

Habitat site selection, crop damage and oviposition preference by *Coniesta (= Haimbachia) ignefusalis* (Lepidoptera: Pyralidae)

(Keywords: oviposition, diapause, stem-borer, *Coniesta* (= *Haimbachia*) *ignefusalis*, pest management, *Pennisetum glaucum* sub-Saharan Africa)

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Abstract. Studies were conducted during 1986-1988 to investigate habitat site selection, evaluate damage, and study the oviposition preference of *Coniesta ignefusalis* (Hampson) on natural and artificial substrates to improve rearing and management techniques. Millet grain weight was negatively correlated with numbers of stem-borer larval exit and entrance holes. Numbers of diapausing larvae and borer larval holes were positively correlated with the location of internodes on millet stems. Survival of *C. ignefusalis* in dry millet stems is significant when stems were stacked as practised by farmers. *C. ignefusalis* female oviposition occurred mostly within leaf sheaths of green millet plants, rarely on green or dry leaves, and seldom on dry millet stems. Paper substrates rarely received eggs when offered to females in association with green millet stems with attached leaf sheath. The implications of our findings for IPM of *C. ignefusalis* are discussed.

1. Introduction

Coniesta ignefusalis (Hampson) (Lepidoptera; Pyralidae) is a serious pest of pearl millet, *Pennisetum glaucum* (L.) R. Br., a major rain-fed staple food crop for many farmers in sub-Saharan Africa. Female moths reportedly lay their eggs in the leaf-sheath (Harris, 1962) and hatched larvae feed within leaf sheath tissue and then tunnel into stems. Damage caused to millet by developing *C. ignefusalis* larvae is usually similar to that of other cereal stem-borers and depends on both larval and plant developmental stages. Damage on young plants results in stand-loss characterized by early plant death ('dead-hearts'), whereas damage from second or third generations results in tunnelling, disruption of nutrient flow, and both direct and indirect losses as a result of stem breakage, poor or no grain formation, and empty earhead. The life cycle is completed in millet stems. At the end of the rainy season, larvae cease feeding, lose their dark spots and become creamy-white in colour, and then enter facultative diapause in dry millet stems. Larvae in diapause become active again with the onset of next year's rains, when emerging adults oviposit first generation eggs on the new millet crop. Understanding of adult and larval behaviour, and relationships between stem-borer damage and yield losses in millet, are paramount for the development of efficient stem-borer management strategies.

The present experiments were conducted to study the relationship between larval damage and millet grain weight, the vertical distribution of damage and diapausing larvae in

millet stems and diapausing larval survival during the dry season to estimate potential population carry-over. Another aspect of these studies was to develop a better understanding of the ovipositional preferences of *C. ignefusalis* on natural and artificial substrates. This understanding is needed to improve mass-rearing to support breeding for host plant resistance and to improve control techniques.

2. Materials and methods

2.1. Habitat site selection, borer damage and population carry-over

Experimental plots in 1986 were located at N'dounga, a substation of the Kolo Research Station of INRAN (Institut National de Recherches Agronomiques du Niger). A single variety and research site minimized possible differences among plots from soil, variety or weather. The site was planted in hills to the millet variety 'Ex-Bornu' on 25 June. The field was 45 m long × 26 rows, and rows were about 80 cm apart.

After crop emergence, the site was weeded and hills were each thinned to three plants. After the millet was mature and stems were dry, 10 plants were sampled per row. Plants were selected for sampling by using the following criteria: (1) no evidence of attack by the millet head-miner, *Heliocheilus albipunctella* de Joannis (Lepidoptera; Noctuidae), or other panicle-feeding insects; (2) stem was not lodged; (3) panicle was filled with grains and not damaged by birds; and (4) grain mould or other grain diseases were not evident. Excised plants were taken intact to the Kolo laboratory where leaves and leaf sheaths were removed. Plants were separated into classes based on the numbers of internodes on each stem. Stem-borer entries, exit holes and diapausing stem-borer larvae were counted and recorded for each internode. Each panicle was threshed using a mechanical thresher to collect seeds. A sample of 1000 grains was taken from each threshed panicle, and weighed collectively. To maintain consistency with the sample size of 1000 grains per head, plants with less than 1000 grains were not included in the analysis.

To determine the dry-season survival and carry-over of *C. ignefusalis* populations in millet stems, a 1987 experiment was conducted at N'dounga in a millet field planted to Ex-Bornu on 3 July as described above for Kolo in 1986. During the week

of 2 December 1987, after the millet was harvested and stems were dry, a farmer used local farmers' practices and excised and stacked all millet stems in the field. All excised stems were placed in a large single stack, and then a random sample of 250 stems was removed from the stack. All remaining stems were taken to a nearby farmer's house where the farmer placed them horizontally in a large stack. The previously sampled 250 stems were then dissected within 3 days of sampling to count the numbers of living or dead larvae. During the week of 9 April 1988, a second sample of 250 stems was taken from the large stack of stored stems near the farmer's house, and these were dissected to count the numbers of dead or living larvae.

2.2. Oviposition preference

2.2.1. Field studies. These experiments followed the population dynamics of eggs, larvae, and pupae in 1986 and 1987 at N'dounga in plots planted as described above. Weekly samples of about 200 plants were taken to inspect plants for eggs, larvae and pupae. The number of eggs and their location were recorded throughout the study to understand the preference of moths to oviposit on the different parts of the millet.

2.2.2. Laboratory studies. During laboratory studies, different types of substrates were exposed to females of *C. ignefusalis* to determine further the sites for oviposition. Four laboratory studies (I–IV) were conducted. Oviposition chambers were constructed from 3-81 Fonda^R paper cylinders about 16 cm in diameter. The floor of each chamber was covered with about 5 cm of sandy soil and dampened with tap water to increase soil rigidity and hold the test substrates. All substrates were about 15 cm in length, and were positioned vertically with about 10 cm of substrate above the soil line and 5 cm below. The mix of substrates sought to examine the ovipositional attractiveness of plant material versus non-plant material to improve rearing technique.

Substrates exposed in Study I consisted of sections of green millet stem with associated leaf sheath, waxed paper, and paper towelling. The waxed paper and paper towelling substrates were each a single sheet rolled to simulate a millet stem. *C. ignefusalis* adult moths were obtained from larvae reared in the Kolo laboratory on artificial diets F9777 or F9782 (Bioserv. Inc., Frenchtown, New Jersey, USA). For a given test, all moths used were from larvae reared on the same diet. Three male/female pairs of *C. ignefusalis* moths were placed in each oviposition chamber (replicate) and the experiment was replicated seven times. The chamber opening was covered with nylon-screening (9 mesh per cm) secured to the chamber to prevent moth escape. A small quantity of cotton was soaked with a 20% solution of glucose and water and placed on the nylon-screening to serve as a food source for the moths. The moths were held in these chambers at ambient temperatures (27–35°C) and relative humidity (49–65%). After 4 days, the moths and substrates were removed, and the eggs on each substrate were counted and recorded. Substrates in Study II consisted of sections of green millet stems with connected leaf sheath, single green millet leaves, and single dry millet leaves. One male/female pair of *C. ignefusalis*

was placed in each oviposition chamber with substrates and the experiment was replicated 19 times. These substrates permitted us to determine *C. ignefusalis*'s ovipositional preference for selected plant parts. Study III exposed sections of green millet stems with and without connected leaf sheaths to newly unmated females (one in each chamber). The experiment was replicated 14 times. This Study provided information on the role of the leaf sheath on the moth preference for oviposition. Study IV exposed sections of green and dry millet stems with the associated leaf sheaths to females, as described for Study III. The experiment was replicated three times. Study IV supplied information on the relative attractiveness of dry versus green stems.

2.3. Data analysis

A correlation analysis (Pearson's Products-Moment correlation) was done using PROC CORR (SAS Institute, 1985a) to test the relationship between grain weight and stem-borer larval holes, stem-borer damage in relation to internode position on stem, and stem-borer habitat site in relation to internode position on millet stem. A *T*-test (SAS Institute, 1985b) was used to compare mean numbers of live larvae in pre- and post-storage dry stems. Data on oviposition substrate experiments were transformed and analysed using an analysis of variance (ANOVA), and mean numbers of *C. ignefusalis* eggs among substrates were separated using Duncan's New Multiple Range Tests (SAS Institute, 1985b). For data on oviposition preference, replicates in which oviposition did not occur on any of the exposed substrates were not included in the analysis. Thus, data analysis included all replicates for Studies I and IV, and 13 and 9 replicates for Studies II and III, respectively. Data from oviposition studies were transformed before analysis to stabilize variances, using a natural log transformation as follows: $Y_T = \log(Y + 1)$, where Y_T was the transformed value, and Y was the number of eggs per substrate per replication.

3. Results and discussion

3.1. Habitat site selection and borer damage and population carry-over

Correlation coefficients between grain weight and *C. ignefusalis* damage (borer holes) were negative for all classes of plants (Table 1, Figure 1(A)–(E)), and statistically significant for the majority of plants bearing 10 internodes per stem ($r = -0.23$, $P = 0.01$) (Table 1, Figure 1(C)). These coefficients were nearly significant for plants with eight internodes per stem ($r = -0.49$, $P = 0.06$) (Table 1, Figure 1(A)). These results indicate that grain weight loss was an effect of stem-borer tunnelling in millet stems. The correlation was not significant for plants with 9, 11, and 12 internodes per stem (Table 1, Figure 1(B), (D) and (E)), an outcome possibly a result of the small numbers of plants within these categories, or of infested plants compensating for borer damage. In previous studies on the effects of other stem-borers on yield, number of borer holes or amount of tunnelling reportedly had a curvilinear relationship with yield, depending on the time of borer attack and growing conditions (Walker, 1981). Results

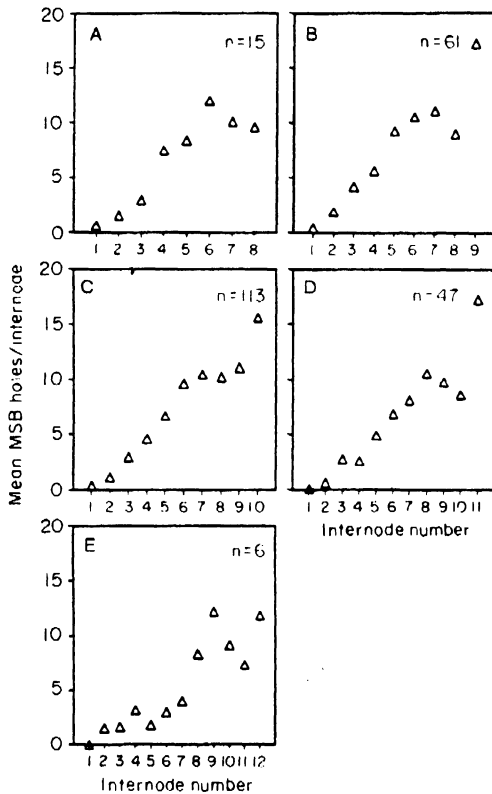


Figure 3. Locational distribution of millet stem borer larva holes in millet stems with 8 internodes (A), 9 internodes (B), 10 internodes (C), 11 internodes (D), and 12 internodes (E).

from the base, and the number of exit holes decreased in the top internodes. Findings from the present studies generally show a similar trend, although in current studies counts of borer holes combined both exit and entry holes.

For all samples (100%), correlation coefficients between damage (borer holes) and the location of internodes on stems were significantly positive ($P < 0.001$, Table 1). Therefore, damage increased and became more severe from the lower to the upper stem internodes (Table 1, Figure 3(A)–(E)). The combination of both entry and exit holes could have contributed to the trend, as many larvae may have caused damage, especially late generation larvae with an overlap in damage from the first generations. As described by Gahukar in 1990, this pattern could also be attributed to larval feeding behaviour. Many larvae may have fed and tunnelled in stems in an upward fashion. Furthermore, it is also likely that there are more stem-borer larvae in the second generation which feed predominantly in the upper sections of the host plant.

The mean number of diapausing *C. ignefusalis* larvae in millet stems sampled in the week of 2 December 1987 was significantly greater than that sampled in the week of 9 April 1988 ($P < 0.001$) (Table 2). The mean number of diapausing *C. ignefusalis* larvae decreased from 1.36 borers per stem ($n = 341$ viable borers) in 1987, to 0.37 borers per stem ($n = 93$ viable borers) in 1988 (Table 2). A decline in numbers from 341 to 93 (73%) suggests high mortality for diapausing

C. ignefusalis larvae. However, 93 living larvae in 250 stems remains a substantial reservoir of live borers, considering the number of dry millet stems (usually > 1000) typically stacked by farmers in or near villages.

Harris (1962) reported that greatest survival of *Busseola fusca* (Fuller) and *C. ignefusalis* occurred in stems stacked in the shade of a tree. Therefore, it is likely that survival of *C. ignefusalis* in excised millet stems is affected by how and where stems are stacked by farmers. Exposure of millet stems to direct sunlight could therefore increase *C. ignefusalis* mortality. Lukefahr *et al.* (1989) reported that the survival of *C. ignefusalis* was greater in stems left standing in the field than in stems cut and left on the soil surface or stems buried 5 cm below ground. They reported 100% borer mortality in stems on the soil surface, 99.7% in stems buried 5 cm below ground, and 95% in stems left standing in the field. Most mortality was attributed to heat stress and possibly desiccation, as temperatures above 55°C were recorded from stems left on the soil surface (Lukefahr *et al.*, 1989). The mortality achieved during our studies is 73%, and thus much lower than reported above. The difference in mortality probably arises because the practice of stacking the stems has a shading effect, whereas spreading the stems increases their exposure to heat from solar radiation. Thus, stacking of millet stems seems likely to reduce the mortality of *C. ignefusalis* and increase population carry-over. Ajayi (1990) suggested destroying or composting millet residues after harvest or spreading out millet stems in thin stacks outside the shade to reduce population carry-over. Because the farmers often use the millet stems for many purposes, recommendations to destroy stems or clean fields before the rainy season would still be difficult to implement. However, assistance in finding alternative material for building houses in rural areas should reduce the need to use stems. Thus, the management of millet crop residues can be an effective component in the reduction of *C. ignefusalis* population carry-over.

3.2. Oviposition preference

Table 3 contains results of oviposition site selection in Studies I–IV. Mean numbers of *C. ignefusalis* eggs were significantly different among substrates in Study I ($F = 79.8$, d.f. = 2,12, $P < 0.001$). Greatest *C. ignefusalis* oviposition (98.8%) occurred on green millet stems with leaf sheaths. Very few eggs (1.2%) occurred on waxed paper, and none were recovered from the paper towelling. Clearly, *C. ignefusalis* did not oviposit on the artificial substrates when millet was present. In Study II, significantly greater *C. ignefusalis* oviposition occurred on green millet with attached leaf sheaths (99.5%) versus dry leaves (0.3%) or green millet leaves (0.2%) ($F = 15.5$, d.f. = 2,24, $P < 0.001$). The mean numbers of *C. ignefusalis* eggs on green leaves were not statistically different from those on dry leaves (Table 3). Nearly significant differences ($P < 0.08$) were detected among mean numbers of *C. ignefusalis* eggs between substrates. Although differences were not significant at the 5% probability level, 91.2% of eggs occurred on substrates consisting of green stems with attached leaf sheaths versus 8.8% for green stems without leaf sheaths (Table 3). Lack of significance at 5% level could be the result of the high variability in numbers of eggs per

Table 1. Correlations between millet stem borer damage and grain weight, diapausing larvae and position of internodes on stems, and damage and position of internodes on stems

Number of internodes per stem	Number of plants sampled	Correlation coefficients ^a		
		Grain weight and entry/exit holes	Diapausing larvae and height of internode ^b	Borer entry/exit holes and height of internode ^b
8	15	0.49NS	0.13NS	0.42***
9	58	0.04NS	0.12** (57)	0.54*** (61)
10	112	-0.23*	0.16*** (108)	0.53*** (113)
11	47	0.17NS	0.24*** (42)	0.52***
12	6	0.44NS	0.20NS (5)	0.54***

^aPearson's Product-Moment; NS, not significant ($P > 0.05$); *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

^b(). The number of plant samples for the given class of internodes when different from that in column two.

from the present studies showed a negative linear relationship between millet grain weight and *C. ignefusalis* larval holes.

For most plants (93.4%), a significant positive correlation existed between height of internode from ground level and habitat site selected by larvae in the internode (Table 1). Figure 2(A)–(E) shows that in most cases a greater number of diapausing *C. ignefusalis* larvae were located in internodes at the middle of stems and mean numbers of diapausing *C. ignefusalis* larvae declined in the three topmost internodes. The decrease was perhaps related to the smaller diameter of those internodes at the top of the millet stem. Furthermore, because damage was most frequent in the upper internodes

(Figure 3(A)–(E)), some larvae may have moved from upper internodes to the larger middle internodes before entering diapause. Some larvae may have fed within the upper internodes but later died before maturity when the stem became less suitable for feeding.

During studies conducted in Senegal, Gahukar (1990) reported that vertical distribution of *C. ignefusalis* was influenced by feeding site, plant height, stem thickness, internode and stem condition. He reported that most larvae occurred at a height of 70–80 cm when plant height ranged from 40 to 130 cm. This pattern was attributed to larval feeding behaviour. Larvae were numerous up to the eighth internode

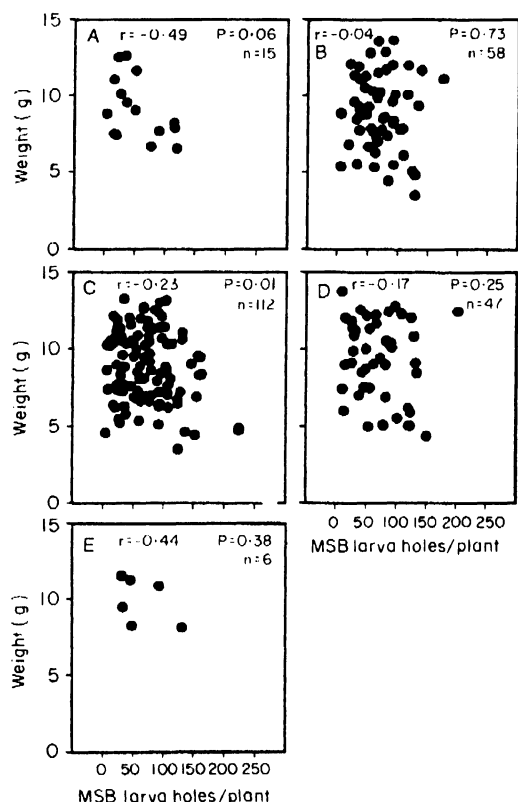


Figure 1. Correlations between grain weights and millet stem borer damage to millet plants with 8 internodes/stem (A), 9 internodes/stem (B), 10 internodes/stem (C), 11 internodes/stem (D), and 12 internodes/stem (E).

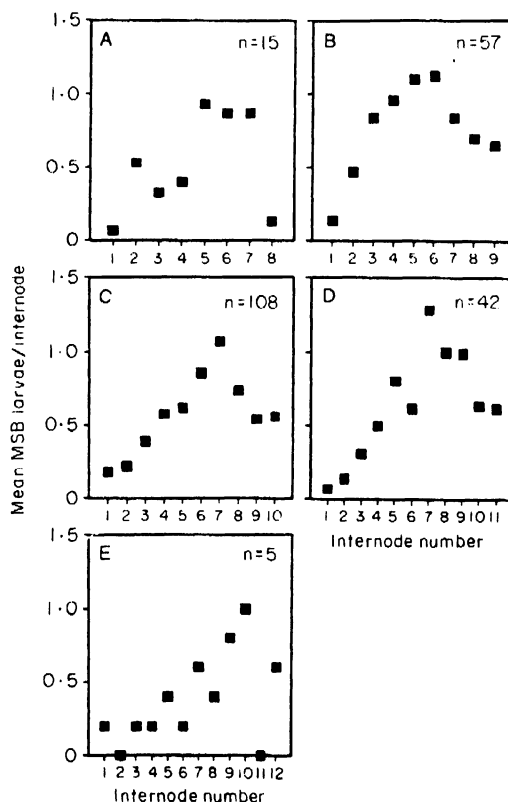


Figure 2. Locational distribution of diapausing millet stem borer larvae in millet stems with 8 internodes (A), 9 internodes (B), 10 internodes (C), 11 internodes (D), and 12 internodes (E).

Table 2 Mean densities of diapausing millet stem borer larvae per stem in December soon after removal from field, and in April after storage in a village

Sample date	Number of stems sampled	Total larvae collected	Number of dead larvae	Number of living larvae	Mean (SE) living ^a larvae per stem
2 December 1987	250	347	6	341	1.36 (0.12) a
9 April 1988	250	127	34	93	0.37 (0.05) b

^aMeans followed by the same letter in a column are not significantly different at $P = 0.05$ (T -test, SAS Institute 1985b)

Table 3 Ovipositional preference of the millet stem borer in the laboratory when provided with different substrates^a

	Substrates	Total eggs/ substrate	% total eggs in a test	Mean (SE) eggs/ substrate ^d
Study I ^c	Green millet stems	2080	98.8	297.1 (78.1) a
	Waxed paper	25	1.2	3.6 (3.4) b
	Paper towelling	—	0	0
Study II ^c	Green millet stems	1056	99.5	81.2 (29.0) a
	Dry leaves	3	0.3	0.2 (0.2) b
	Green leaves	2	0.2	0.1 (0.1) b
Study III ^d	Green millet stems with leaf sheaths	103	91.2	11.4 (5.8) a **
	without leaf sheaths	10	8.8	1.1 (0.5) a
Study IV ^e	Green millet stems	100	100	33.3 (31.8)
	Dry millet stems	0	0	

^aFor a given study, means within a column followed by the same letter are not significantly different ($P < 0.05$, SAS Institute, 1985b). ** $P < 0.08$. ANOVA not performed for study IV.

^bData was transformed as $\log(y + 1)$ before analysis.

^cANOVA, Duncan's New Multiple Range Test (NMRT) (SAS Institute, 1985b).

^d T -test (SAS Institute, 1985b).

^eLeaf sheath present on stem substrates.

female, and the number of replications for the tests; numbers of *C. ignefusalis* eggs on green millet stems with leaf sheaths were 10-fold (91.2% of eggs) greater than on stems without attached leaf sheaths. In Study IV, *C. ignefusalis* oviposition occurred on green millet stems with leaf sheaths, but did not occur on dry millet stems even when associated with leaf sheaths (Table 3). Thus, *C. ignefusalis* strongly preferred green stems for oviposition versus dry stems when leaf sheaths were present on both substrates. This indicates that moisture could also play a role in the selection by *C. ignefusalis* for an oviposition substrate.

Results from the present study are consistent with the senior author's field observations in 1986 and 1987 on oviposition sites by *C. ignefusalis*. During these two years, a total of 3954 plants of different stages were sampled from four plots, and 4672 *C. ignefusalis* eggs were collected (Table 4). All eggs collected were located in leaf sheaths of green millet stems or green tillers, although dry stems and tillers were available in the plots. *C. ignefusalis* oviposition in leaf sheaths could reduce egg mortality by reducing exposure to certain natural enemies or to adverse weather. Field observations have shown that newly hatched larvae do not readily enter millet stems, but feed within leaf sheath tissues during the first few days prior to entering stems.

In summary, a negative correlation was detected between grain weight and *C. ignefusalis* entry/exit holes. Diapausing *C.*

ignefusalis larvae were present in all internodes of the millet stems. A positive correlation existed between *C. ignefusalis* entry/exit holes and the position of internodes on stems. Although many diapausing *C. ignefusalis* larvae died during the dry season, the number of surviving larvae is large enough to cause severe infestation problems the following season if stems are stacked as practised by farmers for multiple-purpose use. Because *C. ignefusalis* larvae occur in all stem internodes, residual populations of larvae in dry-season stems and subsequent damage to next season millet could be minimized or reduced by discouraging farmers from stacking which provides shade and separation from soil heat or using millet stems in or around villages which are often close to fields of new crops.

C. ignefusalis females prefer green plant matter as an oviposition substrate over either dry plant or non-plant material, and green millet stems with connected leaf sheaths versus those without leaf sheaths. *C. ignefusalis* oviposition was most often associated with leaf sheaths where eggs were concealed against the stem than on exposed substrates such as dry or green leaves. These results are similar to *C. ignefusalis* field oviposition where eggs occur in stem leaf sheaths of green millet plants. These studies should be useful in improving rearing of *C. ignefusalis*. Furthermore, different leaf sheath morphologies and attachments can subsequently be studied to explore the potential use of such characteristics

Table 4 Observations on oviposition site preference by *C. ignefusalis* in the field during 1986 and 1987

Year	Number of eggs collected from					Total
	Total plants sampled	Green stems with leaf sheaths	Dry stems with leaf sheath	Green leaves	Dry leaves	
1986	2031	4041	0	0	0	4041
1987	1923	631	0	0	0	631

in breeding for resistance such as non-preference for oviposition by female *C. ignefusalis*.

Acknowledgements

We thank the 'Institut National de Recherches Agronomiques du Niger' (INRAN) in Niger for providing research facilities, Djibo Kondo for his technical assistance, and anonymous reviewers for their very useful and constructive comments. This research was supported by the USAID Grant DSAN/XII/G-0149 through the International Sorghum/Millet Collaborative Research Support Program (INTSORMIL) and the Texas Agricultural Experiment Station (Texas A&M University System). This manuscript was approved as a journal article JA No. 1523 by ICRISAT.

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