



Morphoagronomics and Nutritional Profile of ‘Mara Guisseiré’ Sorghum Landrace from Chad

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Abstract: Sorghum is the most consumed cereal in Chad. In rural areas, this crop is characterized by many variants among which the cultivar Mara Guisseiré. Lines of this cultivar were then obtained through selection work. The study aims to determine the main morphological traits, to evaluate their agronomic performance and nutritional profile. Six (6) lines were evaluated by 11 qualitative and 13 quantitative traits. The physicochemical constituents were determined by classical analytical methods. A low phenotypic variability was observed within the lines. However, highly significant differences were observed for several quantitative traits. MG-7 is the earliest (Heading stage : 55.00 days ; Maturity stage : 88.75 days), most productive (2168.25 kg.ha⁻¹) with highest Thousand-Seeds weight (TSw : 27.50 g). The moisture contents, protein, starch, tannin, ash and fiber vary from (9.44% - 10.40%), (8.75% - 12.00%), (58.75% - 68.20%), (62.00 mg CE/100 g -160.00 mg CE/100 g), (1.93% - 2.28 %), (2.44% - 3.25 %) respectively. The mineral contents vary from (11.27 - 18.59 mg/100g), (4.58 - 9.30 mg/100g), (4.73 - 6.35 mg/100g), (0.00 - 0.83 mg/100g) for calcium, iron, zinc and copper. This study shows the genetic importance of cultivars and their potential can be used in varietal improvement programs.

Keywords: Morphoagronomics traits, Nutritive value, Sorghum, Landrace, Mara Guisseiré, Chad.

INTRODUCTION

Plant genetic resources are among the priorities of the international bodies of the United Nations System. An International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) has been drafted and adopted by many countries. [1] reported that this Treaty contributes to improving people's livelihoods by combating hunger and preserving biological diversity. These authors also emphasized that this Treaty recognizes the contribution that local and indigenous communities and farmers have made to the conservation and valorization of plant genetic resources for food and agriculture. The main methods of managing plant genetic resources for food and agriculture are “*in situ*” and “*ex situ*” management. “*In situ*” conservation and on-farm management of these resources are essential to support the adaptation process in their natural or usual habitats. It has been reported that small farmers most often use the “*in situ*” management method [2].

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most widely cultivated species worldwide, particularly in Africa. Global production is estimated at 57, 298,318.42 t for 39, 851,368 ha. In Africa, production is estimated at 25,954,458 t for 27,654,217 ha [3]. In Chad, sorghum, along with millet, is the most widely consumed cereal. For the 2024-2025, the area planted with rain-fed sorghum is 1,005,413 ha, with a production of 720,086 t

[4], compared with 1,103,688 ha for 877,520 t produced during the previous season [5]. There has been a decline in production of 157,434 t over the last two years.

In general, sorghum has multiple uses and is intended for human, animal, and industrial consumption. It has numerous cultivars, which are most often preserved by farmers who use them on small family farms. Indeed, the importance of farmers' involvement in the management of sorghum landraces has been reported in numerous studies. [6] Teshome et al. showed that the five most common landraces represented by 44 accessions named by farmers in North Shewa and South Welo in Ethiopia formed dissimilar groups, suggesting that the names given by farmers are relevant and do indeed represent different local sorghum landraces. In addition, an exceptional variety of sorghum, with more than 1,500 varieties, was revealed by Seignobos and Iyébi Mandjek [7] in the Far North Province of Cameroon. [8] also showed that out of 674 accessions collected in India, 138 are popular landraces with specific traits and traditional uses. Similarly, [9] reported that a high level of phenotypic diversity in local sorghum varieties is maintained and managed by the Donga people in northwestern Benin. Moreover, by evaluating the agro-morphological and physiological traits that enable improved production performance in sorghum-cowpea combinations, [10] revealed that landraces are the most widely used by farmers, with 82.5% of them indicating that the types of varieties chosen are important.

In terms of agromorphology and genetics, various research topics on sorghum landraces have been conducted around the world. In India, [11] indicated in a study evaluating the genetic diversity of 96 kharif sorghum varieties that there was high heritability, indicating strong potential for selection. In Indonesia, the production potential of 40 sorghum accessions was evaluated which 5 had high biomass productivity and 2 had high combined biomass and grain yield [12]. Furthermore, [13] showed that the rich genetic heritage of four sorghum landraces genotypes from different countries offers an excellent opportunity to find traits adapted to different stress scenarios.

At the level of nutritional value, the physicochemical compositions of sorghum landraces have also been evaluated by many authors. Of particular note are the studies by [14] on landraces originating in India, those by [15] on 15 landraces from Burkina Faso, and those by [16] on 53 sorghum landraces from 5 different countries. [17] pointed out in a comparative study of 34 improved and local varieties from different agro-ecological zones in Ethiopia that some local varieties have high protein, iron, and tannin content. It has also been reported that brown and red varieties of sorghum, grown mainly in the South African climate, are rich in nutrients and various phenolic compounds [18].

In Chad, research has also been conducted on sorghum. At the national level, given its important role in the diet, many studies have shown the importance of rural communities in their practices for managing sorghum landraces. This work has highlighted their agronomic performance and genetic potential. In the country's Sudanian zone, following prospecting, work has been carried out particularly on rainfed sorghum accessions and sweet sorghum. In 1951, mass selection applied to certain local or introduced ecotypes made it possible to isolate a good rain-fed variety of sorghum from Chad, variety 51-69 or Tarouch [19].

Recently, other authors have also highlighted significant genetic diversity managed by farmers in Sudanian zone [20] and in south-central area [21]. In terms of nutrition, very

little work has been done on the physicochemical constituents of rainfed sorghum landraces. [22] reported nutritional values for five sorghum varieties grown in Chad. [23] revealed significant variability and richness in nutrients but among flood-recession sorghum landraces. In this study, it should be noted that sorghum landraces, including Mara Guisseïré, were collected during various surveys conducted in the region of Guera in the sahelian zone. For this specific landrace, variants were observed in the collection. Following selection work and, above all, successive self-pollination at the heading and flowering stages, lines were obtained. Thus, for the preservation and enhancement of these lines, it is necessary to determine some of their morphological traits, to evaluate their agronomic performance and nutritional values.

MATERIAL AND METHODS

Plant Material

The plant material consists of 6 lines of the Mara Guisseïré landrace from the collection of the Institut Tchadien de Recherche Agronomique pour le Développement (ITRAD) (Table 1).

This landrace comes from a prospective study and germplasm collection conducted in 2016 in six departments of 3 regions in south-central Chad. These are Guéra rural, Mangalmé, Abtouyour, and Barh Signaka from the Guéra region (11°30' N and 18°30'E), Dababa in Hadjer Lamis (12°23'N and 17°03'E) and Fitri in Batha (12°52'N and 17°35'E). This landrace is mainly collected in Guéra region and the lines are the result of selection work.

Table 1: Names and origin of the lines of landrace Mara Guisseïré

Région	Origin	Vernacular name	Lines names	Lines code
Guéra	Local	Mara Guisseïré	Mara Guisseïré-2	MG-2
			Mara Guisseïré-7	MG-7
			Mara Guisseïré-9	MG-9
			Mara Guisseïré-11	MG-11
			Mara Guisseïré-14	MG-14
			Mara Guisseïré-17	MG-17

Study Site

The study were conducted in a controlled environment at the ITRAD experimental site located in the Sahelian zone during the 2021-2022 rainy season from July to October. The isohyets is between 600 mm and 700 mm. The climate is hot and humid tropical with a rainy season and a dry season. Temperatures are highly variable, ranging from 25°C to 45°C. The average annual temperature was 27.3°C. The vegetation is characterized by grassy savannas and pseudo-steppes dominated by Mimosaceae. The soils are hydromorphic, ferruginous tropical with little leaching and subarid brown or reddish-brown soils.

Experimental Design And Crop Cultivation

The trial was carried out in Fisher design with 4 replications. After plowing, each block was delimited. A 1.5 m aisle separates the blocks. The experimental unit was represented by 6 rows of 5 m each. The spacing was 0.80 m between rows and 0.50 m between holes. Each row had 10 holes. The useful plot consisted of 4 central rows with 8 plants. Cultivation operations began with cleaning the plots and cross-plowing. This was followed by marking out and staking the plots. Seeds were sown at a rate of 5 to 6 seeds per hole at a depth of 3 to 5 cm. Fifteen (15) days after sowing, the seedlings were thinned to two plants per hole, and the first weeding was carried out three weeks later. Others weeding and phytosanitary treatments were done when it were necessary. Recommended fertilizer (NPK 20-10-10) and urea were applied respectively at the rate of 100 kg.ha⁻¹ and 50 kg.ha⁻¹.

Data Collection

The observations and data to be collected were mainly qualitative and quantitative characteristics. These operations began at the seedling stage and were completed with the determination of harvest data. Characterization data were collected using the sorghum descriptor.

Evaluation of Qualitative Traits

The different organs were evaluated using 11 qualitative traits ranging from 0 to 12 (Table 2).

Table 2: Qualitative traits and modalities

Traits	Codes	Variants
Seedling Vigour	SVi	3 Low ; 5 Intermediate ; 7 High
Plant Colour	PCo	1 Pigmented ; 2 Tan
Leaf Midrib Color	LMc	1 White ; 2 Dull green ; 3 Yellow ; 4 Brown ; 5 Purple ; 6 Other
Waxy Bloom	WBo	3 Slightly present ; 5 Medium ; 7 Mostly bloomy ; 9 Completely bloomy
Stalk Juiciness	SJu	0 Not Juicy (dry) ; + Juicy
Glume Colour at Maturity	GCo	1 White ; 2 Sienna ; 3 Mahogany ; 4 Red ; 5 Purple ; 6 Black ; 7 Grey ; 8 Other
Inflorescence Exsertion	IEx	1 Slightly exserted (<2 cm) ; 2 Exserted (2-10 cm) ; 3 Well-exserted(>10 cm) ; 4 Peduncle recurved
Awns	AWn	0 Absent (awnless) ; + Present (awned)
Inflorescence Compactness and Shape	ICs	1 to 13
Grain Colour	GCo	1 White ; 2 Yellow ; 3 Red ; 4 Brown ; 5 Buff ; 6 Other
Grain Covering Rate. At maturity.	GCr	1 25% grain covered ; 3 50% grain covered ; 5 75% grain covered ; 7 Grain fully covered ; 9 Glumes longer than grain

Seedling Vigour (SVi) ; Plant Colour (PCo) ; Leaf Midrib Color (LMc) ; Waxy Bloom (WBo) ; Stalk Juiciness (SJu) ; Glume Colour at Maturity (GCo) ; Inflorescence Exsertion (IEx) ; Awns (AWn) ; Inflorescence Compactness and Shape (ICs) ; Grain Colour (GCo) ; Grain Covering Rate at Maturity (GCr).

The general aspects of the plant included Seedling Vigor (SVi), Plant Color at harvest (PCo), Leaf Midrib Color (LMc), Waxy Bloom (WBo), Stalk Juiciness (SJu), Glume Color at Maturity (GCm), and the absence or presence of awns (AWn). For the panicle, the type of Inflorescence Exsertion (IEx) and the Inflorescence Compactness and Shape (ICs) were observed. For the seeds, the evaluation concerned the Grain Colour (GCo), and the Grain Covering Rate at maturity (GCr).

Evaluation of Quantitative Traits

The 13 quantitative traits determined are: Plant height (PHe), Leaf length (LLe), Leaf Width (LWi), Stem Diameter (SDi), Neck Length (NLe), Panicle Length (PLe), Panicle Width (PWi). These different parameters were measured on five plants in each repetition for each line. For Days of Heading at 50 % (DHe 50 %), Number of Days at 50 % flowering (NDf 50 %), at 95 % maturity (NDm 95 %), Grain Yield (GYi), and Biomass Quantity (BQu), observations and data were collected across the entire useful plot. The Thousand-Seed weight (TSw) was determined on eight samples from each line on the useful plot.

Analyses of Physicochemical Constituents

The major biochemical constituents and physicochemical elements were determined using various chemical assay methods. The moisture content was determined by using the NF V 03-707 method [24]. Kjeldahl method and the NF V 03-050 standard [25], were used to evaluate the protein content. For the starch content, it was determined using the Luff-Schoorl method. For fiber, the samples, after mineralization and filtration, were incinerated at 400°C in a muffle furnace and measured using the NF V 03-041 method [26]. The ash content was determined using the NF V 03-760 method [27]. The Folin Denis colorimetric method described by [28] was used to measure tannins. All measurements of mineral constituents (calcium, iron, zinc and copper) were performed using X-ray fluorescence spectrometry.

Statistical Analyses

Qualitative traits were evaluated using the list of descriptors for *Sorghum bicolor* (L.) Moench [29]. Quantitative data analyses were performed using XLSTAT-Pro software version 2013.5.01. These data were analyzed using descriptive statistical methods. They were then subjected to analysis of variance using Student's Newman-Keuls tests.

RESULTS AND DISCUSSION

Morphoagronomics Traits of Mara Guisséiré Landrace Lines

Sorghum is the main cereal cultivated in Chad. The landrace Mara Guisséiré have been introduced into Chad from Sudan for more than thirty years. It seems very promotive and is highly appreciated because of the sticky aspect of its dough and its red color which is assimilated by rural communities to a good nutritional value. Currently, its culture has exceeded the boundaries of the Guéra region and has spread to all the central southern regions. This area is part of the territory where there is a significant diversity of landraces

owned by farmers. This was confirmed by [21] through a prospecting and significant collection of landraces from different crops in the area. However, it should be noted that the different variants of the landrace Mara Guisseiré have only been observed in this region and they are of caudatum race. On the other hand, in the Sudanian zone of the country, Yagoua [30] showed that the most frequent breeds are the guinea-caudatum, durra-caudatum and guinea-bicolor hybrids.

Variability of Morphological Traits

The morphological qualitative traits of the lines studied in this study relate to the plant and certain aspects of the panicles and seeds (Table 3).

Table 3: Qualitative traits and rate of the variants of the lines

N°	Traits	Codes	Variants	Rate (%)
1	Seedling Vigour	SVi	High	100
2	Plant Colour	PCo	Pigmented	100
3	Leaf Midrib Color	LMc	Dull green	100
4	Waxy Bloom	WBo	Completely bloomy	100
5	Stalk Juiciness	SJu	Juicy	100
6	Glume Colour at Maturity	GCm	Greyed-green	16,67
			Purple	83,33
7	Inflorescence Exsertion	IEx	Slightly exserted (<2 cm)	100
8	Awns	AWn	Awnless	100
9	Inflorescence Compactness and Shape	ICs	Compact Elliptic	100
10	Grain Colour	GCo	Red	83,33
			Brown	16,67
11	Grain Covering Rate	GCr	50 % grain covered	100

All lines show good plant vigor. In terms of plant color, all lines studied are pigmented with a green midrib. They are also completely waxy with juicy stems. The panicles are all elliptical in shape but have poor exsertion. The traits relating to the panicles and seeds of the different lines are shown in **Figure 1**. At maturity, 83.33 % of the glumes are purple in color and 16.67 % are greyed-green. As for the seeds, 83.33 % are red and 16.67 % are brown. All lines have seeds covered at 50 % by glumes and are all awnless. The morphological traits of the lines observed are generally identical except for two parameters, the color of the glumes at maturity and of the seeds. The landrace MG-7 is the only cultivar whose color of glumes at maturity greyed-green unlike other landraces which are purple. The seeds of MG-7 are brown while other landrace have red seeds. This low variability at the qualitative level was also observed in 139 cultivars of Korean sorghum. Indeed, for each genotype, the types of endosperm and panicle, the panicle density and the coloration of the seeds were evaluated. The majority of these traits showed low variation within these genotypes according to Lee [31]. In general, phenotypic variability is important in sorghum landraces. Works reported by several authors confirm this assertion. This is the case of Semere et al. [32] on 358 landraces from 4 zones of Tigray in northern Ethiopia, Tuina et al. [33] on types of sorghum cultivated in Burkina, ecotypes from Morocco by Boukrouh et al. [34], on the morphological diversity of sorghum cultivated in northern Côte d'Ivoire reported by Koffi et al. [35] and on that of the panicles and sorghum seeds in Chad by Nadjiam [21]. However, in this study, the low

morphological variability observed can be explained by the fact that the number of qualitative traits used in the evaluation is not exhaustive. The second explanation comes from the fact that these are variants of the same landrace. Similarly, the trial was conducted in a single agroecological area. Which significantly reduces the effects of the environment.

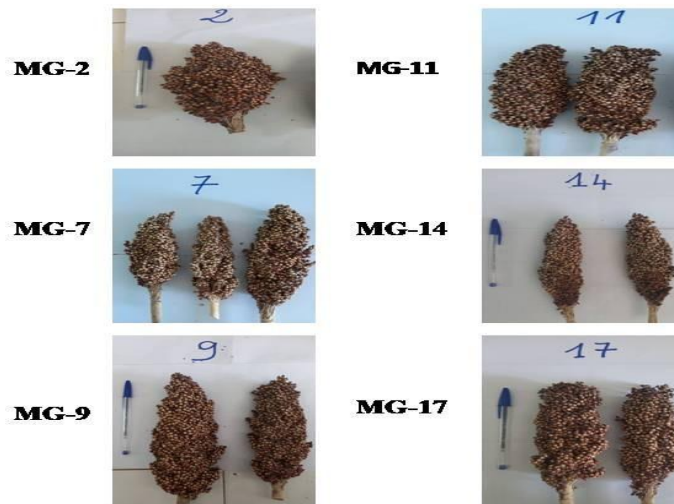


Figure 1: Major morphological traits of the panicles of the different lines

Descriptive Analyses of Quantitative Traits

Significant gaps are observed for variables such as leaf length (LLe), neck length (NLe), biomass quantity (BQu), and grain yield (GYi). For the others, the differences are less pronounced. Indeed, for leaf length (LLe), the values range from 60 to 89 cm, with an average of 76.15 cm. For neck length (NLe), they range from 21 to 45 cm. For biomass, the difference is even more significant, ranging from 1,833 to 5,583 kg/ha. Similarly, for yield, it ranges from 566,00 to 2,608 kg/ha. Intermediate differences concern panicle length (PLe), panicle width (WiP), number of days to 50% heading (DHe 50 %), number of days to 50 % flowering (NDf 50 %), and number of days to 95 % maturity (NDm 95 %). Compared to the other variables, namely plant height (PHe), leaf width (LWi), stem diameter (SDi) and thousand-seeds weight (TSw), the differences are smaller. For all variables, the coefficients of variation range from 2.9 for the number of days after sowing to reach 95 % maturity (NDm 95%) to 40.9 % for grain yield (Table 4). In relation to the height of the plants, the name of the cultivar Mara Guisséïré literally means « short or small woman ». It is a particular type of rainfed sorghum cultivated particularly in specific areas of the provinces of central-southern Chad. The average height of the plants of the lines is 137 cm. The minimum value is 95 cm and 178 cm for the largest plant. The Mara Guisséïré lines are generally highest than the sorghum ecotypes from the collection of the Faculty of Sciences and Technologies of Tangier in Morocco, which have an average of 131.79 ± 3.34 cm [36]. However, they are significantly shorter than the values reported by Koffi et al. [35], whose heights of the studied plants range from 206 to 513.6 cm with an average of 349.9 ± 6.5 cm. This is also the case for the work by Ganeme et al. [10] on 50 varieties of sorghum including 17 cultivars collected from farmers whose average plant height is 227 cm. For the length of the leaves, we notice that line MG-14 has leaves that

have on average the highest lengths (79.45 cm) of all the lines studied. Compared with other works, the average leaf length of the lines is 76.15 cm. It's higher than that of the sorghum ecotypes of Ethiopia which measures only 70.3 cm [37] and even smaller for the Kharif ecotypes of India which is 67.12 cm [11]. The width of leaves from plants in line MG-2 is on average higher (10.64 cm) than that of others that are identical. The widths of the leaves of the lines are on average 9.73 cm. This average is larger than that of the ecotypes of Ethiopia which measures 8.2 cm, indicated by Adugna [37] and that of India which is 6.20 cm according to Pugahendhi et al. [11]. It is even longer than the 3.4 cm of the ecotypes of northern Morocco resulting from the work of Boukrouh et al. [34]. Depending on the neck of the plant, the average length is 32.14 cm. Furthermore, the study reveals that the panicles length of all lines vary from 17.00 cm to 29.00 cm with 21.76 cm on average. Regarding their width, the average is 8.06 cm and it is significantly higher than 5.13 cm reported by Pugahendhi et al. [11].

Table 4: Descriptive data for the quantitative traits of the lines

Traits	Minimum	Maximum	Mean	SD	CV (%)
PHe (m)	0.95	1.78	1.37	0.119	8.60
LLe (cm)	60.00	89.00	76.15	5.304	6,90
LWi (cm)	7.40	13.50	9.73	0.981	10.00
SDi (cm)	1.20	2.50	1.82	0.276	15.10
NLe (cm)	21.00	45.00	32.14	3.305	10.20
PLe (cm)	17.00	29.00	21.76	1.990	9.10
PWi (cm)	3.20	10.00	8.06	0.916	11.30
DHe 50 % (days)	55.00	66,00	60.83	3.371	5.40
NDf 50 % (days)	57.00	69.00	64.46	2.874	4.40
NDm 95 % (days)	88.00	98.00	94.08	2.827	2.90
BQu (kg.ha ⁻¹)	1833.00	5583.00	3770.75	828.713	21.50
GYi (kg.ha ⁻¹)	566.00	2608.00	1424.92	595.518	40.90
Tsw (g)	2.00	2.90	2.38	0.238	10.00

SD: Standard Deviation; CV: Coefficient of Variation PHe : Plant Height ; LLe : Leaf Length ; LWi : Leaf Width ; SDi : Stem Diameter ; NLe : Neck Length ; PLe : Panicle Length ; PWi : Panicle Width ; DHe 50 % : Number of Days to heading at 50 % ; NDf 50 % : Number of Days at 50 % flowering ; NDm 95 % : Number of Days at 95 % Maturity ; GYi : Grain Yield ; BQu : Biomass Quantity Tsw :Thousand Seeds weight.

Variances Analyses of Morphological Quantitative Traits

The results show significant differences for several variables (Table 5). With regard to plant height (PHe), stem diameter (SDi), and panicle length (PLe), the analysis reveals no significant differences between the lines. However, leaf length (LLe), leaf width (LWi), neck length (NLe), and panicle width (PWi) show significant differences between lines (p-value <0.05). In terms of leaf length, the MG-14 line had the longest leaves on average (79.45 cm) of all the lines studied. The leaf width of plants from the MG-2 line is on average greater (10.64 cm) than that of the others, which are identical. Based on the length of the plant necks, three groups can be distinguished. The MG-7, MG-9, and MG-11 lines have longer necks. The MG-2 and MG-17 lines have necks of intermediate length, while the MG-14 line has the shortest neck, at only 30.43 cm. In addition, the study reveals that the panicles of all lines have statistically non-different average lengths between 21.10 cm and 22.70 cm. In terms of width, the panicles from MG-9 and MG-14 are

on average larger than those of the others. The MG-7 line has the smallest panicle widths, at around 7.54 cm.

Table 5: Variances analyses of the morphological traits of the lines studied

Lines	PHe (cm)	LLe (cm)	LWi (cm)	SDi (cm)	NLe (cm)	PLe (cm)	PWi (cm)
MG-2	1.354	75.300 ^a	10.640 ^b	1.910 ^b	31.050 ^{ab}	21.100 ^a	7.880 ^{ab}
MG-7	1.355	74.175 ^a	9.495 ^a	1.660 ^a	33.250 ^b	22.095 ^a	7.535 ^a
MG-9	1.356	78.250 ^{ab}	9.635 ^a	1.810 ^{ab}	33.100 ^b	21.345 ^a	8.335 ^b
MG-11	1.359	74.775 ^a	9.700 ^a	1.860 ^{ab}	33.075 ^b	21.660 ^a	8.130 ^{ab}
MG-14	1.399	79.450 ^b	9.670 ^a	1.850 ^{ab}	30.425 ^a	22.700 ^a	8.375 ^b
MG-17	1.419	74.925 ^a	9.250 ^a	1.800 ^{ab}	31.965 ^{ab}	21.675 ^a	8.120 ^{ab}
p-value	0.349	0.004	0.0001	0.084	0.019	0.144	0.035
	NS	*	**	NS	*	NS	*

Values with same letters and in the same column are not significantly different according to the test of Student Newman-Keuls at 0.05; NS: Non-Significant; *: Significant ; **: Highly Significant.

Variances Analyses of Growth and Yield Traits

Significant to highly significant differences were observed for growth and yield traits of the lines except biomass. In terms of the number of days to reach the 50 % heading stage, only the MG-7 line reached this stage early, at 55 days after sowing. This was also the case at the 50 % flowering and 95 % maturity stages for the same line, with 59.75 days and 88.75 days, respectively. In terms of grain yield, the MG-17 line had the lowest value at only 979.75 kg/ha, compared to the best yield achieved by the MG-7 line at 2168.25 kg/ha. The other lines had intermediate yields. For thousand-seeds weight (TSw), there were four clearly identified groups. The MG-2 and MG-17 lines have the lowest thousand-grain weights of around 21.88 g, while MG-7 has the heaviest grains, weighing 27.50 g. The MG-11 and MG-14 lines have intermediate weights that are statistically identical but significantly different from MG-9 (Table 6). Indeed, significant differences were observed in relation to the dates of 50 % heading, 50 % flowering, 95% maturity and grain yield. Compared to the 50 % heading stage, only line MG-7 reached this stage early at 55 days after sowing. This is also the case at the 50 % flowering stage and 95 % maturity for the same line with 59.75 and 88.75 days after sowing. For comparison, on average, the lines studied reached the stage of 50 % flowering at about 64.46 days which is close to 66 days reported by Ganeme et al. [10] but less than 81.6 days reported by Boukrouh et al. [34]. For sorghum grown in northern Côte d'Ivoire, the 50 % of flowering stage is reached at 89.1 ± 1.2 days according to Koffi et al. [35]. The maturity stage is reached on average at 94 days for the lines. For the ecotypes of Morocco, this stage is reached at 113 days [34]. According to Pugahendhi et al. [11], the Kharif ecotypes of India are also late, reaching maturity on average at 109 days. The grain yields of Mara Guisséiré lines are low for MG-17, intermediate for MG-2, MG-9, MG-11, MG-14 and better for MG-7. The average of all lines is 1424.92 kg.ha⁻¹. This average is lower than the average reported by Gamene et al. [10] and much lower than the results on sorghum ecotypes from northern Morocco [34]. As for the quantities of biomass, they are statistically identical. The average is 3770.75 kg.ha⁻¹. This is lower than the average of 4375 kg.ha⁻¹ reported by Ganeme et al. [10]. For the thousand seeds weight (TSw), were identified 4 groups among the lines. This weight varies

from 20 g to 29 g with an average weight of 23.8 g. These results are different compared to those of Koffi et al. [35] which vary from 8.2 to 27.4 g.

Table 6: Variations in growth and yield traits of the lines

Lines	DHe 50 % (days)	Ndf 50 % (days)	NDm 95 % (days)	GYi (kg. ha ⁻¹)	BQu (kg. ha ⁻¹)	TSw (g)
MG-2	60.50 ^b	64.25 ^b	94.25 ^b	1389.00 ^{ab}	3541.75	21.88 ^a
MG-7	55.00 ^a	59.75 ^a	88.75 ^a	2168.25 ^b	4062.50	27.50 ^c
MG-9	62.00 ^b	65.25 ^b	95.25 ^b	1659.00 ^{ab}	4124.75	23.13 ^{ab}
MG-11	63.00 ^b	66.25 ^b	95.75 ^b	1183.00 ^{ab}	4020.75	23.88 ^b
MG-14	62.50 ^b	65.75 ^b	95.75 ^b	1170.50 ^{ab}	3479.00	24.75 ^b
MG-17	62.00 ^b	65.50 ^b	94.75 ^b	979.75 ^a	3395.75	21.88 ^a
p-value	0.001	0.003	< 0.0001	0.038	0.712	<0.0001
	*	*	**	*	NS	**

Values with same letters and in the same column are not significantly different according to the test of Student Newman-Keuls at 0.05. NS : Non-Significant ; * : Significant ; ** : Highly Significant.

Proximate Composition and Micronutrients

The results of the descriptive analyses indicate that the differences are high for the variables such as tannin, calcium, iron, and copper content (Table 7). Contrary, the differences for moisture, starch, ash, and fiber content are smaller. Overall, the coefficients of variation range from 2.80 for water content to 50.30 % for copper. In general, these coefficients of variation are low (2.8 to 18.10 %) for most variables. For copper content (50.30%), they are very high. However, these values are intermediate for iron (27.40 %) and tannin (28.00 %).

Table 7: Descriptive analyses of the nutritional and physicochemical constituents

Variable	Minimum	Maximum	Mean	SD	CV (%)
Moisture (%)	9.440	10.400	10.083	0.284	2.80
Protein (%)	8.750	12.000	10.378	1.142	11.00
Starch (%)	58.750	68.200	63.951	3.521	5.50
Tannin (mg CE/100g)	62.000	160.000	103.783	29.008	28.00
Ash (%)	1.930	2.280	2.092	0.099	4.70
Fiber (%)	2.440	3.250	2.885	0.227	7.90
Calcium (mg/100g)	11.270	18.590	14.548	2.638	18.10
Iron (mg/100g)	4.580	9.300	5.828	1.594	27.40
Zinc (mg/100g)	4.730	6.350	5.520	0.590	10.70
Copper (mg/100g)	0.000	0.830	0.493	0.248	50.30

Descriptive Analyses of Proximate Composition of the Lines

The lines of the Mara Guisséiré cultivars analyzed have a promoter nutritional profile. A significant variability was highlighted within these cultivars. The moisture content varies from 9.44 to 10.4 % with an average of 10.08 %. For 9 sorghum landraces from the National Sorghum Breeding Program, Melkassa Agricultural Research Center of Ethiopia, the results are similar because the water contents are between 9.12 and 10.72 % as reported by Dasa [17]. Protein contents are 8.75 % for the lowest and 12 % for the richest value with an average of 10.38 %. This average is lower than that of the Tigray sorghum landraces in

Northern Ethiopia which was estimated at 11.40 % by Semere et al. [38]. However, it is higher than the average value of 9.55 % determined on 361 landraces and 4 checks improved varieties from Ethiopia, reported by Endalamaw et al. [39]. All these results are generally very similar and are confirmed with the average crude protein content of sorghum varieties from 9.60 to 11.30 % of dry matter revealed by Rihacek et al. [40]. Starch contents range from 58.75 % to 68.20 % with an average of 63.95 % lower than the average content of 68.75 % in sorghum landraces from Ethiopia [39]. They are also lower than the results of 20 improved varieties implemented at the Machache station in Lesotho, which range from 71.60 % to 84.06 % according to Ts'ephe et al. [41]. It should also be noted that the ash contents of 1.62 % determined in red sorghum varieties from South Africa by Nemukondeni et al. [18] are low compared to the average of 2.09 % for the Mara Guisséirés' lines. This is also the case for the results reported by other two authors who are Belay et al. [42] and Treviño-salinas et al. [43]. It is the same case for fibers because the content of 2.30 % of Nemukondeni et al. [18] is slightly lower than 2.89 % obtained in the present study. The lines of Mara Guisseiré also have very low fiber concentrations compared to the values reported by Belay et al. [42] which range from 4.85 to 8.96 % and even much lower than those of Treviño-salinas et al. [43]. Tannin contents range from 62 to 160 mg CE/100 g. The average being 103.78 mg CE/100 g. Compared to the berbéré, a type of flood-recession sorghum landrace grown in Chad whose contents ranged from 25.00 to 42.00 mg CE/100 g with an average of 34.12 mg CE/100 g according to Nadjiam [23], the lines of Mara Guisséiré are richer in tannin.

Descriptive Analyses of the Micronutrients

For the micronutrients, the average concentrations obtained in the lines are for iron 5.83 mg/100 g, zinc 5.52 mg/100 g and copper 0.49 mg/100 g. These concentrations are very low compared to 51.6 mg/100 g for iron, 27.00 mg/100 g for zinc and 2.9 mg/100 g for copper revealed by Semere et al. [38]. Nutritional quality variation among fourteen sorghum accessions from Malawi, Tanzania and Zambia, Ng'uni et al. [44] showed that iron content mean is 4.4 mg/100 g and for zinc is 3.3 mg/100 g. The Mara Guisseiré lines have on average, more iron and zinc content than these three Southern African sorghum accessions. For the calcium, the minimum content is 11.27 mg/100 g and 18.59 mg/100 g for the maximum value. The average determined in all lines is 14.55 mg/100 g which is high to the value 7.56 mg/100 g of parbhani moti but low to 35.27 mg/100 g of parbhani super moti, two Indian landraces from India reported by Gajmal et al. [14]. On the other hand, these levels are significantly lower than the average observed by Shegro et al. [45] in 31 sorghum landrace accessions from the Institute of Biodiversity Conservation, Ethiopia.

Variances Analyses of the Proximate Content

The analysis of variances of the proximate content varies greatly between lines (**Table 8**). Significant differences are observed between the different contents for each variable. The contents per line are significant and demonstrate the importance of the Mara Guisséiré landrace. Protein contents are high in MG-11, MG-14, and MG-17. This content is low in MG-7 (8.77 %). Starch and tannin levels are also high. MG-9 and MG-11 have the highest tannin concentrations, while MG-14 has the lowest level at 63.5 CE mg/100 g. The line

MG-14 has the lowest water content while MG-11 has the highest rate. Individuals MG-11, MG-14 and MG-17 are richer in proteins by 11 to 12 %. On the other hand, starch richness estimated at 68 % is observed in lines MG-2 and MG-7. As for the ash contents, it is the cultivar MG-17 which has the highest values of all the lines. This is also the case for MG-2 but for fiber contents. However, for these two constituents, line MG-7 has the lowest concentrations. Furthermore, landraces MG-11, MG-14 and MG-17 have statistically the same intermediate fiber contents which are estimated at 2.88 %. Similarly, MG-2, MG-11, and MG-14 both have an intermediate and identical ash content of 2.10 %. For the tannin contents, MG-9 and MG-11 have the highest contents, respectively 156.5 and 121.1 mg CE/100 g. The lowest concentration is observed in MG-14 with 63.5 mg CE/100 g. These contents are significantly lower than those obtained in the red-grained Alföldi1 variety of sorghum from Hungary. However, the lines of Mara Guisséiré have similar values to the ES Foehn variety from the same country as reported by Nagy et al. [46]. Similarly, Dasa [17] determined higher tannin levels for nine sorghum cultivars from different agroecological zones of Ethiopia, except in the cultivar Jigurti where this concentration is almost three times lower than in the lines of Mara Guisséiré. Compared to the work of Lee [31], the contents range from 0.12 to 428.95 mg CE/ g with a mean of 224.35 mg CE/ g indicating that these genotypes have high contents except for two cultivars which have very low values 0.12 and 0.48 mg CE/ g. Compared to these 2 cultivars, the lines of Mara Guisséiré have significantly higher values.

Table 8: Variances analyses of the proximate composition of the lines

Lines	Proximate composition					
	Moisture %	Protein %	Starch %	Tannin (mg CE/100g)	Ash %	Fiber %
MG-2	10,27 ^c	9,56 ^b	68,18^d	93 ^{bc}	2,11 ^c	3,23^d
MG-7	10,19 ^{bc}	8,77 ^a	67,68^d	90,1 ^b	1,94 ^a	2,46 ^a
MG-9	10,09 ^b	9,58 ^b	66,22 ^c	156,5^e	2,03 ^b	2,99 ^c
MG-11	10,38^d	11,21^c	61,40 ^b	121,1^d	2,10 ^c	2,87 ^b
MG-14	9,50 ^a	11,17^c	60,86 ^b	63,5 ^a	2,11 ^c	2,88 ^b
MG-17	10,08 ^b	11,99^d	59,38 ^a	98,5 ^c	2,27^d	2,89 ^b
	**	**	**	**	**	**

Values with same letters and in the same column are not significantly different according to the test of Student Newman-Keuls at 0.05. **: Highly Significant. Values in bold are the most important.

Variances Analyses of the Mineral Content

Regarding the variances analysis of the mineral constituent, MG-11, MG-14 and MG-17 are rich in calcium with a more pronounced dominance for MG-11 (**Table 9**). Indeed, the highest value, 18.47 mg/100 g, was determined in MG-11. This value is higher than the values of certain improved varieties reported by Ts'ephe et al. [41] but significantly lower than those of the landraces accessions from Ethiopia determined by Shegro et al. [45]. For the iron content, it is MG-17 that clearly has the highest value, 9,29 mg/100 g. However, all lines have higher iron and zinc concentrations than the landraces reported by Dasa [17]. Regarding zinc levels, the Mara Guisseiré lines are rather poor than the 31 landraces accessions evaluated by Shegro et al. [45] but higher than most sorghum accessions except two of them evaluated by Ng'uni et al. [44]. However, MG-7 is poorer in iron, copper, and calcium but rich in zinc (6,05 mg/100 g). Similarly, MG-9 has low zinc

values but intermediate in iron and copper. The highest zinc content was determined in MG-2 and copper in MG-11. But these values in zinc and copper are significantly lower than those of the 21 selected sorghum landraces of Tigray, Northern Ethiopia reported by Semere et al. [38].

Table 9: Variances analyses of the micronutrients of the lines

Lines	Mineral constituents			
	Calcium (mg/100g)	Iron (mg/100g)	Zinc (mg/100g)	Copper (mg/100g)
MG-2	12,25 ^b	5,70 ^e	6,35^f	0,60 ^d
MG-7	11,29 ^a	4,59 ^a	6,05^e	0,00 ^a
MG-9	12,66 ^c	4,71 ^b	4,73 ^a	0,45 ^b
MG-11	18,47^f	5,25 ^c	4,84 ^b	0,82^e
MG-14	16,88^e	5,44 ^d	5,71 ^d	0,51 ^c
MG-17	15,75^d	9,29^f	5,45 ^c	0,59 ^d
	**	**	**	**

Values with same letters and in the same column are not significantly different according to the test of Student Newman-Keuls at 0.05. **: Highly Significant. Values in bold are the most important.

CONCLUSION

Chad is characterized by a multitude of cultivars of different speculations which are generally preserved *in situ* by the farmers. Sorghum is one of the crops whose richness in cultivars has been demonstrated through numerous research works. It is the most consumed cereal and one of the national priorities. In the present study, the lines of the sorghum landrace Mara Guisséïré are characterized by a low level of phenotypic diversity but by a significant variability in quantitative traits. At a nutritional level, each line has specific physicochemical components. The production of seeds of these lines will contribute to improving agricultural production after the procedures of their inclusion in the national catalogue. Their morphoagronomics traits and nutritional potential can be valued in agri-food fields and varietal improvement programs.

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