An on-farm study of *Striga* as constraint to improved sorghum cultivar production in Mali

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Introduction

Sorghum (*Sorghum bicolor*) is the most important food crop in savanna areas of the West and Central Africa (WCA) region, including Mali, where grain yield averaged 0.71 t in 1999 (FAO 2001). Improved *caudatum* sorghum cultivars have not been widely adopted in Mali (Yapi and Debrah 1998). However, some of these cultivars such as ICSV 1063 and ICSV 1079 were introduced in the Kolokani area (about 130 km north of Bamako) by Catholic missionaries in the late 1980s. They have since spread and are being cultivated under the name "Gadiabani" by many farmers in over 100 villages (SEPD 1995).

With the introduction of improved *caudatum* cultivars, head-bug is becoming a concern. A study was conducted in 1997 and 1998 that showed that the level of infestation and damage by this pest was influenced not only by the sorghum cultivar per se, but also by the size of the fields and their genotypic environment (Ratnadass et al. 2008).

On the other hand, *Striga hermonthica* affects the livelihood of some 300 million people in Africa, causing severe and moderate damage in 21 and 22 countries, respectively (Berner et al. 1996). As *Striga* infestation is considered to be a major biotic constraint to sorghum production in the Kolokani area (Hoffmann et al. 1997), we measured this factor mainly to verify the extent to which differences in yield could be ascribed to head-bugs (Ratnadass et al. 2008). The trial design (particularly the change in design between 1997 and 1998) made it also possible to assess the influence of sowing date on *Striga* infestation.

Materials and methods

The experimental design of the trial conducted in 1997 and 1998 in the three Malian villages of Tioribougou, Wenia and Ntiobougou), with four sorghum cultivars, Bibalawili, Gadiabani, ICSH 89002 and Malisor 84-7) have been published by Ratnadass et al. 2008. Further to head-bug observations, grain weight was also recorded on the second central row of each plot. In addition, the total number of *Striga* plants per plot was also recorded.

During the 1997–98 dry season, soil samples from the top 30 cm layer were taken in all large plots, at the four angles, at the center, and half-way from the center on the diagonal, respectively, and the nine samples thus obtained were then sun-dried, pooled and divided using a box-divider so as to obtain a single composite sample of 300–600 g. Subsequent analyses were carried out on these composite samples at the International Crops Research Institute for the Semi Arid Tropics (ICRISAT), Niger, Niamey: H^+; Al^{3+}; Na^+; K^+; Ca^{2+}; Mg^{2+}; ECEC (cmol+ kg^{-1}); pH-H_2O and pH-KCL (1:2.5); organic C (%); Bray-P1 (mg P kg^{-1}).

Individual and combined analyses of variance were performed using SAS software (SAS Institute Inc. 1999–2001). Results regarding small plots were analyzed separately for each year due to the change in design. For large plots, a combined analysis was conducted by keeping only two DPB (distance from plot border) levels for 1998. *Striga* numbers were analyzed after log (n+1) transformation. Differences between cultivars and treatments were determined with the *F*-test, and means were compared using LSD at the $P < 0.05$ threshold.

Results

In small plots. In our analysis of the 1997 small plot data, the effect of cultivar in small plots was not significant for *Striga* infestation and grain yield (Table 1). The cultivar effect in large plots was significant for *Striga* infestation, but not for yield. The effect of locality was highly significant for *Striga* infestation and yield. There were no significant interactions involving *Striga* infestation and yield in small plots in 1997.

In the analysis of the 1998 small plot data, the effect of cultivar in small plots was significant for *Striga* infestation, but not for grain yield (Table 2). The cultivar effect in large plots was highly significant for *Striga* infestation and grain yield. The locality effect was significant for grain yield, but not for *Striga* infestation. There were significant interactions between cultivars in large plots and locality for *Striga* infestation and grain yield.

In 1997, grain yield in small plots was significantly higher for ICSH 89002 than for Malisor 84-7, with the other cultivars being intermediate (Table 3), while in 1998, Malisor 84-7 and Bibalawili still had the lowest and highest yield, respectively, but the differences were not significant (Table 4). In 1997, grain yield in small plots taken as a whole was higher when located along the border of a large Malisor 84-7 plot, and significantly lower when located along the border of a large Gadiabani plot (Table 3).

In 1998, overall grain yield in small plots was higher when they were located in the center of ICSH 89002 and Malisor 84-7 plots, and significantly lower when located in the center of large Gadiabani and Bibalawili plots (Table 4).

As for *Striga* infestation, there were no differences between cultivars in small plots, irrespective of the cultivar in large plots in 1997, while infestation of small plots within the large Gadiabani plot was significantly higher (Table 5). In 1998, overall infestation was lower than in 1997, and remained high (about the same level as in 1997) only in small Bibalawili plots, and in small plots within the large Bibalawili plots, respectively (Table 6).

Table 1. Mean squares (MS) and their significance[1] from a combined analysis of variance of *Striga* infestation and sorghum grain yield in small plots in 1997.

Source of variation	df	*Striga* infestation MS[2]	Grain yield MS
Residual	9	1.586	0.1464
F1 (cultivar in small plot)	3	0.49 NS	0.3731 NS
F2 (cultivar in large plot)	3	6.47 *	0.5203 NS
F3 (locality)	2	16.70 **	2.799 ***
F1 × F2	9	0.42 NS	0.1179 NS
F1 × F3	6	1.19 NS	0.1850 NS
F2 × F3	6	4.03 NS	0.3422 NS
F1 × F2 × F3	18	0.66 NS	0.2011 NS

1. Significance in the *F*-test: * = Significant at 5% level; ** = Significant at 1% level; *** = Significant at 0.1% level; NS = Not significant at 5% level.
2. Natural logarithm of number of *Striga* plants per plot plus 1.

Table 2. Mean squares (MS) and their significance[1] from a combined analysis of variance of *Striga* infestation and sorghum grain yield in small plots in 1998.

Source of variation	df	*Striga* infestation MS[2]	Grain yield MS
Residual	9 (6)	0.413	0.1805
F1 (cultivar in small plot)	3	2.43 *	0.2781 NS
F2 (cultivar in large plot)	3	8.20 ***	2.9100 ***
F3 (locality)	2 (1)	0.95 NS	2.6654 **
F1 × F2	9	0.58 NS	0.2658 NS
F1 × F3	6 (3)	0.08 NS	0.1570 NS
F2 × F3	6 (3)	1.98 *	0.9350 *
F1 × F2 × F3	18 (9)	0.87 NS	0.2404 NS

1. Significance in the *F*-test: * = Significant at 5% level; ** = Significant at 1% level; *** = Significant at 0.1% level; NS = Not significant at 5% level.
2. Natural logarithm of number of *Striga* plants per plot plus 1.

In large plots. This analysis was conducted on means of the two or three DPB levels. Although the design slightly changed, an effort was made to combine data from both years, while keeping only the extreme two DPB levels in 1998, so that the data from that year would match those of 1997. Large plot variance was significant for grain yield and *Striga* infestation. There was no significant effect for the latter, while for grain yield (with an overall mean of 1.22 t ha^{-1}), the only significant effects concerned the locality and cultivar-year interaction. There was no difference in *Striga* infestation based on the DPB in the large plots (overall mean of 0.5 plants m^{-2}).

Besides biotic stress (*Striga* and head-bugs; see Ratnadass et al. 2008), soil quality did not account for variations in yield between localities, or between plots in the same locality, since the only noteworthy result was the higher H^+ and Al^{3+} content, and consequently lower pH (and to a lesser extent K^+, Ca^{2+} and Mg^{2+} contents) in Bibalawili and ICSH 89002 plots at Ntiobougou. This likely explains the lower yields on large plots recorded at Ntiobougou, and also the significant effects and interactions involving yield observed in small plots.

Discussion

In the absence of any biotic stress, the border effect should be reflected by lower competition between sorghum plants grown in plots bordering large plots, and therefore higher yield. In the absence of a difference in *Striga* infestation, differences in head-bug damage (as reported in Ratnadass et al. 2008) could account for the absence of a significant difference in yield.

The significant interaction between year and cultivar with respect to *Striga* infestation could be ascribed to the differences in sowing dates. Differences in planting dates in 1998 could have accounted for differences observed in *Striga* infestation via differences in soil temperature (ie, in case of delayed crop planting, *Striga* seeds are unable to germinate and seedlings fail to attach to host root systems due to unfavorably low soil temperatures during the middle of the rainy season, according to Hoffmann et al. 1997).

Actually, it is striking that in 1997, when all cultivars were sown at the same time (Ratnadass et al. 2008), there was no difference in *Striga* infestation in small plots of all

Table 3. Grain yield (t ha^{-1}) of sorghum cultivars observed in small plots: combined analysis of 1997 data at Tioribougou, Wenia and Ntiobougou in Mali.

	Cultivars in small plots				
Cultivars in large plots	Bibalawili	Gadiabani	ICSH 89002	Malisor 84-7	Mean[1]
Bibalawili	1.250	1.032	1.536	1.005	1.206ab
Gadiabani	1.347	0.883	0.773	0.646	0.912b
ICSH 89002	1.209	1.074	1.360	1.066	1.177ab
Malisor 84-7	1.377	1.503	1.631	1.165	1.419a
Mean[2]	1.296AB	1.123AB	1.325A	0.971B	1.184

1. Means within the column followed by the same lower case letters are not significantly different, Bonferroni test, $P = 0.05$.
2. Means within the row followed by the same letters are not significantly different, Bonferroni test, $P = 0.05$.

Table 4. Grain yield (t ha^{-1}) of sorghum cultivars observed in small plots: combined analysis of 1998 data at Tioribougou, Wenia and Ntiobougou in Mali.

	Cultivars in small plots				
Cultivars in large plots	Bibalawili	Gadiabani	ICSH 89002	Malisor 84-7	Mean[1]
Bibalawili	1.267	1.044	1.111	0.644	1.017b
Gadiabani	1.244	0.933	0.844	0.933	0.989b
ICSH 89002	2.089	2.311	2.000	1.289	1.922a
Malisor 84-7	1.467	1.467	1.556	1.867	1.589a
Mean[2]	1.517A	1.439A	1.378A	1.183A	1.307

1. Means within the column followed by the same lower case letter are not significantly different, Bonferroni test, $P = 0.05$.
2. Means within the row followed by the same letter are not significantly different, Bonferroni test, $P = 0.05$.

Table 5. ***Striga*** **infestation (no. per m²) observed on sorghum cultivars in small plots: combined analysis of 1997 data at Tioribougou, Wenia and Ntiobougou in Mali.**

Cultivars in large plots	Cultivars in small plots				Mean[1]
	Bibalawili	Gadiabani	ICSH 89002	Malisor 84-7	
Bibalawili	1.2 (2.06)[2]	0.4 (1.34)	1.7 (1.57)	0.7 (1.49)	1.0 (1.61b)
Gadiabani	2.0 (2.70)	2.3 (2.81)	3.9 (2.86)	1.9 (2.74)	2.5 (2.78a)
ICSH 89002	2.6 (1.95)	0.2 (1.19)	0.2 (0.92)	0.2 (0.80)	0.8 (1.22b)
Malisor 84-7	0.2 (1.00)	0.3 (1.52)	0.6 (1.63)	0.1 (0.83)	0.3 (1.24b)
Mean[3]	1.5 (1.93A)	0.8 (1.71A)	1.6 (1.74A)	0.7 (1.47A)	1.2 (1.69)

1. Means within the column followed by the same lower case letter are not significantly different, Bonferroni test, $P = 0.05$.
2. Log (1+n) – transformed values (total number of plants per 15 m² plots) are given in parentheses.
3. Means within the row followed by the same letter are not significantly different, Bonferroni test, $P = 0.05$.

Table 6. ***Striga*** **infestation (no. per m²) observed on sorghum cultivars in small plots: combined analysis of 1998 data at Tioribougou, Wenia and Ntiobougou in Mali.**

Cultivars in large plots	Cultivars in small plots				Mean[1]
	Bibalawili	Gadiabani	ICSH 89002	Malisor 84-7	
Bibalawili	4.2 (2.95)[2]	0.5 (1.34)	1.1 (1.78)	0.7 (1.42)	1.7 (1.87a)
Gadiabani	0.4 (1.64)	0.1 (0.46)	0.3 (1.52)	0.1 (0.83)	0.2 (1.11b)
ICSH 89002	0.0 (0.23)	0.1 (0.46)	0.0 (0.37)	0.0 (0.00)	0.0 (0.26c)
Malisor 84-7	0.3 (1.11)	0.1 (0.60)	0.4 (1.00)	0.0 (0.00)	0.2 (0.68bc)
Mean[3]	1.87 (1.48A)	0.2 (0.72BC)	0.5 (1.17AB)	0.2 (0.56C)	0.5 (1.16)

1. Means within the column followed by the same lower case letter are not significantly different, Bonferroni test, $P = 0.05$.
2. Log (1+n) – transformed values (total number of plants per 15 m² plots) are given in parentheses.
3. Means within the row followed by the same letters are not significantly different, Bonferroni test, $P = 0.05$.

cultivars (Table 5), while in 1998, small plots of Bibalawili, which were sown ahead of other cultivars (due to its longer cycle), sustained significantly higher infestation (Table 6). Similarly, overall infestation of small plots was significantly higher in large plots of Gadiabani in 1997 (when this cultivar was sown on the same date as all other cultivars, including Bibalawili; see Table 5), while in 1998, this overall infestation of small plots was significantly higher in Bibalawili, the only early-planted cultivar (Table 6).

So, it was sowing date which seemed to influence *Striga* infestation, at least for the cultivars considered (notably guinea vs caudatum).

However, late sowing may also have a negative impact on yield. Therefore, a technique such as mulching, which both allows early sowing (due to water conservation) and *Striga* suppression (via lower soil temperature) would be more advisable. Actually, in northern Cameroon, *Brachiaria* mulch was observed to have a positive effect on the main sorghum crop, notably by lowering soil temperature, which resulted in lower *Striga* incidence (Naudin 2002).

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