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Genotypic Response of *Sorghum bicolor* (L) Moench Landraces to Sodium Carbonate Application in Control of *Striga hermonthica* in the Sudano-Sahelian Zone of Cameroon

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Abstract: The parasitic weed *Striga hermonthica* poses a serious threat to sorghum production in Northern Cameroon. To evaluate the response to *S. hermonthica* of 24 genotypes of rainfed sorghum and the effect of sodium carbonate on this parasite, field and pot experiments were conducted at Touboro (North Cameroon) in 2016 and 2017. In pot and in field, under striga infestation, results showed varietal responses of sorghum for the number of emerged *Striga*, the height of sorghum, the stem diameter, the number of leaves per plant, the panicle weight and the grain yield. Globally, *Striga* infestation significantly reduced the height, the stem diameter, and the number of leaves, the panicle weight and the grain yield of sorghum accessions by 28.94%, 19.54%, 17.78%, 28.24% and 44.17% respectively. Application of natural sodium carbonate salt reduced significantly the emerged *Striga* and the host plant damage by 74.29% and 41.94%. Under *Striga* infestation, sodium carbonate also increased the growth and yield sorghum accessions. Among the 24 studied genotypes, complete resistance was no recorded, but landraces LMO-LT18, LMO-LT22, KW-CP09 and LMT-21 appeared as the most resistant and tolerant to *S. hermonthica*. Combination of sodium carbonate with resistant and tolerant genotypes should be investigated as a major component of integrated packages to the effective control of *Striga* on sorghum in northern Cameroon.

Keywords: Sudano-Sahelian zone; *Sorghum bicolor*; *Striga hermonthica*; sodium carbonate, varietal resistance.

INTRODUCTION

Sorghum, *Sorghum bicolor* (L.) Moench is a cereal and forage grass of tropical origin. It is the 5th most dry cereal widely grown in the world and the second most important cereal crop after maize in sub-Saharan Africa [1]. It is the main food crop of millions of people in the semi-arid tropics of Central Africa, West and Asia [2]. Sorghum constitutes the main staple food of the population in northern Cameroon. In fact, sorghum cultivation, like other cereals, is facing the harmful pressure of birds, diseases, pests, declining soil fertility, weeds and the hazards of rainfall. It is estimated that 50 million hectares and 300 million farmers in Sub-Saharan Africa are affected by the parasitic weed species *Striga hermonthica* [1] .Cereals are considered to be the most sensitive crops for infection by this weed. *Striga hermonthica* is the major biotic constraints to sorghum production, especially in the infertile semi-arid areas of Africa [2]. Depending on the variety and the degree of infestation, the damage can range from a small decrease in yield to a total failure of the crop [1, 3, 4]. A single *Striga* plant can produce up to 500 000 seeds that remain viable for long as 20 years [3]. Seeds remain dormant for several months, and will germinate when exposed to favorable moisture and temperature for several days (preconditioning) and only in the presence of germination stimulant exuded by the hosts [3]. In North Cameroon, sorghum yield losses due to *Striga* were estimated at 40% on average [5]. Because of this significant economic damage and the fact that it can cause famine and poverty for farmers and the people, effective control of *Striga* and good management are respectively imperative not only to maximize the yield of sorghum but also to improve the socio-economic well-being of the population [6]. According to Parker [7], problems with *Striga* are generally caused by low economic resources, poor soil fertility, newly infested areas due to unclean sowing material, and continuous cropping of host plants. Control programs against *Striga* had four main objectives: prevent *Striga* to enter the fields, reduce the seed bank in the soil, prevent *Striga* to reproduce and reduce crop losses. Several *Striga* control methods have been used, including hand-weeding, soil fertility improvement, rotation or intermediate farming, chemical control to biological approach and cultural control methods but with limited success [7]. The *S.*

hermonthica problem may be too widespread and too severe to control using single approach [1, 7].

In northern Cameroon, some farmers mentioned the use of mineral fertilizers or organic manure, herbicides and host plant resistance as keys methods of controlling *Striga* on cereals [5, 7, 8].Some farmers also use the application of sodium carbonate decahydrate (Na_2CO_3, $10H_2O$) salt locally named 'natron' or '*kilbou*' to control *Striga hermonthica* on cereal crops. Sodium carbonate, a white, crystalline and hygroscopic powder, can be produced from minerals and large deposits exist in Africa [8]. This salt is locally used as food additive for humans and cattle, for soaking, for medicine and for production of chemicals. Today, efforts are being made to mitigate the problem of parasitic weeds in striga infested soils through appropriate strategies as host plant resistance and improved soil fertility [9-11]. The abandonment of old native accessions to new high-producing varieties also benefits *Striga* [7]. In northern Cameroon, improved varieties S35 and CS54 have been widely promoted for their tolerance to *S. hermonthica* [9]. Numbers of resistant or tolerant varieties have been selected elsewhere andthe resistance mechanisms have been suggested [12-15]. These included low stimulant production, mechanical barriers to parasite ingress, chemical defense in which the crop plants produce chemical compounds that discouraging subsequent development of striga seedlings, and hypersensitivity where the host cells surrounding the endophytic part of the haustorium die and preclude further development of the parasite. Very little work in Northern Cameroon has been carried out on local accessions of sorghum to *Striga*. Most traditional cultivars of cereal crops sensitive to striga possess some kind of defense mechanism that limits yield reduction, most probably as result of selection in infested sites [16]. Hassan *et al.*, [13] noted that *Striga* germination was significantly decreased with NaCl solution. Jamil *et al.*, [17] showed that diammonium phosphate application reduced the production of strigalactones, the germination and the emergence of *Striga*, and increase by 47 to 142% the yield of three sorghum cultivars. The effects of salts on *S. hermonthica* emergence were also highlighted by Daffala *et al.*, [18] on sorghum and Osman *et al.*, [19] on maize. Al-Khateeb*et al.*, [20] observed that salinity reduced the germination of the seeds of parasitic plant *Orobanche cernua* on tomato. This study was therefore conducted to examine the response of 23 sorghum landraces for traits associated with resistance to *S. hermonthica*, and determine the effects of sodium carbonate salt on *Striga* incidence and sorghum yield.

MATERIALS AND METHODS

Plant materials

The materials used in this study consisted of the improved variety S35 released by the Institute of agricultural research for development (IRAD) and 23 rainfed sorghum landraces widely grown by farmers in Mayo Danay, Mayo Kani, Mayo Louti, Mayo Tsanaga and Mayo Rey divisions, namely: GD-CPP01 (*Panaré*), GD-MT02 (*Ngabouri 1*), GD-LT03 (*Tchokloum Nenhouli*), GD-MP04 (*Konen*), 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*).

Field Experiments

Field Experiments were conducted during the rainy season 2016 and 2017 at Touboro (North region of Cameroon, latitude: 07°46'N; longitude: 15 22'E; altitude: 788 m) in a farm early abandoned by sorghum farmers due to high *Striga* infestation. Touboro belongs to the Sudano-Sahelian agro-ecological zone with an average annual rainfall of 1280 mm recorded in the rainy season (June to October) [21]. The average annual temperature is 26°C and the soil is ferruginous on sandstone, sandy to sandy clay and, poor in organic matter [21]. Field trials were conducted on an experimental unit of 1200 m^2 (30 x 40 m). The experimental design was a split plot consisting of 24 sorghum genotypes (treatments), two sub-treatments (infested-*Striga* soil with sodium carbonate and control without salt) with four replications. Each experimental unit consisted of one row of 2 m long and 0.8 m wide (1.6 m^2). Rows and hills were spaced 0.5 m and 0.3 m respectively. Soil was artificially prepared two weeks before sowing. Sodium carbonate salt purchased on the local market was incorporated on the soil seven days before sorghum planting at the rate of 12g per 1.6 m^2corresponding 75 $kg.ha^{-1}$.Sorghum planting was carried out on 15 June and one year old *Striga* seeds were infested on the same day as, and prior to sorghum planting. Three grams of *Striga* seeds-sand mixture (2/98 g) was inoculated approximately 5 cm deep in each planting hole and the holes were covered with soils. Three sorghum seeds were planted per infested hill and later thinned to have one plant per hill at two weeks after planting. A first manual weeding took place 15 days after emergence (DAE) and regular manual weeding was carried out on all weeds at an interval of two weeks except *Striga*. Data were collected from the central part of each plot. *Striga* count was calculated per 1.6 m^2 corresponding to an experimental unit and the host plant damage was rated based on the scale of 1 to 9 (1: normal growth, no visible damage symptoms, to 9: severe damage or death) at 80 days after sowing [22-24]. Plant height, stem diameter and the number of leaves per plant were recorded at 70 DAS. Plant height (m) was measured from the soil surface to the tip of the main stem on ten plants randomly chosen. For yield parameters, panicles from the ten selected plants in each plot were harvested, sun dried, threshed, weighed, and kernels from each panicle were also weighed. The relative gain (RG) was calculated as:

$$RG = [(Ys - Yc) / Yc] \times 100$$

Where *Ys* is the average of plants of a specific genotype on plot with sodium carbonate and *Yc* is the observed values of plants grown under *Striga* infestation in control plot.

Pot experiments

Pot experiments were also conducted during 2016 and 2017 rainy season at Touboro. Pots were laid out in a split plot design with 24 varieties (treatments) and two sub-treatments (*Striga*-infected and control) with four replications. Each sorghum line was sown in twenty 12-l plastic pots of 20 cm in diameter filled with ferruginous topsoil collected from *Striga*-free area. One year old *Striga* seeds previously collected from sorghum fields were used for infestation. A 6 cm deep hole dug in each pot was infested by placing 5 g of sand-mixed *S. hermonthica* inoculums (2:98). Pots were watered to allow preconditioning of the *Striga* seeds. After one week, four sorghum seeds were sown into each hole and the plants were thinned to one per hill two weeks later. The pots were watering daily to prevent moisture deficit. At 80 DAE, data were collected on sorghum height, stem diameter, leaves per plant, panicle weight and grain yield per panicle. The random sample of ten plants was selected from each experimental unit. The relative loss due to striga (RL) was calculated as outlined by Rodenburg *et al.*, [24]:

$$RL = [(Yc - Ys) / Yc] \times 100$$

Where *Yc* is the average value of control plants of a specific genotype and Ys is the observed value of plants grown under *Striga* infestation

Statistical analysis

All data were subjected to descriptive statistics and analysis of variance (ANOVA) using computer program STAGRAPHICS Plus. When the F-test was significant at $p<0.05$ for a parameter, the differences among genotypes was tested by Least Significant Difference (LSD) at 5% level of probability. The significance of percentage was tested by t-test at 5% level of probability.

RESULTS

Analysis of variance

For the field trials, the analysis of variance (ANOVA) showed that the number of emerged *Striga*, the host damage score, the sorghum height, the number of leaves per plant, the sorghum stem diameter and sorghum grain yield were influenced significantly ($p<0.01$) by the genotypes, the sodium carbonate application and their interaction (Table-1). The replication effects were globally no significant. For all studied parameters, the investigated sorghum accessions showed specifically response under *Striga* infestation and salt application.

Table-1: F-values from analysis of variance of 24 sorghum genotypes tested in field under sodium carbonate salt application and *Striga* infestation

Source of variation	Df	Emerged *Striga*	Host damage	Sorghum height	Stem diameter	Number of leaves	Kernel yield
Genotype (G)	23	23.84**	25.09**	1.76**	1.29**	11.46**	19.98**
Salt application (S)	1	16.04**	14.82**	2.80**	2.13**	16.18**	38.25**
S×E interaction	23	14.94**	19.96**	2.28**	1.71**	13.82**	29.12**
Repetition	3	0.81ns	1.12 ns	0.32 ns	0.41 ns	1.01 ns	2.35 ns

**: Significant at $p<0.01$; ns: not significant; df: degree of freedom

Genotypic response of sorghum and effect of salt on *Striga hermonthica* in field

Analysis of variance for the number of emerged *Striga* at 80 DAE (Table 2) showed significant difference among genotypes ($p<0.01$) in field trials. The first emergence of *Striga* plant was recorded at 45 days after sowing (DAS) in control and at 60 DAS in soil treated with Na_2CO_3. On *Striga*-infested fields (control), the number of emerged *Striga* per 1.6 m^2 ranged from 8.8 (KW-CP09) to 60.9 (LMO-CP17). The accessions heavily infested by *S. hermonthica* were LMO-CP17, ZD-CPP1, GCD-CP14, GD-MT02 and GD-LT03 while those less infested than the reference variety S-35 were KW-CP09, LMO-LT18, LMO-LT21, LMO-LT22, GD-MP07 and TO-MPP15. On *Striga*-infested soils treated with sodium carbonate salt, the number of emerged *Striga* decreased significantly and ranged from 0.8 (LMO-LT18) to 24.95 (GD-MT02). Only two accessions GD-MT02 and GD-LT03 showed considerable number of parasites on soils treated with Na_2CO_3.The average number of emerged *Striga* was 23.84 in the control and 6.04 in plots saturated with Na_2CO_3. The reduction rate due to salt application varied with genotypes and ranged from 48.66% (GD-LTO3) to 92.69% (GCD-CP14).

Sorghum damage induced by *Striga*, as measured by the 1 to 9 scale was generally low for the tested genotypes (mean = 1.30) and varied in the control from 0.00 (LMO-LT22) to 4.88 (LMO-CP17) with a value of 0.88 to the reference check S-35(Table 2). Landraces LMO-T22, KW-MPP08, SD-CPP11, GD-

CPP01, LMO-LT18 and improved line S35 showed the lowest damage score. In the soil with sodium carbonate application, the damage decreased significantly, and the values ranged from 0.00 (LMO-LT22) to 4.38 (LMO-CP17). The reduction rate due to salt application was significantly noted on all tested genotype except GDO-MP07 and LMO-LT22, and ranged from 0.00% (LMO-LT22) to 100% (GD-CPP01 and SD-CPP11) with an average value of 41.94%.

Tabl-2: Effects of genotype and salt application on *Striga* emergence and on host damage score on sorghum grown in infested field

Accessions	Number of emerged *Striga* per 1.6 m^2			Host damage score		
	Control	Na_2CO_3	R (%)	Control	Na_2CO_3	R(%)
GCD-CP14	43.65^{bc}	3.40^{defghij}	92.69**	3.88^{b}	2.25^{e}	41.94**
GD-CPP01	16.66^{efgh}	5.44^{defghi}	60.93**	1.13^{ij}	0.00^{k}	100.00**
GD-CPP05	21.90^{def}	5.35^{defghij}	74.94**	2.38^{cde}	1.38^{g}	42.11**
GD-LT03	37.92^{c}	18.90^{b}	48.66**	2.38^{cde}	1.00^{h}	57.89**
GD-MP04	27.41^{d}	5.95^{defg}	78.76**	4.50^{a}	3.13^{c}	30.56*
GD-MPP06	18.30^{defg}	3.75^{defghij}	78.36**	2.25^{def}	1.00^{h}	55.56**
GD-MT02	51.25^{b}	24.95^{a}	52.01**	2.50^{cde}	1.63^{f}	35.00**
GDO-MP07	11.71^{gh}	4.15^{defghij}	64.97**	4.63^{a}	3.63^{b}	10.26ns
HW-MPP10	19.43^{def}	4.75^{defghij}	75.26**	2.13^{ef}	1.13^{h}	47.06**
KW-CP09	8.88^{h}	1.35^{ij}	79.55**	1. 38^{hi}	0.63^{i}	54.55**
KW-MPP08	18.65^{defg}	6.45^{defg}	65.46**	0.88^{jk}	0.25^{j}	71.43**
LMO-CP17	60.91^{a}	11.90^{c}	80.36**	4.88^{a}	4.38^{a}	41.33**
LMO-LT18	9.66^{gh}	0.83^{j}	92.0**	1.13^{ij}	0.38^{j}	66.67**
LMO-LT19	21.55^{def}	3.95^{defghij}	81.98**	2.13^{ef}	1.38^{g}	35.29*
LMO-LT20	26.33^{d}	7.22^{d}	73.22**	1.88^{fg}	1.10^{h}	21.62*
LMO-LT21	11.62^{gh}	2.12^{ghij}	81.76**	1.50^{ghi}	1.00^{h}	33.33**
LMO-LT22	11.88^{gh}	2.05^{ghij}	82.51**	0.00^{l}	0.00^{k}	0.00ns
LMO-LT23	24.54^{de}	6.75^{def}	71.73**	3.63^{b}	2.63^{d}	27.59*
LMO-MPP16	24.85^{de}	2.84^{efgij}	88.2**	2.75^{c}	1.63^{f}	40.91**
SD-CPP11	14.75^{fgh}	2.34^{fg}	82.88**	0.50^{k}	0.00^{k}	100.00**
TO-MPP15	11.12^{gh}	5.73^{defghi}	48.68**	1.38^{hi}	0.63^{i}	54.55**
YD-CPP13	14.35^{fgh}	4.25^{defghij}	70.68**	2.63^{cd}	1.38^{g}	47.62**
ZD-CPP12	52.60^{ab}	6.95^{de}	86.82**	1.63^{gh}	0.38^{j}	76.92**
S35	12.42^{gh}	3.65^{defghij}	70.66**	0.88^{jk}	0.38^{j}	47.49**
Mean	**23.84**	**6.04**	**74.29**	**2.20**	**1.30**	**41.94**
LSD 5%	**9.12**	**4.55**		**0.43**	**0.21**	

R (%): Per cent reduction of *Striga* emergence or host damage score due to sodium carbonate application; Values followed by the same letter in a column are not significantly different at p<.0.05;**: Significant at p<0.01;*: Significant at p< 0.05; ns: not significant; LSD: Least significant difference at p<.0.05

Effects of striga infestation on sorghum growth

Sorghum growth, as indicated by stem diameter, plant height and number of leaves per plant was significantly (p<0.01) affected by genotype, salt application and their interaction (Table 3). Sorghum height varied from 1.07 m (YD-CPP13) to 2.97 m (LMO-LT23) in control, and oscillated between 1.65 m (KW-CP09) and 4.38 m (LMO-LT20) in salt-treated soil .The average height was 1.76 m in control and 2.81 m in Na_2CO_3 treatment. Gain of sorghum height due to salt application ranged from 11.71% (LMO-LT18) to 178.66% (LMO-LT20) with an average gain of 59.38%. The effects of sodium carbonate were important on genotypes less infected by *striga* namely LMO-LT18, KW-MPP08, GCD-MP04, GDO-MP07, GCD-MP04, S35 and LMO-LT22.The stem diameter of sorghum plants varied from 0.72 cm (KW-MPP08) to 1.80 cm (LMO-LT23) in control (mean = 1.29 cm), and from 9.93% (LMO-MPP16) to 163.21% (LMO-LT19) in salt-treated soil (mean = 2.13cm). Gain rate for stem diameter ranged from 9.93% (LMO-MPP16) to 163.21% (LMO-LT19) (average =.65.12%).

The mean number of leaves per plant was 11.46 in the control and 16.18 in the soil saturated with Na_2CO_3 showing a relative gain of 41.19%. In *Striga*-infested plots, the number of leaves per plant varied from 5.00 (GD-CPP01) to 19.25 (LMO-LT20) while with Na_2CO_3, this value ranged from 8.30 (GCD-CP14) to 21.5 (LMO-LT18). The effects of salt application were not significant on genotypes LMO-LT23, TO-MPP15, YD-CPP13, GD-LT03, LMO-CP17, LMO-LT20 and S35.

Table-3: Plant height, stem diameter and number of leaves per plant of 24 sorghum genotypes under sodium carbonate application and *Striga* infestation in field

Genotype	Height (m)			Stem diameter (cm)			Numberof leaves		
	Control	Na_2CO_3	RG (%)	Control	Na_2CO_3	RG (%)	Control	Na_2CO_3	RG (%)
GCD-CP14	1.45^{fg}	1.78^{ij}	22.76*	1.35^{cde}	2.33^{cdefg}	72.59**	6.25^{mn}	8.30^{l}	32.80*
GD-CPP01	1.31^{h}	1.84^{hij}	41.00**	0.92^{hi}	1.79^{jkl}	94.57**	5.00^{n}	11.25^{jk}	125.00**
GD-CPP05	1.32^{gh}	3.55^{b}	168.56**	1.27^{efg}	2.28^{defgh}	79.53**	7.76^{jk}	14.61^{hi}	88.27**
GD-LT03	2.17^{bc}	3.57^{b}	64.52**	1.41^{cde}	2.56^{abcde}	81.56**	14.50^{d}	15.75^{e}	8.62^{ns}
GD-MP04	1.63^{efg}	2.23^{fgh}	36.81**	1.51^{bcde}	2.35^{bcdef}	55.63**	8.03^{j}	10.50^{jk}	30.76*
GD-MPP06	1.57^{efg}	2.76^{cde}	76.36**	1.59^{abc}	2.68^{abc}	68.55**	9.32^{i}	11.75^{j}	26.07*
GD-MT02	2.36^{bc}	3.53^{b}	49.89**	1.47^{bcde}	2.64^{abcd}	79.59**	17.54^{b}	20.50^{ab}	16.88*
GDO-MP07	2.46^{b}	3.06^{c}	24.44*	1.58^{abcd}	1.89^{ijk}	19.62*	10.5^{gh}	18.55^{de}	76.67**
HW-MPP10	1.41^{fg}	2.57^{def}	82.56**	1.07^{fgh}	2.40^{bcdef}	124.30**	12.66^{e}	17.75^{e}	40.21**
KW-CP09	1.44^{fg}	1.65^{j}	14.63*	1.04^{fgh}	1.85^{jk}	77.88**	7.13^{k}	19.25^{cd}	169.99**
KW-MPP08	2.07^{cd}	2.52^{def}	21.50*	0.72^{i}	1.26^{m}	75.00**	10.75^{g}	18.75^{cde}	74.42**
LMO-CP17	1.57^{efg}	2.07^{ghi}	31.53*	1.55^{abcd}	1.97^{ghij}	27.10*	10.00^{ghi}	10.50^{jk}	5.00^{ns}
LMO-LT18	1.50^{fg}	1.67^{ij}	11.71^{ns}	1.31^{def}	2.23^{efghi}	70.23**	9.50^{i}	21.50^{a}	126.32**
LMO-LT19	1.84^{de}	4.35^{a}	136.78**	1.06^{fgh}	2.79^{a}	163.21**	8.25^{i}	20.25^{ab}	145.45**
LMO-LT20	1.57^{efg}	4.38^{a}	178.66**	0.96^{hi}	1.93^{hij}	101.04**	19.25^{a}	20.50^{ab}	6.49^{ns}
LMO-LT21	2.79^{a}	4.36^{a}	56.55**	1.47^{bcde}	2.40^{bcdef}	63.27**	9.25^{i}	18.75^{cde}	102.70**
LMO-LT22	2.97^{a}	4.17^{a}	40.40**	1.03^{gh}	2.71^{ab}	163.11**	13.76^{d}	16.40^{fg}	19.19*
LMO-LT23	2.08^{cd}	4.05^{a}	94.71**	1.80^{a}	2.13^{fghij}	18.33*	19.00^{a}	17.50^{ef}	0.00^{ns}
LMO-MPP16	1.66^{ef}	2.36^{efg}	41.87**	1.41^{cde}	1.55^{klm}	9.93^{ns}	9.25^{i}	17.75^{e}	91.89**
SD-CPP11	1.56^{efg}	2.62^{def}	67.63**	1.04^{fgh}	2.14^{fghij}	105.77**	11.75^{g}	18.00^{de}	53.19**
TO-MPP15	1.56^{efg}	2.04^{ghij}	30.87**	1.41^{cde}	1.78^{jkl}	26.24*	18.75^{a}	18.25^{de}	0.00^{ns}
YD-CPP13	1.07^{h}	1.71^{ij}	59.81**	1.50^{bcde}	1.83^{jk}	22.00*	9.75^{hi}	10. 00^{k}	2.56^{ns}
ZD-CPP12	1.72^{ef}	2.83^{cd}	64.72**	1.70^{ab}	2.11^{fghij}	24.12*	10.5^{gh}	13.75^{i}	30.95*
S35	1.27^{h}	1.73^{ij}	36.22**	0.86^{hi}	1.43^{lm}	66.28**	16.66^{c}	18.25^{de}	9.54^{ns}
Mean	**1.76**	**2.81**	**59.38**	**1.29**	**2.13**	**65.12**	**11.46**	**16.18**	**41.19**
LSD 5%	**0.31**	**0.41**		**0.27**	**0.36**		**0.87**	**1.32**	/

Values followed by the same letter in a column are not significantly different at 5%. *, ** and ns: significant at $p<0.05$) and $p<0.01$); ns: not significant respectively.Na_2CO_3: Infested soils treated by sodium carbonate; LSD: Least significant difference; RL: Relative gain due to sodium carbonate

In pots experiments, the difference observed between sorghum genotypes for height, stem diameter and the number of leaves in infected pots (IS) and uninfected pots (NIS) showed that *S. hermonthica* influenced negatively plant growth parameters, especially on sensitive accessions (Table 4). Losses from *Striga* infestation to growth parameters of sorghum were in the range of 1.51 to 45.56% (mean = 28.94%) for the height, 0 to 50.59% (mean = 19.54%) for stem diameter, 0 to 36.84% (mean = 17.78%) for the number of leaves per plant respectively. The lowest reduction for sorghum growth parameters was noted on genotypes LMO-LT18, LMO-LT21, and GDO-MP07.

Effects of striga infestation on sorghum yield

In field trials, sorghum yield components varied according to genotype, sodium carbonate application and their interaction (Table-4). Panicle weight varied from 18.60g (GCD-CP14) to 75.73g (LMO-LT18) in control (mean = 40.56g). All sorghum accessions have a panicle weight value greater than that of the improved line S-35 (33.74g). The maximum values were on plots treated with sodium carbonate salt for LMO-LT18, LMO-LT18, LMO-LT20 and LMO-LT22, and LMO-LT23 ecotypes showed the greatest values for panicle weight. Salt application improved panicle weight by 4.72% (LMO-CP17) to 279.97% (YD-CPP13). Depending on genotype, the salt had less positive effect on the weight of the GD-LT03, GD-MT02 and LMO-CP17 accessions comparing to GD-MP04, KW-CP09, HW-MPP10, ZD-CPP12 and YD-CPP13 accessions.

The weight of kernel per panicle was 19.98g in infested soils and 38.25g in infested soils treated with sodium carbonate, showing an average yield gain of 91.44%. In the control, the kernel weight fluctuated between 9g (HW-MPP10) and 44.58g (LMO-LT20). In soil that received salt application, this variable ranged from 18.48g (S-35) to 67.55g (LMO-LT20). The application of salt increased the grain weight from 3.58% (KW-MPP08) to 247% (HW-MPP10).

Table-4: Effects of *Striga* infestation on the height, neck diameter and number of leaves of 24 sorghum genotypes in pots

Accessions	Sorghum height (m)			Stem diameter (cm)			Number of leaves per plant		
	NIS	IS	RL (%)	NIS	IS	RL (%)	NIS	IS	RL (%)
GCD-CP14	1.69^{gh}	1.29^{i}	23.96**	1.74^{bcde}	1.51^{cde}	13.22**	10.0^{hi}	8.0^{h}	20.00**
GD-CPP01	1.50^{i}	1.32^{ghi}	12.33**	1.34^{de}	0.89^{ghi}	33.58**	11.0^{fg}	8.0^{h}	27.27**
GD-CPP05	1.85^{g}	1.46^{g}	21.35**	1.66^{cde}	0.76^{i}	54.22**	8.5^{j}	7.0^{i}	17.65**
GD-LT03	3.00^{de}	2.35^{d}	21.70**	1.35^{de}	1.75^{bcd}	0.00^{ns}	16.5^{d}	12.0^{d}	27.27**
GD-MP04	1.59^{hi}	1.36^{ghi}	14.47**	1.70^{bcde}	0.84^{hi}	50.59**	9.5^{i}	9.0^{fg}	5.26^{ns}
GD-MPP06	1.82^{g}	1.24^{ij}	31.87**	1.53^{de}	1.39^{defgh}	9.15*	9.5^{i}	9.0^{fg}	5.26^{ns}
GD-MT02	2.48^{f}	1.35^{ghi}	45.56**	2.71^{a}	2.07^{ab}	23.62**	18.0^{c}	13.0^{c}	27.78**
GDO-MP07	1.66^{gh}	1.64^{f}	1.51^{ns}	1.69^{bcde}	1.27^{defghi}	24.85**	10.0^{hi}	8.5^{gh}	15.00**
HW-MPP10	1.51^{i}	1.45^{g}	4.30^{ns}	1.93^{bcde}	1.18^{efghi}	38.86**	10.5^{gh}	9.0^{fg}	14.29**
KW-CP09	1.40^{i}	1.18^{j}	16.07**	2.02^{abcd}	1.74^{bcd}	13.86**	11.5^{f}	8.5^{h}	26.09**
KW-MPP08	1.52^{i}	1.30^{hi}	14.19**	1.32^{de}	0.94^{fghi}	28.79**	8.0^{j}	8.0^{h}	0.00^{ns}
LMO-CP17	1.53^{hi}	1.34^{ghi}	12.13**	1.42^{de}	1.15^{efghi}	19.01**	11.0^{fg}	8.5^{gh}	22.73**
LMO-LT18	3.08^{d}	2.93^{b}	4.72^{ns}	1.43^{de}	1.50^{cde}	0.00^{ns}	21.0^{a}	16.5^{a}	21.43**
LMO-LT19	3.37^{c}	2.79^{b}	17.09**	2.31^{abc}	2.04^{abc}	11.69**	18.0^{c}	13.5^{c}	25.00**
LMO-LT20	3.75^{b}	2.84^{b}	24.40**	2.39^{ab}	2.07^{ab}	13.39**	18.5^{c}	15.5^{b}	16.22**
LMO-LT21	2.83^{e}	2.55^{c}	9.73ns	1.91^{bcde}	2.45^{a}	0.00^{ns}	19.5^{b}	17.5^{a}	10.26**
LMO-LT22	4.30^{a}	3.15^{a}	26.74**	1.27^{e}	1.18^{efghi}	7.09*	10.0^{hi}	8.0^{h}	20.00**
LMO-LT23	3.05^{de}	2.55^{c}	16.39**	1.67^{cde}	1.46^{def}	12.57**	17.0^{d}	15.0^{b}	11.76**
LMO-MPP16	1.75^{gh}	1.68^{ef}	4.29^{ns}	1.72^{bcde}	1.04^{efghi}	39.53**	9.5^{i}	6.0^{j}	36.84**
SD-CPP11	1.47^{i}	1.30^{hi}	11.26**	1.56^{de}	1.31^{defghi}	16.03**	10.0^{hi}	9.5^{f}	5.00*
TO-MPP15	1.52^{i}	1.30^{hi}	14.52**	1.77^{bcde}	1.15^{efghi}	35.03**	10.0^{hi}	9.0^{fg}	10.00**
YD-CPP13	1.41^{i}	1.12^{j}	20.28**	1.67^{cde}	1.35^{defgh}	19.16**	10.0^{hi}	9.0^{fg}	10.00**
ZD-CPP12	2.51^{f}	2.45^{cd}	2.20^{ns}	1.96^{bcde}	1.21^{defghi}	38.27**	10.5^{hi}	9.0^{fg}	14.29**
S35	1.57^{hi}	1.44^{gh}	7.99*	1.61^{cde}	1.40^{defg}	13.04**	13.0^{e}	10.5^{e}	19.23**
Mean	**2.54**	**1.81**	**28.94**	**1.74**	**1.40**	**19.54**	**12.54**	**10.31**	**17.78**
LSD 5%	**0.22**	**0.14**		**0.71**	**0.55**		**0.95**	**0.83**	

Values followed by the same letter in a column are not significantly different at 5%. *, ** and ns: significant at $p<0.05$, $p<0.01$ and not significant respectively. NIS: not infested by *Striga*; IS: infested by *Striga*; LSD: Least significant difference; RL: Relative loss due to *Striga*

Table-5: Effects of genotype and Na_2CO_3 on panicle weight, kernel weight and grain yield of sorghum under *Striga* infestation in field

Accessions	Panicle weight (g)			Grain yield per panicle (g)		
	Control	Na_2CO_3	RG (%)	Control	Na_2CO_3	RG (%)
GCD-CP14	18.60^{h}	42.75^{kl}	129.84**	12.13^{jk}	18.73^{m}	54.41**
GD-CPP01	29.55^{fg}	76.00^{hi}	157.19**	16.30^{hi}	41.40^{fg}	153.99**
GD-CPP05	42.92^{cde}	71.59^{i}	66.82**	10.88^{k}	34.05^{hi}	213.03**
GD-LT03	38.55^{def}	50.20^{jk}	30.22**	24.43^{de}	45.55^{def}	86.45**
GD-MP04	28.30^{gh}	98.25^{cde}	247.17**	16.85^{ghi}	32.18^{hij}	90.98**
GD-MPP06	39.19^{def}	71.83^{i}	83.27**	17.50^{ghi}	55.90^{b}	219.43*
GD-MT02	23.54^{gh}	85.53^{efgh}	263.32**	17.70^{ghi}	36.25^{gh}	104.80**
GDO-MP07	45.10^{cd}	83.13^{fghi}	84.31**	15.75^{ij}	29.68^{ijk}	88.44**
HW-MPP10	27.99^{gh}	90.70^{defg}	224.04**	9.00^{k}	31.23^{hijk}	247.00**
KW-CP09	44.87^{cd}	49.57^{jk}	10.48*	20.40^{efgh}	21.13^{lm}	3.58^{ns}
KW-MPP08	26.82^{gh}	75.32^{hi}	180.87**	20.55^{ef}	46.70^{de}	127.25**
LMO-CP17	55.90^{b}	58.54^{j}	4.72^{ns}	17.33^{gi}	31.85^{hij}	83.79**
LMO-LT18	75.73^{a}	120.20^{a}	58.73**	38.85^{b}	49.85^{cd}	28.31*
LMO-LT19	$51.20b^{c}$	91.37^{defg}	78.45**	36.08^{bc}	54.93^{bc}	52.25**
LMO-LT20	59.09^{b}	114.90^{ab}	94.45**	44.58^{a}	67.55^{a}	51.53**
LMO-LT21	55.22^{b}	103.47^{bcd}	87.39**	15.90^{ij}	46.23^{d}	190.75**
LMO-LT22	69.33^{a}	107.65^{abc}	55.28**	33.35^{c}	42.10^{ef}	26.24**
LMO-LT23	69.54^{a}	109.74^{abc}	57.81**	25.25^{d}	50.00^{cd}	98.02**
LMO-MPP16	26.48^{gh}	79.13^{ghi}	198.81**	12.48^{jk}	34.20^{hi}	174.04**

SD-CPP11	35.59^{def}	94.38^{def}	165.17**	18.78^{fghi}	27.73^{jk}	47.66**
TO-MPP15	25.16^{gh}	72.50^{i}	188.21**	10.78^{k}	26.25^{kl}	143.51**
YD-CPP13	24.64^{gh}	93.63^{def}	279.97**	11.13^{k}	29.88^{ijk}	168.46**
ZD-CPP12	34.64^{ef}	109.38^{abc}	215.75**	21.70^{def}	46.23^{d}	113.04**
S35	25.62^{gh}	33.74^{l}	31.69**	11.90^{k}	18.48^{m}	55.29**
Mean	**40.56**	**82.65**	**103.76**	**19.98**	**38.25**	**91.44**
LSD 5%	**9.83**	**12.93**		**4.13**	**5.23**	

Values followed by the same letter in a column are not significantly different at 5%. *, ** and ns: significant at $p < 0.05$, $p < 0.01$ and not significant respectively.Na_2CO_3: Infested soils treated by sodium carbonate; LSD: Least significant difference; RL: Relative gain due to sodium carbonate

In pots, analysis of yield parameters showed that *Striga*-infestation reduced the panicle weight (28.5%), and the kernel yield (44.17%) (Table-6). Among genotypes, the reduction ranged from 3.44% (LMO-LT22) to 58.61% (GD-LT03) for panicle weight, and from 20.05% (KW-MPP10) to 74.70% (LMO-LT19) for kernel weight per panicle. The reference variety S35 showed a reduction of panicle weight and kernel yield of 27% and 26.6% respectively.

Table-6: Effects of *Striga* infestation on panicle weight, panicle grain weight and grain yield of 24 sorghum accessions tested in pots

Genotype	Panicle weight (g)			kernel weight per panicle (g)		
	NIS	IS	RL(%)	NIS	IS	RL (%)
GCD-CP14	53.73^{f}	36.00^{g}	32.99**	15.92^{l}	10.91^{j}	31.45**
GD-CPP01	35.08^{hi}	20.3^{k}	41.90**	27.95^{fgh}	18.20^{ef}	34.88**
GD-CPP05	28.83^{ij}	23.90^{k}	17.09*	19.91^{jkl}	11.85^{j}	40.45**
GD-LT03	75.80^{d}	31.38^{hi}	58.61**	58.11^{c}	21.15^{cd}	63.60**
GD-MP04	67.65^{e}	41.99^{f}	37.93**	38.22^{e}	23.39^{bc}	38.77**
GD-MPP06	37.46^{h}	27.63^{j}	26.24*	17.72^{kl}	12.75^{ij}	27.97*
GD-MT02	91.10^{a}	63.68^{b}	30.10**	34.15^{ef}	22.30^{c}	34.70**
GDO-MP07	70.64^{de}	61.75^{bc}	12.58^{ns}	48.51^{d}	25.65^{b}	47.11**
HW-MPP10	67.23^{e}	57.36^{de}	14.68**	22.50^{ijk}	10.87^{j}	51.69**
KW-CP09	26.98^{i}	21.63^{k}	19.83*	21.00^{ijkl}	14.58^{hi}	30.57**
KW-MPP08	44.75^{g}	29.93^{ij}	33.13**	18.95^{jkl}	15.15^{gh}	20.05*
LMO-CP17	28.29^{j}	21.63^{k}	23.54*	30.90^{fg}	16.08^{fgh}	48.22**
LMO-LT18	82.25^{bc}	34.25^{gh}	58.36**	54.45^{c}	22.20^{c}	59.23**
LMO-LT19	84.75^{b}	62.48^{b}	26.28*	59.33^{c}	15.00^{ghi}	74.70**
LMO-LT20	88.65^{ab}	58.50^{cd}	34.01*	80.35^{a}	44.15^{a}	45.05**
LMO-LT21	49.29^{fg}	43.35^{f}	12.04*	31.62^{f}	11.00^{j}	65.19**
LMO-LT22	73.38^{de}	70.85^{a}	3.44^{ns}	64.60^{b}	44.15^{a}	31.66**
LMO-LT23	82.80^{bc}	71.20^{a}	14.01*	24.15^{hi}	11.41^{jo}	52.80**
LMO-MPP16	25.22^{j}	21.80^{k}	13.54*	21.49^{ijk}	11.55^{j}	46.25**
SD-CPP11	45.63^{g}	29.15^{ij}	36.11**	26.11^{ghi}	19.55^{de}	25.10*
TO-MPP15	31.86^{hij}	22.15^{k}	30.47**	19.89^{jkl}	15.53^{gh}	21.92*
YD-CPP13	31.08^{hij}	26.75^{j}	13.92*	23.40^{hij}	18.70^{ef}	20.09*
ZD-CPP12	77.10^{cd}	54.53^{e}	29.28*	23.65^{hij}	17.25^{efg}	27.06*
S35	27.93^{j}	20.31^{k}	27.30*	21.55^{ijk}	15.81^{gh}	26.68*
Mean	**55.31**	**39.69**	**28.25**	**33.51**	**18.71**	**44.17**
LSD 5%	**6.70**	**3.17**		**5.27**	**2.67**	

Values followed by the same letter in a column are not significantly different at 5%; *, ** and ns: significant at $p < 0.05$, $p < 0.01$ and not significant respectively. NIS: Not infested by*Striga*; IS: Infested by *Striga*; LSD: Least significant difference; RL: Relative loss due to *Striga*

DISCUSSION

In the field, *Striga* infestation, host damage, sorghum height, stem diameter, growth and yield parameters were highly influenced by genotype, sodium carbonate application and their interaction. The tested genotypes had differential response to salt application. These results corroborate the findings of Sinebo and Drennan [25] and Showemimo *et al.*, [26] for nitrogen x genotype in sorghum, and Noubissié *et al.*, [6] for interaction between sorghum accessions and inorganic fertilization. In infested plots, the number of emerged *Striga* and the visual evaluation of *Striga* damage symptoms varied among the 24 genotypes. According to Showemimo [27], when screenings for *Striga* resistance, the most important traits are plant damage, few *Striga* attached to the crop plant and grain yield. The number of emerged *Striga* plants depends on soil infestation level and gives an indication of the level of host resistance [27, 28]. Generally *Striga* emergence increased with increasing seed bank. Considering the previous studies [6, 10, 12], the number of emerged *Striga* per m^2 noted in this study was high, showing the high degree of land infestation. Based on *Striga* count, complete resistance against this parasite was not recorded in this study as many researchers highlighted that immunity to *Striga hermonthica* has not been developed [22, 28]. Genotypes KW-CP09, LMO-LT18, LMO-LT21, LMO-LT22, GDO-MP07 and TO-MPP15 showed the highest resistance to *Striga*. The mechanism of resistance was attributed to low germination stimulant production and post-infection cellular growth inhibition [12, 22]. A resistant plant stimulates germination of *Striga* but does not allow it to attach the root or kills the seedlings when attached [12, 16, 22, 24]. The best understood resistance mechanism to striga in sorghum is weak stimulation of striga seed germination by strigolactones produced by the host [1]. The cultivar S35 is not the only appropriate source of resistance to *Striga hermonthica* as suggested early studies [6, 9, 10].

The rate of striga damage is an index of tolerance while emerged *Striga* is an index of resistance [24, 28]. A tolerant crop do not affects *Striga* in any way, however it has a higher stover, grain production and it is less damaged than the non-tolerant genotype [24]. In this study, most of the genotypes showing a high degree of resistance to *Striga* also showed tolerance according to their damage score. In the absence of complete resistance, tolerance to infection in combination of low stimulant producers may be an effective control method [23, 24].

Application of sodium carbonate salt inhibited significantly *Striga* emergence on sorghum by48.66 to 92.69% and reduced the host plant damage. According to Hassan *et al.*, [13] in Sudan, application 50 to 75 mM of Nacl on soil reduced *Striga* infestation on sorghum by 65 to 100%, reduced haustorium initiation by 66% and delayed emergence for more than two weeks. Furthermore, our results also agree with Al-Khateeb [20], who displayed that tomato pot experiment irrigated with 75mM NaCl resulted in complete absence of *Orobance cernua* emergence and attachment. On maize, Tarfa *et al.*, [29] noted that calcium and magnesium applications on soils suppressed *Striga hermonthica* emergence by inhibiting the development of the haustorium. Nitrogen and phosphate are said to have the effect of reducing strigolactone production from the host plants and therefore inhibit germination of striga seeds [17, 18, 25, 30, 31]. Salinity might affect root exudation of chemicals required for *Striga* seed germination.

In infested soils, the growth of sorghum is retarded and crop yield lowered. Sorghum plant height, stem diameter, panicle weight and kernel yield were significantly reduced by infection. Yagoub *et al.*, [23] noted that *Striga* infestation reduced sorghum height by 35 to 74% as compared to uninfected control. Similarly, Osman *et al.*, [32] noted that the plant height and the total number of leaves per plant were negatively affected under *Striga* infestation. In contrast to our findings, Yagoub *et al.*, [23] found that generally *Striga* infestation had no significant effect on sorghum leaf number. The result of this study on yield agree with those of Ayongwa *et al.*, [5], Showemimo [27] and Yagoub *et al.*, [23] that *Striga* infestation in sorghum cause substantial damage to yield components and eventually loss of crop to farmers. Moreover, the difference is highly significant between sorghum accessions. According to Ast [28] differences in root architecture and the resulting early infection and higher *S. hermonthica* numbers are partly responsible for the stronger effects of the parasite on sensitive accessions. Noubissié *et al.*, [6] Kosma *et al.*, [10], Gebremedhin *et al.*, [31], Dzomeku and Amegbor [33] also showed that cereal height and other growth parameters were significantly affected by varietal effect under striga infestation. Ast [28] found that *Striga* reduces the growth and development of the host plant by mainly affecting photosynthesis. The reduction in the growth of the host results from competition for carbon assimilates, water, mineral nutrients and amino acids [28, 31]. *Striga* also causes the disturbance of hormonal balance of the host [28]. The assimilate production of an infected plant will also be reduced as a result of a reduction of the number of leaves. Change in growth regulators in the host are thought to be responsible for the reduced shoot growth [23]. *S. hermonthica* through haustorium also diverts the water, the minerals and the organic matter necessary for the development of the host. Gebremedhin *et al.*, [31] noted that in a deficit of water and nutrients, sorghum strategically diversifies the distribution of dry matter in the root and leaf system.

Under infestation, sorghum yield components were differentially affected by genotype and sodium carbonate application. *Striga hermonthica* significantly decreases sorghum crop yield. In striga-infested areas, cultivation of resistant varieties results in fewer striga plants and higher crop yield. This may be justified by the fact that the damage caused by the parasite greatly affects sorghum at the time of flowering and initiation of the panicle [25]. The reduction in kernel yield resulted from a reduced number of kernels per panicle and a reduction of panicle and kernel weight [34].Grain fill is sustained largely by photosynthesis of flag leaves and this is impaired in sorghum plants affected by *Striga*. In general, the effects of *Striga* on plant production are attributed directly to the parasite acting as an additional sink for carbon, inorganic solutes and water on one hand, and indirectly to the phytotoxic or pathological effects of the parasite on the host. Because a small number of *Striga* attachments can cause high level of yield reduction, it is recommended to develop varieties that combine resistance with high level of tolerance [14]. Sodium carbonate improved the growth and yield of sorghum under infestation by reducing the number of parasites attached to the host. As this salt increase the alkalinity and the pH of the soil it is important to choose the appropriate rate to reduce salt stress [35]. Many authors [1, 3, 22, 23] have emphasized the need for implementing several control methods as an integrated control approach that may improve efforts to maintain the *Striga* population at manageable levels and also reduce crop losses. The development of high-yielding, striga-resistant and –tolerant crop varieties, combined with the vulgarization of sodium carbonate application, may play a key-role in *Striga*-infested area. In this study, some local accessions showed a high degree of tolerance and resistance to *Striga hermonthica* comparing to the reference check S35 but no line was completely resistant. Other sources of resistance are required to satisfy the needs of sorghum breeding programs.

CONCLUSION

Among the 23 sorghum accessions studied, landraces LMO-LT18, LMO-LT22, KW-CP09 and LMT-21 appeared as the most resistant and tolerant to *S. hermonthica*. These landraces could be promoted for breeding programs in the Sudano-Sahelian zone of Cameroon. Application of sodium carbonate significantly reduced the striga-infestation and host damage particularly on susceptible and tolerant genotypes, and increase their growth and kernel yield. In order to improve this integrated approach further studies are required for determining the appropriate the period of application and the concentration of sodium carbonate salt.

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