Original Research Article

Analysis of rainfed *Sorghum bicolor* (L.) Moench variabilities *(Njigaari and Mbayeeri)* ecotypes for their improvement and *Striga hermonthica* (Del.) Benth controls in the sudano-sahelian zone of Cameroun.

ABSTRACT

The agromorphological and genetic parameters of sorghum and their tolerance or resistance levels to the parasitic plant *Striga hermonthica* are key variables in rainfed sorghum production processes. To know the genetic diversity and agromorphological characteristics under striga infestation of this cereal in the Sudano-Sahelian zone of Cameroon, a survey near to 230 farmers followed by a collection of rainfed sorghum accessions was conducted in 2015 and 2016 in 16 villages of the 4 departments namely Mayo-Danay, Mayo-Kani, Mayo-Louti and Mayo-Rey. The field trials were conducted in Touboro from 2016 to 2017 with a split plot design and composed of 24 factors (accessions) in a naturally striga-infested plot. Results showed that sorghum ecotypes varied significantly ($P < .05$) in sorghum height, stem diameter, number of leaves, panicle weight and seed yield. Eight (8) genetic and agro-morphological diversity groups were defined from Principal Component Analysis (PCA) and Ascendant Hierarchical Classification (AHC). These groups are distinguished by the $r=0.988$ value of the similarity coefficient. Surveys resulted in 14 endogenous striga control techniques divided into three categories, namely cultural control, chemical control and biological control. The agro-morphological parameters that determine the choice of ecotype by the farmers were among others edaphic constraints, climatic constraints, pest pressure, taste quality, culinary uses, glume and grain colour, size and length of the ripening cycle which can be very early, early and late.

Keywords: *Rainfed sorghum, Ecotypes variability, Striga control, Sudano-Sahelian zone and Cameroon*.

1. INTRODUCTION

Sorghum bicolor (L.) Moench is a cereal that is the main food crop for millions of people in the semi-arid tropics [1]. In the tropics, sorghum is mainly grown for its grain primarily for human consumption [3]. In many parts of Africa, beers are made from the sprouted grain [2]. This drink is called 'bil bil' in North Cameroon or 'Tchapalo' in West Africa. Dolo, a traditional Sahelian drink not fermented by yeast and prepared from sorghum. The whole plant can be used [4]. Sorghum stalks are used to make sweet syrup, sorghum alcohol, considered in China [5]. The straw of this cereal is used for animal feed or as fuel or building material [6]. Perrot *et al.* (2005) in North Cameroon grouped local sorghum accessions into three categories, namely rainfed sorghum (*Njigaari* and *Mbayeeri*), intermediate types (*Baburi*) and off-season sorghum (*muskuwaari*). The *Njigaari* and *Mbayeeri* types are grown in the rainy season on sandy-clay or sandy-clay soils, sandy-silt or sandy-silt soils, in fallows, in grazed fallows. In addition, the *Mbayeeri* types, which are late rainfed sorghum, are also grown on flood-prone soils and are therefore resistant to flooding, whereas the *Njigaari* types can be very early and early and are sensitive to stagnant water during flood periods. In Cameroon sorghum production was estimated at 1.5 million tons in 2013. This low profitability is one of the causes of recurrent food insecurity in the northern region which leads to importation or food aid [8] & [9]. Several factors are at the origin of this yield decline, including biotic factors, in particular crop weeds and specifically Striga [10]; [11] & [13]. This species is a real scourge that inflicts considerable damage to several cereal crops causing a significant decrease in their yield, on average 70 to 90% or even 100% for sorghum [14] & [15]. This infestation is all the more accentuated in poor soil [16]. Several control methods against Striga have been used, including chemical control, cultural control and biological control but with limited success [44]. Sorghum varieties resistant to *Striga hermonthica* have been studied, namely S35, CS54 and Défé Gala [6]. This poor yield is also explained by the lack of knowledge on the agro-morphological and genetic characteristics of sorghum ecotypes and the lack of technical knowledge and the ability of varieties to resist or tolerate striga. Some local ecotypes are much more resistant than others to this pest that fails to attach to their roots [17].

This study describes the agro-morphological and genetic characteristics of 24 local rainfed sorghum accessions in the Sudano-Sahelian zone of Cameroon and their ability to resist or tolerate the striga parasite.

2. MATERIAL AND METHODS

2.1. Plant material

It consisted of 24 accessions of rainfed sorghum widely cultivated by farmers in the Departments of Mayo-Danay, Mayo-Kani, Mayo-Louti and Mayo-Rey in the Sudano-Sahelian zone of Cameroon and the *Striga hermonthica* Plant. These sorghum ecotypes were designated by vernacular names and codified according the name of the collecting village and subdivision. The size, the development cycle of the plant and an order number were affected to ecotypes, namely S35, GD-CPP01 (*Panaré*), GD-MT02 (*Ngabouri 1*), GD-LT03 (*Tchokloum Nenhouli*), GD-MP04 (*Konen bi bolé*), GD-CPP05(*Gara Koulou*), GD-MPP06 (*Choré Gueré*), GDO-MP07 (*Aré Gaoyang*), KW-MPP08 (Raïna), KW-CP09 (Aré Wirjin), HW-MPP10 (Gueling Hougno), SD-CPP11 (*Gara Koulou*), ZD-CPP12 (*Panaré Mbango*), YD-CPP13 (*Gara Gueden*), GCD-CP14 (*Aré Made Tabai*), TO-MPP15 (*Gueling Saotchai*), LMO-MPP16 (*Njigaari Lebri 1*), LMO-CP17 (*Njigaari Lebri 2*), LMO-LT18 (*Mbayeeri 1*), LMO-LT19 (*Mbayeeri 2*), LMO-LT20 (*Mbayeeri 3*), LMO-LT21 (*Mbayeeri 4*), LMO-LT22 (*Mbayeeri 5*), and LMO-LT23 (*Mbayeeri 6*).

2.2. Ethnoagricultural surveys

Surveys on endogenous methods of control of *Striga hermonthica*

Ethnoagricultural surveys of farmers on traditional methods of controlling *S. hermonthica* were conducted in 16 villages randomly selected in four departments according to the importance of sorghum cultivation, the prevalence of *S. hermonthica,* and the relative ease of access, as well as the absence of scientific work on striga in the area. A total of 230 farmers from about 200 randomly selected households were interviewed. The respondents were selected on the basis of their ability to farm, especially sorghum, and included young people, women, men and the elderly. The questions used were pre-structured and individual interviews. These structured interviews are composed of closed and open questions. Generally, these farmers were met either at home, sitting under a tree in front of their compound, or in the field at harvest time, or even at the well drawing water, or at the local market selling sorghum, or at the bil bil pot. These surveys focused on farmers' methods of controlling *Striga hermonthica* and sorghum ecotypes were collected if possible at the same time.

2.3. Experimental site

The experiments were conducted from 2016 to 2017 in Touboro subdivision, Division of Mayo Rey in the Northern Region located between 13°34' and 12°07' East Longitude and 7°21' and 15°01' North Latitude. This part of Cameroon belongs to the transitional Sudano-Sahelian agro-ecological zone between Adamaoua (Sudano-Guinean type) and the Far North (Sudano-Sahelian type). Touboro is located at an altitude of 524 m between 15°22' East longitude and 7°46' North latitude, at 400 km from south-east of the Benue Division. The average annual rainfall is 1280 mm. The climate is tropical with two seasons: the rainy season (June to October) and the dry season (November to May). The average annual temperature is 26°C [18]. The soil is ferruginous on sandstone, sandy to sandy-clay and is poor in organic matter [19]. This area was chosen because of the importance of sorghum cultivation and the prevalence of striga. The main activities are agriculture and cattle breeding. Agriculture is practised mainly by the indigenous farmers Mboum and Laka, as well as migrant farmers from the Far North region, particularly the Toupouri, Mafa and Mofou.

A split plot design with 24 main treatments (sorghum accessions) and one secondary treatment (striga infestation) with four replications was used. A total area of 400m² (10m×40m) was considered. The spacing between stands was 0.3m and 0.5m between rows. Shrubs and twigs in the field were artificially cut by hand two weeks before sowing. The trials were sown in June (2016) and May (2017), at the beginning of the rainy seasons. Five seeds were placed at a depth of 3 to 4 cm in the seed hole. A first manual weeding took place 14 days after sowing (DAS) and the removal of 2 plants per seed hole was done 15 days after emergence. Manual weeding was carried out on all plots on weeds at an interval of two weeks except for striga.

2.4. Evaluation of the parameters studied on sorghum

The heading dates of the sorghum accessions were taken. The date of heading was the date at which the panicles of 50% of the sorghum plants of an accession started to appear. The height of the sorghum plants was taken. This is the measurement of the height of 4 plants in the central clusters, randomly selected in each replication.

The stem diameter of sorghum plants was taken using a decameter. This measurement was calculated by the following formula:

Stem diameter = Stem circumference / π

The number of leaves of the sorghum accession was counted. This is the number of leaves of 4 plants randomly selected from the central patches in each of the four replications. This count was done one week before harvest. All leaves of the sorghum plant from the bottom to the panicle stalk were counted. Susceptibility to mildew, lodging (ability to stand or not) and bird pressure were recorded.

2.5. Evaluation of yield components

At the end of the development cycle, sorghum panicles were harvested, dried, weighed and threshed. Four panicles from one accession were randomly selected from each experimental unit. They were weighed after sun-drying using a digital precision balance.

Afterwards the panicles were weighed, they were threshed resulting in a pile of seeds per panicle, so the seed weight per panicle was also taken. This measurement was made after mechanical threshing. It was taken in grams and then evaluated in kg/ha to express the seed yield.

2.6. Genetic and statistical analyses

2.6.1. Statistical analyses

The data collected during the surveys and trials were processed and analysed at the biodiversity and sustainable development laboratory of the University of Ngaoundéré. All data were subjected to descriptive statistical analysis using Excel 2007. The data on quantitative traits were then subjected to a Principal Component Analysis (PCA), followed by a Hierarchical Ascending Classification (HAC) with XLSTAT 2007 software for the morphological characterisation of sorghum accessions.

2.6.2. Genetic analysis

The description of the accessions was done on the basis of surveys collected from farmers in the cultivation area and characterized from qualitative and quantitative traits of sorghum accessions obtained during field trials and which were described by ICRISAT [20] & [7]. The panicles of the sorghum accessions described below are all borne by a straight peduncle (port).

3. RESULTS AND DISCUSSIONS

3.1. Analysis of the variability of sorghum

The analysis of the rainfed sorghum diversity was based on the Hierarchical Ascending Classification (HAC) of five quantitative variables. Eight different groups with different characteristics of sorghum accessions were formed. This analysis underlines an important discrimination between the eight groups defined by the distances between the ecotype parameters. The Principal Component Analysis (PCA) has allowed the determining of the affinities between the ecotypes around the quantitative variables. A very high affinity was found between the accessions GD-MPP06, LMO-LT18, LMO-LT20, LMO-LT21, LMO-LT22 and ZD-CPP12 according to the panicle weight variables and grain weight per panicle, whereas this affinity was low between the accessions GD-CPP01, GD-CPP05, KW-CP09, KW-MPP08, SD-CPP11 and YD-CPP13 for the same variables (Fig. 1)

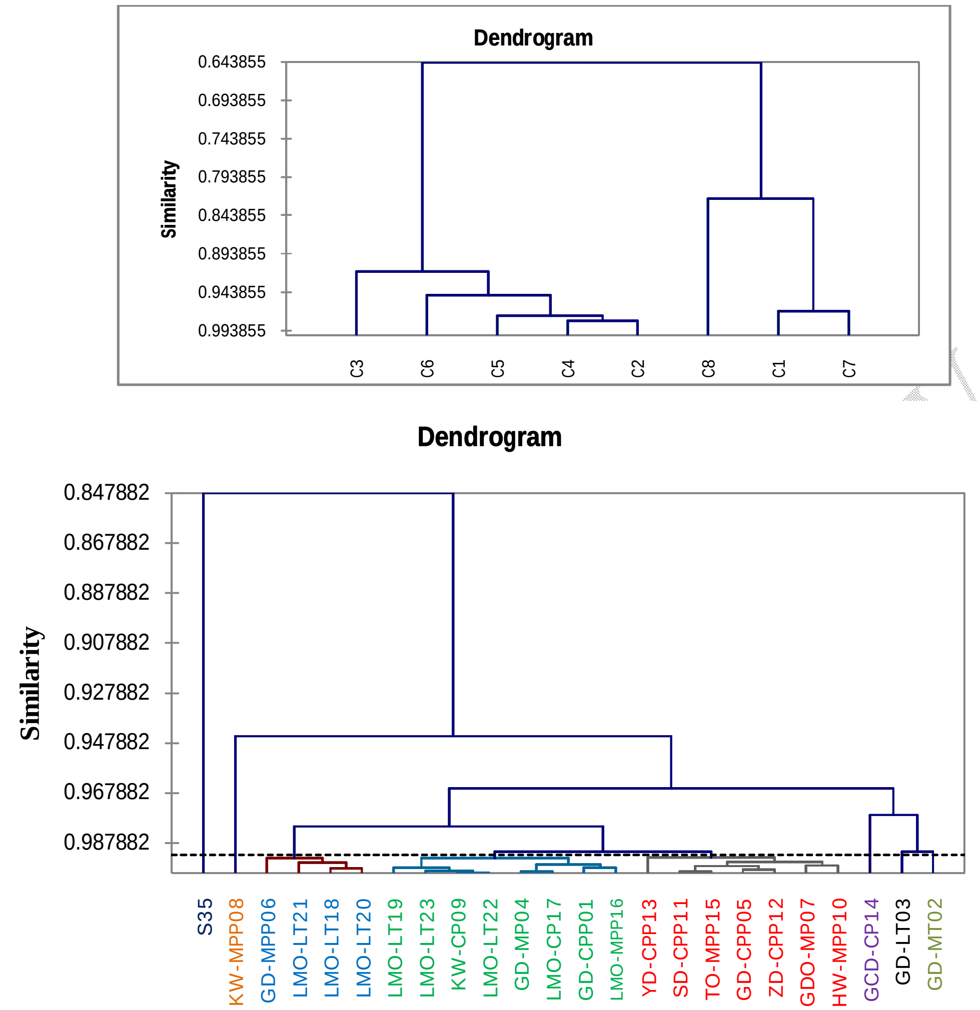

Figure 1: Dendrogram from the Ascending Hierarchical Classification (HHC) of sorghum ecotypes

On the other hand, GD-LT03, GD-MT02, GD-MP07, LMO-LT19 and LMO-LT23 are very strongly related to each other according to the sorghum plant height variables, number of leaves and stem diameter in opposite to GD-CP14, GD-MP04, HW-MPP10, LMO-MPP16, LMO-CP17, TO-MPP15 and S35 accessions which are weakly related to these same variables (Fig. 2).

To examine the grain yield performance and stability status of the genotypes and select the best genotype for variety release for commercial use in Ethiopia, principal components analysis (PCA) was used by Admas & Tesfaye, (2017) via the Additive Main and Multiplicative Interaction model.

Similar results have been reported by Abdou *et al.* (2015) in Niger on 15 onions ecotypes that differ in morphological and agronomic variables.

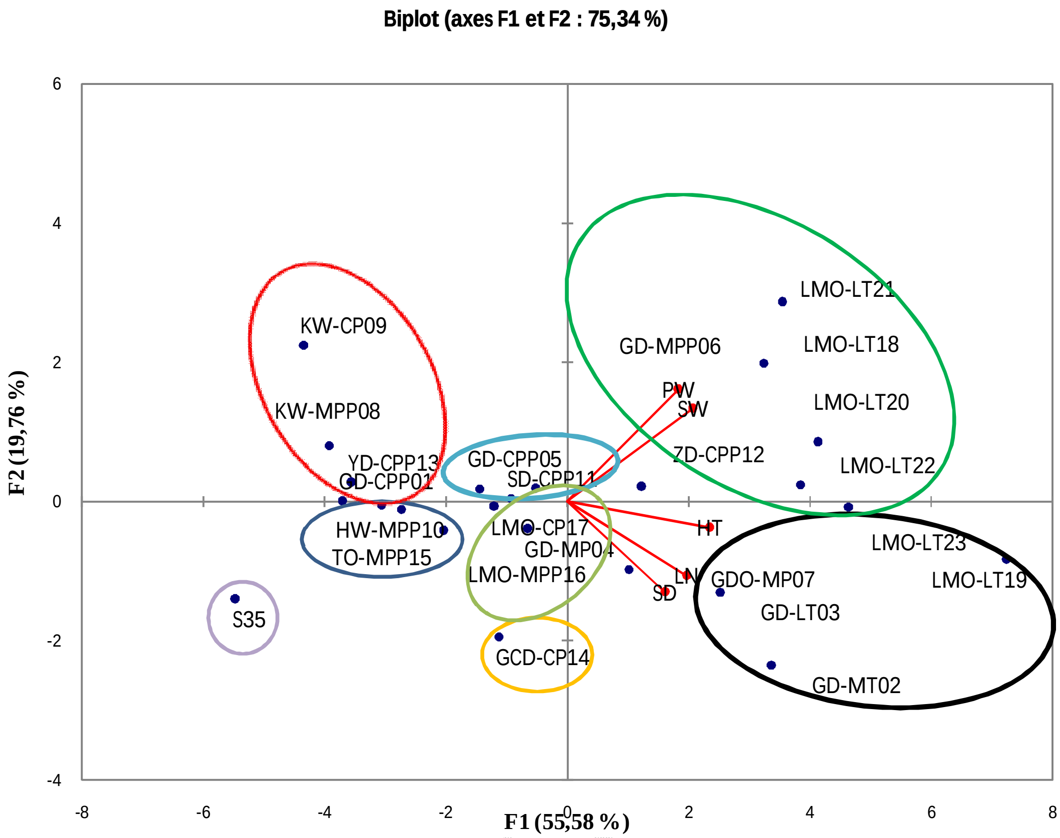

Figure 2: Principal Component Analysis of affinity to quantitative parameters

PW = Panicle weight; **SW** = Seed weight; **HT** = Height; **LN** = Leaves number; **SD** = Stem diameter

It can be seen in Table 2 that all linear correlations are positive, which means that all variables vary, on average, in the same direction. There are strong correlations between panicle weight and grain weight per panicle (0.89) and between sorghum height and number of leaves per plant (0.76). They are average correlations between the stem diameter and the number of leaves per plant (0.61); between heights and stem diameter (0.56), between height and panicle weight (0.53), between height and grain weight per panicle (0.66). Other correlations are rather weak, ranging from 0.37 to 0.16 between the other sorghum traits.

Similar correlations were noted by Arunkumar, (2013) in Karnataka-India between genotypic and phenotypic characters of sorghum namely days to 50% flowering with ear head breadth (0.605) and fodder yield/plant (0.846) at genotypic and with fodder yield/plant (0.729) at phenotypic level. Seed set % had positive correlation with grain yield per hectare (0.705 and 0.615) at both genotypic and phenotypic levels. Ear head length and Ear head breadth (0.529), Test weight (0.512) is positively associated with grain yield per hectare at genotypic level.

Agronomic parameters such as days 50% flowering, plant Height, ear head length, ear head breadth, seed set percent (%), test weight in grams, grain yield/plant, fodder yield/plant and grain yield/Ha were noted in India (Karnataka) to analyse genetic variability of Sorghum [23].

Table 1: Pearson correlation matrix between discriminant quantitative traits of sorghum

Variables	HT (m)	SD (cm)	LN	PW	SW
HT	**1**				
SD	**0.568**	**1**			
LN	**0.762**	**0.612**	**1**		
PW	**0.533**	0.193	0.336	**1**	
SW	**0.661**	0.301	0.373	**0.890**	**1**

Values in bold are the significant coefficients of correlation at 5%.
PW = Panicle weight; **SW** = Seed weight; **HT** = Height; **LN** = Leaves number; **SD** = Stem diameter.

Sorghum accessions ecotypes vary significantly (P > .05) according to the resistance to striga (number of emerged striga) and the sorghum tolerance to the same parasite (sorghum seed weight) (Table 2). The number of emerged striga vary from 8.8 (KW-CP09) to 60.9 (LMO-CP17) and the sorghum panicle seed weight vary from 9g (HW-MPP10) to 44.58g (LMO-LT20). Some varieties show a high tolerance towards the pest, which allows them to tolerate its presence without their yield being affected too much.

A striga-resistant variety is one that has the capacity to promote less striga development and better yield in a striga-infested environment [12]. Some local sorghum varieties are known to be more resistant to striga than others. In a striga-infested environment, a tolerant variety has a better yield than a susceptible one [24].

Three genotypes of sorghum were used in South Africa (Ujiba landrace, PAN8816 and Macia) to evaluate Water Productivity of sorghum under rainfed conditions and strong correlations were noted between phenological parameters and Water Productivity [25].

Table 2: Tolerance and resistance of sorghum ecotypes after testing

Accessions	(Nu. Str)	Resistance	(SW in g)	Tolerance
HW-MPP10	19.4^{defg}	More resistance	9^{h}	Weak tolerance
TO-MPP15	11.1^{gh}	Average resistance	10.78^{gh}	More tolerance
GD-CPP05	21.9^{def}	More resistance	10.88^{gh}	More tolerance
YD-CPP13	14.35^{fgh}	More resistance	11.13^{gh}	More tolerance

S35	**12.4^{gh}**	**More resistance**	**11.9^{fgh}**	**More tolerance**
GD-CP14	43.65^{bc}	Weak resistance	12.13^{fgh}	More tolerance
LMO-MPP16	24.85^{de}	More resistance	12.48^{fgh}	More tolerance
GDO-MP07	11.7^{gh}	Average resistance	15.75^{efgh}	Average tolerance
LMO-LT21	11.6^{gh}	Average resistance	15.9^{efgh}	Average tolerance
GD-CPP01	16.6^{efg}	More resistance	16.3^{efg}	Average tolerance
GD-MP04	27.4^{d}	Weak resistance	16.85^{efg}	Average tolerance
LMO-CP17	60.9^{a}	Weak resistance	17.33^{defg}	Average tolerance
GD-MPP06	18.3^{defg}	More resistance	17.5^{defg}	Average tolerance
GD-MT02	51.25^{b}	Weak resistance	17.7^{defg}	Average tolerance
SD-CPP11	14.75^{fgh}	More resistance	18.78^{cdef}	Average tolerance
KW-MPP08	18.65^{defg}	More resistance	20.4^{cde}	Average tolerance
KW-CP09	8.8^{h}	Most resistance	20.55^{cde}	Average tolerance
ZD-CPP12	52.6^{ab}	Weak resistance	21.7^{cde}	Average tolerance
GD-LT03	37.9^{c}	Weak resistance	24.43^{cd}	Average tolerance
LMO-LT22	24.5^{de}	More resistance	25.25^{c}	Average tolerance
LMO-LT23	11.8^{gh}	Average resistance	33.35^{b}	Most tolerance
LMO-LT19	21.55^{def}	More resistance	36.08^{b}	Most tolerance
LMO-LT18	9.6^{h}	Most resistance	38.85^{ab}	Most tolerance
LMO-LT20	26.3^{d}	Weak resistance	44.58^{a}	Most tolerance

Nu. Str = Number of striga; **SW** = Seed weight

Values followed by the same letter in a column are not significantly different at 5%.

3.2. Morphogenetic characterization of germoplasm

The dendrogram based on the means of five quantitative traits (number of leaves, stem diameter, height, panicle weight and seed weight per panicle) identified eight groups of agro-morphological diversity within the 24 sorghum accessions (Fig. 1 and 2). These groups are distinguished by the r=0.988 value of the similarity coefficient. Accessions GD-MPP06, LMO-LT18, LMO-LT20, LMO-LT21 belong to one group; accessions GD-MP04, GD-CPP01, KW-CP09, LMO-MPP16, LMO-CP17, LMO-LT19, LMO-LT22 and LMO-LT23 also belong to another; The other group includes accessions GD-CPP05, GD-MP07, HW-MPP10, SD-CPP11, TO-MPP15, YD-CPP13 and ZD-CPP12. However, the ecotypes GD-CP14, KW-MPP08, GD-LT03, GD-MT02 and the variety S-35 differ from the other ecotypes and from each other.

Perrot *et al*. (2005) identified 45 local accessions of off-season transplanted sorghum (muskuwaari) in Northern Cameroon. These researchers grouped the sorghum accessions into three categories, namely rainfed sorghum (*Njigaari* and *Mbayeeri*), intermediate types (*Baburi*) and off-season transplanted sorghum or flood accession sorghum (*Muskuwaari*). Upadhyaya *et al*. (2017) in West and Central Africa recorded 8020 sorghum accessions of which Cameroon alone recorded 2569 accessions of genus of sorghum.

In northern Cameroon and in the large flooded areas of Lake Chad, there has long been a transplanted crop of flood recession sorghum. Given the type of soil they occupy and their cropping cycle, they are divided into two groups: the Muskwari, which are durra or durra-caudatum, and the Babouri, which are durra-caudatum.

3.3. Qualitative typology of accessions

All the sorghum accessions studied have a straight panicle (stalk) habit. Table 3 presents the agro-morphological parameters characterising sorghum accessions and which often determine their choice by farmers. These parameters are of various nature namely edaphic, climatic constraints, pest pressure, taste quality, glume colour, grain colour and culinary uses [20]. These same parameters were defined by Perrot *et al.* (2005) to study the biodiversity and food use of muskuwaari sorghum in northern Cameroon.

3.4. Phenological characterizations of sorghum accessions

The heading dates (Fig.3) allow a phenological characterisation of the cultivars. These dates were taken according to the number of days after sowing (DAS). They vary from 50 to 130 days after sowing within the sorghum accessions. After determining the heading dates, the earliness of the accessions was established and structured into four groups very early accessions with a heading date between 50 and 59 days after sowing (GCD-CP14, GD-MP04, LMO-CP17, KW-CP09 and the variety S35) early accessions (60 and 70 DAS): GD-CPP01, GD-CPP05, ZD-CPP12, SD-CPP11, YD-CPP13, GDO-MP07, HW-MPP10, LMO-MPP16, TO-MPP15, KW-MPP08 and GD-MPP06. Only the accessions GD-LT03 and GD-MT02 are semi-late with a heading date between 100 and 110 days. The other accessions, namely LMO-LT18, LMO-LT19, LMO-LT20, LMO-LT21, LMO-LT22, LMO-LT23 with a heading date between 111 and 130 DAS are late.

Similar results were reported by Verdier, (2015) resulting in four earliness groups namely very early accessions, early and semi-early accessions, semi-late and late accessions.

Yehouenou (1997) showed that striga does not affect the flowering of sorghum, which depends mainly on the sowing date, given that these are light-sensitive varieties that flower at a specific date during the season. From the seven cultivars he studied, flowering dates ranged from 90 to 132 from the date of sowing (DAS).

Bazile *et al*. (2003) showed that sorghum is considered as short-day plant (or nyctiperiodic) and will only flower if the photoperiod is below of certain value, called the critical photoperiod. These researchers also found that, whatever the sowing date, sorghum varieties will flower at a relatively fixed date, which allows grain ripening to take place at the beginning of the dry season. Consequently, earlier is the sowing, the longer is the vegetative cycle. Depending on the sowing date, the same photoperiodic variety will have a cycle varying from 90 to 160 days. The farmer can be sure that his varieties will reach maturity at the end of the rainy season, even if they encounter water constraints at the beginning of the season.

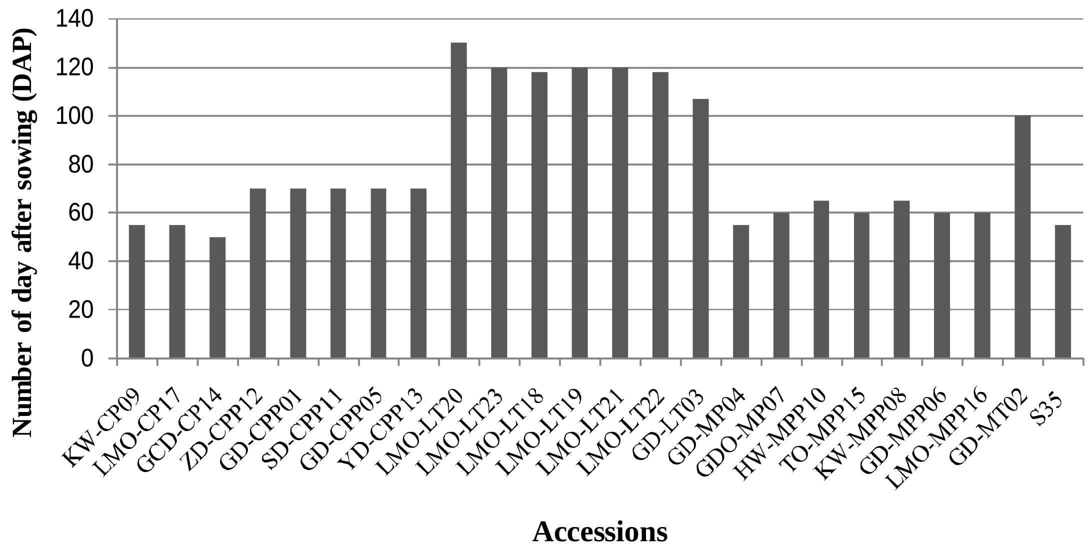

Figure 3: Heading dates according to genotypes

3.5. Agro morphological description of sorghum accessions

The degree of resistance, tolerance and confirmation of the results of the sorghum accessions surveys were established after the analyses of the field trial data reported in Table 1.

3.5.1. GD-CPP01 accession (*Panaré ma ti yondon*)

This accession harvested in Golonhobé, Datcheka district (GD) is locally called *'Panaré ma ti yondon'* by the farmers (panicle shaped like a woman's udder and slightly rounded). It requires very fertile soil, is fairly tolerant and moderately resistant to striga. However, it has a high yield when the soil is fertile. The short stems are wind resistant and therefore facilitate manual harvesting. It is a short-heihgt ecotype and has a semi-early cycle (CPP). It has a compact flattened round panicle that bears brown glumes and reddish seeds.

3.5.2. GD-MT02 accession *(Ngabouri)*

This is a fairly tolerant accession with low resistance (very susceptible to striga) according to the Toupouri farmers who found this accession among the Peuhl, hence its name in Fulfulde 'Ngabouri'. It is adapted to floodable soils with a very low prevalence of striga. It is a medium-sized accession with a semi-late cycle (MT). The semi-compact spindle-shaped panicle is crowned with reddish glumes on which are carried the light yellow seeds that are hard to grind by hand.

3.5.3. GD-LT03 accession *(Tchokloum nenhouli)*

This is a fairly tolerant late genotype with low resistance to striga, adapted to flooded soils, which is why it is called *'Tchokloum'*. Spikelets completely cover the seeds and thus protect them from granivorous birds, hence the name *'nenhouli'*. It is a long-lived accession with a semi-late development cycle (LT). The creamy-white seeds on creamy-white glumes are hard and weevil resistant. The loose spindle-shaped panicle bears whorled tufts.

3.5.4. GD-MP04 accession *(Konen bi bolé)*

This accession is productive even on degraded soils or sandy loam soils and is tolerant to striga. It was collected in the village Golonhobé in Datcheka subdivision. Its name Toupouri *'Konen bi bolé'* results from its earliness and means: 'Ecotype that looks into the granary'. So the women say that when this accession sees that the provisions are finished in the granary (often in August and September), it ripens. It is a medium-height accession with a very early cycle (MP). The flattened, semi-compact spindle-shaped panicle ends in whorled terminal spikelets. The purplish colored seeds are inserted in blackish glumes. It is a fairly striga tolerant sorghum accession but with low resistance.

3.5.5. GD-CPP05 accession *(Red Koulou Gara)*

It is referred to by farmers as 'semi-early rainfed sorghum', hence its designation *'Gara koulou'* in Toupouri. This ecotype is short in stature and has a semi-early development cycle (CPP). It is a moderately tolerant and striga resistant accession and is not wind resistant. It has a semi-compact spindle-shaped panicle that bears glumes and reddish seeds.

3.5.6. GD-MPP06 accession *(Gueré Tchoré)*

Like the previous accessions, *'Tchoré gueré',* which means twin millet in Toupouri, was collected at Golonhobé in the Datcheka subdivision. It is a double-seeded accession, hence its name by the farmers. It is fairly tolerant and moderately resistant to striga and has a good yield even on impoverished soils often invaded by this parasite. But the mature ears are very sensitive to rain and the seeds can easily leave the husks when shaken. It has a medium height and has semi-early development cycle sorghum (MPP). Its loose flattened oval panicle with whorled spikelets supports black glumes containing whitish seeds.

3.5.7. GDO-MP07 accession *(Aré gaoyang)*

"Aré' which means early in Toupouri, *Aré gaoyang* was collected in Gaoyang village in Doukoula subdivision, hence the initial of its name code 'GDO'. It is a medium height and early (MP) accession. It is fairly tolerant and resistant to striga and can grow well on impoverished soil and even on sandy loam soils. The whitish seeds are borne on black glumes and are hard to mill by hand and resistant to weevils, but the mature ears are very much affected by rain which quickly causes them to germinate on the field. It has a semi-compact spindle-shaped panicle.

3.5.8. KW-MPP08 accession *(Raina)*

It is called 'KW' because it was harvested in Kourbi in Wina subdivision of by the Massa people, from which it takes its name *'Raïna'*, meaning seeds that fall very easily to the touch'. The seeds of this accession are highly appreciated by farmers for their taste and are therefore good for couscous and porridge. The white seeds are not firmly fused to the black hulls and leave them easily on mechanical contact, making it easy to remove the seeds from fresh ears and even for manual threshing. The stems, which are very sensitive to late season wind, are topped by a loose, slightly flattened spindle-shaped panicle with whorled terminal spikelets. This accession has a medium height and a semi-early development cycle (MPP). It is fairly tolerant and moderately resistant to striga and is highly sought after by granivorous birds.

3.5.9. KW-CP09 accession *(Aré wirjin)*

This ecotype is resistant and fairly tolerant to striga and has short stems with a very early development cycle (CP). It was collected at Kourbi in the Wina subdivision (KW). It is undemanding to fertile soil and matures often at 90 days after sowing when living conditions are favorable. The stems bear a loose flattened oval panicle with whorled spikelets. The seeds are red in color and fused to brown glumes and are less appreciated by farmers for their taste.

3.5.10. HW-MPP10 accession *(Gueling hougno)*

This ecotype, collected at Hougno in Wina subdivision (HW), has medium- stems that are sensitive to tornado winds and a semi-early development cycle. It is moderately resistant and has low tolerance to striga and grows best in clay soils according to farmers. The white tinted seeds are very susceptible to mould when the mature ears are in contact with high relative humidity. The panicle is spindle-shaped and semi-compact and is covered with brown glumes.

3.5.11. SD-CPP11 accession *(White Koulou Gara)*

It is referred to by the Toupouri farmers of Saddiele in Datcheka subdivision (SD) as 'semi-early rainfed sorghum', hence its designation *'Gara koulou'*. This ecotype has a short stature and a semi-early development cycle (CPP). It is a fairly tolerant and moderately resistant accession to striga and favors sandy loam soils. The panicle is spindle-shaped and semi-compact. The whitish seeds on blackish glumes are susceptible to mould in contact with high relative humidity.

3.5.12. ZD-CPP12 accession *(Panaré mbango)*

This accession is susceptible to striga (low resistance) and fairly tolerant. It requires very fertile soil. It has a high yield when grown on nutrient rich soil. It was harvested in Zouaye in Datcheka subdivision (ZD). It is called *'Panaré mbango'* in Toupouri (a panicle shaped like the udder of young women and found in the south of Doukoula subdivision). This short-pruned accession facilitates manual harvesting and has a semi-early development cycle (CPP). The reddish seeds welded to the brown glumes are articulated on a compact fusiform panicle.

3.5.13. YD-CPP13 accession *(Gara gueden)*

The Toupouri farmers of Youaye at Datcheka subdivision (YD) call this accession *'Gara gueden'* which means 'very short rainfed sorghum'. It is a very short stature accession that has a semi-early development cycle (CPP). It has a medium tolerance and resistance to pests and requires fertile soil. When the right conditions are met, this accession gives a good yield. The semi-compact spindle-shaped panicle is slightly flattened and surmounts a straight stalk. The reddish seeds covered by blackish glumes are much sought after by women for making the local beer (bil bil).

3.5.14. GCD-CP14 accession *(Aré ma de Tabaï)*

Very early sorghum with brown seeds *(Aré ma de tabaï)* is the name of this accession given by the Toupouri of Goloncheon in Datcheka subdivision (GCD). It is an ecotype of medium tolerance and low resistance to striga and often matures before striga flowering. It is productive even on poor soils. The brown seeds are less appreciated by farmers and even birds because of its bitterness. This ecotype has a short height and a very early development cycle (CP). The panicle of this accession is spindle-shaped and semi-compact and covered with reddish glumes.

3.5.15. TO-MPP15 accession *(Gueling saotchai)*

This accession was harvested in Touloum in Porhi subdivision (TO). This sorghum was first brought to the Toupouri zone in Saotchai, hence the name *'Gueling saotchai'*. It is a medium-sized genotype with a semi-early development cycle (MPP). It is moderately tolerant and fairly resistant to striga and gives good yields even on poor soils. The greyish colored seeds, firmly attached to the blackish glumes, are weevil resistant and much sought after by women for making bil bil wine. The panicle is spindle-shaped and loose.

3.5.16. LMO-MPP16 accession *(Njigaari lebri 1)*

This is a Fulfulde rainfed sorghum (*Njigaari*) accession that was collected in Mayo-Lebri, hence its name *"Njigaari lebri"* in Mayo-Oulo subdivision (LMO). It is a moderately tolerant and moderately resistant accession to striga, susceptible to flooded soils and lodging. It has medium height and a semi-early cycle (MPP). It is cultivated in this zone by the indigenous Guidar and Guiziga people and migrants from the Far North, particularly the Toupouri, Massa and Mandara. It has a semi-compact spindle-shaped panicle. The dark red seeds are attached to reddish glumes.

3.5.17. LMO-CP17 accession *(Njigaari lebri 2)*

This accession has the same spatial and cultural characteristics as the previous one. In addition, this genotype has a medium height and has an early development cycle. It is a fairly tolerant accession with low resistance to striga and has a loose flattened fusiform panicle with whorled spikelets. The brown colored glumes contain reddish seeds.

3.5.18. LMO-LT18 accession *(Dark yellow Mbayeeri)*

According to the surveys, its name *'Mbayeeri'* in Fulfulde means 'rainfed sorghum with a late development cycle'. All *'Mbayeeri'* accessions were collected in Mayo-Lebri in the Mayo-Oulo subdivision (LMO) from the Guidar and Guiziga people. All these accessions have long height and have a late development cycle (LT). They are mostly fairly resistant and fairly tolerant to striga and yield well under favorable conditions. They bear loose spindle-shaped panicles. They are highly adapted to flooded soils and are however grown on marshy edges. The stems of these ecotypes are often used as hut stubble because of their strength, and the seeds are also very hard and weevil resistant, giving a better emergence rate. All of the above characteristics are found in the *'Mbayeeri'* accessions below. Differences are observed in seed color, glumes and only slightly encountered in panicle shape. The seeds of the dark yellow 'LMO-LT18' ecotype are borne on blackish glumes. This accession of 'Mbayeeri' is the only accession that is both resistant and tolerant to striga.

3.5.19. LMO-LT19 accession *(Mbayeeri with light red grains)*

In addition to the characteristics of the above 'Mbayeeri' varieties, this accession bears light red seeds on brown glumes. It is tolerant and moderately resistant to striga.

3.5.20. LMO-LT20 accession *(White Mbayeeri with yellow glume)*

In this ecotype, the whitish seeds are set on yellowish glumes carried by a semi-compact fusiform panicle. It is a tolerant ecotype with low resistance to *Striga hermonthica*.

3.5.21. LMO-LT21 accession *(White Mbayeeri with black glume)*

Fairly tolerant and fairly resistant to striga, this ecotype is often very productive. The white seeds are borne on blackish glumes.

3.5.22. LMO-LT22 accession *(White Mbayeeri with brown glume)*

Its particularity lies in the color of the husk, which is brown, and in the whitish seeds on the husks. It often has a good yield and has a medium level of resistance and tolerance to striga.

3.5.23. LMO-LT23 accession *(Red Mbayeeri)*

It is characterised by a high yield. The brown husks bear reddish seeds that are widely used by women to prepare bil bil wine. It is tolerant and fairly resistant to striga.

3.5.24. S-35 Variety

It is a sorghum variety improved and characterised by the Agronomic Institut of Research for the Development (IRAD). It is a moderately resistant and moderately tolerant variety to *Striga hermonthica* which was used in this study as a reference variety (Table 1). It has an average yield, very fragile seeds and is very susceptible to weevils. It is also noted that this variety has a very early development cycle, a straight peduncle, a semi-compact fusiform panicle, yellow glumes and creamy white seeds.

In Cameroon, on the basis of the shape of the stalk, the shape of the panicle and grain characteristics, six major traditional types of sorghum are recognised among the Muskwari and two major types among the Babouri, which are more homogeneous [29]. According to Comas & Gómez (2001), the diversity of flood accession sorghums is great in terms of adaptation to different cropping systems (transplanted or non-replanted crops, cold or hot dry season crops etc.). It is also important in terms of panicle shape and grain type (color, vitrosity, glume coverage, etc.).

Aboubakar, (2002) has shown that *njiigari* (red and white sorghum) are varieties of sorghum grown in the rainy season in sablo-clay and limono-clay soils.

Table 3: Qualitative Characterisation of Sorghum Accessions

Accessions	Attitude to wind	Mustiness sensitivity	Bird pressure	panicle compactness	panicle form	Colour of chaff	Colour of seed	Edaphics need
GCD-CP14	S	S	S	loose	fusiform	brown	Red-dark	weak
GD-CPP01	R	R	S	compact	Round-flat	brown	red	high
GD-CPP05	S	R	S	semi-compact	lanceolate	red	red	higher
GD-LT03	S	VR	R	loose	Wordled tuft	white-cream	White-cream	higher
GD-MP04	R	S	VS	loose	Lanceolate-flat	black	purple	weak
GD-MPP06	R	R	S	loose	oval-flat	black	white	weak
GD-MT02	VR	VS	VR	loose	lanceolate	red	Yellow-light	higher
GDO-MP07	R	R	VS	loose	lanceolate	black	white	weak
HW-MPP10	R	VS	S	semi-compact	lanceolate	brown	White-tinted	high
KW-CP09	S	R	S	Very loose	oval- flat	brown	red	weak
KW-MPP08	VS	R	VS	loose	lanceolate-flat	black	white	higher
LMO-CP17	S	R	S	Very loose	lanceolate	brown	red	weak
LMO-LT18	R	VR	R	loose	lanceolate	black	yellow-dark	higher
LMO-LT19	VR	VR	R	loose	lanceolate	yellow	white	higher
LMO-LT20	R	VR	R	loose	lanceolate	black	white	higher
LMO-LT21	VR	VR	R	loose	lanceolate	brown	white	higher
LMO-LT22	VR	VR	R	loose	lanceolate	brown	red	higher
LMO-LT23	R	VR	R	loose	lanceolate	brown	Red-light	higher
LMO-MPP16	VS	R	S	loose	lanceolate	red	red-dark	higher
SD-CPP11	S	S	S	semi-compact	fusiform	black	white	higher
TO-MPP15	R	R	S	loose	lanceolate	black	grey	weak
YD-CPP13	R	R	S	loose	Lanceolate-flat	black	red	high
ZD-CPP12	R	R	S	compact	fusiform	brown	red	high
S35	S	S	TR	loose	fusiform	yellow	white-cream	weak

R = Resistant; S = Sensitive; VR = Very Resistant; VS = Very Sensitive.

3.6. Endogenous control strategies for *Striga hermonthica*

Participatory surveys of 230 farmers in 16 villages in the Sudano-Sahelian zone of Cameroon revealed that 14 endogenous methods of controlling *Striga hermonthica* are used (Table 4). More than 80% of the farmers interviewed felt that the presence of striga was mainly associated with soil infertility. In addition, 9.13% of the farmers surveyed did not know of any control methods for striga. The farmers take into account their effectiveness and the possibilities of implementation. The comparison of the percentages shows a significant difference between the endogenous methods of controlling *S. hermonthica.* Generally, farmers combine several control methods, especially when they are less costly.

The main strategies applied by sorghum farmers are: use of compost or manure (23.05%), fertilisation of plots with chemical fertilisers (21.74%), crop rotation (13.04%), spreading of natron (10.87%), practice of grazed fallow (10.43%), crop association (6.09%), spreading of ash or rock salt (6.09%). Other endogenous methods, in particular the use of early sorghum varieties or those resistant to striga, the use of ant-hill or termite mound soils, fertilisation with leaf powder of certain woody species, the use of tolerant varieties and finally the manual uprooting of striga seedlings, are little practised by the farmers.

Twelve striga control methods have been characterized by Oswald, (2005) in Kenya namely Crop-rotation, Intercropping, Soil fertility-organic, Soil fertility-inorganic, Managed fallow, Hand-weeding, Genetic resistance, Chemical control, Biological control, Transplanting, Catch-cropping and Seed-dressing.

3.6.1. Prevention

The best efficient method of striga control is to prevent its emergence. Farmers keep domestic animals often oxen and sheep for a few days, a week or more; then move them from one place to another in the field for the grazed fallow either in the rainy season or in the dry season so that they leave their excrement there. When the rainy season arrives, these plots are sown and the striga cannot emerge. Other farmers put down in their field organic manure for the fertilization to prevent striga emergence.

3.6.2. Cultural control

- **Organic fertilization**

Organic fertilisation appears to be the main method used by farmers to control striga. This method includes compost made by farmers from organic debris, and manure obtained from animal dung (cattle and goats). Organic fertilisers are spread in the field preferably before sowing. Farmers believe that organic fertilisation is quite effective in controlling striga and is inexpensive. However, it is more practiced by agro-pastoralists.

Esilaba *et al,* (2004) determined that nitrogen is a determining factor and its appropriate application can result in 4 times more sorghum biomass and 4 times less *S. hermonthica* biomass. In addition, nitrogen fertilisation causes rapid growth of the host, which is thus more likely to resist the pest. Weber *et al*. (1995) showed that the usual use of organic matter for soil fertilisation by farmers in the Nigerian savannah is very effective in reducing the emergence of striga

Crop rotation

This consists of growing a non-host species that causes suicidal germination of striga (cotton) or a nitrogen-fixing species that fertilises the soil (groundnut) one year or two before planting sorghum in that field. The rotations generally practiced are: cotton-sorghum, groundnut-sorghum and cotton-arachid-sorghum.

Akanvou *et al*. (2002) have shown that crop rotation, crop association, manual weeding and the use of chemical or organic fertilisers are the most widely applied methods. Similarly Hess & Dodo, (2004) state that mixed cropping of millet and sesame practiced in West Africa shows that striga infestation is reduced when sown together in the same plantation.

- **Spreading mineral substances (natron, ash, rock salt)**

This method is widely used by farmers as a direct method. It consists of either mixing sorghum seeds lightly with white natron powder and sowing them; or spreading the natron powder behind the young sorghum plants a little before and at the beginning of striga emergence. This method is very effective and less costly but only overdosing can prevent the seeds from germinating.

Rock salt and ash are either spread on the field a few days before sowing or directly behind the sorghum seedlings a little before and during striga emergence. Thus slash-and-burn is not a sustainable method for development. Sodium carbonate salt was been used in northern Cameroon by farmers to reduce striga emergence [45].

- **Practice of grazed fallow and simple fallow**

This method consists of keeping domestic animals, often oxen and sheep, for a few days, a week or more; then moving them from one place to another in the field for grazing fallow in either the rainy or dry seasons so that they can leave their excrement. When the seasons come, these plots are sown. As for the simple fallow, the duration can go from one year to two years or more to let the field rest without cultivation and without animals before putting sorghum on it. On the other hand, the lack of land poses a problem because in recent decades, the areas have become increasingly populated, especially in the Far North of Cameroon, causing the migration of farmers from this region to the North and Adamaoua. They cannot leave the land to rest because they will not have enough to eat. Olivier, 1995 found that striga is absent in long fallows (8 to 10 years) and natural environments.

- **Use of ant hill, termite mound and clay soil**

It consists of spreading these different soils on the land before sowing or by transplanting the sorghum seedlings onto the land amended with clay soil, or directly near the anthill or termite mound. This method gives a very good yield.

- **Use of foliar powder**

Woody species such as *Entada africana, Senna singueana, Afzelia africana, Prosopis africana, Acacia albida* and other shrubs are used after making a powder of their leaves to control striga either mixed with sorghum seeds or spread in the field before sowing or spread directly behind sorghum seedlings before striga emergence. Noubissié *et al,* 2012 showed that a mixture of leaf powders of the leguminous trees *Entanda africana, Acacia albida* and *Prosopis Africana*, applied at 10cm depth in the soil at a rate of 12t/ha decreased striga emergence by 31.5% and host damage by 20.47% and on the other hand increased sorghum height by 22.36% and grain yield by 23.25%. Olivier, (1995) showed that *Parkia biglobosa* pod powder is used by the Burkinabe for the reduction of striga seed germination.

- **Manual harvesting**

This involves cutting or pulling out striga plants from the soil or surface either during hoeing or ploughing or manually with the hands. This is a very limited method as it often occurs during the time when striga has already done its underground work at the roots of young sorghum plants and therefore has no happy ending. Thalouarn & Fer, (1993) have shown that this method is beneficial but not effective in reducing striga as it only prevents the reproduction of emerged striga.

3.6.3. **chemical control** (Use of chemical fertilizers or herbicides)

Some chemicals such as herbicides (Roundup or glyphosate, atrazine, gramazone) and mineral fertilisers (NPK, urea and foliar fertilisers) are used by farmers to fertilise the fields and to control *S. hermonthica.* Farmers believe that mineral fertilisation is very effective in controlling striga but the cost of fertilisers is high.

Olivier (1995) shows that chemical fertilisers and appropriate herbicides are quite effective, but not very accessible to poor farmers. Maximum grain yield (3725kg/ha) was obtained from application of 15 g /ha Chlorsulfron with variety Deber in Ethiopia [37]. The application of 2 g of sodium carbonate per pot was the optimal rate to control Striga hermonthica and improve the main agro-morphological parameters of sorghum with 78.27% increase in g of kernel yield and simultaneously inhibited striga infestation by 98.62% [38]. In northern Cameroon, efforts are being made to improve soil fertility to cope with parasitic weeds and to improve sorghum yields [39].

Ahonsi *et al*. (2004) in Nigeria found that the use of herbicide (nicosulfuron) and application of NPK fertilizer at 90kg/ha reduced striga emergence by 80%.

3.6.4. Biological control

This method consists either in cultivating crop varieties that can cohabit in the same field (polyculture), namely: sorghum-fallow, sorghum-cucumber, sorghum-arachid, sorghum-liana (Urena). It is also worth noting the association of sorghum with certain nitrogen-fixing plant species such as *Crotalaria retusa* to cope with striga. This last method was popularised by SODECOTON and has been questioned by farmers because, they say, interspecific competition for light, water and certain nutrients considerably reduces sorghum yield. Ramahiah, (1991) showed that combining crops, setting up trials combining nitrogen fertilisation, hand-pulling and crop rotation gives good results. A combination of the bacterial strains *Azospirillum brasilense* and *Pseudomonas putida; A. brasilense* and *Azomonas spp; Azotobacter vienlandi* and *Bradyrhizobium japonicum; A. brasilense* and *Azomonas spp.* inhibited germination by 18 to 34% in comparison to the corresponding control in Ethiopia [46].

3.6.5. Integrated control

This method is widely used by farmers as a direct method. It consists of either mixing the sorghum seeds lightly with white natron powder and sowing them; or spread the natron powder behind the sorghum seedlings a little before and at the beginning of the emergence of striga. This method is very effective and less expensive but only overdosing can prevent seeds from germinating.

This involves cutting or uprooting striga plants from the ground or above ground either during hoeing or plowing or by hand. This is a very limited method because it often occurs during the time when striga has already done its underground work at the level of the roots of young sorghum plants and therefore endlessly happy.

Integrated control had been used combining maize varieties, ammonium sulphate and chicken manure to enhance the performance of maize in infested Striga field [39]. The IR hybrids with ST yielded 3564 kg/ha of grain when coated with imazapyr and 3266 kg/ha otherwise. The findings indicate that coating of IR/ST maize seeds with imazapyr improved tolerance to witchweed [47].

Accessions namely TO-MPP15; KW-CP09; GD-CP14; GDO-MP07; GD-MP04 and LMO-CP17 are cultivated by farmers because of precocity and resistance.

3.6.6. Genetic control

- **Adoption of resistant, tolerant or early varieties**

The farmers' surveys revealed that accessions such as Mbayeeri in general (LMO-LT18; LMO-LT19; LMO-LT20; LMO-LT21; LMO-LT22; LMO-LT23 and GD-LT03) are cultivated because of their resistance to Striga hermonthica despite the late development cycle; while the accessions TO-MPP15; KW-CP09; GD-CP14; GDO-MP07; GD-MP04 and LMO-CP17 are grown by farmers because of earliness and resistance. Kenga *et al*. (2006) in northern Cameroon showed that the improved varieties S35 and CS54 are grown for reasons of drought and striga situations. Ramahiah & Parker, 1982 showed that some local ecotypes of the striga host are much more resistant than others to this parasite which fails to attach to their roots. These methods also include the use of resistant or tolerant varieties.

Perrot *et al.* (2005) showed that 70% of the muskuwaari varieties were adopted in the Far North zone for their hardiness and earliness, allowing them to adapt to unfavourable soil conditions. In addition, the same authors have shown that farmers have adopted a safraari-like variety called "armoured" for its drought resistance qualities on the hardé and that on land with prolonged flooding called "yaayre", farmers also use early varieties which are commercially interesting because they arrive early on the market and can be sold at a higher price before the harvest of other types of muskuwaari.

In Cameroon, sorghum varieties resistant to *Striga hermonthica* have been studied, namely S35, CS54 and Défé Gala [6].

Table 4: Endogenous methods of controlling *Striga hermonthica*

practiced Methods	Favorable responses (%)	Efficiency	Cost of work
Organic fertilization (manure, compost)	23.05^{a}	average	affordable
Chemical fertilization (urea, NPK) or herbicide	21.74^{a}	fairly high	high
Crop rotation (sorghum-peanut-cotton)	13.04^{b}	poor	very affordable
Natron Spreading	10.87^{b}	medium	very affordable
Grazed fallow	10.43^{b}	efficient	Fairly high
Association of cultures	6.09^{c}	medium	affordable
Ash spread	6.09^{c}	medium	affordable
Natural fallow (2 to 3 years)	4.78^{cd}	poor	affordable
Use of resistant varieties	4.78^{cd}	average	very affordable
Use of early varieties	3.91^{d}	poor	very affordable
Manual stripping of the striga	3.48^{d}	mediocre	very affordable
Spreading rock salt	2.17^{de}	average	affordable
Spreading of anthills or termite mounds	1.30^{e}	medium	affordable
Use of leaf powder (*E. africana, A. albida…*)	1.30^{e}	poor	affordable

Values followed by the same letter are not significantly different at the 5% threshold

4. CONCLUSIONS

The sorghum accessions studied have a major socio-economic and spatio-temporal importance for farmers in the Sudano-Sahelian zone of Cameroon. These investigations have enabled us to provide more precision on the agro-morphological and genetic characteristics of the ecotypes, namely: seed weight, heading date, tolerance and resistance to striga, plant size, susceptibility to bio-pests, etc. These accessions are distributed in eight different agro-morphological diversity groups with differential distances and affinities between and around the quantitative variables traits. The earliness of the accessions was established and structured into four groups: very early accessions with a heading date between 50 and 59 DAS; early accessions (60 and 70 DAS); semi-late accessions with a heading date between 100 and 110 DAS and late accessions with a heading date between 111 and 130 DAS.

Fourteen (14) main techniques to control the parasitic weed *Striga hermonthica* were used. Mainly the use of compost or manure (23.05%) fertilising plots with chemical fertilisers (21.74%), crop rotation (13.04%), spreading natron (10.87%), grazing fallow (10.43%), combining crops (6.09%), spreading ash or rock salt (6.09%). Only the accession LMO-LT18 is both resistant and tolerant to *S. hermonthica* while the accessions LMO-LT19, LMO-LT20 and LMO-LT23 are tolerant with very high grain weight per panicle but are fairly resistant for LMO-LT23, moderately resistant for LMO-LT19 and less resistant for LMO-LT20. As for the accession KW-CP09, it appears resistant to striga with a very low number of emergences but it is quite tolerant.

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