 4).

Local sorghum. White long sorghum

We have recorded that there are two types of white local sorghum:

A. White long sorghum with vertical panicle (WLS.VP).

It constitutes a high percentage in the agricultural field between 85 to 95% for white long sorghum. It is characterized by the number of nodes and a relatively higher distance between nodes, which are light solid or open with a broad base, in addition to the large spindle-shaped panicle (Fig. 3).

B. White long sorghum with curved panicle (WLS.CP).

It constitutes a low percentage in the agricultural field between 5 to 25% for white long sorghum. It is characterized by the number of nodes and a relatively higher distance between nodes which is often solid spindle-shaped and hooked holder down, in addition to the large spindle-shaped panicle (Fig. 4).

White Short sorghum

We also recorded two types of white short sorghum found in the fields, which are characterized by a relatively short main stem with a short distance between nodes and a relative abundance of the number of successive leaves on the main stem.0

White short sorghum with vertical panicle (WSS.VP)

It constitutes a high percentage in the agricultural field, between 80 to 90% for white short sorghum. It is preferred as fodder for livestock due to its abundant vegetation, i.e. the number of successive leaves on the relatively short main stem. It is also distinguished by its large spindle-shaped panicles, usually solid with a broad base (Fig. 5).

White short sorghum with curved panicle (WSS.CP)

It is preferred too as fodder due to its abundant vegetation, i.e. the number of successive leaves on the relatively short main stem. It constitutes a relatively low percentage for short sorghum, and also distinguished by its large spindle-shaped panicle, and it is usually solid or relatively open with a wide base, but the panicle holder is hooked at the bottom. (Fig. 6).

Red sorghum

Generally, it represents a low percentage in the agricultural field (5 to 15%), especially in recent years, and is characterized by its dark red panicles and it has the same morphological characteristics as its white counterpart, we have recorded that there are two types of red local sorghum:

Red long sorghum with vertical panicle (RLS.VP)

It constitutes a high percentage in the agricultural field between 80 to 90% for red long sorghum, and it is characterized by the number of nodes and a relatively higher distance between nodes, in addition to the large spindle-shaped panicle, which are light solid or open with a broad base (Fig. 7).

N°	Local name	Codes	Origin	Collecting area	Local
S1	Taffsout Elbida Touila1	WLS.VP	Local	El Maleh, Javo Emttiaze, 500ha	Sahla Foggarat Ezzoua
S2	Taffsout Elbida Touila2	WLS.CP	″	El Maleh, Javo Emttiaze, 500ha	Zaouia /Sahla Foggarat Ezzoua
S3	Taffsout Elbida Ksira1	WSS.VP	″	Zaouia / El Maleh Emttiaze, 500ha	Zaouia /Sahla Foggarat Ezzoua
S4	Taffsout Elbida Ksira2	WSS.CP	″	Zaouia / El Maleh Emttiaze, 500ha	Zaouia /Sahla Foggarat Ezzoua
S5	Taffsout Elhamra Touila1	RLS.VP	″	El Maleh, Javo Ammar 115ha	Sahla El Barka2
S6	Taffsout Elhamra Touila2	RLS.CP	″	El Maleh, Javo Ammar 115ha	Sahla El Barka2
S7	Taffsout Elhamra Ksira1	RSS.VP	″	El Maleh, Javo/ Ammar 115ha	Sahla El Barka2
S8	Taffsout Elhamra Ksira2	RSS.CP	″	El Maleh, Javo Ammar 115ha	Sahla El Barka2
S9	Taffsout lemkhalta	Mix. S	″	Zaouia / El Maleh Emttiaze, 500ha	Zaouia /Sahla Foggarat Ezzoua
S10	Khartal	DS. Am.	Domesticated	El Barka4	El Barka4

Table 4. List of sorghum phenotypes with their local names and locations in the Tidikelt. WLS.VP: Sorghum white long vertical panicle; WLS.CP: Sorghum white long curved panicle; WSS.VP: Sorghum white short vertical panicle; WSS.CP: Sorghum white short curved panicle; RLS.VP: Red long Sorghum vertical panicle; RLS.CP: Red long Sorghum curved panicle; RSS.VP: Red Short Sorghum Vertical panicle; RSS.CP: Red Short Sorghum curved panicle; Mix. S: Mixed sorghum; DS. Am: Sorghum domesticated American. Source: Field Survey, 2019.

Red long sorghum with curved panicle (RLS.CP)

It constitutes a low percentage in the agricultural field between 10 to 20% for red long sorghum. Generally, it is characterized by large, dark red, spindle-shaped panicles, which are solid or open with a broad base (Fig. 8).

Red short sorghum

It characterized by a relatively short main stem with a short distance between nodes and a relative abundance of the number of successive leaves on the main stem, and res dark panicle. It also includes two varieties of short red sorghum:

Red short sorghum with vertical panicle (RLS.VP)

It makes up about 10 to 20% for red sorghum in the fields; it is distinguished by the straightness of the panicle holder and its dark red panicle (Fig. 9).

Red short sorghum with curved panicle (RLS.CP)

It forms the lowest percentage in the agricultural field, about 1 to7 % of red sorghum, and is characterized by the panicle holder turning downward, and its dark red panicle (Fig. 10)

Mixed sorghum

It is locally called "*Taffsout lemkhalta*". The mixed sorghum is considered an hybrid on the basis of the color of its slightly reddish white spikes. This hybrid variety constitutes a low to rare percentage, i.e. about: 3-5% of the total sorghum cultivated in the region. It also has the same morphological characteristics as long white corn with a columnar-bearing panicle (Fig. 11).

Domesticated sorghum (DS. Am)

The local common name "Khertal" means oats

	Morphological characteristics		HP	LN	NN	L 3L	W 3L	SD	PL	PW	PC
Sorghum varities	1	WLSVP	217.25 ± 18.9	16 ± 0.82	15 ± 0.82	38.10 ± 4.11	4.95 ± 0.4	1.29 ± 0.11	11.05 ± 0.71	393 ± 0.51	Off white
	2	WLSCP	18200 ± 4.42	17 ± 1.54	16 ± 1.53	46.82 ± 0.66	7.35 ± 0.09	1.66 ± 0.06	12.75 ± 0.64	552 ± 0.07	White
	3	WSSVP	137.87 ± 8.80	21.50 ±0.50	20.0 ± 0.82	55.03 ± 1.38	7.53 ± 0.02	1.57 ± 0.05	11.23 ± 0.86	490 ± 0.13	Off white
	4	WSSCP	11625 ± 5.56	17 ± 2.06	16 ± 1.29	60.00 ± 4.71	8.61 ± 1.11	2.27 ± 0.32	12.4 ± 0.59	560 ± 0.62	White
	5	RLSVP	25025 ± 3.30	20 ± 0.80	19.25± 0.50	55.35 ± 2.55	6.30 ± 0.87	2.10 ± 0.21	10.66 ± 0.49	535 ± 0.08	Off red
	6	RLSCP	24866 ± 2.33	20 ± 0.07	19 ± 0.02	56.38 ± 1.98	7.64 ± 0.11	2.08 ± 0.03	11.06 ± 0.33	609 ± 0.05	Dark red
	7	RSSVP	14244 ± 0.81	18 ± 1.04	17 ± 0.83	57.41 ± 2.01	6.99 ± 0.07	2.05 ± 0.02	11.09 ± 0.22	589 ± 0.32	Off red
	8	RSSCP	1398 ± 0.75	17 ± 0.08	16 ± 0.43	56.04 ± 1.20	6.48 ± 1.01	1.97 ± 0.03	12.04 ± 1.07	588 ± 0.61	Dark red
	9	Mix S	21720 ± 011	17 ± 0.61	16 ± 0.30	3922 ± 0.15	544 ± 101	213 ± 0.04	1201 ± 0.20	526 ± 0.15	Reddish white
	10	SD Am	20775 ± 1065	15 ± 2.58	14 ± 2.23	58.25 ± 4.85	5.20 ± 0.91	1.30 ± 0.18	25.10 ± 2.07	1186 ± 1.40	Dark brown
	Mean		18595	1785	1683	5226	665	184	1294	603	
	Maximum		25025	2150	2000	6000	861	227	251	1186	
	Minimum		11625	1500	1400	3810	495	129	1066	393	
	SD		4911	203	196	795	119	036	433	214	

Table 5. Morphological characters of sorghum varieties in plant maturity stage of Tidikelt region. HP: Height Plant (cm); LN: Leaf Number; NN: Nodes Number; L.3L: Length of the third upper leaf (cm); W.3L: Width of the third upper leaf (cm); SD: Stem Diameter (cm); PL: Panicle Length (cm); PW: Panicle Width (cm); PC: Panicle Color. Source: Field Survey, 2020.

- it is not oat at all. Generally, it is used as a year-round forage, and it grows back after each harvest. The farmers explained that this regeneration is thanks to the main root that has a protected area. It is characterized by large, relatively open panicles in the form of an inflorescence (Lemgharbi et al., 2017) (Fig. 12).

Field measurements of sorghum

All morphological observations and measurements were evaluated in order to gain a better understanding of the sorghum phenotypic diversity in this region; these phenotypes of sorghum present a very large morphological variation amongst themselves. The most significant variations were observed in HP, LN, SD, and NN on the main stem, especially, the color, and panicle form (Table 5).

In general, we record significant differences in the HP of local and domesticated sorghum phenotypes cultivated in the region, where the red varieties with a vertical panicle holder (RLS.VP) are distinguished by the length of their main stem at a rate of 250.25 ± 3.30, then followed by the long red varieties with a curved panicle (RLS.CP) at a rate of 248.66 ± 2.33, then the white long vertical panicle (WLS.VP) with a height of 217.25 ± 18.90. We recorded the shortest height of plant for white short sorghum curved panicle (WSS.CP) at a rate of 116.25 ± 5.56, while the average height for domesticated sorghum (DS. Am) was at a rate of 207.75 ±10.65.

As we noticed, the LN on the main stem has no relationship to the length of the plant. On the contrary, we recorded that, the white and red short sorghum with a vertical panicle holder are characterized by a relatively greater number of successive leaves on the main stem, where the rate varies between 21.50 ± 0.50 for white short sorghum (WSS.VP) and 20 ± 0.80 for red short (RLS.VP, RLS.CP) respectively (Lemgharbi et al., 2016; 2017).

We also record that, there is a direct proportion between the LN and the NN on the main stem of short sorghum, regardless of the color of the panicle, as it ranges between 18 ± 1.04 to 21.50 ±0.50 leaves, which explains the abundance of shoots (number of leaves) in short varieties, whether white or red alike, these morphological characteristics of sorghum are preferred as fodder for local farmers, especially those engaged in livestock breeding (Lemgharbi et al., 2016, 2017).

On the contrary, we did not record significant differences with regard to other morphological characteristics such as: the dimensions of the third leaf (L.3L and W.3L), the dimensions of the mature panicle (PL and PW), and the SD of the main stem, except for a clear significant difference with the domesticated sorghum (DS. Am) which was characterized by relatively large panicle on the shape of an open compound inflorescence. In this case, we recorded the largest dimensions of the panicle with a PL of 25.10 ± 2.07 and a PW of 11.86 ± 1.40, compared to those of local varieties, whose dimensions of the panicle ranged from 10.66 ± 0.49 to 12.75 ± 0.64 in relation to the PL and between 3.93 ± 0.51 to 6.09 ± 0.05 in relation to the PW (Table 6, Fig. 13).

Physical characteristics of sorghum

We have recorded through diagnosis and examination in the laboratory that, sorghum are classified into four main groups: white, red, mixed, and domesticated dark brown sorghum (Fig. 22). The color of the grain is a very important factor in determining the quality of the grain, for example, if we want to prepare a meal for porridge, it is better to use white sorghum grains (Gomez et al., 1997). The color of the grain depends on the genetic factor and on the environmental conditions of the region during and after ripening (Rooney & Miller, 1982). The grain moisture percentage (Mc%) is one of the most important information that must be known, because it affects the storage period and some grain quality characteristics, such as the density and yield of grain grinding. Grains containing moisture levels equal to or greater than 12% are subject to rot (Gomez et al., 1997).

The moisture values of sorghum grain samples ranged between 7.90% and 11.47%, with an average of 10.17%, with slight differences, where we recorded the lowest moisture percentage for domesticated sorghum grain (SD. Am) at average 7.90%, with weak dispersion measures (Table 6).

When comparing our results, we find that they are lower than those obtained by Buffo et al., (1998a) when they studied 26 types of sorghum grains grown in Nebraska during the years 1993 and 1994 (13.80%–13.95%) and with the results of 52 samples of commercial sorghum grains planted in 1992 in the same region (Buffo et al., 1998b). We conclude from these results that,

Figure 3. White long sorghum with vertical panicle (WLS.VP). Figure 4. White long sorghum with curved panicle (WLS.CP). Figure 5. White short sorghum with vertical panicle (WSS.VP). Figure 6. White short sorghum curved panicle (WSS.CP). Figure 7. Red long sorghum vertical panicle (RLS.VP). Figure 8: Res long sorghum curved panicle (RLS.CP). Figure 9. Red short sorghum vertical panicle (RSS.VP). Figure 10. Res short sorghum curved panicle (RSS.CP). Figure 11. Mixed sorghum (Mix. S). Figure 12. Domesticated sorghum (DS. Am). Source: Field Survey, 2020.

sorghum grains grown in southern Algeria (Tidikelt region) are characterized by low moisture, and therefore can be stored without being subjected to rotting.

For the sorghum grains, dimensions changed between 4.32 mm and 5.16 mm, with an average value of 4.75 mm, for the GL and between 3.79 mm and 4.66 mm, with a value of 4.21 mm, for the GW dimension, and between 2. 30 mm and 2.70 mm, with an average value of 2.48 mm, for the GT dimension (Table 6).

The values of contrast and coefficient of variation were very weak (Table 6), whereas the dimensions of local sorghum grains grown in southern Algeria are relatively high when compared to the dimensions of domesticated American commercial sorghum grains, which estimated at 4.32 mm for the GL, 3.89 mm for the GW, and 2.5 mm for the GT (Serina-Saldivar & Rooney, 1995). It also falls within the studied field of sorghum grain grown in Kenya, according to the results of the work of Mwithiga & Sifuna (2006). In this cultivation, the average value of the GL dimension was less than that of the Guinia cultivar (which is 4.93 mm) and greater than the other cultivars Durra (4.55 mm), Bicolor (4.40 mm), both grow in Sudan, and to Caudatum (4.06 mm), that grows in Uganda.

As for the average dimension, our grains are close to Durra (4.11 mm) that grows in Sudan, and are larger than Bicolor (3.51 mm), Guinia (3.91 mm) and Caudatum (3.57 mm) (Dahlberg et al., 2002) (Table 6).

The average value of the surface areas (S) of local sorghum grains was 36.59 mm^2, which expresses the range from 35.01 mm^2 to 38.53 mm^2

N°	Varieties	Characters GC	Mc (%)	Grain dimensions (mm) GL	GW	GT	Dg (mm)	(Ø)	S (mm^2)	W100 (g)	PFE
1	WLS VP	Off white	0.989 ±0.96	443 ±0.30	391 ±0.33	245 ±0.24	375	0.85	3442	303 ±0.08	Starchy
2	WLSC P	White	1045 ±0.45	459 ±0.35	451 ±0.39	255 ±0.25	377	0.82	37 02	380 ±0.10	Starchy
3	WSSV P	Off white	1079 ±0.02	471 ±0.08	415 ±0.09	270 ±0.07	375	0.80	3702	350 ±0.03	Starchy
4	WSSC P	White	1147 ±0.22	486 ±0.10	466 ±0.08	250 ±0.25	388	0.80	3789	382 ±0.10	Intermediate
5	RLSV P	Off red	0.955 ±0.09	483 ±0.09	404 ±0.11	245 ±0.06	390	0.81	3583	289 ±0.05	Intermediate
6	RLSC P	Dark red	1013 ±0.01	516 ±0.09	446 ±0.11	259 ±0.01	392	0.76	3853	356 ±0.12	Intermediate
7	RSSV P	Off red	1010 ±0.02	492 ±0.39	379 ±0.30	239 ±0.20	357	0.73	3501	206 ±0.04	Intermediate
8	RSSC P	Dark red	1127 ±0.23	497 ±0.38	449 ±0.34	236 ±0.38	410	0.82	3699	377 ±0.22	Intermediate
9	Mix S	Reddish white	1017 ±0.05	442 ±0.26	439 ±0.07	247 ±0.18	373	0.81	3586	375 ±0.09	Corneous
10	SD Am	Dark brown	0.790 ±0.11	432 ±0.39	389 ±0.10	230 ±0.10	356	0.82	3341	227 ±0.04	Corneous
Mean			1017	472	423	248	380	0.80	3620	325	
Maximum			1147	516	466	270	410	0.85	3853	382	
Minimum			790	432	379	230	356	0.73	3341	206	
SD			1.06	0.27	0.32	0.12	0.17	0.03	1.69	0.67	

Table 6. Physical properties of sorghum grains grown in the Tidikelt region GC: Grain Color; Mc (%): Grain moisture content; GL: Grain Length; GW: Grain Width; GT: Grain Thickness; W100(g): Weight of 100 grain; Dg (mm): Geometric; Diameter (mm) Ø: Degree of Sphericity; S (mm2): Grain surface by mm; PF: Proportion of the Floury Endosperm.

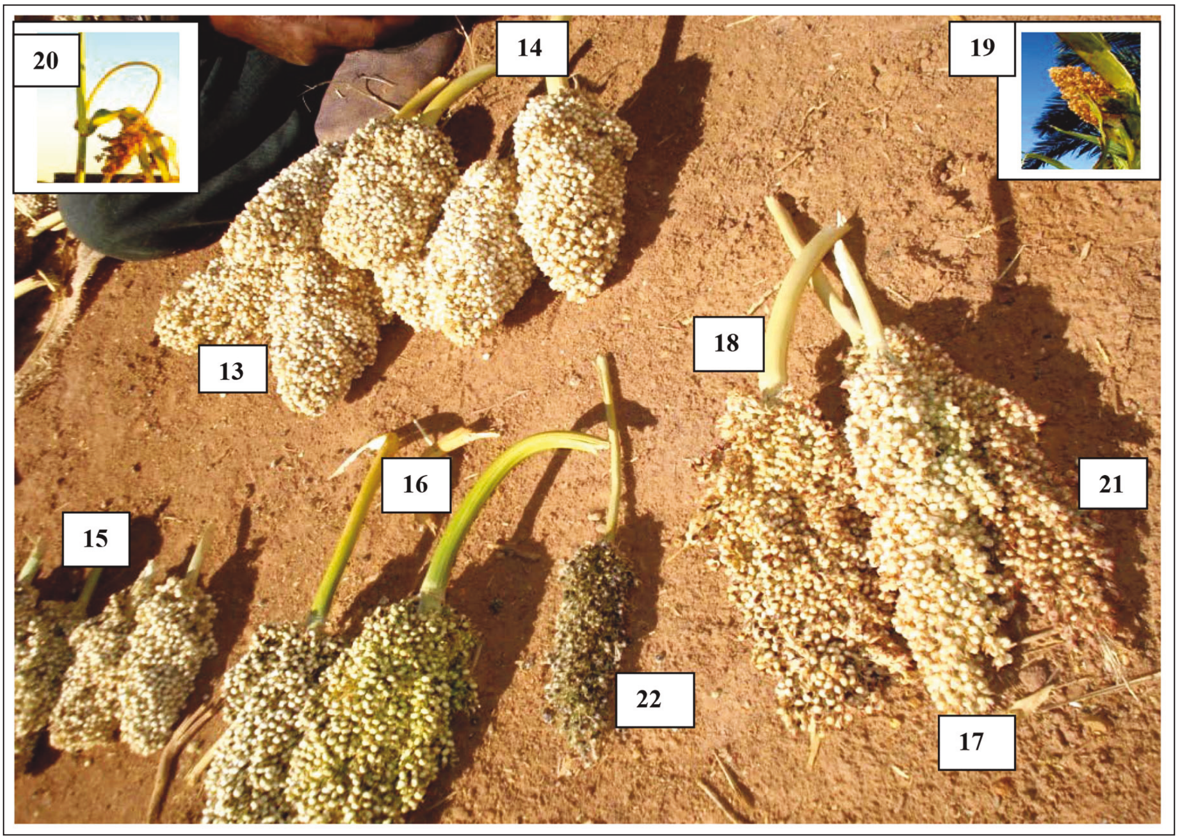
with contrast and a weak coefficient of variation, while we recorded a relatively less area for domesticated sorghum, at a rate of 33.41 mm^2 (Table 6).

Table 6 shows that the values of the weight of one hundred grains of the studied sorghum samples change between 2.06 g and 3.82 g, with an average of 3.25 g, and the percentage of variation was very weak. The International Institute for Research on Cereal Crops in Semi-arid and Tropical Regions (ICRISAT, 2020), where it was found that the value changes in the range from 1.30 g to 5.70 g, and the average value is 2.8 g (Jambunathan et al., 1984), and it is also high for the values of commercial American sorghum grain weights.

Our results concerning the W100(g) are considered high compared to the results of the last evidence estimate for 100 samples of sorghum grain measured in the laboratory of ICRISAT (2020), where it was found that the average value is 2.8 (see above Jambunathan et al., 1984). It is also high for the values of commercial American sorghum grain weights given by Sullins (1972), Serina-Saldivar & Rooney (1995) and Buffo et al., (1998a). From the previous results, our grains can be classified within the grains whose weight per grain is close to Heavy grain variety (Figs. 23–26). In practice, grains are suitable for grinding according to Gomez et al., (1997) because the masses of one hundred grains are greater than 2 g (Table 6).

We also recorded that there is a direct positive relationship between the three grain dimensions (L, W, and T), Dg, S, and grain weight (Gomez et al., 1997).

Through the results of the grain cytological sections, it was found that the waxy zone ranges between the two values 0–95 %, and the middle zone percentages range between 5–100%, while the mealy zone percentage varies between 0–60 %. Our



Figures 13–22: Models of the shapes and colors of sorghum cultivated in the Tidicult region. Fig. 13: WLS.VP; Fig. 14: WLS.CP; Fig. 15: WSS.VP; Fig. 16: WSS.CP; Fig. 17: RLS.VP; Fig. 18: RLS.CP; Fig. 19: RSS.VP; Fig. 20: RSS.CP; Fig. 21: Mix. S; Fig. 22: SD. Am. Source: Field Survey, 2020.

grains can be classified according to their endosperm structure as shown in Table 6.

Sorghum grain endosperm is usually divided into two parts: a vitreous peripheral located immediately below the protein-rich aleurone with a mealy central core. The relationship between the vitreous and mealy layers influences the grind of graproteins. It also determines the texture of the grain which influences the technological properties of grinds and the in vitro digestibility of starch (Wong et al., 2000). The results of the analysis of endosperm sections of the types of sorghum cultivated in the region, after examining them with a magnifying glass, showed that these grains can be classified into the waxy, intermediate, and mixed types in varying proportions (Figs. 27–29).

CONCLUSIONS

Through the results of the field study of sorghum cultivation in the Tidikelt region, it became clear that there is an important biodiversity in relation to the local and domesticated sorghum crop. The results of the physical study of the panicles and grains of this crop in the laboratory, confirmed the existence of clear differences for some morphological and cytological characters for the four groups; white and red of both kinds (long and short), mixed, and domesticated.

Despite this important phenotypic diversity of Sorghum and the availability of high-quality grains for its varieties, compared to common pills, however, we point out that the local population does not depend on these grains as food, especially in recent years, but rather relies on wheat and barley as an alternative, which requires attention and agricultural strategy, and an in-depth study to preserve these local natural resources with a view to the future development of cultivation and exploitation of these crops.

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Figures 23-26. Sorghum grain color; 23: White; 24: Red; 25: Mixed; 26: Domesticated.
Figures 27-29. Endosperm sections of sorghum grain; 27: Starchy; 28: Intermediate; 29: Corneous.

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