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Selection of sorghum (*Sorghum bicolor* (L.) Moench) varieties resistant to the parasitic weed *Striga hermonthica* (Del.) Benth.

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Summary: Résumé: Zusammenfassung

Pot and field experiments were performed in Burkina Faso in 1987 and 1988 to evaluate the resistance of selected 'low-stimulant' sorghum (*Sorghum bicolor* (L.) Moench) varieties to the parasitic weed (*Striga hermonthica* (Del.) Benth. In a pot experiment, the variety IS-7777 supported the lowest number and had the latest emergence of *Striga*, compared with the other varieties tested. The varieties IS-14825, IS-6961, IS-7739, IS-14928 and IS-14975 also had significantly lower numbers of emerged *Striga* per pot than the resistant control Framida. The resistance of IS-7777 was confirmed in field experiments, as was that of IS-7739, IS-6961 and IS-14928. However, the yield potential of these poorly adapted varieties was low in *Striga*-infested fields. The varieties IS-14975, IS-14825 and Seguetana Niarabougou exhibited a low susceptibility associated with a grain yield equivalent to that of the other varieties in farm fields infested by *Striga*. As Seguetana is already grown by Sahelian farmers, its use could be recommended in the absence of resistant varieties adapted to Sahelian agroclimatic conditions. The exceptionally high level of resistance exhibited by IS-7777 could be exploited in studies on the genetics and mechanisms of resistance of the host plant to the parasite, as well as in sorghum improvement programmes.

*Sélection de variétés résistantes de sorgho (*Sorghum bicolor *L. Moench) a l'adventice parasite* Striga hermonthica *(Del.) Benth.*

Des essais en pots et en plein champ ont été réalisés au Burkina Faso en 1987 et 1988 pour évaluer la résistance de variétés de Sorgho choisies à l'adventice parasite *Striga hermonthica* (Del.) Benth. Dans un pot expérimental, la variété IS 7777 a supporté le plus faible nombre et a eu la levée la plus tardive de *Striga* en comparaison des autres variétés testées. Les variétés IS 14825, IS 6961, IS 7739, IS 14928 et IS 1497 S également ont eu un nombre significativement plus bas de *Striga* levés par pot que le témoin résistant Framida. La résistance de IS 7777 a été confirmée en expérimentation de plein champ, ainsi que celle de IS 7739, IS 6961 et IS 14928. Cependant le rendement potentiel de ces variétés était faible dans les champs infestés par le striga. Les variétés IS 14975 et IS 14825 et Seguetana Niarabougou ont exprimé une faible sensibilité associée à un rendement en grain équivalent de celui des autres variétés dans des champs d'exploitation infestés par le *Striga*. Comme le Seguetana est déjà cultivé par les agriculteurs sahéliens, son usage pourrait être recommandé en l'absence de variétés résistantes adaptées aux conditions agroclimatiques du Sahel. L'exceptionnel haut niveau de résistance exprimé par IS 7777 pourrait être utilisé dans des études sur la génétique et les mécanismes de résistance de la plante hôte au parasite, ainsi que pour des programmes d'amélioration du sorgho.

*Selektion resistenter Varietäten der Sorghumhirse (*Sorghum bicolor *(L.) Moench) gegen das parasitische Unkraut* Striga hermonthica *(Del.) Benth.*

In Gewächshaus- und Freilandversuchen in Burkina Faso wurde in den Jahren 1987 und 1988 die Resistenz von ausgewählten 'wenig stimulierenden' Varietäten der Sorghumhirse gegen das parasitische Unkraut *Striga hermonthica* (Del.) Benth. untersucht. In einem Gefäßversuch förderte die Varietät IS-7777 im Vergleich zu anderen die geringste Zahl von *Striga* und führte zur spätesten Keimung. Die Varietäten IS-14825, IS-6961, IS-7739, IS-14928 und IS-14975 führten auch zu signifikant geringerer Keimung als bei der resistenten Kontrollsorte 'Framida'. Sowohl für IS-7777 als auch IS-7739, IS-6961 und IS-14928 bestätigte sich die Resistenz in Freilandversuchen. In mit *Striga* verseuchten Feldern waren jedoch die Erträge dieser wenig angepaßten Varietäten niedrig. Die Varietäten IS-14975, IS-14825 und 'Seguetana Niarabougou' erwiesen sich auf Praxisflächen, die von *Striga* befallen waren, als wenig anfällig und hatten vergleichbar hohe Kornerträge wie anderere Varietäten. Nachdem 'Seguetana' bereits von Sahel-Bauern angebaut wird, kann ihr Anbau unter ähnlichen klimatischen Bedingungen empfohlen werden, wenn keine resistenten Sorten zur Verfügung stehen. Die außergewöhnlich hohe Resistenz von IS-7777 könnte sowohl für genetische Untersuchungen über den Mechanismus der Resistenz der Wirtspflanze gegenüber dem Parasiten als auch bei der züchterischen Verbesserung der Sorghumhirse eingesetzt werden.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the most important crops of semi-arid Africa, where it is the staple cereal in the diet of many millions of people, but the parasitic weed *Striga hermonthica* (Del.) Benth. causes significant damage to this crop. Losses of yield amount to many billions of dollars per year (F.A.O., 1986).

The existence in sorghum of varietal differences in resistance to *S. asiatica* (L.) Kuntze has been reported by Saunders (1933). Evidence of some degree of varietal resistance to *S. hermonthica*, based on the number of emerged parasites, has also been presented (Doggett, 1952, 1965; Wilson-Jones, 1953). For many years, a number of research programmes have attempted to identify sorghum varieties resistant to *S. hermonthica* and to transfer this resistance to high-yielding, well-adapted varieties (Andrews, 1970; King, 1975; Obilana, 1983; Ramaiah, 1983). Resistance has often been associated with low yield potential and/or poor grain quality of sorghum (Ramaiah & Parker, 1982). However, little progress has been made in transferring resistance to adapted varieties (Ramaiah, 1987), and small-scale farmers in Africa must still rely on susceptible varieties, with their associated loss of yield. In view of the relative failure of these breeding programmes, there is an urgent need for varieties with very high resistance potential. Such varieties would be useful for the study of the mechanisms and genetics of resistance, as well as for transfer of the resistance to varieties with desirable food quality and stable high-yielding potential under African farm conditions.

Several possible resistance mechanisms have been suggested. Among them, a low level of production of *Striga* germination stimulant by the host roots has been reported (Kumar, 1940; Williams, 1959), the seed of the parasite germinating only when exposed to a stimulant that is exuded by the host under natural conditions. In 1985, 615 sorghum germplasm lines, known for their low production of the germination stimulants of *S. asiatica* in India (ICRISAT, 1981) were screened in pots for their resistance to *S. hermonthica* by Ramaiah in Burkina Faso (ICRISAT, 1986). About 80 of the lines that showed the lowest rates of emergence of *S. hermonthica* were screened again in 1986 (ICRISAT, 1987), and nine that showed promising levels of resistance were selected for the present study. The latter was undertaken in order to identify sorghum varieties that are highly resistant to *S. hermonthica* under the field conditions of Sahelian countries.

Material and methods

Pot experiment

A pot experiment was performed in Kamboinse in 1987, using 12 sorghum varieties (Table 1), including nine known to be low stimulants for

Table 1. Origin and grain colour of the sorghum varieties tested

Variety	Origin	Grain colour
IS-6961	Sudan	White
IS-7739	Nigeria	White
IS-7777	Nigeria	White
IS-8140	Uganda	Reddish brown
IS-14825	Cameroon	Straw
IS-14829	Cameroon	Straw
IS-14928	Cameroon	Light red
IS-14975	Cameroon	White
IS-16184	Cameroon	Light brown
Seguetana	Mali	White
Framida	South Africa	Brown
CK-60B	U.S.A.	White
S-29	Burkina Faso	White

the germination of *S. asiatica* in India (IS-6961, IS-7739, IS-7777, IS-8140, IS-14825, IS-14829, IS-14928, IS-14975 and IS-16184), one susceptible control (CK-60B), one control known to be resistant to *S. hermonthica* (Framida) (Ramaiah, 1984) and one local variety from Mali (Seguetana Niarabougou). Seeds were supplied by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Burkina Faso.

Five sorghum seeds were sown on 7 May in each 22 cm-pot filled with a mixture of *c.* 2 kg of clay soil, 1 kg of sand and 1 kg of farmyard manure. About 150 mg of *S. hermonthica* seeds collected in Kamboinse during October 1986 were mixed in the top 5 cm of the soil prior to sowing. Sorghum was thinned to one plant per pot 13 days after sowing, and watered daily in order to prevent water stress. The number of days to emergence of *Striga* was recorded for each pot. The number of emerged *Striga* was determined 39, 50, 67, 82 and 98 days after sowing. *Striga* plants were harvested 142 days after sowing, dried at 80°C for 48 h, and weighed. A randomized complete block design with 10 replicates was used.

Striga-*infested field experiments*

A trial was conducted on a silty loam in a farm field infested by *S. hermonthica* in Farako-ba during 1987 and 1988. This trial included the same 12 varieties that were tested in pots, except that the susceptible control used in 1987 was the improved local variety S-29, instead of CK-60B.

Planting took place on 14 June 1987 and 4 July 1988. Plots were 5 m long and included four rows spaced 80 cm apart. The seeds were spaced 40 cm apart along the rows. About five seeds were planted in each seed hole, and plants were thinned to two sorghum plants per seed hole 25 days after planting. In 1988, all the test entries were replaced in the two external rows by CK-60B, a susceptible control variety. All observations were made on the two central rows.

Fertilizer was applied before planting, at the rates recommended by the agricultural extension services in Burkina Faso, e.g. 14 kg ha^{-1} N, 10 kg ha^{-1} P and 12·5 kg ha^{-1} K. Plots were hand-weeded twice before *Striga* emergence. Numbers of emerged *Striga* were counted on the two central rows of each plot 102 days after planting in 1987 and 79 days after planting in 1988. The number of days to 50% flowering of sorghum was noted. The panicles were harvested 135 and 131 days after planting in 1987 and 1988, respectively, sun-dried, threshed and the grains weighed. A randomized complete block design with four replicates was used each year.

Statistical analyses

The data were subjected to standard analysis of variance. Where two sets of data were available, combined analysis of annual data was performed. Varieties were compared using the Waller-Duncan test of multiple comparison at $k = 100$ (Waller & Duncan, 1972). *Striga* counts and dates of emergence were analysed after logarithmic transformation [log (datum+1·1)]. Analyses of grain yields of sorghum and dry weight of *Striga* were performed after square-root transformation [(datum $\pm$ 0·5)$^{1/2}$].

Results

Pot experiment

Striga *plants per pot.* The variety IS-7777 supported a significantly ($P < 0{\cdot}0001$) lower number of emerged *Striga* per pot than any other variety (Table 2). No *Striga* were observed on this variety, compared with 41·6 plants per pot for the susceptible control CK-60B. Six of the eight other reportedly '*S. asiatica* low-stimulant' varieties tested supported significantly fewer *Striga* plants than the supposedly resistant control Framida.

Table 2. Mean numbers, days to first seedling emergence and mean dry weight of *Striga* for 12 sorghum varieties grown in pots at Kamboinse in 1987

Variety	No. of *Striga*/pot* (82 days after sowing)	No. of days to first emergence of *Striga**	Dry weight of *Striga*† (g)
IS-7777	0·00 a§	168·0‡ a	0·0 a
IS-14825	2·70 b	118·6 b	10·6 ab
IS-6961	2·60 bc	90·3 c	18·5 bc
IS-14928	5·80 bc	77·9 cde	28·2 cd
IS-7739	5·33 bc	78·0 cde	19·4 bc
IS-14975	5·30 bc	60·0 ef	29·2 cd
IS-16184	6·00 c	83·6 cd	35·9 cde
IS-8140	13·30 d	66·5 cde	42·5 def
IS-14829	28·80 ef	50·0 fg	68·0 f
Seguetana	14·60 d	74·4 cde	29·6 cde
Framida	20·20 de	63·1 def	40·2 def
CK-60B	41·60 f	45·3 g	51·6 ef
Mean	12·24	81·3	31·2
Standard error	3·51	9·1	8·6

*Analyses were performed after logarithmic transformation of data [log (× +1·1)].

†Analyses were performed after square-root transformation of data (weight+0·5)$^{1/2}$.

‡The maximum value of 168 days marks the end of the experiment and indicates that no emergence of *Striga* occurred.

§Mean values followed by the same letter do not differ significantly according to the test of Waller-Duncan at $k = 100$.

Striga *seedling emergence*. Emergence of *Striga* did not occur in IS-7777 pots. The variety IS-14825 supported a significantly ($P < 0·0001$) later emergence of *Striga* than any of the other varieties tested (Table 2). *Striga* emergence in IS-6961 pots occurred significantly later than in Framida pots.

The number of emerged *Striga* per pot at five sampling dates after sowing is shown for each variety in Fig. 1. *Striga* emerged early and profusely in CK-60B and IS-14829 pots, while only a few plants emerged late in IS-14825 and IS-6961 pots. No emergence of *Striga* was observed in IS-7777 pots.

Striga *biomass*. Three varieties, IS-14825, IS-6961 and IS-7739, had significantly ($P < 0·0001$) lower biomass of *Striga* than Framida (Table 2). No *Striga* emerged in IS-7777 pots.

Striga-*infested field experiments*

Striga *counts*. No significant year X variety interaction was observed for the counts of *Striga* ($P = 0·9982$), but counts differed between years ($P = 0·0464$). The 13 sorghum varieties tested can be separated into four significantly ($P < 0·0001$) different classes for the number of emerged *Striga* per plot according to the Waller-Duncan test: very susceptible, moderately susceptible, low susceptible and resistant (Table 3). The resistance of IS-7777 observed in pots was confirmed in the field, with a mean number of 0·09 emerged *Striga* m^{-2} over the 2 years of the experiment, as compared to 31·75 plants m^{-2} in the susceptible local control S-29 plots. The varieties IS-7739, IS-6961 and IS-14928 also showed a high level of resistance. The local

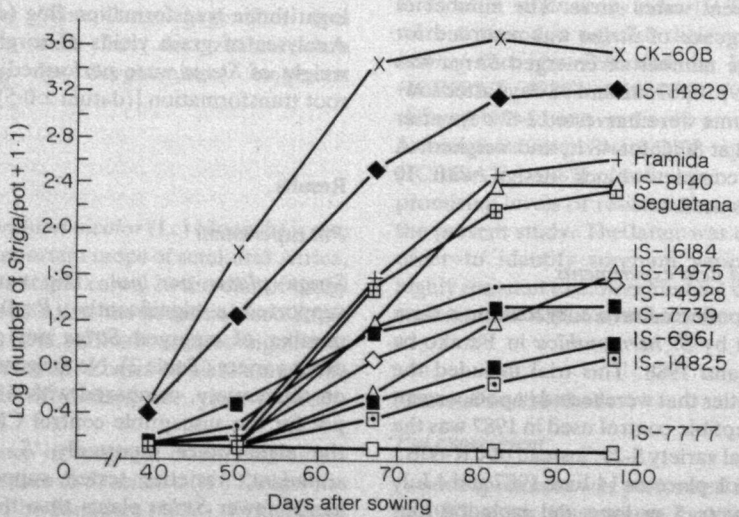

Fig. 1. Mean number of emerged *Striga* per pot at different dates for 12 sorghum varieties at Kamboinse in 1987.

Table 3. Mean number of *Striga* plants, number of days to 50% flowering and grain yield of 13 sorghum varieties in a farm field at Farako-ba in 1987 and 1988

Variety	*Striga* seedlings* (no. m^{-2})	No. of days to 50% flowering of sorghum	Grain yield† (kg ha^{-1})
IS-7777	0·09 a‡	125·5 f	—
IS-14825	1·42 b	79·1 d	985·2 ab
IS-6961	0·31 a	88·5 e	324·2 c
IS-14928	0·50 a	80·4 d	672·1 b
IS-7739	0·34 a	125·0 f	—
IS-16184	9·23 c	68·1 b	771·9 ab
IS-14975	1·97 b	67·4 b	1129·7 a
IS-8140	5·58 c	62·8 a	853·9 ab
IS-14829	18·39 d	75·5 c	994·0 ab
Seguetana	1·20 b	79·6 d	958·6 ab
Framida	7·63 c	74·6 c	1100·0 ab
CK-60B§	19·16	71·3	312·5
S-29¶	31·75	84·8	889·1
Mean	6·01	83·7	838·9
Standard error	2·27	0·7	134·8

*Analyses were performed after logarithmic transformation of data [log (no. *Striga*+1·1)].

†Analyses were performed after square-root transformation of data [(weight+0·5)$^{1/2}$].

‡Mean values followed by the same letter do not differ significantly according to the test of Waller-Duncan at $k = 100$.

§Data for 1 year only (1988).

¶Data for 1 year only (1987).

variety from Mali, Seguetana Niarabougou, had a low susceptibility, and the reportedly resistant check Framida had a moderate susceptibility when compared with the other varieties, on the basis of the number of emerged *Striga*.

Sorghum *yield*. No significant year × variety interaction ($P = 0·5523$) was observed for the grain yield, there being significant differences from one year to another ($P < 0·0001$). Grain yields in fields infested with *Striga* were low, irrespective of the variety (Table 3). The very susceptible, moderately susceptible and low susceptible varieties, with the exception of the susceptible control CK-60B, yielded significantly ($P = 0·0003$) more grain than did the resistant varieties, except for IS-14928. The grain yield of IS-14928 was significantly lower than that of the variety IS-14975 alone. The varieties IS-7777 and IS-7739 were just flowering at harvest time in 1987 and 1988 (Table 3), so no grain could be harvested.

Discussion

The variety IS-7777 showed a very high level of resistance in the pot experiment in 1987. There was no emergence of *Striga* on this variety despite a high general level of infestation. This high level of resistance was confirmed in the field in 1987 and 1988 with a mean of only 0·09 *Striga* plants m^{-2}. Indeed, we observed only one and five *Striga* plants, respectively, out of the four plots in 1987 and 1988. Low production of stimulants for the germination of *S. asiatica* has been reported for this variety, and the same may be true of *S. hermonthica*, although this has yet to be confirmed. It is of particular interest because the low production of stimulants for the germination of *S. asiatica* was reported to be under the control of a single recessive allele in sorghum (Ramaiah *et al.*, 1990). This character could then be easily transferred into elite varieties. Mechanical obstruction to the penetration and establishment of the haustorium may also help to explain this very high degree of resistance (Olivier *et al.*, 1991).

The varieties IS-14825, IS-6961, IS-7739, IS-14928 and IS-14975 also supported a low number of emerged *Striga* in pots. This low infestation was associated in IS-14825 and IS-6961 with a later emergence and a lower dry weight of *Striga* than in the reportedly resistant control Framida. In fact, seven varieties supported fewer *Striga* per pot than did Framida. The resistance of IS-7739, IS-6961 and IS-14928 was confirmed in the field, while the varieties IS-14825 and IS-14975 showed low susceptibility. All these varieties performed better than Framida in the field with regard to resistance to *S. hermonthica*.

Resistance to *Striga* was, however, associated with low grain yield. This problem has already been reported for other varieties resistant to *Striga* (Ramaiah & Parker, 1982) and is also reported for the resistance of many crop species to pathogens and insects. In the present case, the main reason for low yield is that IS-7777 and IS-7739 are late-flowering varieties, and did not reach maturity in either the 1987 or the 1988 growing seasons. Their long growth cycle and photosensitivity render them unsuitable crops for the Sahelian zone. The yield of the variety IS-6961 was significantly lower than that of all of the varieties tested in farm fields with *Striga*, with the exception of the susceptible control CK-60B. The grain yield of IS-14928 in the field was equivalent to that of other varieties, except for IS-14975, but its light-red-coloured grain could result in its rejection by most Sahelian

farmers on account of its unsuitable food quality. Thus no resistant line is acceptable to farmers on the basis of yield and colour of the grain.

Two low-stimulant varieties which show low susceptibility in the field, IS-14975 and IS-14825, also exhibited the highest grain yield. However, the yield was low. The grain of IS-14825 is straw coloured, and that of IS-14975 is white. These two varieties from the Cameroon could in some way be useful in farm fields infested with *Striga*. However, we should mention that they do not show the highest level of resistance to *Striga*, and their food quality has yet to be established.

Another variety, Seguetana Niarabougou, showed low susceptibility in the field and was less infested by *Striga* than the control Framida. Its yield in the field, although low, was not less than that of the other varieties in our study. As many farmers already grow this local variety from Mali, Seguetana Niarabougou appears to be suited to cropping in some *Striga*-infested areas of Sahel. However, as this variety is not completely resistant, its use would not prevent the build-up of the seedbank in the soil, even though it could retard it. Nevertheless, its use could be recommended because of the shortage of well-adapted resistant varieties with good cooking and agronomic qualities available to Sahelian farmers.

In this study, we have identified some varieties with a level of resistance significantly higher than that of Framida, which has been known as a resistant variety for many years. In our opinion, it would be better to classify Framida as tolerant or partially resistant, rather than completely resistant. Framida remains a 'low-stimulant' and high-yielding variety in *Striga*-infested fields, and its use is of interest for some farmers, even though it cannot prevent the build-up of the seedbank in the soil. Many farmers use it despite the brown colour of the grain, particularly for making beer in Burkina Faso and Ghana.

The present study has demonstrated the high resistance of a few sorghum varieties. These varieties could be used in breeding programmes for the improvement of sorghum for resistance to *S. hermonthica*. Among them, the variety IS-7777 showed a particularly high degree of resistance, and its use as a resistant gene source in sorghum improvement programmes should be considered. It could also be used as a resistant control in studies on the genetics and the mechanisms of resistance to the parasitic weed. Even though its agronomic characters are not well-suited to the Sahelian environment, IS-7777 exhibits an exceptionally high level of resistance that renders it the optimum choice for many studies on the resistance of sorghum to *S. hermonthica*.

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