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Potential for sesame to contribute to integrated control of *Striga hermonthica* in the West African Sahel

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Abstract

Striga hermonthica is an important constraint to the production of pearl millet, a staple cereal in many parts of sub-Saharan Africa. Sesame is an important oilseed crop well adapted to the sandy soils of the West African Sahel. Intercropping of sesame and pearl millet has been reported to reduce emerged striga numbers, but formal research into the potential for sesame to contribute to control of the parasite is lacking. Field trials were undertaken to evaluate the potential of sesame grown in rotation with pearl millet to reduce striga infestation of the cereal. Emerged striga numbers and striga fruiting were strongly reduced on pearl millet following sesame compared to sole millet. To maximize cereal yield, soil fertility enhancement and water conservation are indispensable elements of integrated striga control. The results can guide future research at a time where sesame is being promoted to diversify agricultural production in the Sahel.

Keywords: Witchweed; *Sesamum indicum*; *Pennisetum glaucum*; Integrated striga control

1. Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is the staple cereal in Niger and most countries of the West African Sahel. The angiosperm root parasite *Striga hermonthica* (L.) Benth. is a significant biotic constraint to production of this food crop in the nutrient poor, drought prone soils of the region (Boukar et al., 1996). An association among *Striga* spp. infestation, low soil moisture, and poor soil fertility has long been conjectured (Basinski, 1955; Portères, 1952; Wilson-Jones, 1953). Pearl millet under nitrogen stress was demonstrated to be more susceptible to attack by the parasite (Boukar et al., 1996).

Sesame (*Sesamum indicum* L.), one of the oldest oilseed crops, is primarily grown in tropical to temperate zones from 40°S to 40°N latitude (Ashri, 1989; Bedigian and Harlan, 1986). It yields well under high temperature and grows on residual moisture at the end of the rainy season. It can be grown in pure stands, but many smallholders cultivate sesame as a component of mixtures where it is secondary to the food crop (Tribe, 1967). In southeastern Tanzania sesame is frequently cultivated in alternate rows with sorghum (*Sorghum bicolor* (L.) Moench) or pearl millet, broadcast into an established sorghum crop, or sown simultaneously with sorghum in the same planting hole or "hill" (Taylor, 1986). Mixed cropping of pearl millet and sesame is also practiced by subsistence farmers in West Africa where it has been reported to reduce striga infestation through sowing in the same planting hole (Saizé, 1991), or sowing in alternate or adjacent hills (Hudu and Gworgwor, 1998; Gworgwor et al., 2001). Many farmers grow sole sesame in rotation with other crops. However, formal studies and published data on the potential of sesame to contribute to striga control are limited.

The effect on striga infestation of sesame and pearl millet sown in the same planting hole was investigated in 1993 and 1994 in pots artificially infested with *S. hermonthica* at the ICRISAT Sahelian Center in Sadoré, near Niamey, Niger. The association between a single pearl millet plant (three pearl millet lines were studied: Sadoré Local, Haïni Kiré Bengou (HKB), and

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Table 1
Cropping sequence in rotation experiments conducted in farmers' fields at Bengou and Sadoré, Niger, from 1995 to 1998

	Controls		Treatments	
Year 1	Pearl millet	Sesame	Pearl millet	Sesame
Year 2	Pearl millet	Sesame	Sesame	Pearl millet
Year 3[a]	Pearl millet	Pearl millet	Pearl millet	Pearl millet

[a] In year 3 pearl millet was sown in all plots to evaluate the residual effect of year 1 and 2 treatments.

Composite inter-variétal de Tarna) and a single sesame plant did not influence emerged striga number in pots (unpublished data). Sesame in rotation with pearl millet was evaluated from 1995 to 1998 in farmers' fields naturally infested with *S. hermonthica* at Sadoré and at Bengou, near Gaya, in southern Niger. Sesame is produced in the Bengou area for local consumption but primarily for export; it is not cultivated by farmers in the Sadoré region. The results of the rotation trials are reported here and the potential role of sesame in integrated striga management in pearl millet-based cropping systems in the West African Sahel is discussed.

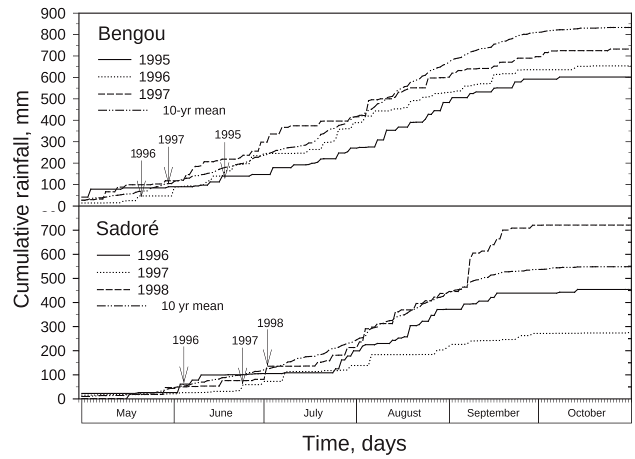

Fig. 1. Cumulative rainfall at Bengou and Sadoré, Niger, during the 3 years of the respective trials. Arrows indicate dates of sowing of pearl millet.

2. Materials and methods

Experiments evaluating pearl millet in rotation with sesame were conducted as a randomized complete block with seven replications at two locations in Niger. Plots were sown to either pearl millet or sesame in the 2 years of experimentation with plots of continuous millet and sesame serving as controls (Table 1). Emerged striga were allowed to flower and produce seed rain. In the third year, all plots were sown to pearl millet to evaluate the residual effect of the treatments on striga infestation and pearl millet growth and yield.

2.1. Bengou

Bengou (11°15′N, 3°18′E), in the Sudanian zone of southern Niger, is characterized by a rainy season of 120 days and 850 mm annual rainfall. The soil is an Alfisol, clayey-skeletal, mixed Isohypothermic family of Udic Rhondastalf (Bationo and Ntare, 2000). The top soil contains 12% clay and 70% sand. A basal application of single super phosphate fertilizer (18%, 13 kg P_2O_5 ha^{-1}) was applied at field preparation. The pearl millet landrace, HKB, and a local sesame variety were obtained from the farmer in whose field the trial was sown. Seeds were sown following rainfall on 17 June 1995 and 20 May 1996 (Fig. 1). Plots of pearl millet consisted of eight rows 7 m in length, spaced 0.75 m apart. Plant-to-plant spacing within the row was 1.2 m. Sesame was sown in plots with 13 rows 7 m in length, spaced 0.5 m apart. Plant-to-plant spacing within the row was 0.4 m. Fields were weeded twice at about 2 and 4 weeks after sowing, as traditionally practiced in the zone. About 30 days after emergence and following rainfall, plots were thinned to three plants per sowing hole or "hill" for pearl millet and two plants per hill for sesame.

The residual effect of the 1995–1996 treatments was evaluated in 1997 when pearl millet was sown into all plots. In the case of the controls, 2 years of pearl millet or 2 years of sesame were followed by the cereal (M–M–M and S–S–M, respectively). For the experimental plots in rotation, sesame was followed by 1 or 2 years of pearl millet (M–S–M and S–M–M, respectively). Sowing was done on 29 May following rainfall on the 28th. The striga soil seed bank (number of striga seed in the soil) was evaluated at the end of the cropping season.

2.2. Sadoré

Sadoré (13°15′N, 2°17′E) is located in the Sahelian zone and has a 90-day rainy season and an average rainfall of 560 mm. Soils are loamy sand classified as sandy, silicious Isohypothermic Psammentic Paleustalf with a clay content of 3% and a silt content of 2% (West et al., 1984). The Sadoré trial was initiated in 1996 and a basal application of single super phosphate fertilizer (18%, 19.7 kg P_2O_5 ha^{-1}) was applied at field preparation. The pearl millet landrace, Sadoré Local, was obtained from the collaborating farmer and the sesame variety from Bengou was used. Pearl millet was sown following rainfall on 3 June 1996 and 23 June

1997 (Fig. 1); sesame was sown somewhat later on 7 July 1996 and 2 August 1997. At Sadoré, farmers maintain small ruminants (sheep and goats) that roam freely and feed on the young crop. Sowing of sesame, which does not tolerate browsing, was delayed until village livestock were either tethered or moved out of the area. Plot size, row length, plant spacing, and crop management were as described for Bengou.

In the third year (1998), pearl millet was sown in all plots on 17 June to evaluate treatment residual effects. Due to poor emergence resulting from a period of drought (Fig. 1), the sowing was repeated on 1 July.

The following observations were made: days from sowing to emergence of striga; days until pearl millet anthesis; counts of emerged striga in each plot at 14-day intervals beginning 2 weeks after emergence of striga in the trial; and dry biomass of the harvested earheads, straw, and threshed grain. In order to better evaluate severity and duration of striga infestations, area under the striga number progress curve (ASNPC) was calculated for each plot (Haussmann et al., 2000).

Analyses of variance were performed for a randomized complete block design considering cropping sequence to be fixed and blocks as random effects. Expected mean squares were computed according to classical methods (Steel et al., 1997). Log transformations were performed on number of fruiting striga, ASNPC and pearl millet biomass data in order to achieve homogeneity of error variances. ANOVA was calculated using the SAS ANOVA procedure (SAS Institute, Cary, NC).

3. Results

3.1. Bengou

Distribution of rainfall at Bengou was good throughout the cropping season in all 3 years but varied in quantity (Fig. 1). In the 1995, 1996 and 1997 cropping seasons (May through September) there were 37, 47, and 49 rainfall events, respectively. In the 10 years from 1991 through 2000, rain fell on an average of 47 days during this same time period. However, each year was somewhat below the 10-year average of 784 mm of precipitation for this 5-month period. 1995 was the driest year with only 605 mm of precipitation; rainfall was below average already in mid-May and remained below average all season. In 1996, 721 mm of rain fell; the year started out below average with increasing rainfall through latter June, but falling again below the average from July onwards. In 1997, rainfall was above average until August when it tapered off, totaling 705 mm for the season.

3.1.1. 1995

In the first year of the trial striga emerged at 48 ($\pm$0.8) DAS on pearl millet and infestation (emerged striga number) was high. No striga plants emerged in the sesame plots. Expressed as ASNPC, striga infestation averaged 4055 ($\pm$822). Grain yields for pearl millet and sesame were 557$\pm$34 and 773$\pm$41 kg ha^{-1}, respectively.

3.1.2. 1996

Striga emerged at 46 ($\pm$1.3) DAS and was unaffected by the previous crop (Table 2). ASNPC was high in plots monocropped to the cereal (5358$\pm$2169). However, in pearl millet plots that had been cropped in sesame in the previous year, both emerged striga number and striga reproduction (number of striga with seed capsules) were significantly reduced with respect to plots sown continuously to pearl millet (Table 2). A 98% fewer striga emerged and of these 98% fewer striga reached the fruiting stage than in plots sown to continuous pearl millet (Table 3). Pearl millet straw yield was higher in plots cropped the previous year in sesame, but neither anthesis nor grain yield were significantly affected (Table 4). Pearl millet straw yield increased by 33% in plots following sesame (Table 5).

Table 2
Analysis of variance of effect of cropping system on days to striga emergence, emerged striga number and number of fruiting striga in naturally infested farmer's fields, Bengou and Sadoré, Niger

Trait mean squares							
Source of variance	Df	Bengou, 1996			Sadoré, 1997		
		Emergence (DAS)[a]	LogASNPC[b]	LogStricap[c]	Emergence	Log(ASNPC+1)	Log(Stricap+1)
Block	6	29.310	0.752	0.1985	546.14	1.1798	0.08715
Treatment	1	25.786	10.136**[c]	5.6093**	540.64	1.4183	0.23302*
Expected error	6	12.119	0.376	1.2388	132.14	0.3708	0.02674

*Level of significance at $P \leqslant 0.05$.
**Level of significance at $P \leqslant 0.01$.
[a] Days after sowing.
[b] Area under the striga number progress curve (Haussmann et al., 2000).
[c] Number of fruiting striga plants (bearing seed capsules).

Table 3
Effect of cropping system on days to striga emergence, emerged striga number, and fruiting striga in naturally infested farmers' fields, Bengou and Sadoré, Niger

Crop sequence[a] Bengou 95–96, Sadoré 96–97	Bengou, 1996					Sadoré, 1997				
	Emergence (DAS)[b]	ASNPC[c]		Stricap[d]		Emergence (DAS)	ASNPC		Stricap	
		Log_{10}	Back-transformed	Log_{10}	Back-transformed		$Log_{10}(n+1)$	Back-transformed	$Log_{10}(n+1)$	Back-transformed
M–M	44.9	3.44	2748	1.502	30.78	85.6	1.67	46.50	0.369	1.34
S–M	47.6	1.74	54	0.236	0.72	98.0	1.04	9.97	0.111	0.29
LSD	4.55	0.802		0.594		13.58	0.796		0.214	

[a] M = pearl millet (Haïni Kiré Bengou at Bengou, Sadoré local at Sadoré); S = sesame.
[b] Days after sowing.
[c] Area under the striga number progress curve (Haussmann et al., 2000).
[d] Number of fruiting striga plants (bearing seed capsules).

Sesame grain yield (392 ± 28 kg grain ha^{-1}), however, was unaffected by the preceding crop (Tables 4 and 5).

3.1.3. 1997

Striga emerged at about 50 DAS, and although cropping sequence did not significantly affect days to striga emergence, it did influence both ASNPC and the number of fruiting striga at harvest (Table 6). Numerous striga emerged in plots monocropped with pearl millet (ASNPC = 1997), but dramatic reductions were seen in plots receiving 1 or 2 years of sesame (ASNPC = 339–475) (Tables 6 and 7). Residual treatments significantly influenced days to anthesis, grain yield, and biomass of pearl millet (Table 8). In 1997, pearl millet plants following 1 or 2 years of sesame reached anthesis significantly earlier (61 and 65 DAS, respectively, $P < 0.01$) than did monocropped pearl millet (68 DAS) (Table 9). Pearl millet grain yield and straw weight were lowest ($P < 0.05$ and 0.01, respectively) on continuous millet (Table 9). Although the mean striga seed bank was reduced in plots cropped to sesame (56 and 40 striga seed kg^{-1} soil after 1 and 2 years of sesame, respectively) compared to the cereal monocrop (68 striga seed kg^{-1} soil) the treatment effect was not significant.

3.2. Sadoré

Rainfall distribution at Sadoré during the 3 years was more variable than in Bengou (Fig. 1). During the 1996 cropping season at Sadoré, 503 mm of rain fell in 30 rainfall events; in 1997, 320 mm of rainfall were received over 24 days. In 1998, 645 mm of rainfall fell over 33 days; of this total, 116 mm were received during a single storm on 7 September.

3.2.1. 1996

Striga emerged at about 58 (± 0.6) DAS and infestation over the season gave an average ASNPC of 1791 (± 406). Grain yields of pearl millet and sesame were 168 (± 13) and 190 (± 16) kg ha^{-1}, respectively.

3.2.2. 1997

In this very dry year, striga emerged late (74–84 DAS) in some plots and not at all in others. Poor striga emergence was reflected in a small average ASNPC of 62 (± 14). The only significant treatment effect was seen for striga reproduction (Table 2). About 78% fewer striga reached the fruiting stage on pearl millet following sesame than in plots sown to continuous pearl millet (Table 3). Pearl millet and sesame plot yields varied 10-fold throughout the experiment and were not significantly affected by cropping sequence. Pearl millet plot yields averaged 556 ± 66 kg ha^{-1}; sesame yielded 132 ± 22 kg ha^{-1}.

Table 4
Effect of cropping system on pearl millet (Haïni Kiré Bengou) anthesis, grain yield, and dry straw weight in a farmer's field naturally infested by *Striga hermonthica* at Bengou, Niger, 1996

Source of variance	Trait mean squares[a]				
	Pearl millet				Sesame
	Df	Anthesis (DAS)[a]	Grain yield (kg ha^{-1})	Straw wt. (kg ha^{-1})	Grain yield (kg ha^{-1})
Block	6	2.571	9572	166725	15429
Treatment	1	0.000	52074	1252834**	234
Expected error	6	0.667	10747	72518	7615

**Level of significance at $P \leqslant 0.01$.
[a] Days after sowing.

Table 5
Effect of cropping system on pearl millet (Haïni Kiré Bengou) anthesis and yield of pearl millet and sesame in a farmer's field naturally infested by *Striga hermonthica* at Bengou, Niger, in 1996

Crop sequence[a] 1995–1996	Pearl millet			Sesame
	Anthesis (DAS)[b]	Grain yield (kg ha^{-1})	Straw wt. (kg ha^{-1})	Grain yield (kg ha^{-1})
M–M	68.6	327	1218	328
S–M	68.6	448	1816	336
LSD	1.07	135.6	352.2	46.6

[a] M = pearl millet; S = sesame.
[b] Days after sowing.

Table 6
Analysis of variance of residual effect of cropping system on days to striga emergence, emerged striga number and number of fruiting striga in naturally infested farmer's fields, Bengou and Sadoré, Niger

Trait mean squares							
Source of variance	Df	Bengou, 1997			Sadoré, 1998		
		Emergence (DAS)[a]	LogASNPC[b]	LogStricap[c]	Emergence	Log(ASNPC + 0.05)	Log(Stricap + 0.05)
Block	6	98.988	0.4725	0.6188*	75.833	0.2184	0.4827
Treatment	3	82.321	0.9259**	0.7860*	848.524**	2.6497**	0.9662**
Expected error	18	41.432	0.1914	0.1806	146.246	0.5528	0.2029

*Level of significance at $P \leqslant 0.05$.
**Level of significance at $P \leqslant 0.01$.
[a] Days after sowing.
[b] Area under the striga number progress curve (Haussmann et al., 2000).
[c] Number of fruiting striga plants (bearing seed capsules).

3.2.3. 1998

Residual effect of the preceding crop sequence influenced days to striga emergence, emerged parasite number and striga reproduction (Table 6). Striga emerged in some plots as early as 60 DAS but never appeared in other plots that had been cropped for 2 successive years in sesame. The period to striga emergence was significantly longer (87 vs. 65 days) and the number of striga that emerged was significantly reduced (ANSPC = 19 vs. 430) following 2 years of sesame compared to sole millet or a single year of sesame (Table 7). However, pearl millet anthesis and grain and straw yields were unaffected by the preceding crop. Pearl millet flowered at about 92 (±0.9) DAS and grain and straw yields were, respectively, 426 (±37) and 1189 (±75) kg ha^{-1}. The striga seed bank was not evaluated at the end of the Sadoré trial.

4. Discussion

Results of preliminary pot trials supported field observations made at Bengou that sowing pearl millet and sesame in the same hill does not influence emerged striga number. However, in these fields sesame served as a marker plant, facilitating the identification of young cereal plants in grassy, overgrown fields at weeding time, and farmers frequently sowed sesame and pearl millet

Table 7
Residual effect of cropping system on days to striga emergence, emerged striga number, and fruiting striga in naturally infested farmers' fields, Bengou and Sadoré, Niger

Crop sequence[a] 1995–1996–1997	Bengou, 1997					Sadoré, 1998				
	Emergence (DAS)[b]	ASNPC[c]		Stricap[d]		Emergence (DAS)	ASNPC		Stricap	
		Log_{10}	Back-transformed	Log_{10}	Back-transformed		$Log_{10}(n+1)$	Back-transformed	$Log_{10}(n+1)$	Back-transformed
M–M–M	47.6	3.30	1997.15	1.47	29.60	65.0	2.63	429.66	0.74	4.50
M–S–M	54.1	2.53	339.41	0.814	6.52	64.4	2.35	223.20	0.57	2.69
S–M–M	50.3	2.55	352.49	0.741	5.51	65.6	2.22	165.82	0.39	1.48
S–S–M	46.4	2.68	475.04	1.14	13.89	87.0	1.31	19.36	0.04	0.10
LSD	7.28	0.491		0.477		13.58	0.763		0.399	

[a] M = pearl millet (Haïni Kiré Bengou at Bengou, Sadoré local at Sadoré); S = sesame.
[b] Days after sowing.
[c] Area under the striga number progress curve (Haussmann et al., 2000).
[d] Number of fruiting striga plants (bearing seed capsules).

together in fields of secondary importance where weeding was subject to delay. A recent report by Gworgwor et al. (2001), related that intercropping (pearl millet and sesame sown in alternate hills) in northern Nigeria reduced striga infestation as compared to sole millet, although no data were provided. There is need for further investigation of intercropping sesame and pearl millet to clarify the roles of crop genotype, striga population, and environment on crop yield and striga infestation.

Multiple cropping is a means to increase productivity and enhance income under uncertain climatic conditions. In the West African region sesame is frequently sown as a rotation crop with the local cereal (sorghum or pearl millet). Niger's current annual production is about 5000 tons, with yields ranging 100–500 $kg\,ha^{-1}$ (Agro-Ind, 2002). Considerable variability was observed in sesame yield at both Bengou and Sadoré. The delayed sowing requirement at Sadoré (34–40 days after pearl millet) contributed to yields that were only about half those from Bengou. Taylor (1986) reported significant yield reduction (53–100%) when sesame was sown late. Poor rainfall distribution after late sowing was a contributing factor, but the main effect may have been to disadvantage the sesame in the crop mixture. In the rotation experiments reported here competition between the crops was avoided.

In spite of considerable environmental variability, the rotation was observed to strongly decrease striga infestation and reproduction at both locations. At Sadoré, the emergence of striga was delayed by about 3 weeks following 2 years of sesame. This treatment was also most effective at reducing emerged and fruiting striga number. However, grain and straw yields of the cereal were not significantly improved. Previous experimentation at Sadoré evaluating the physical removal of striga from infested plots demonstrated the need for fertility enhancement of depleted soils before a yield response in pearl millet will result from reduced striga infestation (Hess and Dembélé, 1999).

At Bengou all three treatments involving sesame reduced striga infestation and reproduction. After 1 year of sesame (1996 experiment), pearl millet straw yield was significantly improved. But 2 years of experimentation (1995–96) allowed for only one cycle of the rotation which was too short to provide a clear residual effect in 1997.

However, these experiments have clearly demonstrated that cultivation of sesame in rotation with pearl millet contributes to reduced striga infestation in the cereal. More rotation cycles carried out at more locations would undoubtedly provide more convincing results, but the potential for sesame to contribute to control of striga in pearl millet-based cropping systems is clear. Including sesame in integrated control packages that also enhance soil fertility and conserve water would

Table 8
Residual effect of cropping system on pearl millet (Haïni Kiré Bengou) anthesis, grain yield, and dry straw weight in a farmer's field naturally infested by *Striga hermonthica* at Bengou, Niger, 1997[a]

Source of variance	Df	Trait mean squares		
		Anthesis (DAS)[a]	Grain yield ($kg\,ha^{-1}$)	Straw wt. ($kg\,ha^{-1}$)
Block	6	6.738	95475.6**	676870**
Treatment	3	70.333**	52272.4*	598950**
Expected error	18	4.389	13792.1	112419

*Level of significance at $P \leqslant 0.05$.
**Level of significance at $P \leqslant 0.01$.
[a] Days after sowing.

Table 9
Residual effect of cropping system on pearl millet (Haïni Kiré Bengou) growth and yield in a farmer's field naturally infested by *Striga hermonthica* at Bengou, Niger, in 1997

Crop sequence[a] 1995–1996–1997	Anthesis (DAS)[b]	Grain yield ($kg\,ha^{-1}$)	Straw wt. ($kg\,ha^{-1}$)
M–M–M	67.6	484	1136
M–S–M	64.9	501	1187
S–M–M	61.0	673	1761
S–S–M	61.1	580	1505
LSD	2.35	131.9	376.5

[a] M = pearl millet; S = sesame.
[b] Days after sowing.

undoubtedly lead to increased pearl millet yield in addition to improved striga control (Hess et al., 2001).

The mechanism by which sesame reduces emerged striga number was investigated in pot trials and in the laboratory by a student (Kabacinski, 2002). Sesame was shown to be an effective trap crop of *S. hermonthica*, stimulating parasite seed germination in the absence of the cereal host. This helps to explain the increased efficiency of crop rotation in controlling striga infestation; a higher density of the trap crop grown in the absence of the cereal host leads to the suicidal germination of a larger number of parasite seeds. The crucial role of the striga seed bank on emerged striga number has been demonstrated in pot and field (Freitag et al., 1996; Kim and Adetimirin, 1997). Consequently, integrated striga management strategies place particular importance on depletion of the striga seed bank (Hess et al., 2001).

Little sesame is consumed by Sahelian producers with most of the production exported through Nigeria and Burkina Faso, which are transit countries for final export destinations in Asia, the Middle East, and Europe (Agro-Ind, 2002). Sesame production is of good quality with high oil yields (over 50% on a w/w base) and low acidity (under 2% v/v) allowing for extended storage of extracted oil. Development potential for sesame in the region is strong, since local, traditional methods of cultivation produce a product that may easily gain the 'organic' label. This should enhance market positioning and sales. Various development projects and non-governmental organizations are investigating this potential as well as other development prospects for the crop (Agro-Ind, 2002).

Sesame is contributing to diversification of the pearl millet-based production system in West Africa. It is a supplementary source of revenue to the subsistence farmer and could serve to diversify his diet, as is the case in rural communities of northern Nigeria (Agro-Ind, 2002). Further, adaptive research will clarify the potential role of sesame to improve the effectiveness of integrated striga management in the West African Sahel.

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