ECOLOGY OF EURYSTYLUS OLDI (POPPIUS) (HEMIPTERA: MIRIDAE): A PEST OF SORGHUM

BY

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DECLARATION

I hereby declare that this thesis has been written by me, that it is a record of my own research work. It has not been presented before in any previous application for a higher degree.

19. 02. 97

Jacques Beyo

Date

The above declaration is confirmed.

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CERTIFICATION

This thesis entitled "Ecology of *Eurystylus oldi* Poppius (*Hemiptera: Miridae*) a Pest of Sorghum", by Jacques Beyo meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contributions to scientific knowledge and literary presentation.

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To

My wife, Tanduomi Marguerite, my mother, Dekari Lassane and my father Kanmi

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ABSTRACT

Eurystylus oldi (Poppius) which was considered to be a minor pest of sorghum, is now a real constraint to sorghum production in West and Central Africa. Field and laboratory experiments were conducted at Samaru (Zaria) on the insect's biology, population dynamics, host range and dry season survival, as well as to screen several sorghum cultivars for sources of resistance. Sorghum cultivars NR 71213 and ICSH 89009 NG were tolerant of E. *oldi,* with reference to grain yield, 1000-grain weight and floaters. Pre-oviposition period for female insects was 6+0.63 days. Eggs hatched after 4.25±0.5 days (for males) and 4.83±0.75 days (for females). There were five nymphal instars on sorghum. Mean longevity from egg to adult was 50±5.03 days for males and 50+3.33 days for females. Adult insects mated around 6 a.m. In 1994 and 1995, the population of *E. oldi* nymphs and adults peaked in the last week of September. Pigeon pea was found to be an alternative host of the insect.

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Chapter 1

INTRODUCTION

Head bugs have been considered for a long time as minor pests of sorghum (Risbec, 1950; Appert, 1957), but recently have become key pests of sorghum, particularly of improved sorghum cultivars (Sharma *et al.*, 1992, Doumbia 1992, Ajayi and Tabo, 1995). Among head bug species damaging sorghum, mirid bugs are the most important in number and levels of damage. A collection of seventeen species made in Samaru, Nigeria showed that 80% of the bugs were mirid bugs (Nwanze, 1985).

Calocoris angustatus (Lethiery), *Creontiades pallidus* (Rambur), *Campylomma* spp and *Eurystylus immaculatus* (Odhiambo), now called *Eurystylus oldi* (Poppius) are the most important mirid bugs threatening sorghum production. Sharma (1985) reported that *E. oldi* is predominant in Africa while *C. angustatus* predominates in India.

Yield losses of up to 86% have been attributed to *E. oldi* (ICRISAT, 1990; Ajayi and Tabo, 1995). This uprising sorghum pest is largely unknown and neglected. An international consultative workshop on panicle insect pests of sorghum and pearl millet held in Niamey (4-7 October, 1993) firmly recommended:

- Clear identification of the complex of the bugs in Africa.
- Additional studies on biology and ecology of *E. (immaculatus) oldi* in West Africa, and
- Surveys on farmers' fields to assess crop losses and determine its natural enemies.

The current study is in line with these recommendations.

Objectives

The present study focused on the following aspects of *E. oldi*.

1. Biology and Bionomics

The objective was to collect information about the biology and population dynamics of the insect so as to understand its life history which is a fundamental element in designing an efficient control strategy (Ghosh, 1989).

2. Host Range

Proper knowledge of the host range of *E. oldi* is necessary for an understanding of its strategies for surviving unfavourable conditions during the off season. This part of the study involved an investigation of alternative host plants that could harbour the insect in the absence of sorghum plant.

3. Survival in the Off-Season

This aspect of the study involved finding out where and how the insect survives off-season harsh conditions. This intended to contribute to the knowledge of initial points of migration of the insect to infest field crops.

4. Host Plant Resistance

The objective was to screen several elite breeders' sorghum lines for sources of resistance to *E. oldi*.

Chapter 2

REVIEW OF LITERATURE

2.1 Sorghum Plant

Sorghum (*Sorghum bicolor* [Moench]) is mainly grown in tropical and sub-tropical areas of the world. It is extensively grown in India, Africa, China and in limited areas of Southern European countries, Japan, Korea, Central and South America, United States of America and Australia (Nagur, 1990).

It is difficult to determine when and where sorghum was first domesticated (de Wet *et al.*, 1970). Cultivated sorghum probably arose from *Sorghum verticilliflorum* which is usually found in its area of domestication, in opposition to *Sorghum arundinaceum* which is a grass of tropical forest and *Sorghum aethiopicum* and *Sorghum virgatum* found in desert regions (House, 1985). Africa is considered to be the center of origin for the cultivation of sorghum with Abyssinia (Ethiopia) as its actual place of origin (Nagur, 1990).

From Abyssinia, sorghum extended along river Nile to the near East and across India to Thailand. Sorghum was probably introduced to Arabia as early as the Sabian Empire (1000 to 800 B.C.) and later spread to the neighbouring regions through the trade routes (House, 1985). Similarly, House (1985) considered that sorghum was introduced to Italy from India and reached China through India. However, sorghum is relatively new to the Americas. It was first introduced into the United States of America in 1857 and is now an important crop in the western states (Doggett, 1965).

Sorghum has been classified in various ways but the most detailed classification was made by Snowden (1955) whose work stands as a tremendous contribution to science. Snowden described 31 cultivated sorghum species and 17 related wild species. Harlan and de Wet (1972) developed a simplified classification for the cultivated sorghum. They partitioned 28 cultivated species and their closest relatives into 15 races with five basic races and ten hybrid races. The basic races include:

- bicolor
- guinea
- caudatum
- kafir and
- durra

The hybrid races are:

* guinea-bicolor
* caudatum-bicolor
* durra-bicolor
* kafir-bicolor
* guinea-caudatum
* guinea-kafir
* guinea-durra
* kafir-caudatum
* kafir-durra
* durra-caudatum

This simplified classification is very important to breeders and the races are easily identified through the mature spikelets only.

2.2 Importance and Uses of Sorghum

Sorghum is a very important crop in the diets of millions of people, particularly in Asia and Africa where over 90% of the sorghum produced is used for human consumption (Swindale, 1982). Sorghum is also important in other parts of the world particularly in the Americas.

Among the major cereal crops, sorghum and pearl millet (*Pennisetum glaucum*) tolerate more drought and could be grown under rather severe conditions (300mm rainfall/year) and therefore constitute good substitutes to rice, wheat and maize which are more exacting in their water requirements and could not be grown under such conditions. Although sorghum responds positively to fertilization, it could be produced on soils of low fertility and still give some reasonable grain yield (Singh and Ndikawa, 1989). Therefore sorghum constitutes an important crop for resource-poor farmers.

Sorghum constitutes an important source of energy for many people and is used in various ways. Traditional uses of sorghum include: unleavened bread, leavened bread, thick porridge, thin porridge, boiled sorghum, snack foods, steam cooked foods and alcoholic and non-alcoholic beverages (Rooney and Murty, 1981). Grain sorghum is also used as feed for animals. The stem and foliage are commonly used for green chop, hay, silage and pasture. In some areas the stem is used as building material. Detailed information about various methods of sorghum consumption have been given by Vogel and Graham (1979).

Grain sorghum also has some promising industrial uses and constitutes a good substitute to other cereals like wheat and barley for certain industrial activities, particularly when these other cereals are not readily available. A symposium (ICRISAT, 1991) jointly organised by ICRISAT, Kano and IAR, Zaria, at Kano (4-6 December, 1989) dealt with the issue. That symposium revealed that:

- Sorghum grains have good and economic milling characteristics following conclusive trials made by the Northern Nigeria Flour Mills Ltd (Obiana, 1990).
- Sorghum could be profitably used in making composite flour products of very high nutritional qualities such as bread, biscuit and snacks (Aluko and Olugbemi, 1990, Olatunji and Koleoso, 1990).
- Sorghum could be used for malting and brewing. Aisien (1990) reported that the ban on the importation of barley in 1988 forced the brewing industry in Nigeria to use sorghum and maize as raw materials for lager beer production.
- Non-alcoholic beverages and weaning foods could be industrially produced from sorghum. Sorghum grains with golden-yellow color and low tannin levels are preferred for malt extraction (Solabi, 1990).
- Sorghum grains could be used as a major component of animal feeds although high tannin sorghum grains are not efficiently utilized by monogastric animals (Umunna and Alawa, 1990).

Baidu-Forson and Ajayi (1995) revealed that Nigeria's ban on importation of major cereal grains led to the replacement of barley with sorghum in the production of lager beer, stout, malt-based drinks and weaning foods.

2.3 Constraints to Sorghum Production

Sorghum possesses a rather high yielding potential comparable to those of maize, rice and wheat. House (1985) reported that yields of 11,000 kg/ha could be obtained when moisture is not a limiting factor. Unfortunately yields from farmers' fields in Cameroon range from 500 kg/ha to 1500 kg/ha (Singh and Ndikawa, 1989). The following factors are frequently incriminated as causing low yields of sorghum.

(a) Low and erratic rainfall distribution over a very short rainy season, which results in frequent moisture stresses. In fact most of the world's grain sorghum production occurs in semi-arid or arid areas where moisture stresses, including water logging, are very common.

(b) Low soil fertility and absence of use of mineral fertilizers occur in the majority of farmers' fields. Deficiencies of major nutrients like nitrogen, potassium and phosphorus are commonly observed and in most cases crop residues are removed from the fields, thus increasing the problem (Singh and Ndikawa, 1989).

(c) Weeds constitute a big problem to sorghum production. Due to labour shortages during the peak period of farming, farmers are not able to adequately control weeds which in most cases results in yield loss.

(d) Diseases are also important limiting factors to sorghum production. Major sorghum diseases include: anthracnose, downy mildew, grain molds, stalk rots, smuts, rusts, foliar diseases and Striga which is a serious problem in some parts of Africa (ICRISAT 1978, Frederiksen, 1982).

(e) Insect pests constitute one of the most important limiting factors to sorghum production. Losses estimated to 565 million dollars per year have been attributed to sorghum insect pests (Nwanze, 1985). Davies (1982) qualified sorghum as the most favourite cultivated plant as food for insects through the ages. Jotwani *et al.* (1980) and Seshu and Davies (1979) reported over 150 insect species as potential sorghum pests. Major insect pests of sorghum according to ICRISAT (1983) and Sharma (1993), include:

* Stem borers - *Chilo partellus* Swinhoe
  - *Busseola fusca* Fuller
  - *Sesamia* spp.
  - *Eldana saccharina* Walker
* Shoot fly - *Atherigona soccata* Rondani
* Sorghum midge - *Stenodiplosis* (*Contarinia*) *sorghicola* Coquillet
* Armyworms - *Spodoptera frugiperda* Smith
  - *Mythimna separata* Walker
* Head caterpillars- *Helicoverpa armigera* Hubner
* Head bugs - *Peregrinus maidis* Ashmead
  - *Poophilus costalis* Walker

- *Locris rubens* Erichson
- *Campylomma* spp.
- *Eurystylus oldi* (Poppius).

2.4 Taxonomy of *Eurystylus oldi*

Eurystylus is a mirid bug of the order Hemiptera. Until recently, its taxonomy caused problems to a number of workers dealing with it. It was not certain whether the head bug of sorghum in West Africa was *E. marginatus*, *E. rufucunealis*, *E. bellevoyei or E. immaculatus* (Doumbia, 1992). ICRISAT (1995) in the proceedings of the "International Consultative Workshop on Panicle Insect Pests of Sorghum and Pearl Millet" recommended research on the taxonomy of *Eurystylus* in order to resolve the confusion. Today there is no more doubt. Stonedhal (1995) has confirmed that the sorghum head bug in West Africa is *E. oldi* (Poppius).

Taxonomic features of this bug according to Odhiambo (1958) and Doumbia (1992), are as follows:

Male insect

E. oldi shows great polymorphisim in shape and colour between the male and female insects. The male *E. oldi* has antennae with laterally compressed segments. The first segment of the antenna is thick and shorter than the frontal length of the head and the lateral margin of the pronotal disc. The second segment is very thick towards its apex. Segments III and IV are rather thin and weakly spindle shaped. The pronotum has straight lateral margins. The calli are flat with posterior margins marked with a deep furrow. The disc and calli are finely transversely rugose. The scutellum is very convex and punctured. The head is not pubescent but the hind femora is densely pubescent with black tubercles on tibiae. The eyes are very large and convex. The rostrum extends to the middle of the mesocoxa with segment I reaching the middle of the probasisternum.

The entire body length of the male is about 5.4 mm (Odhiambo, 1958). The body colour varies with that of the grains it infests and with the different parts of the body. Yellowish, brownish and even reddish colours are observed in adult and nymph populations. The head, rostrum and antennae are usually yellow. The antenna is darker towards its apex. The scutellum and pronotum are also yellow. The legs are yellow with brown to reddish spots on the femora.

Female insect

The head of the female appears shorter from the side. Antennal segment I is more compressed laterally compared to that of the male insect. The basal margin of the pronotum is sinuate and the pronotum itself is punctured. The female insect is larger than the male insect (5.9 mm versus 5.4 mm long for female and male insects, respectively). The female has a long chitinized ovipositor that is as long as the abdomen. The female *E. oldi* is usually paler in colour than the male. The antennae and pronotum are yellow.

2.5 Distribution

E. oldi is as widely distributed as its host plant which covers the arid and semi-arid areas of the world. First identified by Poppius (1912) and redescribed by Odhiambo (1958) in Uganda, East Africa, *E. oldi* was reported in West and Central Africa by Ratnadass (1991), Ratnadass *et al.* (1991), Sharma *et al.* (1991), Doumbia (1992), in Asia by Sharma (1985), Sharma and Lopez (1991), Sharma *et al.* (1992) and Gahukar (1991) and in America by Teetes (1985).

The relative abundance and damage on sorghum plants is not the same all over its area of occurrence. *E. oldi* is predominantly present in West Africa where its increasing population in recent years constitutes a serious problem to sorghum production (Gahukar *et al.*, 1989, Doumbia and Bozi 1989, McFarlane 1989, Steck *et al.*, 1989, Doumbia and Teetes 1991, Doumbia 1991, Ratnadass *et al.*, 1991 and Ratnadass *et al.*, 1992).

However, an extensive survey needs to be conducted on farmers' fields in areas where *E. oldi* is a major problem to get a real picture of its distribution. Such a survey has been initiated in West and Central Africa by ICRISAT, Nigeria (ICRISAT, 1994, 1995).

2.6 Biology and Bionomics

In recent years some progress have been made in the knowledge of the biology of *E. oldi*. Some works done by Doumbia (1992), ICRISAT, Nigeria (1994) and Ratnadass *et al.* (1994) on the biology of this bug have shown that nymphal development passes through five instars with differences in the duration of the different instars as shown in Table 1.

According to Ratnadass *et al.* (1994), the female *E. oldi* inserts its eggs into developing sorghum grains at the milk stage. The creamy white eggs hatch in 5 to 7 days. There are five nymphal instars. The nymphal stage lasts for about 6 to 11 days. Detailed studies carried out at ICRISAT, Nigeria (1994) revealed that adult longevity was about 25.75 days for the male insect and 21.68 days for the female. The mean number of egg laid per female was 248±89 while the maximum number of eggs per female was 517. Egg hatch was maximum at 4 to 12 days after egg laying.

Doumbia (1992) described *E. oldi* egg as whitish, sword shaped with the truncated end equipped with an operculum. The eggs are inserted into the grains in such a way that the truncated end faces outward. During hatching the nymphs simply push the operculum to get out. The newly emerged nymphs are easily recognized by their large and red eyes.

The above biological studies showed that the population of *E. oldi* could be a very dynamic one. Several generations could be completed on the same crop and over a single cropping season, particularly in areas where farmers adopt different planting dates and/or mix sorghum cultivars with different maturity cycles. The late maturing or late planted sorghum will surely suffer heavy infestation from *E. oldi*.

Table 1. Durations of nymphal instars of *E. oldi*

Nymphal stage	Duration (days)	
	ICRISAT, Nigeria (1994)	Ratnadass *et al.* 1994
1st Instar	2.06	1-3
2nd Instar	1.00	1-2
3rd Instar	0.98	1-2
4th Instar	1.02	1-3
5th Instar	2.24	1-3
Egg-adult	12.62	-

Source: Compiled from ICRISAT, Nigeria annual Report for 1994, and Ratnadass et al., 1994.

2.7 Damage to Sorghum Plant

As mentioned earlier in the introductory chapter, *E. oldi* is becoming increasingly harmful to sorghum production in West Africa (Doumbia and Bonzi 1989, Gahukar *et al*. 1989, Steck *et al*. 1989; Sharma and Lopex, 1990). This bug damages sorghum grains in two ways resulting in different categories of losses. The damage may be through their feeding or oviposition activities.

Feeding activities

Nymphs and adult *E. oldi* mainly suck sap from developing sorghum kernels, causing them to remain unfilled and shrivelled. Under severe infestation the panicles become completely chaffy. Heavy yield losses are observed when infestation occurred at an early stage of development of the grains. Later infestations result in quality loss. One should also note that the bugs occasionally feed on tender parts of the sorghum plant (Ballard 1916, Sharma and Lopez 1989, Sharma *et al*. 1992). Natarajan and Babu (1988) also reported that the adult bugs consume three times as much as fourth instar nymphs.

Oviposition activities

The adult female of *E. oldi* inserts its eggs inside the grains at the milk stage. The grain tissue around the eggs become reddish or brownish, thus spoiling the grain quality.

In general, damaged grains show red-brown feeding punctures and under heavy infestation they become tanned with low starch and protein content and high level of free aminoacid (Natarajan and Babu 1987, Sharma and Lopez 1989, Sharma *et al.* 1992, Gahukar 1991). Such damage also causes losses in seed germination, 1000 grain weight and number of grains per panicle (Natarajan and Babu 1988).

The economic injury level for *E. oldi* is 1.5 bugs per panicle (Baidu-Forson and Ajayi, 1995). However the threshold reported by Natarajan and Babu (1988) for *C. angustatus* was 8-15 nymphs, 5-10 feeding adults or 0.06-0.12 ovipositing adults per panicle.

Damage by head bugs could also bring in secondary problems particularly diseases and storage insect pests. Sharma and Lopez (1992) observed that damaged sorghum grains were more prone to mold incidence than the healthy ones.

2.8 Alternative Host Plants

Knowledge of alternative host plants of insect pests is very important in designing control measures. An insect's strategy for overcoming off-season hard conditions in some cases depends mainly on the availability of its alternative hosts. So far little has been done to properly identify alternative hosts of *E. oldi*. No literature has been found dealing with the issue. However, unconfirmed reports have mentioned lemon grass, mango tree and pigeon pea as potential sources of alternative food of *E. oldi*. This bug was observed feeding on pigeon pea at the ICRISAT research farm at Bagauda near Kano. ICRISAT (1996) also reported *Crotalaria naragutensis* (Hutch), mango and post-rainy season sorghum as dry season hosts. More research needs to be carried out to confirm these observations. Some other species of *Eurystylus* have also been observed feeding on cotton plants (Deeming 1981, Silvie *et al.*, 1989; Ratnadass, 1993).

2.9 Control Measures

The development of control measures against *E. oldi* is of very recent origin (Ratnadass, 1993). More work is being done as *E. oldi* is becoming a major insect pest of sorghum. Some of the existing measures against other insect pests were found to be quite efficient against *E. oldi* are indicated below.

2.9.1 Chemical control

Chemical control of *E. oldi* as well as of other bugs infesting sorghum panicles is not always economical. The use of chemicals in controlling sorghum head pests could be only justified in a few cases, notably in seed production, where the grain quality is of prime concern and in the production of sorghum in large quantities for industrial uses (Ratnadass, 1993).

Carbaryl and demeton-s-methyl have been successfully tested in India against head bugs (Rao *et al.* 1974, Sharma and Lopez 1987, Ratnadass 1993). The efficiency of cypermethrine and diazinon varies with the severity of the infestation by *E. oldi* (ICRISAT 1991, ICRISAT 1992). There is a need to have data on the real cost of treatment and the efficiency of the so tested pesticides in order to determine the economic injury level of *E. oldi* (Ratnadass, 1993).

2.9.2 Varietal resistance

Frankel and Bennet (1970) and Sharma (1985) qualified varietal resistance as the best plant protection measure for the future, because of its relevance to subsistence farming systems of the semi-arid tropics. Pest control through host plant resistance offers many advantages. Virtually no skill in pest control is needed and cash investment is not involved (Sharma, 1985). Plant resistance is also compatible with other control measures and could thus be adjusted to cultural, chemical and biological methods in order to achieve integrated pest control. Several techniques have been designed to screen for resistance to sorghum head bugs. Sharma *et al.* (1993) described the following techniques.

Field Screening

This method takes into consideration planting dates, the infester row technique and hot spot selection. It stipulates that sowing dates should be adjusted to coincide flowering with maximum head bug density in order to achieve good screening. The infester row technique involves planting susceptible materials 20 days earlier than the test materials. Sorghum cultivars of different maturity cycles should be mixed and planted in order to help the build up of the head bug population. Hot spots could also be selected for field screening.

Head cage technique

This appears to be the most effective technique to screen sorghum for resistance to head bugs. The method allows the head bug population build up and grain damage to be studied under no-choice condition. Maximum damage is thus expected and real resistant materials could be sorted out. The following cultivars have been identified as having resistance to *E. oldi* by Sharma *et al.* (1992): Malisor 84-7, IS-14332, CSM-388, Sakoila, IS-2474, IS-907, SK-86, IS-22227, E-1140, SK-140, Kamboinse local and S-29.

2.9.3 Cultural practices

Cultural practices like mixed cropping could reduce head bug infestation. Ajayi and Tabo (1995) reported a decrease of up to 22% and 49% infestation by *E. oldi* in the 1989 and 1991 cropping seasons when sorghum was intercropped with soybean. Ratnadass (1993) and Ajayi and Tabo (1995) reported that planting date affects *E. (immaculatus) oldi* incidence and could therefore be adjusted to escape *E. oldi* attack.

Although the way the bug spends its off season is unknown, crop sanitation is expected to reduce infestation. Destruction of volunteer crops, and planting sorghum cultivars with the same maturity cycle is probably a way of reducing *E. oldi* population.

2.9.4 Biological control

The biological control of *E. oldi* has not yet been properly studied. McFarlane (1989) identified *Orius* spp as a potential control agent. Abdel-Kader (1991) reported that spiders, especially *Diasperatus erythrocephalus* (Olivier), and the earwig, *Forficula senegalensis* Servile are potential predators of sorghum head bugs. But the real impact of these predators needs to be determined (Ratnadass, 1993).

Chapter 3

MATERIALS AND METHODS

3.1 Biology, Bionomics and Host Plant Resistance

3.1.1 Bionomics and host plant resistance

Six early maturing sorghum cultivars (three varieties and three hybrids) were used for monitoring *E. oldi* population in the field. Varieties NR-71150, NR-71168 and NR-71213 were collected from IAR/ABU breeding section, Samaru while the hybrids ICSH-89002-NG, ICSH-89009-NG and ICSH-91003-NG were obtained from ICRISAT, Kano.

For the 1994 cropping season, a randomized block design with four replications was used. Each plot consisted of four rows of 5m long and 0.75m apart. The plant spacing within the rows was 0.15m. The experiment was sown on July 2nd, 1994 and thinning was done to one plant per hill 15 days after planting. Fertilizer at a rate of 30kg N, 30kg P and 30kg K per hectare was applied at planting time. An additional 30kg N/hectare was applied at booting stage as top dressing. The plants were left to natural infestation by *E. oldi*.

For 1995 cropping season, the same experimental design as in 1994 was used but there were three sets of contiguous trials: one was left to natural infestation by the bugs, another one was artificially infested with five pairs of *E. oldi* per panicle and the third one was completely protected from all insects. The trial was planted on July 18th, 1995. The technique used for artificial infestation and protection was the headcage technique (Plate 1) described by Sharma *et al.* (1992).

Plate 1: Head cage technique for artificial infestation and screening.

As soon as sorghum heads started emerging, five plants per plot were selected randomly and covered with muslin cloth. At the milky stage *E. oldi* adults collected from an early planted field were sorted into five pairs (five males and five females) and introduced into the cages.

At the milk stage and a day before infestation, the caged heads were sprayed with 100% alcohol to kill head caterpillars and other predatory insects. Twenty days after infestation, infested heads were sprayed with 100% alcohol and the bugs were collected. The heads were left in the field to complete maturity and rated for insect damage before harvesting.

Data Collection

Plant stand after final thinning

All the plants in the two central rows per plot were counted and recorded after final thinning.

Plant height

The mean height of five randomly chosen plants per plot was measured in centimeters at maturity and recorded.

Grain yield

Panicles in the two central rows of each plot were harvested, threshed and the grains were weighed in kilograms.

Grain damage rating

Grain damage was evaluated at maturity on a 1-9 scale (Sharma *et al.*, 1992) as follows:

1 = all grains fully developed with few feeding

punctures.

2 = 1-10% grain damage

3 = 11-20% grain damage

4 = 21-30% grain damage

5 = 31-40% grain damage

6 = 41-50% grain damage

7 = 51-60% grain damage

8 = 61-70% grain damage

9 = 71-100% grain damage. Most of the grains remained undeveloped and not visible outside the glumes.

Floaters

One thousand grains out of the bulked harvest from each plot were sampled and their moisture content equilibrated overnight at room temperature. The grains were then soaked for 30 second in a sodium nitrate solution of 1.31 specific density. The number of floating grains was counted and expressed as a percentage of the total number of grains (Sharma *et al.*, 1992).

Yield loss estimation

Grain yield loss due to panicle pests was estimated as follows:

$$\text{Yield loss (in \%) due to all panicle pests} = \frac{P - NI}{P} \times 100$$

$$\text{Yield loss (in \%) due to } \textit{E. oldi} \text{ alone} = \frac{P - AI}{P} \times 100$$

Where P = Sorghum grain yield (in kg) under protection against panicle pests.

NI = Sorghum grain yield (in kg) under natural infestation by panicle pests.

AI = Sorghum grain yield (in kg) under artificial infestation by *E. oldi*.

Sampling of head bugs

Sampling of head bugs for naturally infested plots began at pre-anthesis and continued to complete maturity. It was done weekly using the modified beat-bucket method (Fuch *et al*. 1988, Sharma and Teetes 1993, Merchant and Teetes 1992).

Five randomly selected sorghum panicles per plot were carefully covered with 45 x 30cm polythene bags. The bags were equipped with cotton swab soaked with 100% alcohol. The panicles were tapped five times to dislodge the bugs. The bags were then gently removed, sealed and brought to the laboratory. The collected insects were sorted into species and counted with the help of a magnifying lens. The collected data were processed statistically using analysis of variance method (Appendix 2).

3.1.2 Biology

A plot of 12 x 12m was planted with ICSH-89002-NG, a hybrid which is susceptible to *E. oldi*. Randomly selected plants were caged at the late booting stage using the headcage technique developed by Sharma *et al.* (1992). At the milk stage, five pairs of *E. oldi* were introduced into the cages for oviposition. Grains containing eggs were collected and cultured in Petri dishes containing filter paper soaked with adequate quantity of distilled water. Emerging nymphs were collected and reared for two complete generations on sorghum grains at the milk stage in ventilated plastic rearing containers (Plate 2).

Plate 2: Laboratory set up for rearing *E. oldi*

The tubes were kept at a mean room temperature of 25.76°C and humidity of 65.46% (Appendix 1). Food waschanged daily. Major changes occurring between instars and the developmental period for each instar were noted. The rearing started October 10th and ended December 22nd, 1994. Temperature and relative humidity of the rearing laboratory were recorded thrice daily during the rearing process.

3.2 Host Range

3.2.1 Host range survey

Plots measuring 20m² were marked out in each sorghum farm and in the bush at distances of 20, 50, 100 and 200m from the edge of the farm. Plants within the marked plots were carefully searched for the presence of *E. oldi*. The surveys were done

at periods corresponding to vegetative, flowering and maturity stages of sorghum near Samaru, Shika and Zaria.

3.2.2 No-choice caging experiments

Three crop plants and seven weed species were selected either because they are often intercropped with sorghum or because they often grew within sorghum fields. These crops and weeds were: maize (*Zea mays*), pearl millet (*Pennisetum glaucum*), and cowpea (*Vigna unguiculata*) for the crops and *Amaranthus spinosus*, *Bidens pilosa*, *Vernonia ambigua*, *Crotalaria retusa*, *Eragrostis tremula*, *Pennisetum violaceum* and *Cassia obtusifolia* for the weeds. These plants were caged and infested with five pairs of *E. oldi* at different stages of their life cycle as scheduled below in Table 2.

Table 2. Three crop plants and seven weed species used for *E. oldi* host range test.

Plant species	*Zea mais*	*Pennisetum glaucum*	*Vigna unguiculata*	*Amaranthus spinosus*	*Vernonia ambigua*
Caged parts	Cob and flowering tassel	Panicles at milk stage	Stem and young pods	Stem, leaves and flowers	Stem, leaves and flowers
Plant species	*Crotalaria retusa*	*Eragrostis tremula*	*Pennisetum violaceum*	*Bidens pilosa*	*Cassia obtusifolia*
Caged parts	stem and young pods	Young panicles	Young panicles	Stem, leaves and flowers	Stem and young pods

Activities of the bugs on the infested plants were observed daily (notably feeding and oviposition). How long the insects survived on the infested plants was also noted.

3.3 Survival in the Off-Season

3.1.1 Survival on non-living sorghum materials

(a) The same field of 12 x 12m planted with ICSH-89002-NG used for biological studies was used. Panicles on ten plants were caged at the booting stage and infested with five pairs of *E. oldi* at the milk stage. Five of these panicles were cut off at the hard dough stage and five at full maturity. The panicles were allowed to dry under the sun and kept in the laboratory at room temperature. Ten uncaged plants were treated similarly. At the end of each successive conservation month one panicle in each condition was examined. With the help of a microscope, grains containing eggs of *E. oldi* were identified, collected and incubated under room conditions.

(b) Residues of sorghum plants from farmers and research fields were collected, examined and equally incubated under room conditions. Incubation was done in Petri dishes fitted with filter paper. The filter paper was moistened with distilled water. Sorghum grains or debris were then placed on top of the filter paper and covered with the Petri dish lid. The Petri dishes were kept in the laboratory at room temperature. Daily observations started four days after incubation and continued for a week, seeking for emerging nymphs.

3.3.2 Survival on plants other than sorghum

This aspect intended to support both off-season survival and host range survey studies. Weekly surveys were organized from September 1994 to June 1995. The surveys covered sorghum fields around Zaria and Shika, "Fadama areas" around Zaria, Shika, Funtua and Kadawa during the off-season. Orchards and green vegetations along rivers were visited for *E. oldi* presence. For the visited sites areas of $50m^2$ were marked and all the plants therein were searched for *E. oldi*.

Chapter 4

RESULTS AND DISCUSSION

4.1 Agronomic Performance of Six Sorghum Cultivars under Different Conditions of Infestation by *Eurystylus oldi*

4.1.1 Natural infestation: 1994 trial

The results (Table 3) showed that IAR variety NR 71213 outyielded the other five cultivars. The yield (2993 kg/ha) was significantly different at 5% level from those of the other five cultivars. NR 71213 was followed by ICSH 89009 NG and ICSH 91003 NG hybrids which yielded 2563 kg/ha and 2224 kg/ha respectively. These two hybrids were not statistically different from one another in terms of grain yields.

The poorest yielder among the six cultivars was found to be the IAR variety NR 71150 which produced 537.3 kg/ha. Part of low yield capacity of this variety could be caused by its low plant density (35,333 plants/ha) due to reduced germination capacity of the seeds. The plants were very short (123 cm) and its grains were very light (13.61g/thousand grain). The above mentioned parameters are some of the essential components of yield. Three cultivars (NR 71213, ICSH 89009 NG and ICSH 91003 NG) outyielded the check ICSH 89002 NG. They produced 2993 kg/ha, 2563 kg/ha and 2224 kg/ha, respectively while the check yielded 1327 kg/ha.

Table 3: Agronomic parameters of six sorghum cultivars tested for their resistance to *E. oldi* under natural infestation at Samaru (Zaria), 1994 field trial.

Entry	Plant Stand/ha	Days to 50% flowering (days)	Plant Height (cm)	Grain yield (kg/ha)	Rank	1000-grain weight (g)
NR 71150	35,333d	73b	123e	537.3d	6	13.61d
NR 71168	43,667c	70de	152d	1315.0c	5	23.17b
NR 71213	49,667b	75a	205a	2993.0a	1	21.48c
ICSH 89002 NG	57,000b	72be	188b	1327.0c	4	22.97b
ICSH 89009 NG	59,417a	71cd	172c	2563.0b	2	23.15b
ICSH 91003 NG	56,667a	69e	190b	2224.0b	3	26.43a
Overakk mean	50,291	72	170	1406.8	-	20.31
LSD at 5% level	4,806	1.26	8.70	341.4	-	1.14
CV (%)	15.53	2.84	8.29	39.44	-	9.14

Figures followed by the same letters in the same column are not statistically different at P = 0.05.

In terms of thousand grain weight, hybrids generally produced bigger grains than the open pollinated varieties, but NR 71168 ICSH 89002 NG and ICSH 89009 NG had grains of similar size (23.47, 22.97 and 23.14g, respectively). However, despite its large grain size, the yield of NR 71168 remained low.

4.1.2 Natural infestation: 1995 trial

The results of this trial are summarized in Table 4. IAR variety NR 71213 (2270 kg/ha) ranked first followed by ICSH 89009 NG (2187 kg/ha). The two cultivars were not statistically different. Similarly, hybrids ICSH 89002 NG (1980 kg/ha) and ICSH 89009 NG (2187 kg/ha) were not significantly different in their yields. Likewise ICSH 89002 NG (1980 kg) and ICSH 91003 NG (1733 kg/ha) had similar yield levels. Varieties NR 71150 (1225 kg/ha and NR 71168 (840 kg/ha) were significantly different at 1% level from the other cultivars and from each other.

Table 4 also shows that variety NR 71213 which ranked first and variety NR 71150 which ranked fifth had similar plant density. The difference in their yield appeared to be brought up by their grain weights and the size of the panicles they produced. One thousand grains of NR 71150 weighed 19.69g while those of NR 71213 weighed 25.20g, a difference of 5.51g per thousand grains. The three hybrids produced grains of similar weights while the three IAR varieties appeared to mature about the same time (days to 50% flowering were not statistically different).

Table 4: Agronomic parameters of six sorghum cultivars tested for their resistance to *E. oldi* under natural infestation at Samaru (Zaria), 1995 field trial.

Entry	Plant stand/ha	Days to 50% flowering (days)	Plant Height (cm)	Grain yield (kg/ha	Rank	1000-grain weight (g)
NR 71150	36,000d	73a	124e	1225d	5	19.16c
NR 71168	41,670c	73a	150d	840e	6	20.73b
NR 71213	34,440d	74a	203a	2270a	1	25.20a
ICSH 89002 NG	52,330b	71b	179c	1980bc	3	19.64c
ICSH 89009 NG	56,670ab	68c	173c	2187ab	2	19.28c
ICSH 91003 NG	59,670a	70b	189b	1733c	4	19.09c
Overall mean	46,777	71	170	1706	-	20.51
LSD at 5% level	4742	1.02	7.83	271.5	-	0.85
CV (%)	16.48	2.33	7.42	25.87	-	2.72

Figures followed by the same letters in the same column are not statistically different at P = 0.05.

4.1.3 Artificial infestation: 1995 trial

Table 5 shows the results of this trial. Hybrid ICSH 89009 NG produced the greatest yield (5,026 kg/ha). It was found to be statistically different at 5% level from the five other cultivars and was followed by NR 71213 (3,632 kg/ha) and ICSH 89002 NG (3,384 kg/ha) whose yields were statistically similar. ICSH 91003 NG (2,806 kg/ha), NR 71168 (1,881 kg/ha) and NR 71150 (1,454 kg/ha) ranked fourth, fifth and six respectively. The last two were found to be statistically similar in yields.

Generally there was not much variability in the grain size. NR 71213 produced the heaviest grains (25.81g) followed by ICSH 89009 NG (24.36g) but both were statistically similar as were those of ICSH 89002 NG (22.17g) and NR 71168 (22.72g). The lightest grains were those of NR 71150 (20.11g) which was statistically similar to those of ICSH 89002 NG (22.17g) and ICSH 91003 NG (21.61g). A little delay in flowering was observed in this trial. Days to 50% flowering increased showing significant differences among the cultivars. This was caused by erratic rainfall and a two week drought spell at planting time that forced some plots to be resown in order to achieve reasonable plant stand. The hybrids matured significantly earlier than the varieties. Compared to the two earlier trials, the yields were higher. An overall mean of 3,030 kg/ha compared to 1406.8 kg/ha and 1706 kg/ha for the first and second trials, respectively.

Table 5: **Agronomic parameters for six sorghum** cultivars tested **for their resistance** to *E. oldi* **under** artificial infestation at Samaru **(Zaria): 1995 field trial.**

Entry	Plant stand/ha	Days to 50% flowering (days)	Plant Height (cm)	Grain yield (kg/ha	**Rank**	1000-grain weight (g)
NR 71150	37,330c	76a	110e	1,454d	6	20.11d
NR 71168	36,670c	72b	133d	1,881d	5	22.72bc
NR 71213	36,000c	76a	200a	3,632b	2	25.81a
ICSH 89002 NG	47,000b	69c	190b	3,384b	3	22.17cd
ICSH 89009 NG	53,000d	69c	175c	5,026a	1	24.36ab
ICSH 91003 NG	54,670a	70bc	200a	2,806c	4	21.61cd
Overall mean	44,110	72	168	3,030	-	22.79
LSD at 5% level	555.1	1.6	8.02	555.1	-	2.30
CV (%)	29.77	3.6	4.46	29.77	-	16.41

Figures followed by the same letters in the same column are not statistically different at P = 0.05.

4.1.4 Protected against head pests, 1995 trial

Under protection the cultivars expressed their yielding capacity better than under natural and artificial infestation. The overall mean grain yield moved from 1,706 kg/ha to 3,169 kg/ha (Table 7). This represented an increase of about 86% in yield. Hybrid ICSH 89009 NG yielded 4,815 kg/ha while NR 71213 produced 3,615 kg/ha. These two were followed by ICSH 91003 NG (3,469 kg/ha), NR 71168 (3,088 kg/ha) and NR 71150 (2,096 kg/ha) which produced the lowest yield.

NR 71213 produced the largest grains (26.59g/1000-grain) compared to ICSH 91003 NG and ICSH 89009 NG (24.44g and 23.34g/1000-grain respectively) which were statistically similar. NR 71168 and NR 71150 generated smaller grains (22.44g and 21.96g/1000-grain respectively). The lightest grains were produced by ICSH-890002-NG (21.40g/1000-grain).

In the light of what has been discussed in the above paragraphs, it appeared that, on average, hybrid ICSH 89009 NG was the best yielder throughout the two cropping seasons (1994 and 1995)(Table 8). This was the result of vigorous plants and heavy and well filled grains that it produced. The hybrid could virtually withstand pest attacks (particularly head pests). Generally, hybrids did better when protected from head pest attacks. Varieties NR 71150 and NR 71168 were poor in their yield performance during the two cropping seasons. In addition, field observations revealed that NR 71168 was very susceptible to long smut *(Tolyposporium ehrenbergii* (Kuhn) Patonillard) attack (5%

Table 6: Agronomic parameters for six sorghum cultivars protected from *Eurystylus. oldi* damage at Samaru (Zaria): 1995 field trial.

Entry	Plant stand/ha	Days to 50% flowering	Plant Height (cm)	Grain yield (kg/ha	Rank	1000-grain weight (g)
NR 71150	36,670c	76a	121	1,934d	6	21.96cd
NR 71168	41,330b	72c	142	2,096d	5	22.44cd
NR 71213	36,000c	75b	195	3,615b	2	26.59a
ICSH 89002 NG	41,330b	72c	189	3,088c	4	21.40d
ICSH 89009 NG	56,000a	68e	159	4,815a	1	23.34bc
ICSH 91003 NG	55,000a	70d	205	3,469bc	3	24.44b
Overall mean	44,388	72	169	3,169	-	23.36
LSD at 5% level	4,409	0.96	7.9	435.7	-	1.50
CV (%)	16.14	2.16	5.10	22.34	-	10.45

Figures followed by the same letters in the same column are not statistically different at P = 0.05.

Table 8: **Yield performance** of six sorghum **cultivars** under different conditions of infestation by *E. oldi*.

	1994		1995						
	Naturally infested		Natural infested		Artificially infested		Protected	Overall mean yield	Rank
Sorghum cultivars	Yield (kg/ha)	*E. oldi* No./panicle	Yield (kg/ha)	*E. oldi* No./panicle	Yield (kg/ha)	*E.oldi* No./panicle	Yield (kg/ha)		
NR 71150	537.3	29.3	1225	45.6	1454	91.75	1934	1288	6
NR 71168	1315.0	23.3	840	25.9	1881	31.50	2096	1783	5
NR 71213	2993.0	56.3	2270	51.6	3632	130.00	3615	3128	2
ICSH 89002 NG	1327.0	38.3	1980	81.6	3384	178.00	3088	2695	3
ICSH 89009 NG	2563	62.8	2187	55.9	5026	40.25	4815	3648	1
ICSH 91003 NG	224.0	63.3	1733	52.3	2806	91.00	3469	2558	4
Mean	1826.6	42.0	1705.9	52.2	2280.5	93.75	3169.5	-	-
LSD at 5%	341.4	38.9	271.5	18.32	555.1	39.64	435.7	-	-
CV (%)	39.44	27.7	25.87	77.72	29.77	68.69	22.34	-	-

of the plants of this variety were attacked in 1994 field experiment). IAR variety NR 71213 ranked second on the average and appeared to be the most stable yielder during 1994 and 1995 cropping seasons.

4.2 Resistance of six Cultivars to *E. oldi*

4.2.1 1994 experiment

Table 9 shows that under natural infestation, the population of *E. oldi* was similar on NR 71213 (56.3 *E. oldi*/panicle), ICSH 89009 NG (52.8/panicle), ICSH 91003 NG (63.3/panicle) and the susceptible check ICSH 89002 NG (58.5 /panicle). However, grain yields and thousand grain weights were significantly different. Disregarding other yield influencing factors, this result indicates that the extent of damage inflicted by *E. oldi* on each cultivar depended mainly on the cultivar.

Table 9: Damage to six sorghum cultivars by *E. oldi* under natural infestation conditions (1994 field trial).

Parameters	Sorghum cultivars							
	NR 71150	NR 71168	NR 71213	ICSH 89002 NG	ICSH 89009 NG	ICSH 91003 NG	LSD at 5%	CV (%)
E. oldi population/panicle	29.5bc	23.3c	56.3ab	58.5a	52.8ab	63.3a	38.9	27.7
Grain yield (kg/ha)	537.3d	1315.0c	2993.0a	1327.0c	2563.0b	2224.0b	39.4	341.4
1000-grain weight (g)	13.61d	23.17b	21.48c	22.97b	23.15b	26.43a	9.1	1.1
Floaters (%)	55.2a	39.32cd	55.82a	40.62bc	33.75d	42.65b	18.3	5.0
Damage rating	9a	6b	2d	4c	4c	4c	2.82	50.0

Figures followed by the same letters in the same row are not statistically different at $P = 0.05$.

4.2.2 1995 experiments

The results are contained in Tables 10, 11 and 12. Table 10 shows that when the six sorghum cultivars were subjected to natural infestation, the bugs (*E. oldi*) preferred hybrids to varieties. This observation agrees with those of Ratnadass (1992) and Sharma (1993) who stated that sorghum head bugs (including *E. oldi*) preferred improved varieties and particularly hybrids to land races.

The highest number of bugs was recorded on the susceptible check ICSH 89002 NG (81.6 insects/panicle), followed by ICSH 89009 NG (55.9), ICSH 91003 NG (52.3), NR 71213 (51.6) and NR 71150 (45.6). NR 71168 hosted the least number of insects (25.9).

Although they harboured large numbers of *E. oldi* (Table 12), hybrids produced acceptable grain yields, indicating that they were tolerant of head bug infestation. ICSH 89009 NG (4,815 kg/ha) ranked first followed by NR 71213 (3,615 kg/ha), ICSH 91003 NG (3,469 kg/ha), NR 71168 (2,096 kg/ha) and NR 71150 (1,934 kg/ha). In spite of the large number of bugs on NR 7123, produced well filled and large grains (26.59g/1000 grains) while NR 71168 with the least number of bugs had grains weighing only 22.44g/1000 grains.

Table 10. **Damage to six sorghum cultivars by *E. oldi* under natural infestation conditions (1995 field trial).**

Parameters	Sorghum cultivars							
	NR 71150	NR 71168	NR 71213	ICSH 89002 NG (check)	ICSH 89009 NG	ICSH 91003 NG	LSD at 5%	CV (%)
E. oldi population/panicle	45.6b	25.9c	51.6b	81.6a	55.9b	52.3b	18.32	77.72
Grain yield (kg/ha)	1,934d	2,096d	3,615b	3,088c	4,815a	3,469bc	435.70	22.34
1000-grain weight (g)	21.96cd	22.44cd	26.59a	21.40d	23.34bc	24.44b	1.50	10.45
Grain mass and floaters (%)	43.75c	40.75c	54.75b	56.00ab	54.50b	61.75d	6.70	21.00
Damage rating	3	4	2	3	2	4	1.39	29.81

Figures followed by the same letters in the same row are not statistically different at P = 0.05.

Table 11. Damage by *E. oldi* to six sorghum cultivars under artificial infestation (1995 field trial).

	Sorghum cultivars							
Parameters	NR 71150	NR 71168	NR 71213	ICSH 89002 NG (check)	ICSH 89009 NG	ICSH 91003 NG	LSD at 5%	CV (%)
E. oldi population	91.75	31.50	130.00	178.30	40.25	91.00	39.64	68.69
Grain yield (kg/ha)	1934	2096	3615	3088	4815	3469	435.7	22.34
1000-grain weight (g)	21.96	22.44	26.59	21.40	23.34	24.44	1.50	10.45
Floaters (%)	11.25	7.00	8.75	20.50	12.00	12.25	5.22	70.96
Damage rating	3	4	1	3	2	4	1.97	41.00

Table 12: Effect of *Eurystylus oldi* infestation on grain mass and grain damage at Samaru, 1995.

	No. of head bugs/panicle		% floaters			Damage rating	
Cultivar	Natural infestation	Artificial infestation	Natural infestation	Artificial infestation	Protected	Natural infestation	Artificial infestation
NR 71150	45.6	91.75	43.75	53.00	11.25	9	3
NR 71168	25.9	31.50	40.75	24.25	7.00	6	4
NR 71213	51.6	130.00	54.75	47.50	8.75	2	1
ICSH 89002 NG	81.6	178.30	56.00	28.00	20.50	4	3
ICSH 89009 NG	55.9	40.25	54.50	18.00	12.00	4	2
ICSH 91003 NG	52.3	91.00	61.75	42.00	12.25	4	4
Mean	52.2	93.8	51.90	35.62	12.00	5	3
LSD (at 5%)	18.32	39.64	6.70	5.96	5.22	2.82	1.97
CV (%)	77.72	68.69	21.00	55.39	70.96	50	41

Generally all the cultivars had high percentage of floating seeds although significant differences existed among them. This high proportion of floating seeds indicates intensive activities of bugs and/or severe infestation of the cultivars by the bugs, because the more the insects suck the sap from the developing grains, the lighter the resulting matured grains are. Light grains are likely to float, leading to high percentages floating seeds. NR 71213 was the least damaged variety in this experiment. However, all cultivars in the experiment recorded low visual damage rating. NR 71168 was the most damaged cultivar.

Based on the results of this experiment, it is concluded that NR 71213 was the most tolerant cultivar to *E. oldi* attack while NR 71150 was the most susceptible with reference to their yield, grain weight and visual damage rating.

Under artificial infestation, a large population of head bugs developed on the susceptible check ICSH 89002 NG (Table 11) from five pairs per panicle to 178.30 bugs/panicle within 20 days. This resulted in the production of grains of low weight (21.40g/1000-grain) and a high percentage of flaters (20.50%) among the seeds.

NR 71150 and NR 71168 yielded less (1934 kg/ha and 2096 kg/ha, respectively) than the check (3080 kg/ha) but the remaining three cultivars yielded more. However NR 71213 and ICSH 89002 NG produced good yields despite the heavy infestation by *E. oldi*. Grain mass and percentage of floaters were low, ranging from 7% to 20%. The weight of one thousand grains was above 21g for all the cultivars.

While the number of head bugs/panicle (Table 12) was generally less under natural infestation than artificial infestation (e.g. 81.6 and 178.30 bugs/panicle for ICSH 89002 NG), the reverse was observed with floaters and damage rating except for NR 71150 which had 43.75% floaters under natural infestation and 53.00% under artificial infestation. This shows that the other panicle pests (Tables 15 and 16) are very important factors in total yield loss inflicted on the sorghum cultivars. All the cultivars had very few grains floating under complete protection. If grain floaters and damage rating under artificial infestation are considered to be only due to *E. oldi* and expressed the real damage to sorghum by this bug, then the six cultivars could be ranked from the most susceptible to the least susceptible as follows: ICSH 89002 NG, NR 71150, ICSH 91003 NG, ICSH 89009 NG, NR 71168 and NR 71213 (Table 12).

4.2.3 Summary of observations on resistance of the cultivars

When the mean yields of the six sorghum cultivars are compared under different conditions of infestation by *E. oldi*, yield was lowest under natural infestation and highest when panicles were uninfested. The yield improved a bit when *E. oldi* alone was allowed to feed on the earheads (Table 7). Exceptions were ICSH 89002 NG, ICSH 91003 NG and NR 71213 which showed slight yield decrease under protection. This decrease was attributed to difficult plant establishment caused by erratic rainfall at planting time which severely affected some plots planted with these cultivars.

As shown in Table 13, an estimated yield loss of 60% was recorded for NR 71168; 10% of this was attributable to *E. oldi*. For NR 71150, 25% out of 37% yield loss was caused by *E. oldi* while 19% out of 50% yield loss in ICSH 91003 NG was due to *E. oldi*. *E. oldi* apparently did not affect the yields of the remaining cultivars. The cultivars then were ranked according to their susceptibility to *E. oldi;* NR 71213 was the least susceptible followed by ICSH 89009 NG, ICSH 89002 NG, ICSH 91003 NG, NR 71168 and NR 71150 in order of increasing level of susceptibility.

Table 13. Estimates of yield loss due to panicle pests, Samarum Nigeria, 1995 (see Table 8).

	Grain yield (kg/ha)			Yield loss (%)	
Sorghum cultivars	P	NI	AI	AHP	E.I
NR71150	1934	1225	1454	37	25
NR 71168	2096	839.5	1881	60	10
NR 71213	3615	2270	3632	37	0
ICSH 89002 NG	3088	1980	3384	36	0
ICSH 89009 NG	4815	2187	5026	55	0
ICSH 91003 NG	3469	1733	2806	50	19

P = protected from head pests

NI = naturally infested

AI = artificially infested with *E. oldi*

AHP = yield loss due to all head pest species

E.I = yield loss due to *E. oldi*

Yield loss for all head pests = $\frac{P - NI}{P} \times 100$

Yield loss due to *Eurystylus* alone = $\frac{P - AI}{P} \times 100$

4.3 Bionomics

The weekly sampling during the two cropping seasons showed that the rise and fall of *E. oldi* populations resembles a normal distribution (Figure) and was strongly affected by the stage of grain development. The bugs infested sorghum panicles by the end of anthesis. Their population then gradually increased and reached a peak by the end of the soft dough and during early hard dough stages. This took about five to six weeks after the bugs appeared on the panicles. The populations of the bugs started declining by the end of the sixth week and the insects disappeared towards the end of the ninth week when the grains had dried (Table 14). This observation agrees with that of ICRISAT, Nigeria (1993) which reported similar population fluctuation pattern for *E. oldi (immaculatus)* at Bagauda, Nigeria.

In Samaru where the study was carried out, *E. oldi* occurred on sorghum panicles for two months - September and October. The bugs were first noticed in the second week of September, and their population reached a peak during the last week of September and early October. The bugs virtually disappeared by the last week of October. Consequently any planting date that will allow sorghum plants not to mature during the population peak period will contribute to the reduction of damage by this bug. Other sorghum panicle insect pests were also monitored.

Table 14. Population dynamics of *E. oldi* on sorghum hybrid ICSH 890002 NG at Samaru (Zaria), 1994 and 1995.

Grain development stage	Month	Standard week	Mean No. of head bugs/panicle/week		Mean
			1994	1995	
Half anthesis	September	1	0	0	0
Milk stage	September	2	2	1	2
		3	6	4	5
Soft dough stage	September	4	14	12	13
		5	58	65	62
Hard dough stage	October	6	93	85	89
		7	29	30	30
Grain maturity	October	8	8	20	14
		9	0	3	2

Table 15 shows the fluctuations of the population of *E. oldi* and other important panicle pest species. Among these were *Locris rubens* and *Poophilus costalis* which are very often associated with the leaf blotch disease of sorghum, *Mylabris abdominalis, Adelphocoris apicalis* and *Creontiades pallidus*. The populations of all the insect species did not fluctuate the same way (Figure 1). Some built up their populations and disappeared within a short period of time while some others built up their population very slowly, leading to a very spread distribution curve.

Although difficult to prove, the presence of many insects of different species (Table 15) struggling to secure food from the same sorghum panicles leads to competition. Therefore the population growth of each species is influenced by the other species. This is reflected in the rates of populations development, and peaks occurring at different times (Figure) in a particular area. If some species happen to predate on others, then reciprocal influence of the population of one species upon another species is greater. In the present case, *Orius* spp has been suspected to prey on *E. oldi* (Ratnadass 1992, Sharma 1993). But their presence on sorghum heads in Samaru was not as much as to cause appreciable fluctuations of the population of *E. oldi*.

Table 16 shows the relative abundance of some panicle insects sampled in the 1994 trial. The number of individuals in a given population depended on the susceptibility of the cultivar (Figure 1).

Table 15. Population fluctuation of some insect species infesting sorghum earheads at Samaru (Zaria).

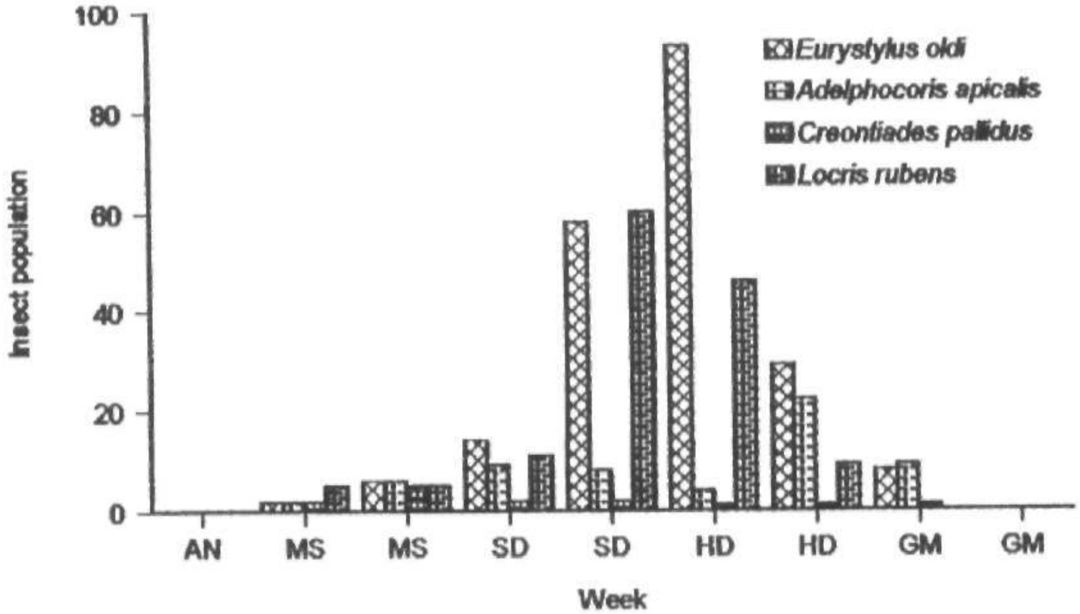
	No. of insects/5 panicle/week									Mean/ week
	Half anthesis	Milk stage		Soft dough stage		Hard dough stage		Grain maturity		
	Standard week									
Insect species	1	2	3	4	5	6	7	8	9	
Adelphocoris apicalis	0	2	6	9	8	4	22	9	0	7
Agonoscelis versicolor	0	0	0	0	0	3	4	2	0	1
Aspavia deuminata	0	0	0	0	5	4	3	10	0	1
Brachypeplus piloselus	0	9	37	29	16	0	0	0	0	10
Carpophilus fumatus	0	19	9	6	0	0	0	0	0	4
Creontiades pallidus	0	2	5	2	2	1	1	1	0	2
Epicauta sp	0	0	2	3	6	14	3	0	0	3
Eurystylus oldi	0	2	6	14	58	93	29	8	0	23
Idgia dimidiata	0	0	0	2	3	4	4	2	0	2
Labotrachelus senegalensis	0	0	0	7	2	3	3	1	0	2
Locris rubens	0	5	5	11	60	46	9	0	0	15
Monolepta sp	0	2	6	3	2	1	0	0	0	2
Mylabris abdominalis	0	4	10	12	16	7	9	4	0	7
Mylabris holosericea	0	2	2	3	5	4	4	4	0	3
Poophilus costalis	0	2	5	3	2	1	0	0	0	1
Psadllus sp	0	8	34	15	17	7	0	0	0	9
Spermophagus sp	0	2	2	3	13	4	0	0	0	3
Sphaerocoris annulus	0	0	0	0	15	23	16	6	0	7
Taylorilygus voseleri	0	4	7	12	23	14	8	0	0	8

Table 16: Relative abundance of some panicle pest species on six sorghum cultivar at Samaru (Zaria), 1994

Insect species	Sorghum cultivars							
	NR 71150	NR 1168	NR 71213	ICSH 89002 NG	ICSH 89009 NG	ICSH 91003 NG	LSD at 5%	CV (%)
Adelphocoris apicalis	13.5a	21.5a	24.0a	15.0a	19.02	16.0a	11.4	41.5
Brachypeplus piloselus	2.8a	0.8a	3.8	5.5a	3.0a	2.3a	4.8	106.9
Carpophilus fumatus	3.5ab	0.5b	4.0ab	6.8a	3.5ab	2.5ab	5.8	110.8
Campylomma sp	14.8a	19.5a	27.8a	25.0a	10.3a	10.3a	18.9	70.1
Cymnus spp	8.0ab	8.5ab	13.3a	11.0a	5.0b	9.8ab	5.6	40.2
Eurystylus oldi	29.5bc	23.3c	56.3ab	58.5a	52.8ab	63.3a	27.7	38.9
Lobotrachelus senegalensis	1.3a	4.5a	6.0a	4.0a	6.3a	4.8d	5.7	84.8
Monolepta spp	6.0ab	1.8b	7.5a	5.5ab	5.5ab	5.3ab	4.8	61.2
Mylabris abdominalis	5.3a	4.5a	3.5ab	0.0c	1.3bc	1.8bc	3.0	92.0
Mirperus jaculus	4.8	2.3	8.3a	2.8b	3.5b	1.5	5.0	121.8
Orius spp	15.3a	12.3a	20.0a	21.0a	14.5a	18.8a	16.0	62.7
Sitophilus zeamais	3.0b	17.8a	14.5ab	13.5ab	19.3a	22.5a	12.3	54.3
Tayloryligus voseleri	2.0a	1.5a	2.8a	2.8a	2.3a	2.0a	2.2	65.2

Figures followed by the same letters in the same row are not statistically different at $P = 0.05$.

Figure: Population fluctuation of some panicle insect pests of sorghum at Samaru, Zaria, 1995.



AN = Anthesis
MS = Milk Stage
SD = Soft Dough Stage
HD = Hard Dough Stage
GM = Grain Maturity

The peak of the population of *E. oldi* corresponds to low population levels of other species as shown on hybrid ICSH 91003 NG. This species appeared to be the most dominant head pest followed by *Campylomma* ssp, *Adelphocoris apicalis* and *Orius* sp. *Sitophilus zeamais*, which is a storage pest, infested sorghum heads right from the field. Other species were found in very low numbers. Sorghum variety NR 71213 had the highest population of the insects (7 out of 13 species) and appeared as the most susceptible of the cultivars but its high grain yield shows that it is not.

4.4 Biology

The studies of biology of *E. oldi* were carried out in the laboratory under ambient conditions of 25.76°C and 65.46% relative humidity. Two generations of insects were obtained through rearing (Plate 2). The results are shown in Table 17.

Pre-oviposition period for female insects was 6±0.63 days after the last moult. The eggs hatched after 4.25±0.5 days for males and 4.83±0.75 days for females. The nymphal period lasted for 13.5±1.58 days for males and 12.84±2.9 days for females.

Nymphs of *E. oldi* developed to adults through five instars. The duration for each instar for male and female are presented in Table 17. Adult males lived for 32.25±4.99 days while adult females lived for 26.83±3.55 days. The mean longevity, calculated from egg to death, was 50±5.03 days for males and 50.50±3.33 days for females.

Table 17. Duration (in days) of developmental stages of *Eurystylus oldi* monitored on ICSH 89002 NG under ambient laboratory conditions at Samaru (Zaria), 1994.

	Male		Female	
	Mean duration (days)	Sd	Mean duration (days)	Sd
Pre-oviposition	-	-	6.00	0.63
Egg hatching	4.25	0.50	4.83	0.75
First instar	3.50	0.58	3.00	0.63
Second instar	2.00	0.00	2.33	0.52
Third instar	2.00	0.00	1.67	0.52
Fourth instar	2.75	0.50	2.67	0.82
Fifth instar	3.25	0.50	3.17	0.41
Adult longevity	32.25	4.99	26.83	3.55
Egg to adult period	17.75	2.08	17.57	3.33
Egg to adult period (male and female combined) duration = 50.30±3.83				

These findings agree with those of ICRISAT, Nigeria (1994) and Ratnadass *et al.* (1994) (see table 1) except for the total developmental period (egg to adult).

Two times during the rearing period, adult insects were observed to mate around 6 a.m for some few seconds, just the way house flies mate.

4.5 Host Range

Intensive and systematic surveys were organized within and around sorghum fields in Samaru, Shika and Funtua. "Fadama" areas and orchards around Samaru and Kadawa were searched as well as different vegetations along rivers during the dry season. No *E. oldi* presence was noticed on the visited plants either in the form of egg, nymph or adult insect. In an attempt to determine the survival of the pest on some suspected plants, three crop plants and seven weed species were used. The results are shown in Table 18. 50% of the bugs died three days after their introduction onto the plants, 30% survived about four to six days and only 20% were able to complete a week on pearl millet panicle at milk stage and on *Crotalaria retusa*. No insect survived more than seven days on any of the ten tested plant species and no egg was found on any of them. The plants are therefore considered non-host to the bug.

Table 18: Longevity of adult *Eurystylus oldi* on seven weed species and three crop plants that usually grow within or in the vicinity of sorghum fields.

Plant species	*Zea mays*	*Pennisetum glaucum*	*Vigna unguiculata*	*Bidens pilosa*	*vernonia ambigua*	*Cassia obtusifolia*	*Crotalaria retusa*	*Eragrostis tremula*	*Pennisetum violaceum*	*Amaranthus spinosus*
Caged plant parts	Flowering tassel	Panicles at milk stage	Stem, leaves and young pods	Stem, leaves and flowers	Stem, leaves and flowers	Stem, leaves and young pods	Stem, leaves, flowers and young pods	Young panicles	Young panicles	Stem, leaves and flowers
Maximum longevity (in days)	3	7	5	3	3	6	7	3	4	3

Mango orchards were surveyed at different times during the dry season but no bug was found on any part of the tree. *E. oldi* was observed to feed on pigeon pea at Bagauda (Nigeria) in ICRISAT experimentation fields. This observation was confirmed by a regional survey of farmers' fields inNigeria, Cameroon and Chad, which in addition to pigeon pea revealed mango tree, *Crotalaria naragutensis* (Hutch) and post rainy season sorghum as dry season alternative hosts of the insect (ICRISAT, 1996).

4.6 Survival in the Off-Season

Investigations were carried out to know whether E. oldi can survive on dry sorghum materials or not. Laboratory analyses which lasted for five months (December 1994 to May 1995) revealed that the bug does not survive on any dry sorghum material.

Infested dry grains of sorghum containing eggs of *E. oldi* were incubated under ambient room temperature (25.76°C) and humidity (65.46%) but the eggs failed to hatch. This indicated that they were no longer viable on such dry material. Different sorghum plant debris collected from farmers' fields as well as from research fields were also incubated but failed to yield any living *E. oldi*. The conclusion of these studies is that *E. oldi* can not survive on dry sorghum materials and consequently could not bridge the off-season gap through this. Moreover, investigation of sorghum ratoon plants showed that the bug was found only on the sorghum plants that bore flowering heads.

The results of surveys intended to establish the place(s) from where *E. oldi* migrates to infest sorghum fields and to record different forms in which the bug survives the dry season were not conclusive. No bug has been seen on the diverse materials investigated during the dry season. No forms of living organ has been found to perpetuate *E. oldi* during the dry season.

CHAPTER 5

SUMMARY AND CONCLUSION

Six sorghum cultivars were screened for their resistance to E. *oldi*. NR 71213 and ICSH 89009 NG were the least susceptible. These can be used in breeding programs as sources of resistance. *NR 71150 was found to be very susceptible,* therefore its cultivation should be avoided in areas where *E. oldi* constitutes a problem.

The population fluctuation of *E. oldi* and other sorghum head pests wea studied. In Samaru this bug reached its peak population during the last week of September and the population died out by the end of October. The peak population occurred when grains were at the end of the soft dough stage, while the population died out when the grains had hardened. The evolution of the population size was a function of the developmental stages of sorghum grains. Among the head pests sample, *E. oldi* was the most abundant during the experiment. This confirms Samaru as a hot spot for field screening of sorghum cultivars against *E. oldi*.

The study of the biology has revealed that nymphal development of E. oldi passed through five instars. The duration of the different instars, pre-oviposition period, and longevity of the adult insect were estimated. However, there is a need to know the effect of extreme temperatures and relative humidity on egg, nymphal and adult survival.

Host range surveys identified pigeon pea as potential alternative host. However, nothing is known about the off-season survival *strategies of the bug. Further studies are* needed to determine the host
range and how *E. oldi* survives during the dry season.

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7. APPENDICES

Appendix 1: Daily means of temperature and humidity of the laboratory during the rearing process of *E. oldi*.

Date	October		November		December	
	Temperature (°C)	Humidity (%)	Temperature (°C)	Humidity (%)	Temperature (°C)	Humidity (%)
1			28	73	25	58
2			28	74	25	59
3			28	70	24	61
4			28	66	25	63
5			29	57	23	58
6			28	56	22	60
7			27	66	23	58
8			58	58	22	61
9			26	62	22	54
10			26	53	22	52
Mean			27.40	63.50	23.30	58.45
11			25	67	22	59
12			26	66	22	56
13			26	65	22	53
14*			26	59	22	61
15			27	55		
16			27	51		
17			26	53		
18			28	51		
19			26	54		
20			27	51		
Mean			26.40	57.20	22.00	57.25
21			26	51		
22			26	50		
23**	29	86	25	61		
24	30	85	25	54		
25	30	84	24	57		
26	29	81	24	55		
27	22	76	24	55		
28	28	88	24	58		
29	29	39	25	57		
30	30	69	25	58		
31	19	70				
Mean	28.44	79.77	28.80	55.60		

Overal mean: Temperature = 25.76 °C; Humidity = 65.46%

* = beginning of the experiment (October 23th, 1994).
** = ending of the experiment (December 14th, 1994).

Appendix 2: Analysis of variance tables.

1. Cropping season 1994 data

a. Grain yield

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
Replication	3	202267.312	674224.104	2.1899	0.1318
Treatment	5	5992266.416	1198453.283	3.8926	0.0184
Error	15	4618233.599	307883.240		
Total	23	12633172.328			

b. *Eurystylus oldi* population

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
Replication	3	2538.833	846.278	2.5007	0.0990
Treatment	5	5539.500	1107.900	3.2738	0.0339
Error	15	5076.167	338.411		
Total	23	13154.500			

c. Thousand grain weight

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
Replication	3	18.988	6.329	0.8366	0.1838
Treatment	5	210.814	42.163	12.2343	0.0101
Error	15	51.694	3.446		
Total	23	281.496			

b. *Eurystylus oldi population*

b1 Natural infestation

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
Replication	3	5542.33	1847.444	1.73	0.2035
Treatment	5	3845.50	769.100	0.72	0.6180
Error	15	16006.17	1067.078		
Total	23	25394.00			

b2 Artificial rnfestation

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
Replication	3	48721.13	16240.375	3.91	0.0301
Treatment	5	60812.71	12162.542	2.93	0.0485
Error	15	62268.60	4151.208		
Total	23	171801.96			

c. Thousand grain weight (artificial infestation)

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
Replication	3	41.92	13.974	1.00	0.4205
Treatment	5	82.24	16.449	1.18	0.3664
Error	15	209.92	13.994		
Total	23	334.08			

d. Grain mass and floaters (artificial infestation)

Source	Degrees of freedom	Sum of squares	Mean square	F value	Probability
Replication	3	908.46	302.819	0.78	0.5245
Treatment	5	3836.38	767.275	0.97	0.3419
Error	15	5840.79	389.386		
Total	23	10585.63			