Seasonal abundance and diversity of sorghum panicle-feeding Hemiptera in South Africa

M. Kruger

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Supervisor: Prof. J. van den Berg
Co-supervisor: Dr. M.J. du Plessis

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YUNIBESITI YA BOKONE-BOPHIRIMA
NORTH-WEST UNIVERSITY
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Abstract

During the past two decades, panicle-feeding Hemiptera have become pests of sorghum in West and Central Africa, and particularly in Mali, where this is a staple food crop. Of the more than 100 sorghum insect pests reported in Africa, 42 species were found to be panicle-feeding pests. Prior to this study, no research had been done on the panicle-feeding Hemiptera in South Africa. The objectives of the study were to determine the abundance and diversity of panicle-feeding Hemiptera on sorghum. A check list was compiled and the temporal distribution of different Hemiptera species determined during the different panicle stages of development. In addition, the effect of insecticide application on Hemiptera numbers was evaluated and the correlation between grain mould severity and Hemiptera feeding damage was investigated. To determine the abundance and diversity of Hemiptera on sorghum panicles, surveys were conducted between November 2004 and June 2006 at 26 sites in four provinces of South Africa. Two methods of collection were used *viz.* the plastic bag and D-Vac methods. The total number of the adults and nymphs collected during this study was 23 798. Forty-three different herbivorous Hemiptera species were collected. The most abundant family was the Miridae (41 %), followed by the Lygaeidae (17 %). *Eurystylus* spp., *Calidea dregii, Campylomma* sp., *Creontiades pallidus*, *Nysius natalensis* and *Nezara viridula* were the most abundant species and also occurred widely in the sorghum production area. Infestation levels of these species were low compared to that in other parts of Africa and it cannot be concluded that they have pest status in South Africa. There was no clear distinction between the stages during which panicles were infested by different species. The general tendency was that nearly all species were present from the flowering stage onwards and that numbers declined when grain hardened. In general, *Campylomma* sp. and *C. pallidus* numbers peaked during the flowering stage and *Eurystylus* spp. and *N. natalensis* during the milk stage. Hemiptera feeding damage resulted in an increase in incidence of seeds with discoloured germ, therefore contributing significantly to reduction in grain quality.

Keywords: *Campylomma* sp., check list, *Creontiades pallidus*, *Eurystylus* spp., grain mould, *Nysius natalensis*, panicle-feeding Hemiptera, population dynamics.

Opsomming

Aarvoedende Hemiptera het gedurende die afgelope twee dekades plaagstatus bereik op sorghum in Wes- en Sentraal-Afrika en spesifiek in Mali, waar sorghum die stapelvoedsel is. Meer as 100 insekspesies, waarvan 42 spesies aarvoedend is, het plaagstatus op sorghum in Afrika. Geen navorsing is voorheen op aarvoedende Hemiptera in Suid-Afrika gedoen nie en die doel van hierdie studie was om die veelheid en diversiteit van aarvoedende Hemiptera op sorghum te bepaal. Veldopnames is gedoen tussen November 2004 en Junie 2006 op 26 lokaliteite in vier provinsies van Suid-Afrika. 'n Spesielys is saamgestel en 'n studie gemaak van die voorkoms van verskillende Hemiptera-spesies oor tyd gedurende die aarontwikkelingsfase van sorghum. Die effek van insekdodertoedienings op Hemiptera-getalle is geëvalueer en die korrelasie tussen die graad van swaminfeksie van graan en Hemiptera-voedingskade is ondersoek. Twee metodes van versameling is gebruik naamlik die D-Vac- en plastieksakmetodes. 'n Totaal van 23 798 volwassenes en nimfe is versamel gedurende die studie. Drie-en-veertig plantvoedende Hemiptera-spesies is versamel. Die familie wat die meeste voorgekom het was die Miridae (41 %), gevolg deur die Lygaeidae (17 %). *Eurystylus* spp., *Calidea dregii, Campylomma* sp., *Creontiades pallidus*, *Nysius natalensis* and *Nezara viridula* was die spesies wat in hoë getalle voorgekom het en was ook algemeen teenwoordig in die sorghum-produksiegebied. Die infestasievlakke van hierdie spesies was egter laag in vergelyking met dié in ander dele van Afrika en hul plaagstatus kan nie in Suid-Afrika bevestig word nie. Geen duidelike onderskeid tussen die groeistadiums waartydens infestasie deur verskillende spesies plaasvind kon waargeneem word nie. Die algemene tendens was dat die meerderheid spesies teenwoordig was vanaf die blomstadium waarna dit afgeneem het met verharding van graan. Getalle van *Campylomma* sp. en *C. pallidus* het toegeneem gedurende die blomstadium terwyl *Eurystylus* spp. en *N. natalensis* grootliks gedurende die melkstadium toegeneem het. Voedingskade deur Hemiptera veroorsaak 'n toename in voorkoms van saad met kiemvrot en dra by tot verlaging in graankwaliteit.

Sleutelwoorde: Aarvoedende Hemiptera, *Campylomma* sp., *Creontiades pallidus*, *Eurystylus* spp., *Nysius natalensis*, swaminfeksie, populasie dinamika, spesielys.

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Chapter 1

Introduction and literature review

1.1 Introduction

Grain sorghum is cultivated in Asia, the Americas and Africa where it is an important staple food (Ratnadass & Butler, 2003). In Africa sorghum is mainly grown in the semi-arid tropics that are characterized by erratic and low rainfall. Although sorghum is the staple diet of many people in Africa, yields are generally low and often unpredictable. According to Leuschner (1985) the average grain sorghum yield is 683 kg ha^{-1} in Africa and 734 kg ha^{-1} in India. Depending on seasonal conditions the grain sorghum yield on commercial scale farms in South Africa varies from 700 kg ha^{-1} to 2459 kg ha^{-1} with an average of 1738 kg ha^{-1}. The area under commercial sorghum production in South Africa has varied between 118 00 ha – 3170 00ha over the past decades with an average of 222 800 ha per annum (Anonymous, 1993). On the other hand, virtually no information exists regarding small scale farmers in South Africa, i.e. neither on the area under grain sorghum cultivation nor on yield. However, average yield of grain sorghum on communal farms in other parts of southern Africa is low, with an average of 493 kg ha^{-1}in Zimbabwe (Mushonga & Rao, 1986) and 735 kg ha^{-1} in Swaziland (Rohrbach & Malaza, 1993).

Sorghum is attacked by many insect species. More than 100 sorghum insect pest species have been recorded in Africa (Ratnadass & Ajayi, 1995). A list of sorghum pests in South Africa is provided in Table 1.1. A checklist compiled from literature on sorghum pests in South Africa indicates that based on the number of species reported, Lepidoptera (52 %) is the most dominant order attacking sorghum (Fig. 1.1). The Coleoptera (11 %), Diptera (11 %) and Homoptera (16 %) are less important, while only 5 % of the species belong to the Hemiptera and Orthoptera (Fig. 1.1).

Panicle feeding insects cause yield loss and reduction in grain quality. Forty-two panicle-feeding pests, have been recorded in Africa (Ratnadass & Ajayi, 1995). In West Africa only a few of these, i.e. sorghum midge *Stenodiplosis sorghicola* (Diptera: Cecidomyiidae) and a complex of head bugs (Hemiptera) are considered to be key pests (Ratnadass & Ajayi, 1995). Minor pests include a range of head caterpillars (Lepidoptera) and head beetles (Coleoptera). In eastern and southern Africa, the panicle-feeding complex consists mainly of African bollworm (*Helicoverpa armigera*) (Lepidoptera: Noctuidae), head bugs (Hemiptera), sorghum midge (Diptera: Cecidomyiidae), Armoured bush cricket (*Acanthoplus speiseri*) (Orthoptera: Tettigoniidae) and aphids (Homoptera) (Leuschner, 1995). Panicle-feeding pests seem to be less important in eastern and southern Africa than they are in Asia, the Americas and West Africa (Leuschner, 1995).

The panicle-feeding Hemiptera is an important group of the insect complex attacking sorghum in Asia, the Americas and in many parts of Africa (Ratnadass & Butler, 2003). During the last two decades, panicle-feeding Hemiptera have become major pests of sorghum in West and Central Africa, particularly in Mali (Ratnadass & Butler, 2003). The complex of Hemiptera feeding on sorghum panicles is dominated by the genus *Eurystylus* (Miridae) (Fig. 1.2), of which several species have been reported, notably *E. bellevoyei* Reuter from Burkina Faso, *E. rufocunealis* (Poppius) from Nigeria and *E. marginatus* Odhiambo from Niger and Mali (Ratnadass & Ajayi, 1995). In India *Calocoris angustatus* Lethierry (Hemiptera: Miridae), *Campylomma* sp. (Hemiptera: Miridae), *Creontiades pallidus* (Ramber) (Hemiptera: Miridae) and *E. bellevoyei* represent 96, 4, 1 and 0.01 %, respectively, of the total number of head bugs collected from panicles of sorghum during the milk stage (Sharma & Lopez, 1993).

In a world review of sorghum panicle-feeding Hemiptera compiled by Harris (1995) (Table 1.3), certain families have been shown to be more prevalent than others. Based on the number of species reported to attack sorghum, the Miridae (32 %) and Pentatomidae (34 %) were reported to be the most prevalent families (Fig 1.2). The families Alydidae (7 %), Coreidae (4 %), Cydnidae (2 %), Lygaeidae (14 %), Pyrrhocoridae (5 %) and Scutelleridae (2 %) were also reported as important but, in lower numbers (Fig. 1.2).

Outbreaks of head bugs in southern and eastern Africa during the 1980's were mainly associated with newly developed compact-panicle, short-duration cultivars (120-130 days to maturity) (Leuschner, 1995). Head bugs are therefore mostly associated with compact-headed sorghum types (generally improved caudatum varieties) while the local guinea cultivars with loose panicles are usually free from these pests (Ratnadass & Ajayi, 1995). Poor agronomic practices such as staggered sowing dates have also been associated with severe head bug damage. Outbreaks have been observed on research stations such as Matopos (Zimbabwe), Kasinthula (Malawi), Dakata and Disesa (Ethiopia), in commercial and semi-commercial production fields in Pandamatenga (Botswana) and at Kilimo/Sasakawa in Tanzania (Leuschner, 1995). In South Africa, Matthee (1974) and Annecke & Moran (1982) in a comprehensive review of grain pests did not report any Hemiptera to cause damage to sorghum. *Calidea dregii* (Fig. 1.4) (Hemiptera: Scutelleridae) was listed as a pest on sorghum (Table 1.1) by Van den Berg and Drinkwater (2000a).

1.1.1 Damage symptoms, yield loss and economic injury levels

Sorghum head bugs feed primarily on panicles where they suck the sap from the developing grains, which results in shrivelling and tanning of grain. Some of the grains may remain undeveloped. Damage symptoms are normally evident on some or all the grains. Head bug damage is generally higher on grains inside the panicle. In some cases, a section of the panicle may be more damaged than the rest, and some grains may be normal while others show damage symptoms (Sharma *et al*., 1992a). Damage severity depends on infestation levels and can range from a few feeding punctures per panicle to grains that are highly shrivelled and only slightly visible outside the glumes (Sharma *et al*., 1992a).

Actual yield losses caused by head bugs in eastern and southern Africa have not been quantified (Harris, 1995). In West Africa in Mali and Burkina Faso, head bug infestation caused a 50 % reduction in seed mass and an additional 30 % quantitative loss, in terms of a reduction of dehulling recovery rate (Ratnadass & Ajayi, 1995). Damaged grains shows distinct red-brown feeding punctures and in cases of severe feeding, become completely tanned. These grains also have lower germination rates, lower grain density and overall yield loss. Such grains are more susceptible to moulds and show poor seed germination (Sharma *et al*., 1992a) (Fig. 1.5). Some species deposit their eggs inside the grain during the milk stage. The grain tissue around the egg becomes reddish-brown and this reduces the grain quality (Sharma *et al*., 1992b). In India, the estimated overall grain yield loss caused by sorghum panicle pests average 4.6 %. However, this figure varies considerably over years (Rana & Singh, 1995). Losses caused by midge and head bug in southern India range between 15 and 30 % for local sorghum varieties while in commercial cultivars, losses range between 6 and 93 % for head bugs alone (Rana & Singh, 1995).

The extent of head bug damage depends on the numbers of bugs per panicle, duration of infestation and panicle development stages (Rana & Singh, 1995). Infestation during early grain development results in more severe damage than infestations during the hard dough stage (Rana & Singh, 1995).

Assisted infection refers to a situation where grain mould fungal infection is aided by biotic factors, especially insects. During feeding and oviposition, the insects puncture grain, which predisposes grain to grain mould by providing suitable micro-conditions for fungal infection and mould development (Marley & Ajayi, 1999). The changes brought about by the grain moulds include decreased size of the grain and chalky endosperm which disintegrates during harvesting and threshing, causing considerable loss in the grain yield and quality which together reduce its market price (Audilakshmi *et al*., 2005). Early indication of this phenomenon occurring in the West and Central African sub-region was provided by Harris (1995) who observed that even on traditional cultivars which ripened when the humidity was still high, grain could be infected by fungi which invaded the seed directly or through punctures made by sucking insects. Steck *et al*. (1989) and Sharma *et al*. (1992a) also reported that bug-damaged grains showed greater mould severity.

The first evidence of the interaction between head bugs and grain mould was provided by Ratnadass *et al*. (1995) in West Africa. He demonstrated a strong relationship between head bug infestation, particularly *E. oldi* and grain moulds. Higher grain mould infection was found and higher numbers of fungal colonies were isolated from bug-damaged grain in Niger (Marley & Ajayi, 1999). Mould infection was further shown to affect seed germination and grain weight (Marley & Ajayi, 1999). Insect infestation of panicles was also reported to encourage mildew infection (Chantereau & Nicou, 1994).

Economic injury levels have been determined for relatively few field crop pests. A quantitative relationship is usually determined between yield and pest density which is then integrated with pest control costs and crop market values to establish these threshold levels (Hall & Teetes, 1982). A yield loss-density relationship based on percentage loss allows producers faced with different gain thresholds to calculate economic injury levels more easily. In sorghum, economic injury levels have been developed for shoot fly, midge, armyworm and some Coreidae and Pentatomidae bugs (Hall & Teetes, 1982). The economic injury level for *N. viridula* in the United States of America was higher than 16 adult bugs per panicle when infestations occurred during the hard dough stage (Hall & Teetes, 1982). In India, Sharma & Lopez (1993) determined the economic injury levels of *Calocoris angustatus* to range between 0.4 and 50 bugs per panicle for different sorghum varieties. The economic injury level for *Nysius plebeius* Distant (Hemiptera: Orsillidae) was reported to be 40 or more bugs per panicle (Sweet, 2000).

1.1.2 Qualitative losses due to head bugs and grain moulds

Grain moulds are becoming a major disease problem in sorghum production throughout the tropical region of Africa, particularly where agricultural intensification is leading to the substitution of traditional varieties with more productive improved varieties (Chantereau & Nicou, 1994). Whereas local varieties escape mould infection by maturing late, normally at the beginning of the dry season, modern cultivars have been developed to flower early (Chantereau & Nicou, 1994). The grains fill while the rains are still heavy and are therefore attacked by those fungi that thrive in humid conditions. In this group of fungi, which varies according to region, the main species are *Fusarium* sp. (Gray) (notably *Fusarium moniliforme*), *Curvularia* sp. (Boedijn), *Alternaria* sp. (Wallroth) and *Helminthosporium* sp. (Fries) (Table 1.3) (Chantereau & Nicou, 1994).

Head bug damage results in increased severity of grain moulds caused by *Fusarium, Curvularia, Phoma* and *Alternaria* species (Sharma *et al*., 1994). Apart from fairly exceptional flower abortions, the main losses result from reduced grain weight and poor grain quality. In effect, the external and internal presence of mildews renders grain less attractive, changes its nutritional value, reduces its storage capacity and reduces germination viability (Chantereau & Nicou, 1994). Furthermore, certain mildews produce mycotoxins that may be poisonous (Chantereau & Nicou, 1994).

Research conducted on mould infection of sorghum breeding lines showed a significant correlation between the isolation of pathogens from embryos, reduced seed germination and seedling vigor (INTSORMIL, 2002). Grains were particularly susceptible to infection during milk and soft dough stages of grain development. Under greenhouse conditions, germination was reduced by an excess of 50 % when heads were inoculated with primary grain mould pathogens at the susceptible stage (INTSORMIL, 2002). Risk analysis based on weather and grain mould interactions in field trails, suggested that the most critical period for infection is 9 – 13 days after anthesis. This is also the period when head bugs start to feed on developing grains (INTSORMIL, 2002).

1.1.3 Biology of panicle-feeding Hemiptera

While many Hemiptera families use sorghum only as a food plant, the Miridae also lay eggs inside the seeds that they feed on. *Calocoris angustatus* lay eggs inside the glumes before anthesis (Sharma & Lopez, 1990). *Creontiades pallidus, E. bellevoyei* and *Campylomma* sp., lay eggs inside the grain during the milk stage. In the absence of food, mirid head bugs are cannibalistic and also predacious on members of other species. Head bugs are also predatory on sorghum midge, *S. sorghicola* (Sharma & Lopez, 1990).

Calocoris angustatus feeds on sorghum panicles as they emerge from the flag leaf, inhibiting grain set and decreasing yields (Cherian *et al*., 1941, cited by Wheeler, 2001). Adults in nearby crops are attracted to plants during the preflowering stage of sorghum, which is preferred for oviposition. No eggs are laid in panicles following grain set. In India *C. angustatus* lay eggs inside the glumes before anthesis. A female lays an average of 182 eggs during the rainy season, after a pre-oviposition period of 2-4 days and 113 eggs during the post-rainy season, after a pre-oviposition period of 5-8 days (Sharma & Lopez, 1990). Eggs hatch in 7-8 days. There are five nymphal instars and the development is completed in 8-12 days. These insects take 15-17 days to complete their life cycle. Females live for 12-23 days (Sharma & Lopez, 1990). As many as 350 nymphs (*C. angustatus*) can be found on a panicle and if the nymphs feed on the panicle before flowering, the panicle may dry up and produce no or little grain (Fig. 1.5) (Cherian *et al*., 1941, cited by Wheeler, 2001).

Females of *C. pallidus* lay eggs inside the grain during the milk stage. Eggs are inserted inside the grain and the tip or operculum of the egg is visible from the outside. The grain pericarp develops a red-brown or black ring around the egg. The pre-oviposition period lasts 2-5 days and eggs hatch in 6-8 days. Females lay 45-251 eggs and development is completed in 11-15 days. Adult longevity is 11 days for males and 13 days for females (Sharma & Lopez, 1990).

Females of *E. bellevoyei* also lay their eggs inside the grain during the milk stage and eggs project outside the pericarp. The entire life cycle takes 14-16 days (Sharma & Lopez, 1990). Eggs hatch in 7 days and nymphal development is completed in 7-8 days. *Campylomma* sp. lays its eggs inside milk grain. Eggs hatch in 5 days and development is completed in 11 days. All four species complete development in 15-20 days and are capable of reaching high population numbers within a single cropping season (Sharma & Lopez, 1990).

Nezara viridula (Linnaeus) (Hemiptera: Pentatomidae) (Fig. 1.6) is highly polyphagous, attacking both monocotylous and dicotylous plants. As many as 145 species within 32 plant families have been recorded as hosts (Kiritani *et al*., cited by Panizzi *et al*., 2000). Nymphs in the early instars are strongly gregarious, but the gregarious habit disappears during the fourth instar. During summer, the developmental time from egg to adult is approximately 35 days (Panizzi *et al*., 2000). In India *N. viridula* preferentially infests developing sorghum grain from the milk stage onwards.

The common name for the Lygaeidae is the "seed bugs" as most of the species are primarily seed feeders. Eggs of *Spilostethus pandurus* (Scopoli) (Hemiptera: Lygaeidae), a pest of sorghum (Table 1.2), are broadly oval and pearly white, becoming purple just before hatching. Females lay up to 10 egg batches underneath fallen leaves or flowers. Each batch contains 50-60 eggs. The nymphs are a conspicuous yellow-orange to orange with brown markings (Sweet, 2000).

Nysius spp. laid eggs until they are seven weeks old, the development take 6 to 12 days and the first adults emerge within 16 to 19 days (Sweet, 2000). The nymphs of *Nysius* spp. are remarkably similar in appearance, with a brown and white striped on the head and thorax and the abdomen a mottled reddish-brown and white (Sweet, 2000). The smaller false chinch bug, *N. plebeius*, infests sorghum from the soft dough stage onwards causing unfilled, shrivelled and spotted grains. Infestation continues until the grain ripening stage after which a decline in numbers is observed (Sweet, 2000).

1.1.4 Wild host plants of head bugs

Alternate host plants play an important role in the ecology of panicle-feeding bugs (Teetes, 1985). Hemiptera adults move from alternate hosts to sorghum during the grain development phase of sorghum. The number of bugs moving into sorghum fields depends upon availability of alternate hosts during the grain development phase, densities of bugs present on these alternate hosts, and specific varietal preferences (Teetes, 1985). For example, castor bean, *Ricinus communis* (Linnaeus) (Euphorbiaceae), was identified as an alternate host of *E. oldi* in West Africa, and it was subsequently suggested that this plant could be the source of reinfestation and of population carry-over (Ratnadass *et al*., 1997). Plant bugs are the most destructive insect pests of castor flowers and fruit. Miridae damage in Kenya and Tanzania is intensified when *R. communis* is grown near large fields of corn or sorghum (Weis, 1971, cited by Wheeler, 2001). In Mali, castor plants occur on riverbanks and in almost every village. The high fertility and humidity of gardens, dumps and wells promote luxuriant vegetative growth, extended flowering and delayed maturity, which could allow high head-bug population levels to persist throughout the year (Ratnadass *et al*., 2001). In South Africa, *Eurystylus* spp. feed on male and female flowers of *R. communis*, causing them to shrivel and die, in some cases, the entire stem dies (Boyes, 1964, cited by Wheeler, 2001). Survival of nymphs of these Miridae depends on the inflorescences of castor. When castor flower becomes unsuitable for *Taylorilygus ricini* (Taylor) (Hemiptera: Miridae), the nymphs search for another castor plant. *Eurystylus* nymphs however are capable of migrating only to another inflorescence on the same plant (Boyes, 1964, cited by Wheeler, 2001).

Spilostethus pandurus attacks more than 40 different host plant species in the world, the most commonly attacked species are sorghum, pearl millet, cotton and groundnuts (Sweet, 2000). The green stink bug, *N. viridula* a cosmopolitan pest that damages sorghum in Thailand, attacks several crops, such as rice, soybean and castor bean (Meksongsee & Chawanapong, 1985). *Ricinus communis* plants are used by *N. viridula* as a temporary host, a source of water and/or nutrients (Panizzi, 1997).

A survey conducted on indigenous host plants of sorghum head bugs in Mali showed that *Creontiades pallidus*, *Campylomma angustior*, *Megacoelum apicale* and *E. oldi* occurred on several plant species (Table 1.4) (Ratnadass *et al*., 1997). Eggs of *C. pallidus* and *C. angustior* were recovered from the stems of various weeds, namely *Cassia nigricans* (Vahl) (Caesalpiniacease), *Cassia tora* (Linnaeus) (Caesalpiniacease), *Crotalaria retusa* (Linnaeus) (Fabaceae), *C. nigricans* and *Crotalaria goreensis* (Guillemin & Perrottet) (Fabaceae). Nymphs of *C. pallidus* and *C. anustior* were collected from *C. nigricans*, *C. tora*, *Cr. goreensis* and *Cr. retusa*. Nymphs of *C. pallidus* were also recorded from

Combretum sp. (Combretaceae) (Table 1.4) (Ratnadass *et al*., 1997). Castor was the only indigenous plant species found to harbour immature stages of all four Miridae species. Eggs and all nymphal instars of *E. oldi* were found on inflorescences of castor along the banks of the Samanko River in Mali. *Eurystylus capensis* (Distant) (Hemiptera: Miridae) was reported as a pest of castor in Mozambique (March 1972, cited by Ratnadass *et al*., 1997), but Stonedahl (1995) maintained that this report was almost certainly based on *E. oldi*. Weiss (1993) (Cited by Ratnadass *et el*., 1997) also mentioned *E. capensis* as an economically important pest of castor in South Africa where it caused severe damage to capsules. *Eurystylus* species was more recently reported as a major pest of castor in Zimbabwe (Tongoona, 1992, cited by Ratnadass *et al*., 1997).

Wild host plants of *Nysius natalensis* (Evans) (Hemiptera: Orsillidae) (Fig. 1.7) are common in South Africa. Du Plessis (2004) recorded 27 plant species as hosts of this pest in the sunflower production area. The most important of these were *Amarantus hybridus* (Amaranthaceae), *Portulaca oleracea* (Asteraceae), *Chenopodium album* (Chenopodiaceous) and *Conyza albida* (Asteraceae). These four species could therefore also play an important role in the ecology of *N. natalensis* and possibly other Hemiptera that occur in sorghum production systems.

1.2 Conclusions

Very little attention has been paid to panicle feeding insects on sorghum in South Africa, probably because they were not economically important in traditional landrace sorghums grown by farmers. Moreover, entomological research in southern Africa has been mainly directed at commercial crops. Until recently, subsistence crops like sorghum have received little attention. It is evident from the literature that panicle-feeding bugs are a serious problem in Central and West Africa (Leuschner, 1995; Ratnadass & Ajayi, 1995) and could therefore also be a problem in South Africa.

1.3 Objectives of this study

1.3.1 General objectives:

The general objectives were to study the diversity and abundance of the Hemiptera complex that occur on sorghum panicles in South Africa and to determine the relationship between head bug damage and fungal infection of grains.

1.3.2 Specific objectives

- to determine the abundance and diversity of panicle-feeding Hemiptera in the sorghum production area.
- to compile a check list of Hemiptera that occur on sorghum panicles in South Africa.
- to determine the temporal distribution of different Hemiptera species on panicles during the reproductive period of plant growth and to evaluate the effect of insecticide application on Hemiptera numbers.
- to determine if there are varietal differences in resistance to head bug damage and to determine the relationship between grain mould severity and Hemiptera feeding damage.

Results of this study will be presented in the form of chapters with the following titles:

- A checklist of panicle-feeding Hemiptera on sorghum in South Africa.
- Temporal distribution of panicle-feeding Hemiptera on sorghum in South Africa.
- Resistance of sorghum varieties to head bugs and the relationships between feeding damage, grain mould and discoloured kernels.

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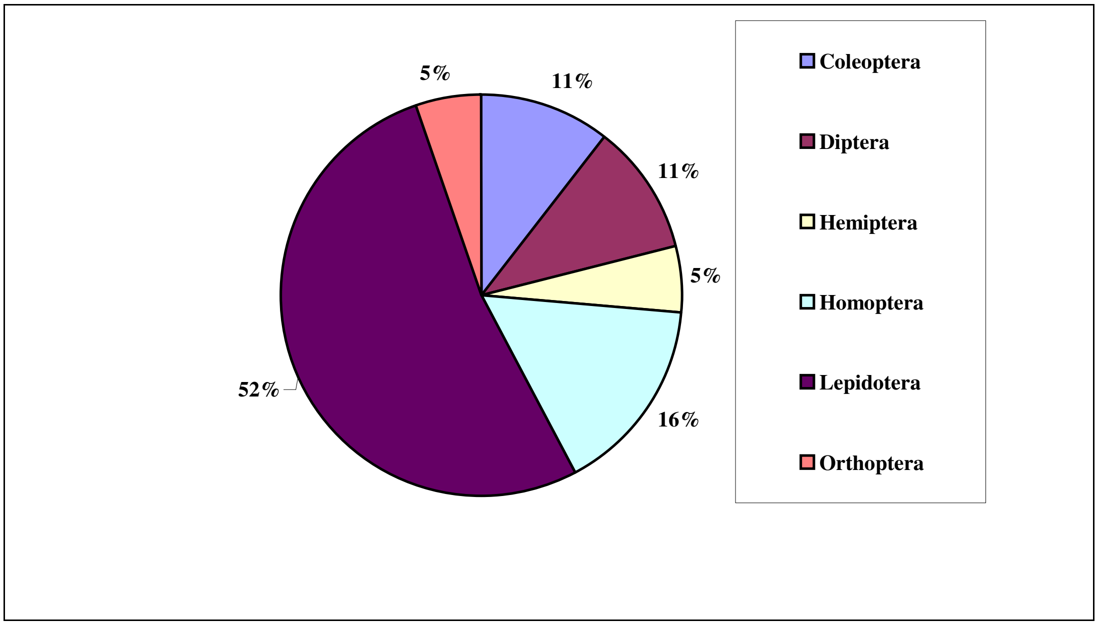

Fig. 1.1. Percentage distribution of Arthropod species reported to attack sorghum in South Africa (Compiled from table 1.1 and calculated from the number of species listed per Order).

Fig. 1.2. *Eurystylus* sp. on developing sorghum grains.

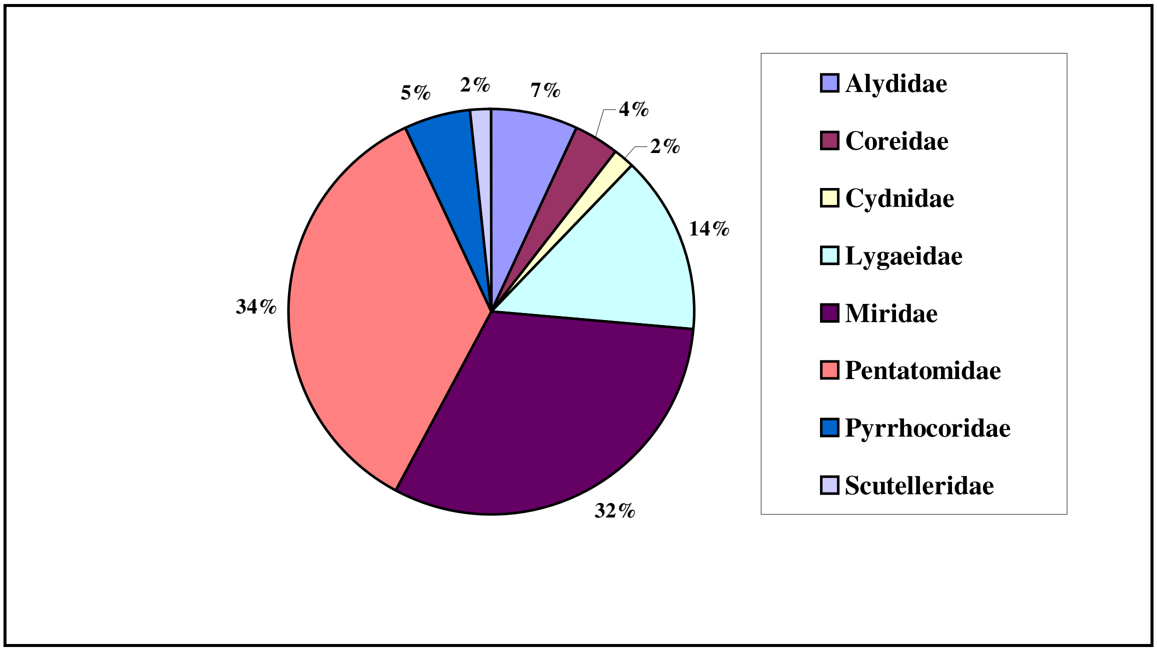

Fig. 1.3. Percentage distribution of species in Hemiptera families attacking sorghum in the world (Compiled from table 1.2 and calculated from the number of species listed per family).

Fig. 1.4. *Calidea dregii* adult on sorghum panicle.

Fig. 1.5. Symptoms of head bug damage to sorghum panicle during early development.

Fig. 1.6. *Nezara viridula* nymph on sorghum panicle.

Fig. 1.7. *Nysius natalensis* adults on sorghum panicles.

Table 1.1. Insect pests of sorghum in South Africa.

Order	**Family**	**Common name**	**Species name**	**Source**
Homoptera	Aphididae	Sorghum aphid	*Melanaphis sacchari* (Zehntner)	Annecke & Moran (1982) Van den Berg (1999)
		Maize aphid	*Rhopalosiphum maidis* (Fitch)	Annecke & Moran (1982) Van den Berg (1999)
		Wheat aphid	*Schizaphis graminum* (Rondani)	Annecke & Moran (1982) Van den Berg (1999)
Hemiptera	Scutelleridae	Iridescent blue-green cotton bug	*Calidea dregii* Germar	Van den Berg & Drinkwater (2000a)
Diptera	Cecidomyiidae	Sorghum midge	*Stenodiplosis sorghicola* Coquillett	Annecke & Moran (1982) Van den Berg & Drinkwater (2000a)
	Chloropidae	Sorghum shoot fly	*Anatrichus erinaceus* Loew	Annecke & Moran (1982)
Coleoptera	Melyridae	Spotted maize beetle	*Astylus atromaculatus* Blanchard	Annecke & Moran (1982) Drinkwater (1997)
	Scarabaeidae	Black maize beetle	*Heteronychus arator* Fabricius	Annecke & Moran (1982) Du Toit (1998) Van den Berg & Drinkwater (2000a)
Lepidoptera	Pyralidae	Sorghum stem borer	*Chilo partellus* (Swinhoe)	Annecke & Moran (1982) Van den Berg (1997)
	Noctuidae	Maize stalk borer	*Busseola fusca* (Fuller)	Annecke & Moran (1982) Van den Berg (1997)
		Pink stalk borer	*Sesamia calamistis* Hampson	Van den Berg (1997) Van den Berg & Drinkwater (2000b)
		Black cutworm	*Agrotis ipsilon* (Hufnagel)	Annecke & Moran (1982) Du Plessis (2000)
		Brown cutworm	*Agrotis longidentifera* (Hampson)	Annecke & Moran (1982) Du Plessis (2000)
		Common cutworm	*Agrotis segetum* (Denis & Schiffermüller)	Annecke & Moran (1982) Du Plessis (2000)
		Grey cutworm	*Agrotis subalba* Walker	Annecke & Moran (1982) Du Plessis (2000)

		African bollworm	*Helicoverpa armigera* (Hübner)	Annecke & Moran (1982) Du Plessis & Van den Berg (1999)
		Lesser army worm	*Spodoptera exigua* (Hübner)	Annecke & Moran (1982)
		Army worm	*Spodoptera exempta* (Walker)	Annecke & Moran (1982)
Orthoptera	Tettigoniidae	Armoured bush cricket	*Acanthoplus* spp.	Van den Berg & Drinkwater (2000a)

Table 1.2. Panicle-feeding Hemiptera reported on sorghum on a worldwide basis.

Family name	**Insect pest**	**Region**	**Source**
Alydidae	*Leptocorisa acuta* (Thunberg)	India	Harris (1995)
	Mirperus spp.	Africa	Harris (1995)
	Mirperus jaculus (Thunberg)	Niger	Steck *et al*. (1989)
	Riportus spp.	Africa	Harris (1995)
Coreidae	*Leptoglossus phyllopus* (Linnaeus)	North America	Harris (1995)
	Leptoglossus zonatus (Linnaeus)	North America	Harris (1995)
Cydnidae	*Aethus laticollis* Wagner	India	Harris (1995)
Lygaeidae	*Geocoris megacephalus* Rossi	Niger	Harris (1995) Steck *et al*. (1989)
	Nysius raphanus (Howard)*	North America	Harris (1995)
	Nysius spp.*	Niger	Harris (1995) Steck *et al*. (1989)
	Nysius plebejus Distant*	China	Rana & Singh (1995)
	Pseudopachybranchius capicolus (Stal)	Niger	Harris (1995) Steck *et al*. (1989)
	Spilostethus pandurus (Scopoli)	Niger / India	Harris (1995) Steck *et al*. (1989)
	Spilostethus rivularis Germar	Africa	Harris (1995)
	Spilostethus spp.	Africa	Harris (1995)
Miridae	*Adelphocoris seticornis* (Fabricius) [= *Adelphocoris apicalis* (Hahn)]	Mali / Nigeria	Harris (1995) Ratnadass & Ajayi (1995)
	Adelphocoris sp.	Africa	Harris (1995)
	Blissus leucopterus (Say)	United States of America	Hill (1983)
	Calocoris angustatus Lethierry	India / Myanmar / Pakistan	Harris (1995) Rana & Singh (1995)
	Campylomma nicolasi Reuter	/ Burkina Faso / Mali / Niger / Nigeria / Senegal / Togo	Harris (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)

	Campylomma angustior Poppius	Burkina Faso / Mali / Niger / Nigeria / Senegal / Togo	Harris (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)
	Campylomma subflava Odhiambo	/ Burkina Faso / Mali / Niger / Nigeria / Senegal / Togo	Harris (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)
	Creontiades pallidus (Ramber)	/ Burkina Faso / Mali / Niger / Nigeria / Senegal / Togo / India	Harris (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)
	Eurystylus argenticeps Odhiambo	Botswana / Burkina Faso / Mali / Niger / Nigeria / Senegal / Togo / Zimbabwe	Harris (1995) Leuschner (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)
	Eurystylus bellevoyei (Reuter)	Botswana / Burkina Faso / Mali / Niger / Nigeria / Senegal / Togo / Zimbabwe / India	Harris (1995) Leuschner (1995) Ratnadass & Ajayi (1995)
	Eurystylus capensis (Distant)	Mozambique	Ratnadass (1997)
	Eurystylus immaculatus Odhiambo [= *Eurystylus oldi*]	Botswana / Burkina Faso / Mali / Niger / Nigeria / Senegal / Togo / Zimbabwe	Harris (1995) Leuschner (1995) Ratnadass & Ajayi (1995)
	Eurystylus marginatus Odhiambo	Botswana / Burkina Faso / Mali / Niger / Nigeria / Senegal / Togo / Zimbabwe	Harris (1995) Leuschner (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)
	Eurystylus rufocunealis Poppius	Botswana / Burkina Faso / Mali / Niger / Nigeria / Senegal / Togo / Zimbabwe	Harris (1995) Leuschner (1995) Ratnadass & Ajayi (1995)
	Leptocorisa spp.	Philippines	Hill (1983)
	Lygus sp.	Africa	Harris (1995)
	Megacoelum apicale Reuter	Burkina Faso / Mali / Niger / Senegal / Togo	Harris (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)

	Paramixia suturalis Reuter	Niger / Nigeria	Harris (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)
	Stenotus transvaalensis (Distant)	Niger	Harris (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)
	Taylorilygus ricini (Taylor)	Mozambique	Hill, 1983
	Taylorilygus vosseleri (Poppius)	Botswana / Ethiopia / Niger / Nigeria	Harris (1995) Leuschner (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)
	Tytthus parviceps (Reuter)	Niger	Harris (1995) Ratnadass & Ajayi (1995) Steck *et al*. (1989)
Pentatomidae	*Acrosternum heegeri* Fieber	Niger	Harris (1995) Steck *et al*. (1989)
	Agonoscelis haroldi Bergroth	Niger	Harris (1995) Steck *et al*. (1989)
	Agonoscelis pubescens (Thunberg) [=*Agonoscelis versicolor*]	Africa	Harris (1995)
	Aspavia armigera Fabricius	Niger	Steck *et al*. (1989)
	Bagrada hilaris (Burmeister)	India	Harris (1995)
	Chlorochroa ligata (Say)	North America	Harris (1995)
	Chlorochroa sayi (Stal)	North America	Harris (1995)
	Diploxys floweri Distant	Niger	Harris (1995) Steck *et al*. (1989)
	Dolycoris indicus (Stal)	Africa	Harris (1995)
	Euschistus servus (Say)	North America	Harris (1995)
	Euschistus impictiventus (Stay)	North America	Harris (1995)
	Euschistus conspersus Uhler	North America	Harris (1995)
	Eysarcoris inconspocuus (Herrich-Schaeffer)	Niger	Harris (1995) Steck *et al*. (1989)
	Loxa flavicollis (Drury)	Brazil	Harris (1995)
	Menida distanti Horváth	Africa	Harris (1995)

	Nezara viridula (Linnaeus)	Cosmopolitan	Harris (1995) Leuschner (1995) Rana & Singh (1995)
	Oebalus pugnax (Fabricius)	North America	Harris (1995)
	Oebalus mexicana (Fabricius)	North America	Harris (1995)
	Piezodorus sp.	Niger	Harris (1995) Steck *et al*. (1989)
	Thyanta spp.	North America	Harris (1995)
Pyrrhocoridae	*Dysdercus koneigii* Fabricius	India	Harris (1995)
	Dysdercus superstitiosus (Fabricius)	Niger	Harris (1995) Steck *et al*. (1989)
	Dysdercus voelkeri Schmidt	Africa	Harris (1995)
Scutelleridae	*Calidea dregii* Germar	Botswana / Malawi / Tanzania/South Africa	Harris (1995) Leuschner (1995) Van den Berg & Drinkwater (2000a)

**Nysius* spp. (Hemiptera: Orsillidae), the family Orsillidae is now considered to be a distinct family from the Lygaeidae (Sweet, 2000)

Table 1.3. Grain mould pathogens recorded on sorghum in West Africa (Chantereau & Nicou, 1994).

Pathogenic agents	Temperate zones		Sub-tropical zones		Tropical zones (Rainy season)	
	Presence	Level of damage	Presence	Level of damage	Presence	Level of damage
Fusarium sp.	+ +	2	+ + +	3	+ +	2
Curvularia sp.	+ +	2	+ + +	3	+ +	2
Alternaria sp.	+ +	2	+ + +	3	+ +	2
Helminthosporium sp.	+ +	2	+ + +	3	+ +	2

Presence — Level of damage

- Not found — 0 = Nil

+ Occasional — 1 = Minor

+ + Frequent — 2 = Moderate

+ + + General — 3 = Major

Table 1.4. Immature stages of sorghum head bugs (Miridae) observed on alternate host plants at Samanko, Mali (Ratnadass *et al*., 1997).

Host plant species	Miridae species							
	Creontiades pallidus		***Campylomma angustior***		***Megacoelum apicale***		***Eurystylus oli***	
	Eggs	Nymphs	Eggs	Nymphs	Eggs	Nymphs	Eggs	Nymphs
Cassia nigricans *	+[1]	+	+	+	-	-	-	-
Cassia tora	+	+	-	+	-	-	-	-
Crotalaria goreensis	-	+	+	+	-	-	-	-
Crotalaria retusa	+	+	-	+	-	-	-	-
Combretum sp.	-	+	-	-	-	-	-	-
Ricinus communis	+	+	+	+	-	+	+	+

1: + = present; - = absent

* *Cassia nigricans* is now considered a synonym for *Charaecrista nigricans* (Lock, 1987).

Chapter 2

A checklist of panicle-feeding Hemiptera on sorghum in South Africa

2.1 Introduction

Sorghum bicolor (L.) Moench is the most important cereal crop in the semi-arid tropics (Leuschner & Pande, 1991). Large-scale commercial farming sectors in Zimbabwe, Botswana and South Africa have demonstrated that sorghum can compete favourably with maize. The yield increases observed during the 1970's-1980's in this agricultural sector resulted from improved varieties and hybrids associated with improved management practices (Leuschner & Pande, 1991). Unfortunately this trend up to now is not observed in the communal small-farming sector in Africa. However, improved technology is increasingly moving into this sector, particularly in Zimbabwe, Botswana, Zambia and Tanzania through Global 2000 and other extension agencies (Leuschner & Pande, 1991).

One hundred and fifty sorghum insect pest species have been recorded on sorghum in the world (Harris, 1995). Fifty-seven of these are panicle-feeding Hemiptera species of which 42 species occur in Africa (Harris, 1995). During the last two decades, panicle-feeding Hemiptera have become major pests of sorghum in West and Central Africa (Ratnadass & Butler, 2003). In Africa the complex of Hemiptera on sorghum panicles is dominated by the genus *Eurystylus*, the most important species *E. bellevoyei* Reuter from Burkina Faso, *E. rufocunealis* (Poppius) from Nigeria and *E. marginatus* Odhiambo from Niger and Mali (Ratnadass & Ajayi, 1995).

Sorghum head bugs feed primarily on developing grain. The extent of damage depends on the bug population per panicle, duration of infestation and panicle development stage. Infestation during the early grain development stage results in more severe damage than during the hard dough stage. Both adults and nymphs can cause economically important damage (Rana & Singh, 1995).

No research has been done on the panicle-feeding Hemiptera in South Africa, despite the fact that they often occur in large numbers on sorghum. From the literature it is evident that panicle-feeding bugs are a big problem in Central and West Africa (Leuschner, 1995; Ratnadass & Ajayi, 1995). More than 20 *Calidea* nymphs were recorded per panicle in Tanzania, while over 100 adults and nymphs of several head bug species per panicle were observed during a survey in Pandamatenga in Botswana (Leuschner, 1995) but its relationship with grain yield and grain quality have not been studied. Since panicle-feeding Hemiptera do occur on sorghum in South Africa they could also be economically important in this country. However, Matthee (1974) and Annecke & Moran (1982) did not report any Hemiptera to cause damage to sorghum in South Africa. Van den Berg and Drinkwater (2000) listed *Calidea dregii* as a pest on sorghum, but provided no quantitative data.

The aim of this study was to compile a list of the panicle-feeding Hemiptera on sorghum in South Africa and to determine the infestation levels at which they occur.

2.2 Materials and methods

Surveys were conducted at 26 sites in four provinces (Fig. 2.1) in the sorghum production areas of South Africa between November 2004 and June 2006. Except for two sites, all samples were collected on farmers' fields. Two methods of collection were used in this study. Whole panicles were sampled by closing them with plastic bags and removing them from the field, while a D-vac was used to sample insects from large numbers of panicles in fields without removing panicles. Sampling for panicle-feeding Hemiptera was done at different plant growth stages between flowering and the hard dough stage. Since the plastic-bag method was time consuming, the D-Vac method was used more towards the end of the 2004/05 season and throughout the 2005/06 season to facilitate sampling from greater numbers of panicles.

While most of the species were recorded during once-off sampling on sorghum fields, several were collected during succession studies during which population development of

Hemiptera was monitored over time (Chapter 3). The total number of insects per species per panicle was calculated and converted to the number of insects per species per 100 panicles. This was done since some species occurred at very low numbers. The minimum and maximum numbers per panicle for each species were also recorded. Although only herbivorous Hemiptera was monitored in this study, an exception was made with the predatory species, *Orius* sp. (Anthocoridae), *Deraeocoris* sp. (Miridae) and *Nabis* sp.1 (Nabidae), since these are well known biological control agents.

Due to the lack of Hemiptera identification expertise in South Africa many species could only be identified to family level. Insects were identified at the ARC-Biosystematics division in Pretoria. Unidentified species were only assigned numbers. Since Hemiptera cannot be identified in the nymph stage these counts were pooled and expressed as the total number of nymphs per panicle. A checklist was compiled after identification of the species.

2.2.1 Panicle collection using plastic bag-method

The plastic bag-method was used in the North-West province at the Potchefstroom, Modderdam and Parys (Free Sate Province) sites (Fig. 2.2). Thirty panicles were randomly collected from each field between 08h00 and 11h00. Sampling was done by putting a plastic bag (20 x 8 x 38 cm) carefully over the panicle and sealing it off with masking tape around the peduncle (Hall & Teetes, 1981). The panicles were then cut off, taken to the laboratory and put in the freezer for 24 hours to kill the insects. Panicles were taken out of the freezer to defrost for 30-60 minutes before insects were collected using the modified Bucket-method (Steward *et al*., 1991). The peduncle was placed between the palms of the sampler’s hands and rotated rapidly (twirled) for 15 seconds. The twirling of the panicle caused the inhabiting Hemiptera to be dislodged and to fall to the bottom of the bucket. The contents of the bucket were then removed with a paintbrush into a glass Petri dish marked with square grids, to facilitate counting and sorting of insects using a stereo microscope. Adult insects were pinned according to the method described by Grobbelaar (1996).

2.2.2 D-Vac sampling

A D-vac (Fig. 2.3) was used to collect insects during the end of the 2004/05 season and the 2005/06 season between 08h00 and 11h00. Sample sites are provided in Table 2.1. At the Potchefstroom, Modderdam and Parys sites, insects from 200 panicles were sampled per field at different sampling dates.

There were three replications of 100 panicles sampled per field at the Castello, Heilbron, Koppies, Nylstroom and Settlers sites. The 100 panicles of each replication were adjacent panicles within a randomly selected row inside the field. The distance between replications was approximately 100m. Because of the small size of fields in small-farming areas at Lebowakgomo, the number of panicles that was sampled was limited to 150 panicles / field (three replications of 50 panicles). Since sorghum was not planted in rows but broadcast at the Lebowakgomo sites, the panicles were sampled in a radius of approximately 5m at three different areas within each field.

The peduncles were tapped against the D-Vac brim, to dislocate the insects into the D-Vac bag. The D-Vac bag and its contents were put into a killing jar containing ethyl acetate for 10-15 minutes after which the contents were emptied into a marked plastic bag. These plastic bags were frozen to preserve the insects. Samples were later defrosted in the laboratory for one hour. Each sample was sifted with a kitchen sieve. The samples were divided into a fine and a rough sample to separate larger insects and plant material from small insects. Samples were inspected in small portions in a glass Petri dish marked with square grids, to facilitate counting and sorting using a stereo microscope. Hemiptera were removed and the adult insects were pinned for identification purposes.

2.2.3. Comparison of the efficacy of the plastic bag- and D-Vac methods

To determine if the plastic bag- and D-Vac methods were similar in their efficacy, a study was done to compare numbers of Hemiptera sampled using these two methods. The study was done on a commercial field at Heilbron (soft dough stage). Three replications of 30 panicles each were sampled at three areas inside the field using each method. The average number of head bugs per panicle was then calculated and the two methods compared using a two-factor ANOVA with NCCS (Hintz, 2001).

2.3 Results and discussion

The results of the two-factor ANOVA indicated no significant difference ($F_{1,14} = 1.42$, $P = 0.25$) between the numbers collected using the D-Vac (mean = 0.63 individuals / panicle) or the plastic bag (mean = 0.54 individuals / panicle) methods. These two sampling methods can therefore be considered to be equally efficient for collection of panicle feeding Hemiptera on sorghum.

The total number of the adults and nymphs collected during this study was 23 798 (14 590 adults and 9 208 nymphs). A total of 43 species of herbivorous Hemiptera was recorded (Table 2.2). The family with the highest occurrence was the Miridae which represented 41 % of the total number of species recorded, followed by the Lygaeidae (17 %) (Fig. 2.4). These results are in contrast to that of Harris (1995) (Table 1.2) who indicated that, on a world-wide basis, Pentatomidae (34 %) was the most abundant followed by Miridae (32 %).

The Cydnidae, which was reported by Harris (1995) was not recorded during this study. *Aethus laticollis* (Cydnidae) is a serious pest on roots of Bajra, a millet crop and is also found on sorghum and wheat in the semi-arid areas in India (Lis *et al*., 2000). The Berytidae and Rhopalidae that was reported in the present study, was not previously reported to occur on sorghum. The cosmopolitan Berytidae is primarily found on plants and most species are phytophagous. Feeding habits of the Berytidae include omnivory and facultative carnivory or saprophagy (Anonymous, 2006). *Liorhyssus hyalinus* (Rhopalidae) occurs worldwide and feeds on sorghum and pistachio fruits. This bug moves onto these crops from nearby wild hosts that are mostly grasses (Schaefer & Kotulski, 2000). *Liorhyssus hyalinus* can be regarded an economically important pest and has been reported to cause up to 100 % yield losses in Venezuela (Cremelli *et al*., 2004). In this study *L. hyalinus* was recorded at low numbers of 0.55 / 100 panicles and numbers ranged between 0.3 and 8.3 / 100 panicles.

Of all the species recorded during this study only ten have previously been reported on sorghum (Harris, 1995). These are: *Mirperus jaculus* (Alydidae), *Geocoris megacephalus* (Lygaeidae), *Spilostethus pandurus* (Lygaeidae), *Spilostethus rivularis* (Lygaeidae), *Campylomma* sp. (Miridae), *Eurystylus* spp. (Miridae), *Stenotus* sp. (Miridae), *Agonoscelis versicolor* (Pentatomidae), *Nezara viridula* (Pentatomidae) and *Calidea dregii* (Scutelleridae).

A number of species occurred only in fields in the Limpopo province were local landraces of sorghum are planted in low-input farming systems. These were *Mirperus jaculus* (Alydidae), Miridae sp. 4, Miridae sp. 5, *Solenostethium liligerum* (Scutelleridae), *Agonoscelis versicolor* (Pentatomidae) and Pyrrhocoridae sp. 1. Miridae sp. 9 was recorded in very large numbers on a commercial field at Nylstroom.

The mean, minimum and maximum number of individuals per 100 panicles from which different species were recorded is provided in Table 2.2. The majority of insects occurred at very low infestation levels (<2 individuals / 100 panicles) while some species were recorded at levels between 2 and 8 / 100 panicles. In only a few instances were infestation levels between 12 and 30 / 100 panicles. Six species occurred in high numbers that could be considered as possible pest outbreaks. These were *N. viridula*, *Eurystylus* sp. 5, *Campylomma* sp., Miridae sp. 9, *Nysius natalensis* and *Eurystylus* sp. 2 that occurred at maximum infestation levels of 40, 61, 105, 134, 246 and 724 per 100 panicles respectively.

The *Eurystylus* complex in South Africa consists of five different species. In this study *Eurystylus* sp. 2 and *Eurystylus* sp. 5 were the most abundant (Table 2.2). The mean number of *Eurystylus* sp. 2 was 164.4 / 100 panicles (0.3-724). *Eurystylus* sp. 5 occurred at a mean infestation level of 11.9 / 100 panicles (0.3-61). These species have the possibility to become pests of sorghum in South Africa. The head bug complex on sorghum in Africa is dominated by the genus *Eurystylus*, of which several species have been reported (Ratnadass *et al*., 1994). *Eurystylus oldi* is the most abundant and injurious of the Hemiptera species (Ratnadass *et al*., 1994). Studies in West Africa showed that *E.*

oldi can occur at levels of 3–11 / panicle during the milk stage and 9-100 during the dough stage (Ajayi *et al*., 2001). Castor bean (*Ricinus communis*) is also damaged by *E. oldi* and can serve as a trap crop for *E. oldi* near sorghum fields (Ratnadass *et al*., 1997).

In this study infestation levels of the Lygaeid *S. rivularis* ranged between 0.3 and 16 / 100 panicles (mean between 1.2 / 100 panicles) (Table 2.2). The pest status of *S. rivularis* and its numbers were low, compared to its pest status on other crops in Africa. *Spilostethus rivularis* was recorded as a pest on cotton, rice and sweet potatoes in the Congo (Mayné & Ghesquiè, 1939, Cited by Slater & Sperry, 1973) and as a minor pest of cotton in Zimbabwe (Golging, 1930, Cited by Slater & Sperry, 1973). Golding (1930, Cited by Slater & Sperry 1973) also recorded nymphs and adults on *Sorghum vulgare*. This species have been reported as a pest of *Sorghum bicolor* in Africa, but its economic importance is unknown (Steck *et al*., 1989; Harris, 1995). *Spilostethus rivularis* together with *S. pandurus* were recorded to feed on the seed of a weedy plant, *Lopholaena coriifolia* (Slater & Sperry, 1973).

In this study *Calidea dregii* occurred at an average of 2.94 / 100 panicles and numbers ranged between 0.3 and 10 / 100 panicles (Table 2.2). Its numbers were low and it cannot be considered to be an economically important pest of sorghum in South Africa. *Calidea dregii* was especially common on fields at Lebowakgomo. Farmers expressed concern about this species and indicated that it caused damage to crops. Based on reports of *C. dregii* on other crops, it could possibly achieve pest status on a sporadic basis in South Africa. *Calidea dregii* is a well-known pest of cotton in the world (Kaufmann, 1966). Harris (1995) and Leuschner (1995) reported it as a pest on sorghum in the West and Central Africa. It is a polyphagous insect feeds on the reproductive parts of many plant species (Javahery *et al*., 2000). In Tanzania, more than 20 *C. dregii* nymphs were recorded on isolated sorghum panicles (Leuschner, 1995).

The *Campylomma* sp. that was recorded in this study occurred at an average of 16.4 / 100 panicles and numbers ranged between 0.3 and 105 / 100 panicles (Table 2.2). *Campylomma* species are major sorghum pests in Africa (Javahery *et al*., 2000) and it could be considered as a potential pest of economic importance in South Africa since it was recorded at levels of more than one per panicle at one site. There are many different *Campylomma* species in the world, each attacking different host plants (Javahery *et al*., 2000). *Campylomma verbasci* is an omnivore that feeds on red mites, two-spotted spider mites and apples in North America (Judd & McBrien, 1994; Javahery *et al*., 2000). *Campylomma angustior* and *C. plantarum* are two economically important species in West Africa (Sharma & Lopez, 1990; Wheeler, 2000). In a study on the abundance of *Campylomma* sp. in West Africa, the average number per panicle during the milk stage ranged between 3 and 13, and during the dough stage between 10 and 105 (Ajayi *et al*., 2001).

In this study *Creontiades pallidus* was recorded at an average of 2.3 / 100 panicles with numbers ranging between 0.3 and 27 / 100 panicles (Table 2.2). *Creontiades pallidus* is economically important pest in West Africa where it has been reported at a maximum infestation of 8 / panicle (Ratnadass & Ajayi 1995). According to Soyer (1942, Cited by Wheeler, 2000) *C. pallidus* was one of the worlds' key pests on cotton during the 20th century. It recently became a pest of sorghum in West Africa where it is encountered among the complex of panicle-feeding Miridae on sorghum (Ratnadass *et al*., 1994).

Nezara viridula has been reported as a pest on sorghum in the United States of America (Hall & Teetes, 1982). Economic injury levels have been calculated by Hall and Teetes (1982) which showed that its injuriousness differs depending on the growth stage that sorghum is infested. Using the Gain Threshold (GT) model developed by Stone and Pedigo (1972) and regression model data describing the *N. viridula* infestation level – yield loss relationship (Hall and Teetes, 1982), an economic injury level (EIL) was calculated for this pest in South Africa. Based on a sorghum price of R1000 / tonne, a yield potential of two tonnes / ha and a chemical control cost of R120 per hectare, the EIL for *N. viridula* will be 4.3 / panicle if infestation would be from the milk to the hard dough stage and 6.8 if infestation commences at soft dough stage (Fig. 2.5). In this study *N. viridula* was recorded only from the soft dough stage onwards and at a mean infestation level of 4.3 / 100 panicles. This indicated that this pest cannot be considered to be of general importance on sorghum in South Africa. The highest infestation level of this pest recorded in this study was 0.4 / panicle (Table 2.2), which is far below the EIL of 4.3 / panicle. *Nezara viridula* is one of the most important Pentatomidae pests in the world (Panizzi *et al*., 2000). Its pest status may be related to climatic factors and small changes in the environment over time, in addition to geographical expansion of a preferred legume or other hosts (Todd, 1989).

Nysius natalensis has not been reported as a pest on sorghum in Africa. In this study it occurred at a mean infestation level of 20 / 100 panicles and the minimum and maximum ranged between 0.3 and 246 / 100 panicles (Table 2.2). *Nysius natalensis* may have potential to reach pest status on sorghum in South Africa and this study showed that it was widely distributed throughout the sorghum production area. It was also reported to be widely distributed on wheat in the Free State province (Matthee, 1974) and on sunflower in the Mpumalanga, North-West and Gauteng provinces where it was reported to be highly polyphagous (Du Plessis, 2004). Observations have shown that *N. natalensis* usually damage sunflower crops from March onwards when headlands or adjacent weedy crop fields, hosting the insect, are cultivated. They also move from weeds during senescence and die-off prior to winter, to late planted sunflower during the seed-fill (Du Plessis, 2004). In this study *N. natalensis* seemed to attack sorghum in high numbers when crops like sunflower and other hosts such weeds were not available during the reproductive growth stage of sorghum. *Nysius raphanus* sporadically infests sorghum in the United States and cause considerable concern because of its high occurrence (Young & Teetes, 1997). In a damage assessment study, it was shown that for each additional ten bugs per panicle, there was 1% increase in the incidence of damaged seed. However, actual yield loss occurred only when 200 bugs per panicle damaged 23% of the seed (Young & Teetes, 1997).

In the absence of food, all Miridae head bugs are cannibalistic and are also predacious on members of other species (Sharma & Lopez, 1990). They are also predatory on the sorghum midge, *Stenodiplosis sorghicola* (Sharma & Lopez, 1990). The predatory Hemiptera, *Orius* sp. and *Deraeocoris* sp., were recorded at all sampling sites. *Orius* sp.

was recorded at a mean level of 5.1 / 100 panicles (range between 0.3-40.3 / 100 panicles), while *Deraeocoris* sp. was recorded at a mean level of 0.2 / 100 panicles (range between 0.3-19.3 / 100 panicles. *Nabis* sp. 1 was recorded at every low numbers of 0.02 / 100 panicles (range = 0.3-1 / 100 panicles).

2.4 Conclusions

Forty-three different herbivorous Hemiptera species was collected on sorghum. Many of these occurred at low infestation levels and none can be considered to be of great importance. However based on evidence from India and West Africa, *Eurystylus* spp., *C. dregii, Campylomma* sp., *C. pallidus*, *N. natalensis* and *N. viridula* could be regarded as potential pests of sorghum. Future research should be directed at establishing the relationship between the incidence of Hemiptera infestation and yield or quality loss of sorghum.

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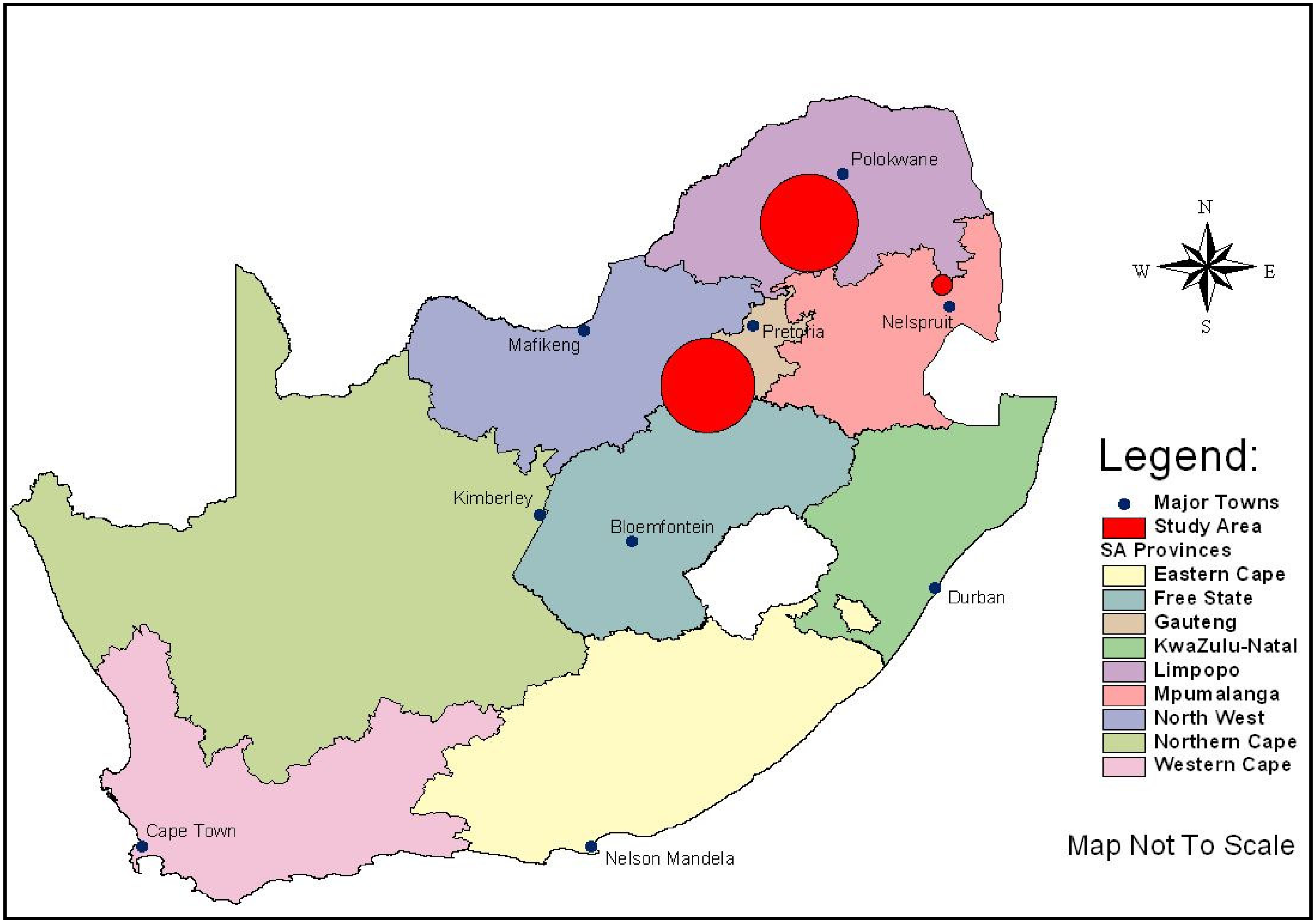

Fig. 2.1. Sampling sites in sorghum production areas.

Fig 2.2. Panicle collection using the plastic bag-method.

Fig. 2.3. Using the D-Vac to collect panicle-feeding insects.

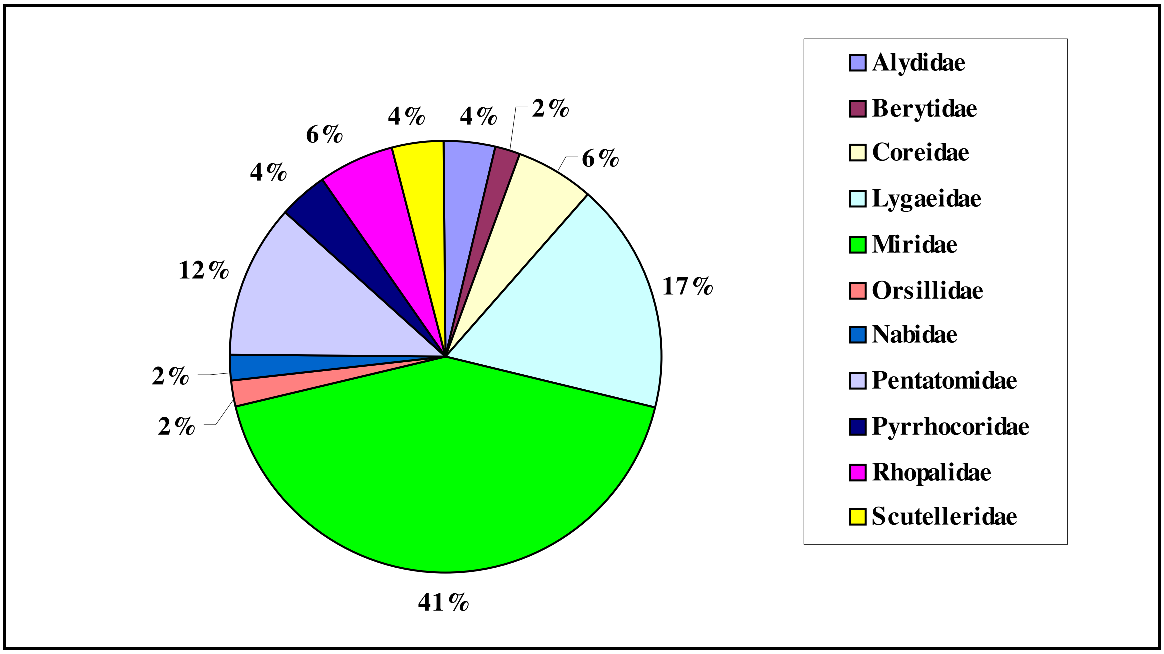

Fig. 2.4. Proportional distribution of Hemiptera families collected on sorghum panicles in South Africa (Compiled from Table 2.2).

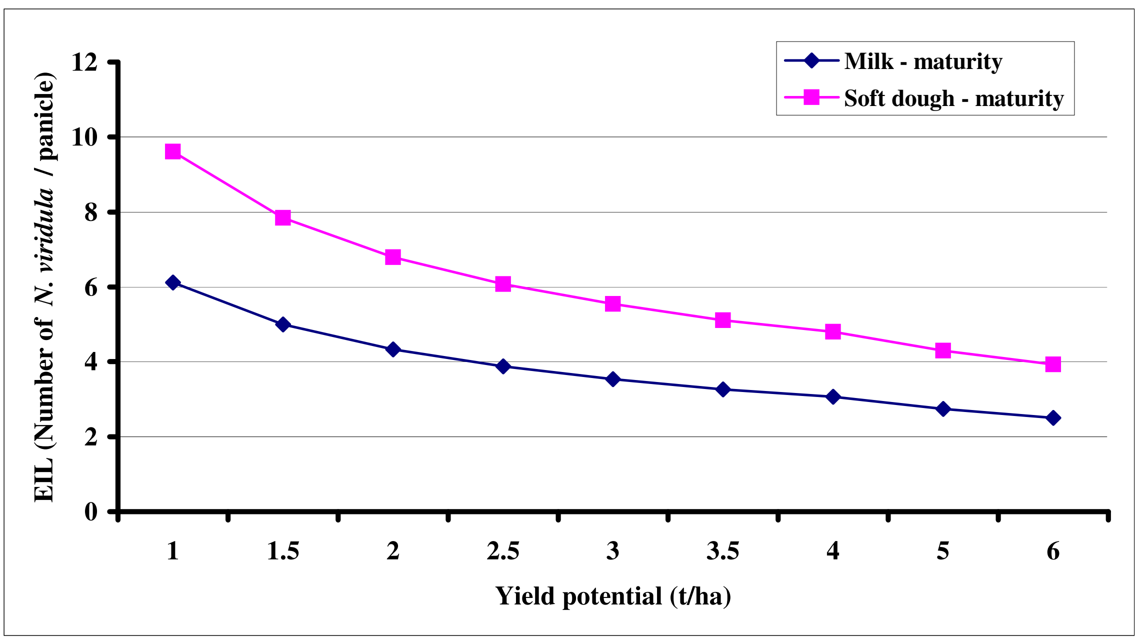

Fig. 2.5. Economic injury levels (EIL's) for *Nezara viridula* at different yield potentials of sorghum in South Africa.

Table 2.1. Sampling sites.

Province	Sample site (Field number)	Sampling sites	GPS coordinates
Free State	1	Heilbron field 1	S 27º 03.996 E 027º 56.548
	2	Heilbron field 2	S 27º 04.429 E 027º 56.298
	3	Heilbron field 3	S 27º 04.746 E 028º 01.358
	4	Koppies field 1	S 27º 10.868 E 027º 27.298
	5	Koppies field 2	S 27º 10.868 E 027º 27.298
	6	Koppies field 3	S 27º 12.141 E 027º 32.563
	7	Koppies field 4	S 27º 11.707 E 027º 32.907
	8	Koppies field 5	S 27º 07.304 E 027º 32.176
	9	Parys Weiveld-farm	S 26º 58.378 E 027º 38.627
Limpopo	10	Lebowakgomo field 1	S 24º 15.859 E 029º 35.722
	11	Lebowakgomo field 2	S 24º 15.877 E 029º 36.736
	12	Lebowakgomo field 3	S 24º 15.849 E 029º 35.729
	13	Lebowakgomo field 4	S 24º 15.815 E 029º 36.377
	14	Lebowakgomo field 5	S 24º 15.877 E 029º 36.792
	15	Lebowakgomo field 6	S 24º 15.776 E 027º 36.803
	16	Nylstroom field 1	S 24º 39.683 E 028º 52.423
	17	Nylstroom field 2	S 24º 40.417 E 028º 53.594
	18	Polokwane	S 23º 50.103 E 029º 41.558
	19	Settlers field 1	S 24º 58.231 E 028º 37.653
	20	Settlers field 2	S 24º 58.200 E 028º 37.079
Mpumalanga	21	Burgershall (Hazyview)	S 28° 22.520 E 32° 25.068
North-West	22	Castello field 1	S 26º 21.416 E 027º 06.565
	23	Castello field 2	S 26º 21.416 E 027º 06.565
	24	Potchefstroom field 1	S 26º 43.846 E 027º 04.822
	25	Potchefstroom field 2	S 26º 43.846 E 027º 04.822
	26	Potchefstroom field 3	S 26º 58.387 E 027º 38.629
	27	Potchefstroom Modderdam	S 26º 44.218 E 027º 08.655

Table 2.2. Mean number, minimum and maximum range of different head bug species collected throughout the sorghum production areas of South Africa.

Family	**Species name**	**Total number of adults collected**	**Average / 100 panicles**	**Range / 100 panicles (minimum – maximum)**	**Field no.: see table 2.1**
Alydidae	*Mirperus faculus* (Thunberg)	10	0.275	0.3 – 0.7	11, 12, 15, 19
	Mirperus jaculus (Thunberg)	1*	0.03	0.3	14
Berytidae	Berythidae sp. 1.	3	0.03	0.3 – 0.3	24
Coreidae	Coreidae sp. 1	1*	0.08	0.3	20
	Brotheolus viridis (Distant)	20	0.20	0.3 – 1.0	10, 11, 13, 14, 16, 17
	Cletus sp. 1	23	0.08	0.3 – 3.0	10, 12, 24, 25
Lygaeidae	Lygaeidae sp. 1	93	0.88	0.3 – 12.7	2, 10, 11, 12, 13, 14, 16, 23
	Lygaeidae sp. 2	2*	0.06	0.06	16
	Lygaeidae sp. 3	2*	0.06	0.06	16
	Geocoris liolestes Hesse	1*	0.03	0.03	14
	Geocoris megacephalus (Rossi)	53	0.63	0.3 – 3.3	1, 2, 3, 4, 5, 10, 11, 23, 24
	Paromius gracillis (Rambur)	61	0.59	0.3 – 2.7	5, 7, 16, 17, 25, 27
	Spilostethus pandurus (Scopoli)	17	1.23	0.3 – 1.0	10, 11, 12, 13, 14, 15, 17
	Spilostethus rivularis Germar	82	0.22	0.3 – 16.0	3, 4, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 23, 24, 25, 27
Miridae	Miridae sp. 1	1*	0.03	0.03	23, 25, 27
	Miridae sp. 2	25	0.78	0.3 – 1.8	7, 22, 23, 24, 25
	Miridae sp. 3	76	2.76	0.3 – 25.5	1, 2, 4, 5, 6, 7, 10, 11, 13, 22, 24, 25, 27
	Miridae sp. 4	75	12.58	3.3 – 27.3	10, 11, 12, 13, 14

	Miridae sp. 5	74	9.33	0.7 – 12.0	10, 11, 12, 13, 14
	Miridae sp. 6	1*	0.03	0.03	1
	Miridae sp. 7	6*	0.18	0.3 – 0.7	2
	Miridae sp. 8	1*	0.03	0.03	18
	Miridae sp. 9	799	22.48	17.3 – 134.7	16, 17
	Miridae sp. 10	2*	0.06	0.06	17
	Miridae sp. 11	7*	0.38	0.38	16
	Campylomma sp.	1710	16.14	0.3 – 105.5	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 24, 27
	Creontiades pallidus (Rambur)	436	2.38	0.3 – 27.7	1, 2, 3, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 24, 25, 27
	Eurystylus sp. 1	1257	8.58	0.3 – 14.7	1, 4, 5, 8, 9, 10, 11, 12, 13, 14, 16, 17, 21, 24, 25
	Eurystylus sp. 2	5338	164.44	0.3 – 724.6	1, 3, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20
	Eurystylus sp. 3	29	0.23	0.3 – 1.3	3, 10, 11, 12, 23, 14, 16, 17, 23
	Eurystylus sp. 4	336	3.24	1.7 – 22.3	10, 11, 12, 13, 14, 16, 20
	Eurystylus sp. 5	1432	11.9	0.3 – 61.0	10, 11, 12, 13, 14, 15, 16, 17, 20
	Stenotus sp. 1	14	0.29	0.3 – 1.0	2, 7, 11, 12, 14, 19, 20, 23, 27
	Stenotus sp. 2	15	0.23	0.3 – 0.3	2, 11
	Stenotus sp. 3	1*	0.03	0.03	16
Orsillidae	*Nysius natalensis* Evans	1699	20.07	0.3 – 246.6	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 16, 17, 19, 20, 22, 23, 25, 27
Pentatomidae	*Agonoscelis erosa* (Westwood)	18	0.66	0.3 – 2.3	10, 16, 17, 18

	Agonoscelis versicolor Fabricius	1*	0.03	0.03	18
	Eysacoris inconspicuous (Herrich-Schaeffer)	21*	0.50	1.0	1, 3 7, 23, 15, 27
	Nezara viridula (Fabricius)	168	4.27	0.3 – 40.0	4, 5, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 25, 27
Pyrrhocoridae	Pyrrhocoridae sp. 1	10*	0.66	0.7	13
	Pyrrhocoridae sp. 2	2*	0.06	0.06	3, 23
Rhopalidae	*Liorhyssus hyalinus* Fabricius	209	1.31	0.3 – 8.3	1, 3, 4, 9, 10, 11, 12, 13, 14, 15, 22, 23, 24, 25
Scutelleridae	*Calidea dregii* Germar	136	2.94	0.3 – 10.0	10, 11, 12, 13, 14, 17, 20
	Solenostethium liligerum (Thunberg)	2*	0.06	0.06	10, 14
Nymphs**		9208	76.48	0.3 – 278.5	1, 2, 3, 4, 6, 7, 8, 10, 11, 12, 13,20, 24, 25, 26, 27

*Only collected at one site.

**Total number of nymphs collected during study.

Chapter 3

Temporal distribution of panicle-feeding Hemiptera on sorghum

3.1 Introduction

Several species of insect pests attack sorghum during its development. Sorghum head bugs feed primarily on developing grain that result in shrivelling and tanning of grain, while some grains may remain undeveloped (Sharma *et al.*, 1992). Economic losses are maximized when damage occurs at this late stage of crop development since the main production inputs would have already been made (Harris, 1995).

Alternate host plants play an important role in the ecology of panicle-feeding bugs of sorghum. Hemiptera adults move from alternate hosts to sorghum during the grain development phase. The number of bugs moving into sorghum fields depends upon availability of alternate hosts during the sorghum grain development phase, densities of bugs present on these alternate hosts, and specific preferences (Teetes, 1985). Panicle-feeding Hemiptera was also reported to infest sorghum at different growth stages (Meksongsee & Chawanapong, 1985; Nwanze, 1985; Ajayi *et al*., 2001). The stage of infestation and subsequent duration of feeding depends on the growth stage of the plant and its suitability for feeding by different insects (Sharma & Lopez, 1990). The extent of head bug damage depends on the numbers of bugs per sorghum panicle, duration of infestation and panicle development stage at the time of infestation (Rana & Singh, 1995).

The aim was to study Hemiptera population dynamics from panicle emergence to physiological maturity of sorghum and to evaluate the effect of insecticide application on Hemiptera numbers.

3.2 Materials and methods

The population dynamics of different Hemiptera species was studied by collecting Hemiptera on sorghum panicles over time. These succession studies were conducted at 16 sites in four provinces (Chapter 2, Fig. 2.1 and Table 2.1) in the sorghum production areas of South Africa between November 2004 and June 2006. Except for two sites located on experimental farms, all samples were collected on farmer's fields. Two methods of collection were used in this study. Panicles selected randomly were covered with plastic bags and removed from the field, while a D-vac was used to sample insects from large numbers of panicles in fields without removing panicles. Sampling of panicle-feeding Hemiptera was done at different plant growth stages between flowering and the hard dough stage. Since the plastic-bag method was time consuming, the D-Vac method was used more towards the end of the 2004/05 season and throughout the 2005/06 season to enable sampling of more panicles at more sampling sites.

The total number of individuals per species per panicle was calculated and converted to the number of individuals per species per 100 panicles. This was done since some species occurred in very low numbers.

3.2.1 Panicle collection using plastic bag-method

The plastic bag-method was used in the North-West province at the Modderdam, Potchefstroom sites. At Potchefstroom, regular sampling (3-4 day intervals) was done during the reproductive stages of sorghum. Thirty panicles were randomly collected at each sampling date from the six spreader rows (approximately 80 m per row) of a trial conducted to evaluate the resistance levels of sorghum varieties to sugarcane aphid. Sampling was always done between 08h00 and 11h00.

Sampling at Modderdam (North-West province) and Parys (Free State province) was done on commercial fields. Thirty panicles were randomly collected at each sampling date. This was done fortnightly during the reproductive stages of sorghum. During sampling a zig-zag pattern was followed through the field, starting 100 m into the field. A panicle was sampled, from every third row 2 m forward from the previous sampling point. This was done until 30 panicles were collected (300 m was covered in each collection trip). Sampling was done by covering the panicle with a plastic bag (20 x 8x 38 cm) and sealing it off with masking tape around the peduncle (Hall & Teetes, 1981). The panicles were then cut off, taken to the laboratory and put in the freezer for 24 hours to kill the insects. Panicles were defrosted in the lab for 30-60 minutes before insects were collected using the modified Bucket-method (Steward *et al*., 1991). The peduncle was placed between the palms of the sampler's hands and rotated rapidly (twirled) for 15 seconds. The twirling of the panicle caused the inhabiting Hemiptera to be dislodged and to fall to the bottom of the bucket. The contents of the bucket were then removed with a paintbrush into a glass Petri dish marked with square grids, to facilitate counting and sorting of insects using a stereo microscope. Adult insects were pinned according to the method described by Grobbelaar (1996).

3.2.2 D-Vac sampling

A D-vac (Fig. 2.2) was used to collect insects during the 2005/06 season. Sampling was done during 08h00 and 11h00. Sample sites are provided in Table 2.1 (Chapter 2). There were three replications of 100 panicles each per field at the Heilbron, Nylstroom and Settlers sites. The 100 panicles of each replication were adjacent panicles within a randomly selected row inside the field. The distance between replications was approximately 100 m. Because of the small size of fields in small-farming areas at Lebowakgomo, the number of panicles that was sampled was limited to 150 panicles / field (three replications of 50 panicles). Since sorghum was not planted in rows but broadcast at the Lebowakgomo sites, the panicles were sampled in a radius of approximately 10 m at three areas within each field.

The peduncles were tapped against the D-Vac brim, to dislocate the insects into the D-Vac bag. The D-Vac bag and its contents were put into a killing jar containing ethyl acetate for 10-15 minutes after which the contents were emptied into a marked plastic bag. These plastic bags were frozen to preserve the insects. Samples were later defrosted in the laboratory for one hour. Each sample was sifted with a kitchen sieve. The samples were divided into a fine sample and a rough sample to separate larger insects and plant material from small insects. The rough samples were inspected in small portions in a glass Petri dish marked with square grids, to facilitate counting and sorting using a stereo microscope. The fine samples were divided into sub-samples due to the extreme volume of contents (Fig 3.1). Because of the large volume of insects and plant material such as pollen bags and kernels found in the D-vac sample, sub-samples were taken. The whole-sample volume was determined using teaspoon scoops. Thirty percent of the scoops were then inspected for Hemiptera. The number of Hemiptera per teaspoon scoop was determined and then calculated for the whole sample. Hemiptera were removed and the adult insects were pinned for identification purposes.

3.2.3 Insecticide trials

The effect of insecticide application on Hemiptera numbers over time was determined in field trials, one at Nylstroom (S 24º 39.683 E 028º 52.423) and one at Settlers (S 24º 58.231 E 028º 37.653) (Fig. 2.1).

At Nylstroom insecticide application was done on one field (100 ha) while another field (70 ha) that did not receive insecticide was used as the control field. The planting dates of both fields were between 12 and 15 January 2006. Parathion was applied by means of an aerial application at 400 g.a.i ha^{-1} during the flowering stage for control of aphids and sorghum midge, and evaluated against the untreated control, which was used for monitoring purposes. Sampling was done by means of the D-vac method (as described under 3.2.2).

Another field trail was done once every three weeks to determine if application of contact insecticides against African bollworm, which infests panicles during the same period as head bugs, affects the general population development of Hemiptera. Cypermethrin and Methomyl 90 SP were applied at dosages of 50 g.a.i ha^{-1} and 180 g.a.i ha^{-1} per hectare on two fields (368 ha and 290 ha respectively). Application was done by means of a tractor mounted sprayer during flowering. The D-Vac method was used to collect samples, from both fields.

3.3 Results

The 17 sites that were monitored were each treated as an individual locality. Plant growth stage was determined when sampling was done (Table 3.1 and Table 3.2). Data on only the most abundant species of the Hemiptera complex found at each site are shown in the figures. A list of all the species that were collected is provided in Table 2.2.

3.3.1.1 Modderdam

The Hemiptera population was dominated by three species, i.e. *Campylomma* sp., *Eurystylus* sp. 1 and *Nysius natalensis*. The latter was the most abundant species between the flowering and soft dough stages. The mean number of adult Hemiptera / 100 panicles during the different growth stages is shown in Figure 3.2. *Nysius natalensis* numbers increased from flowering to the soft dough stage but decreased over time as the grains hardened (Fig. 3.2). In contrast, *Campylomma* sp. occurred in low numbers during the early growth stages, increased after the soft dough stage and reached infestation levels of more than four / panicle. *Eurystylus* sp. 1 was present at very low numbers during the hard dough stage.

3.3.1.2 Potchefstroom

Two fields were sampled at this site. The population dynamics for field one and two were the same from the flowering stage to the soft dough stage. As a result of bird damage to panicles, sampling could not be continued on field two after the soft dough stage.

Campylomma sp., *Creontiades pallidus*, *Eurystylus* sp.1 and Miridae sp.3 were present during the early flowering stage and again during the milk stage (Fig. 3.3 & 3.4). The

Hemiptera complex was dominated by *Eurystylus* sp.1, which was present at relatively high numbers in comparison to the other species (Fig. 3.3). The mean number of adult Hemiptera / 100 panicles during the different growth stages of sorghum at site 1 is shown in Figure 3.3. *Creontiades pallidus* was present at very low numbers throughout panicle development.

Numbers of all species to increased after the flowering stage. There was however a reduction in numbers of three of the species early during the soft dough stage, for a period of two to three sampling dates (approximately 10 days). This reduced incidence of head bugs could possibly be ascribed to poor weather conditions that could have affected sampling efficiency. Numbers of all species to decreased during the hard dough stage. Numbers of *C. pallidus* however increased and peaked during the hard dough stage.

3.3.1.3 Heilbron

The average number of adult Hemiptera per 100 panicles for the three fields that were sampled is shown in Figure 3.5. Compared to field two and three, field one had the highest number of species during all growth stages. The most abundant Hemiptera species was *Nysius natalensis*, which made up 71% (field one), 60% (field two) and 64% (field three) of the population. Other Hemiptera species were present in very low numbers. *Nysius natalensis* numbers decreased from the milk stage onwards (Figure 3.6). No bugs were present during the hard dough stage.

3.3.1.4 Lebowakgomo

The population dynamics were determined on six individual fields. The average number of nymphs and adults / 100 panicles is shown in Figure 3.7. Sampling dates instead of growth stage was used since fields differed slightly in growth stages. Field one had the highest number of Hemiptera (200 / 100 panicles). The Hemiptera complex was dominated by *Eurystylus* spp. The average number of adult *Eurystylus* spp. / 100 panicles for each field is shown in Figures 3.8-3.13. *Eurystylus* sp. 3 and 4 were present in very low numbers.

The most abundant species in field one was *Eurystylus* sp. 5 at levels of 48 / 100 panicles during the flowering until the hard dough stage (Fig. 3.8). The number of *Eurystylus* sp. 1 and 2 ranged between 25 and 28 /100 panicles. The population dynamics for field two (Fig. 3.9) and three (Fig. 3.10) were similar. *Eurystylus* sp. 5 was the most abundant species at 41 and 26 /100 panicles for the two respective fields, followed by *Eurystylus* sp. 2 (33 and 21 / 100 panicles). At field four (Fig. 3.11) *Eurystylus* sp. 1 was the most abundant species from the late flowering stage until the hard dough stage with a maximum of 35 / 100 panicles. *Eurystylus* sp. 2 was present with a maximum of 21 / 100 panicles during milk stage, after which numbers decreased. The most abundant Hemiptera species for field five was *Eurystylus* sp. 1 at 26 / 100 panicle during the flowering and milk stage (Fig. 3.12). A decrease in numbers occurred from the milk stage until the hard dough stage, while *Eurystylus* sp. 5 numbers stayed the same during the flowering stage until the soft dough stage and decreased during the hard dough stage. *Eurystylus* sp.1 occurred at very low numbers during the reproductive stages. On field six (Fig. 3.13) only two *Eurystylus* spp. was recorded. *Eurystylus* sp. 2 occurred at numbers of 5 / 100 panicles during the milk and soft dough stage after which numbers decreased. *Eurystylus* sp. 5 occurred at very low numbers.

3.3.2 Insecticide trials

3.3.2.1 Nylstroom

Miridae sp. 9 and *Nysius natalensis* were the dominant species in both the control and sprayed fields. The mean number of adult Hemiptera / 100 panicles is shown in Figure 3.14. Miridae sp. 9 occurred in high numbers (31 / 100 panicles) during the milk stage after which it decreased on the control field. On the sprayed field, Miridae sp. 9 decreased from the milk stage to the soft dough stage and did not occur again for the rest of the growing season. *Nysius natalensis* was recorded from the milk stage until the beginning of the hard dough stage in the control field, while on the sprayed field they occurred in very low numbers after the soft dough stage.

3.3.2.2 Settlers

The field at Settlers were treated with contact insecticides during flowering. Numbers only started to decline during hard dough stage. The mean number of adult Hemiptera from the different species ranged between 1 and 10 /100 panicles (Figures 3.15 and 3.16). The Hemiptera complex was dominated by *Campylomma* sp., *Creontiades pallidus*, *Eurystylus* sp. 2 and *Nysius natalensis*.

3.4. Discussion

Eurystylus spp., *C. dregii, Campylomma* sp., *C. pallidus*, *N. natalensis* and *N. viridula* are panicle-feeding species that occur in significant numbers on sorghum in South Africa (Chapter 2). *Calidea dregii* occurred widely but at insignificant numbers. The time of infestation of various species may vary depending on local rainfall conditions and maturity stages of the sorghum (Steck & Teetes, 1989). In this study all species were present from the flowering stage until the hard dough stage, except *N. viridula* that was only recorded from the soft dough stage onwards. In general, *Campylomma* sp. and *C. pallidus* numbers peaked during the flowering stage and *Eurystylus* spp. and *N. natalensis* during the milk stage. Numbers of *Campylomma* sp., *C. pallidus*, *N. viridula* and *N. natalensis* peaked during the soft dough stage. According to the literature *Campylomma* species is associated with panicles during the first weeks after panicle emergence (Nwanze, 1985), while *N. viridula* feeds on sorghum from the soft dough stage until maturity (Meksongsee & Chawanapong, 1985). The optimum stage for sampling *Eurystylus oldi* is during the soft dough stage (Ajayi *et al*., 2001).

The insecticide parathion that was applied at Nylstroom to control aphids and sorghum midge is a contact insecticide that is especially effective against aphids (Nel *et al*., 2002). Although the results from the Nylstroom experiment are in no way conclusive, it seemed as if this insecticide could be effective against head bugs. There are however, no insecticides registered for control of panicle-feeding bugs in South Africa.

The contact insecticides, cypermethrin and methomyl 90 SP, which were used at Settlers for control of African bollworm, did not seem to have an effect on head bug numbers. Although there was no control field to compare data to, numbers of bugs per panicle was high compared to the average infestation levels of the species reported in Table 2.2, and numbers only started to decrease during the hard dough stage, several weeks after insecticide application. In a study by Sharma & Leuschner (1992), carbaryl was found to be the most effective of the contact insecticides, followed by fenvalerate, chlorpyrifos and quinalphos. Of the systemic insecticides, demeton-S-methyl was the most effective and was superior to carbaryl. Because of the sucking type of feeding behaviour of head bugs, the insects also imbibed translocated / absorbed residues of the systemic insecticide; this possibly led to a better control through demeton-S-methyl compared with carbaryl.

3.5. Conclusions

Sorghum panicles may be infested by a wide range of insect pests from flowering stage to grain maturity. Only a few species have been reported elsewhere to cause economic damage. *Eurystylus* spp. which dominated at the majority of sites were not present in large numbers but can be considered the most important species in the Hemiptera complex in South Africa. Future research should be aimed at determining the injuriousness of the different species and development of chemical control strategies.

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Fig. 3.1. The fine samples were divided into sub-samples due to the high volume of the sample.

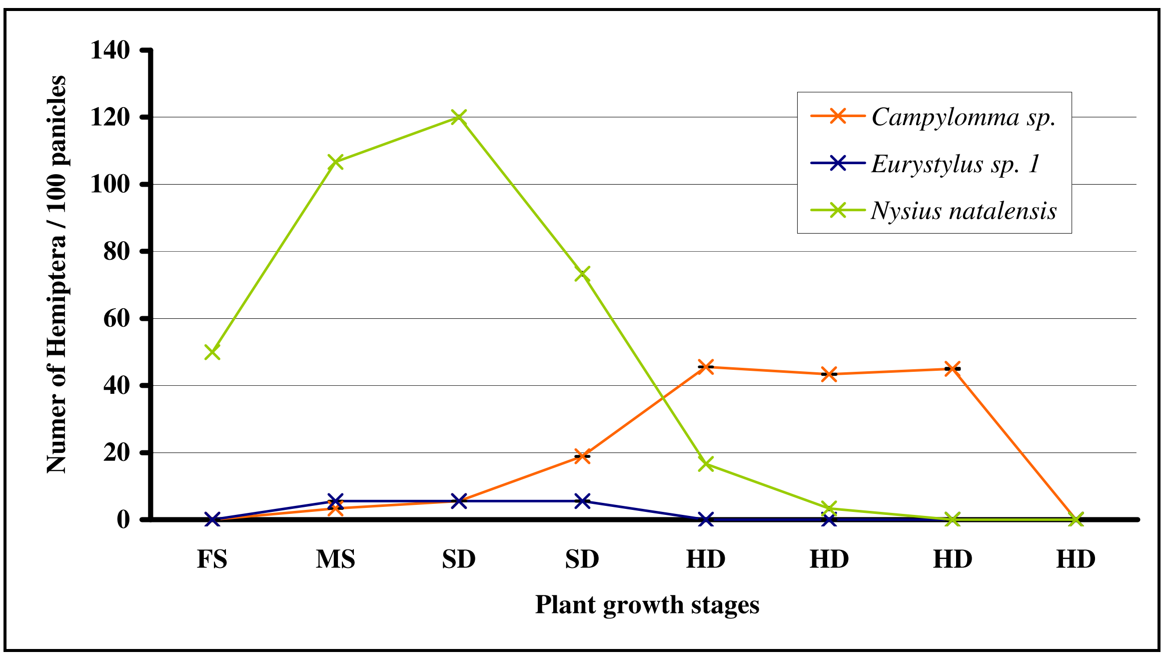

Fig 3.2: Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Modderdam (Standard errors were small and is not visible due to scale of axis) (FS – Flowering stage, MS – Milk stage, SD – Soft dough stage, HD – Hard dough stage).

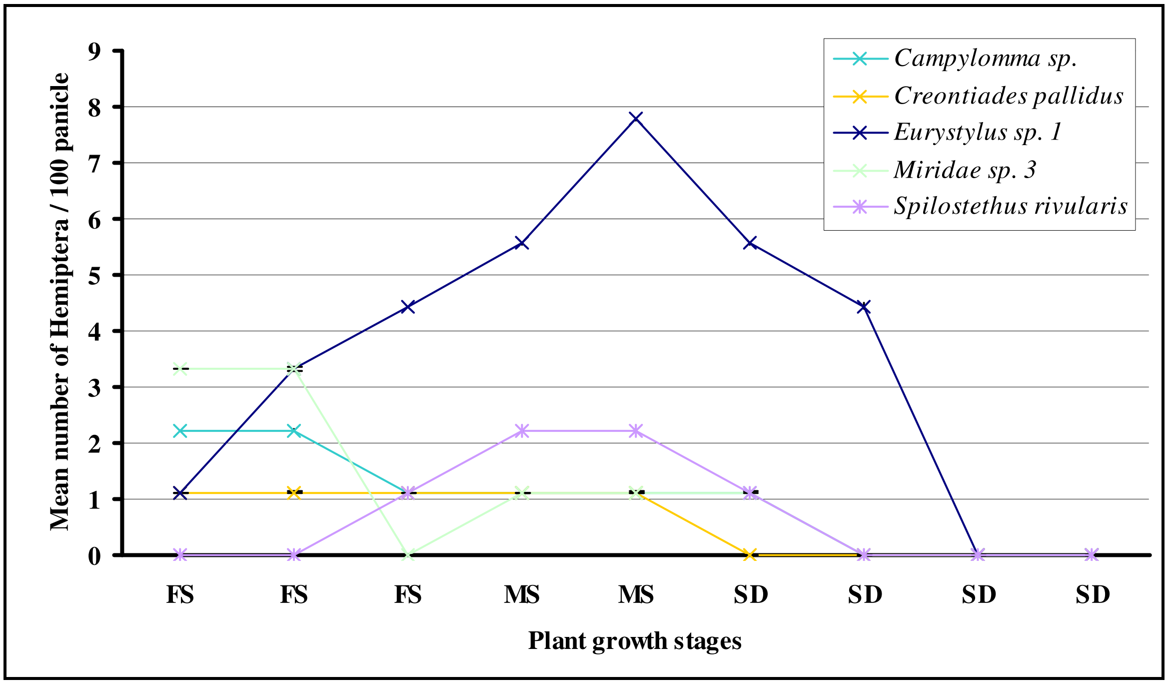

Fig 3.3. Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Potchefstroom (field one) (Standard errors were small and is not visible due to scale of axis) (FS – Flowering stage, MS – Milk stage, SD – Soft dough stage).

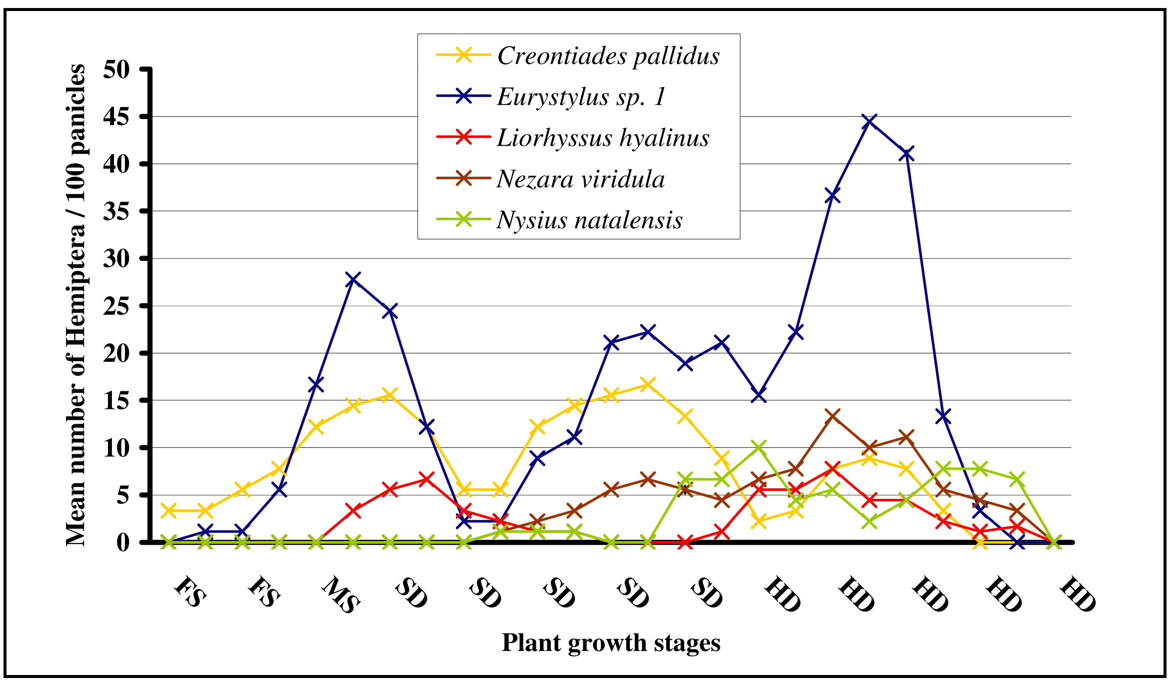

Fig 3.4. Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Potchefstroom (field two) (Standard errors were small and is not visible due to scale of axis) (FS – Flowering stage, MS – Milk stage, SD – Soft dough stage, HD – Hard dough stage).

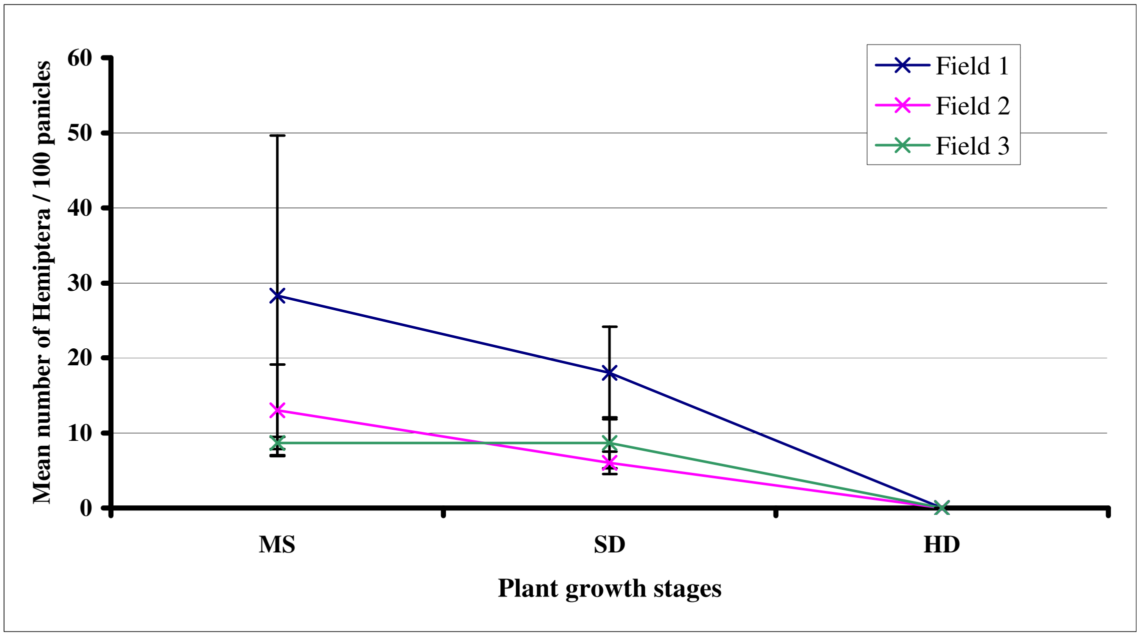

Fig. 3.5. Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Heilbron (Bars = Standard errors) (MS – Milk stage, SD – Soft dough stage, HD– Hard dough stage).

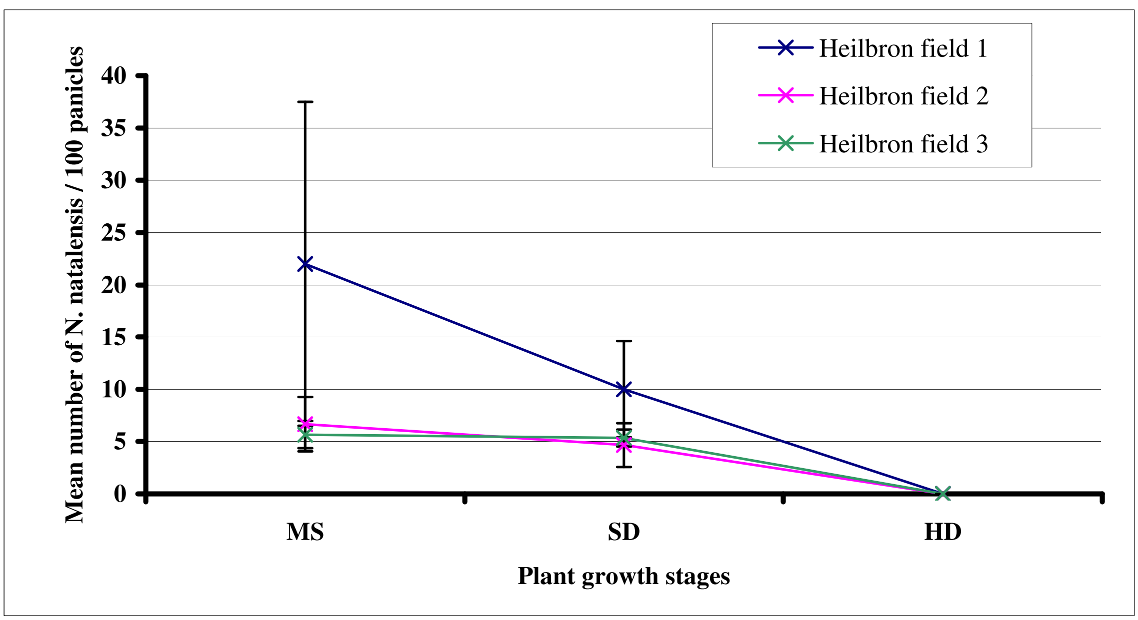

Fig. 3.6. The average number of adult *Nysius natalensis* per 100 panicles during the different growth stages of sorghum at Heilbron (Bars = Standard errors) (MS – Milk stage, SD – Soft dough stage, HD – Hard dough stage).

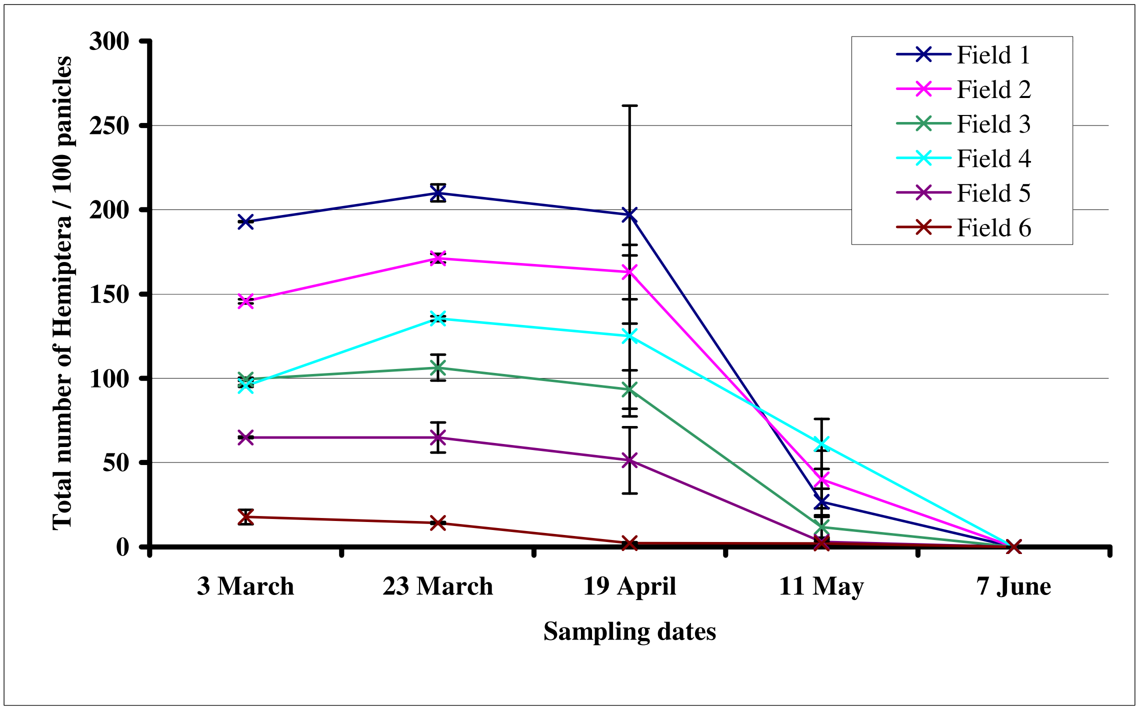

Fig. 3.7. Occurrence of adult Hemiptera during the different sampling dates of sorghum at Lebowakgomo (Bars = Standard errors).

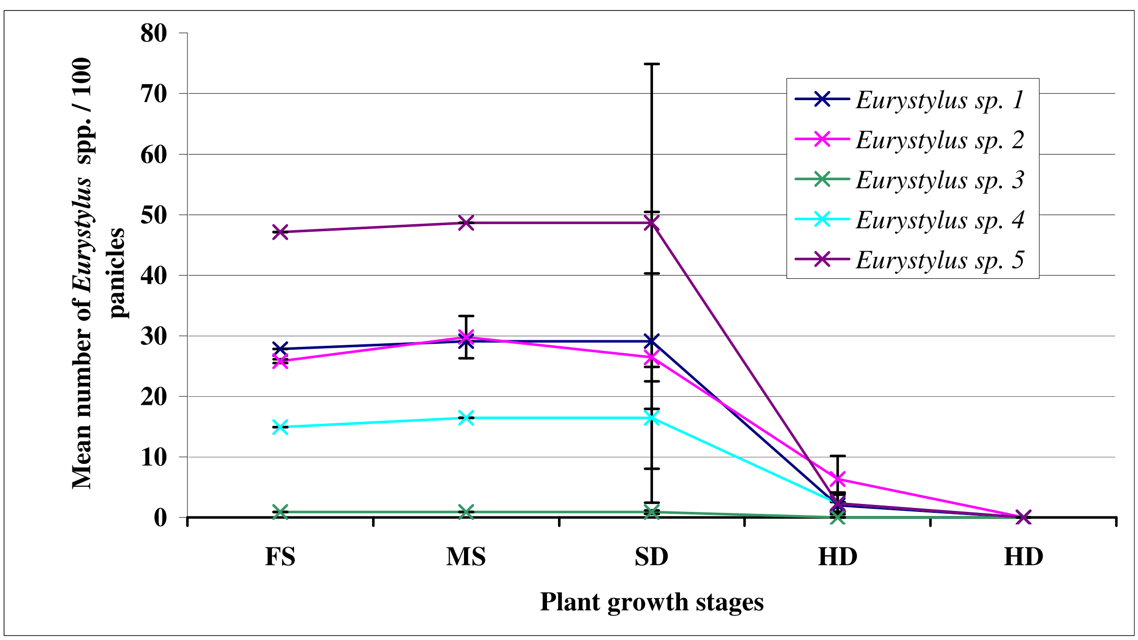

Fig. 3.8. Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Lebowakgomo (field one) (Bars = Standard errors) (FS – Flowering stage, MS - Milk stage, SD – Soft dough stage, HD – Hard dough stage).

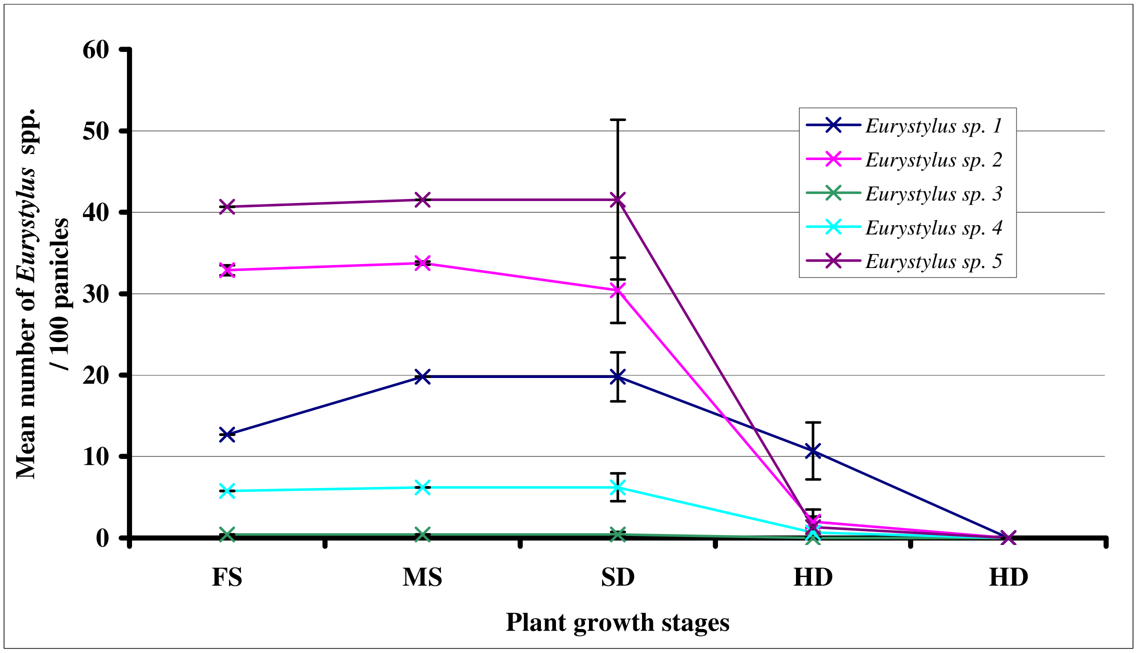

Fig. 3.9. Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Lebowakgomo (field two) (Bars = Standard errors) (FS – Flowering stage, MS - Milk stage, SD – Soft dough stage, HD – Hard dough stage).

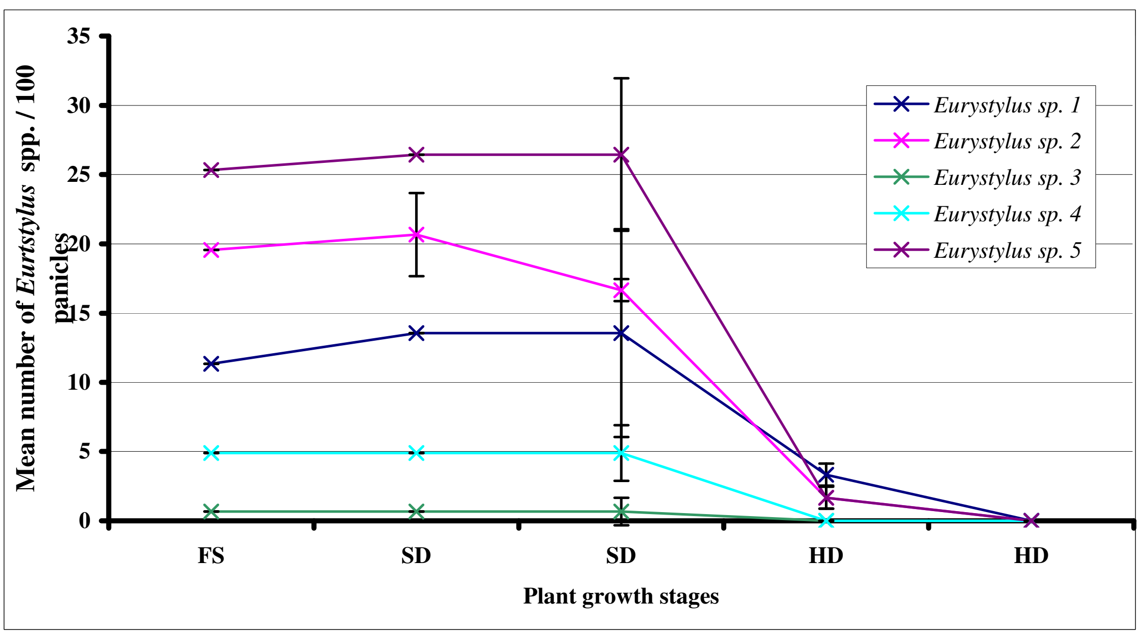

Fig. 3.10. Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Lebowakgomo (field three) (Bars = Standard errors) (FS – Flowering stage, SD – Soft dough stage, HD – Hard dough stage).

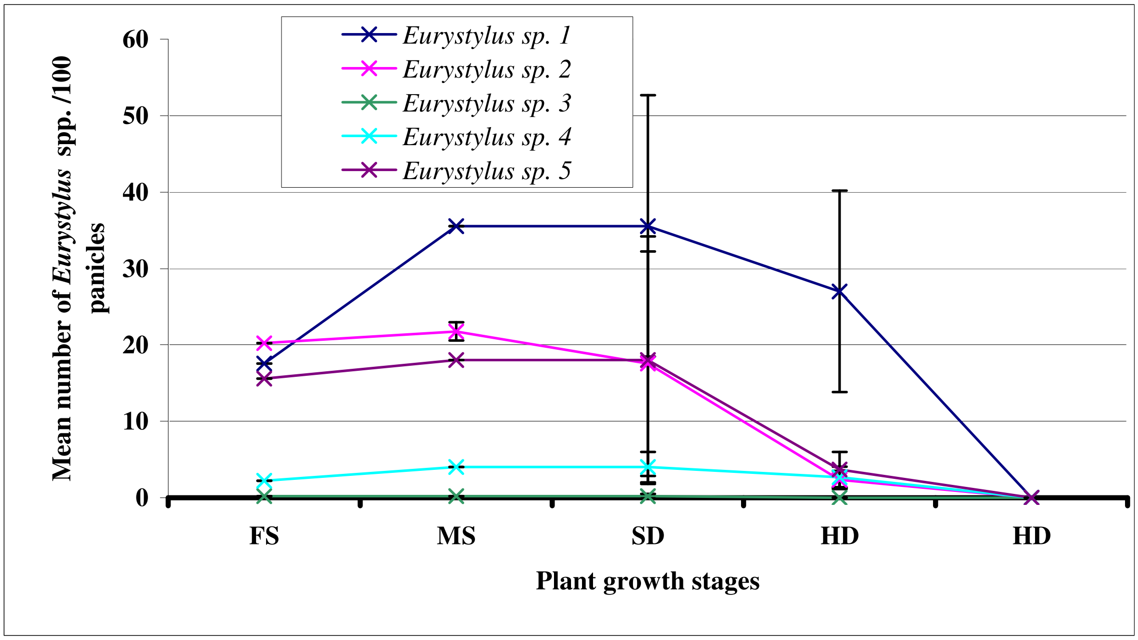

Fig. 3.11. Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Lebowakgomo (field four) (Bars = Standard errors) (FS – Flowering stage, MS – Milk stage, SD – Soft dough stage, HD – Hard dough stage).

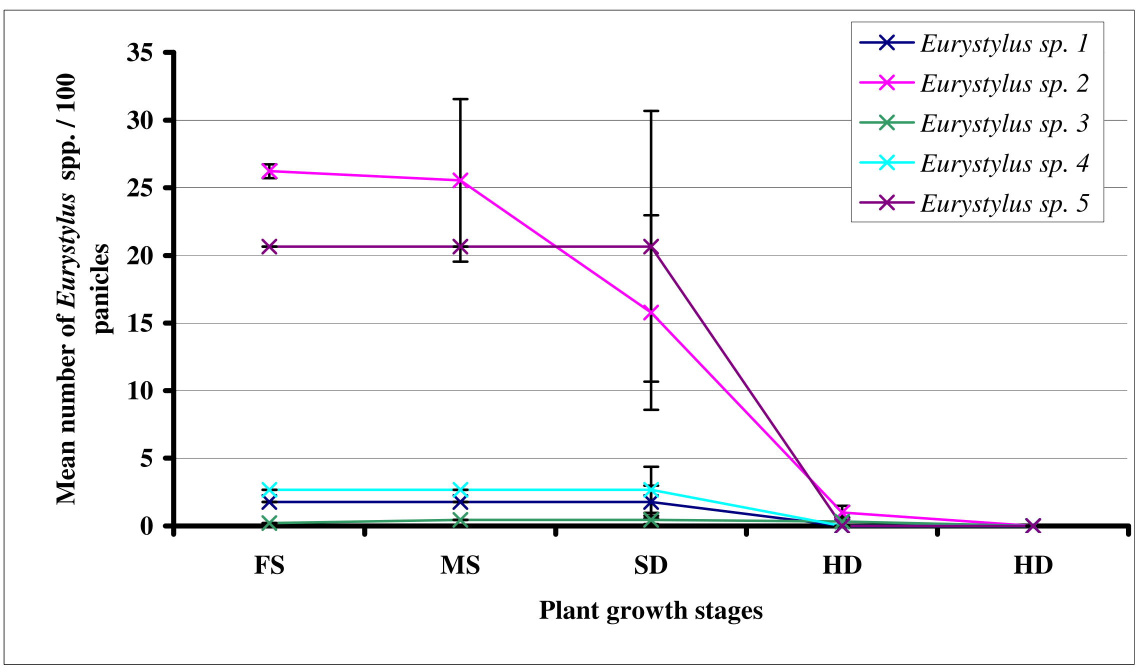

Fig. 3.12. Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Lebowakgomo (field five) (Bars = Standard errors) (FS – Flowering stage, MS – Milk stage, SD – Soft dough stage, HD – Hard dough stage).

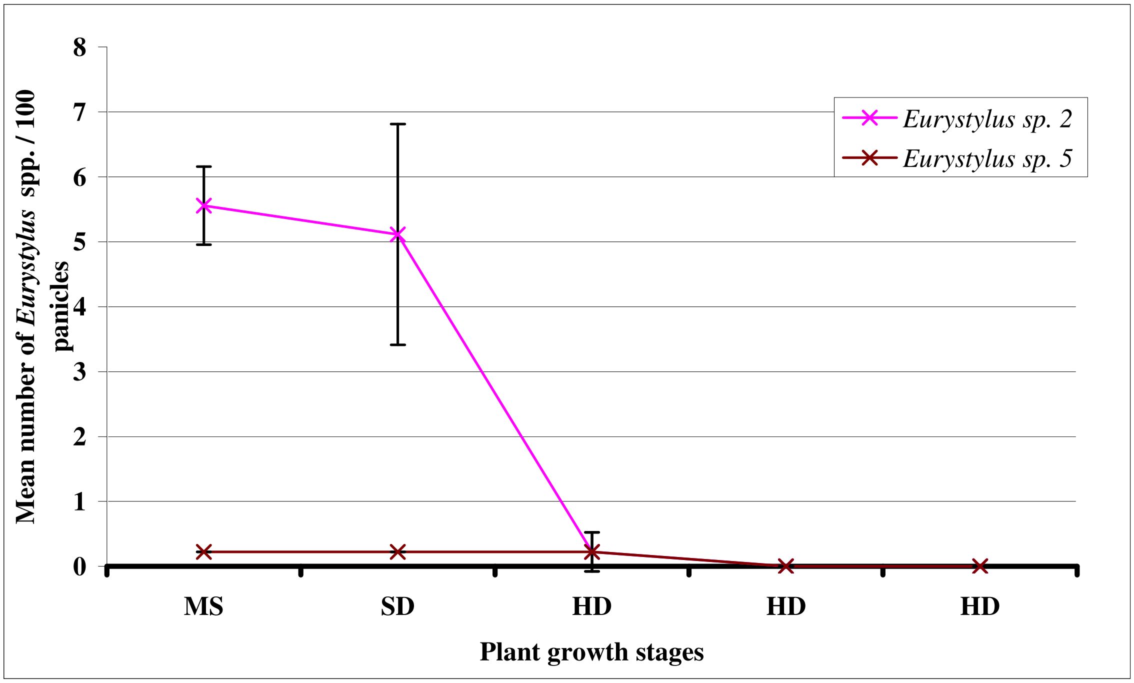

Fig. 3.13. Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Lebowakgomo (field six) (Bars = Standard errors) (MS – Milk stage, SD – Soft dough stage, HD – Hard dough stage).

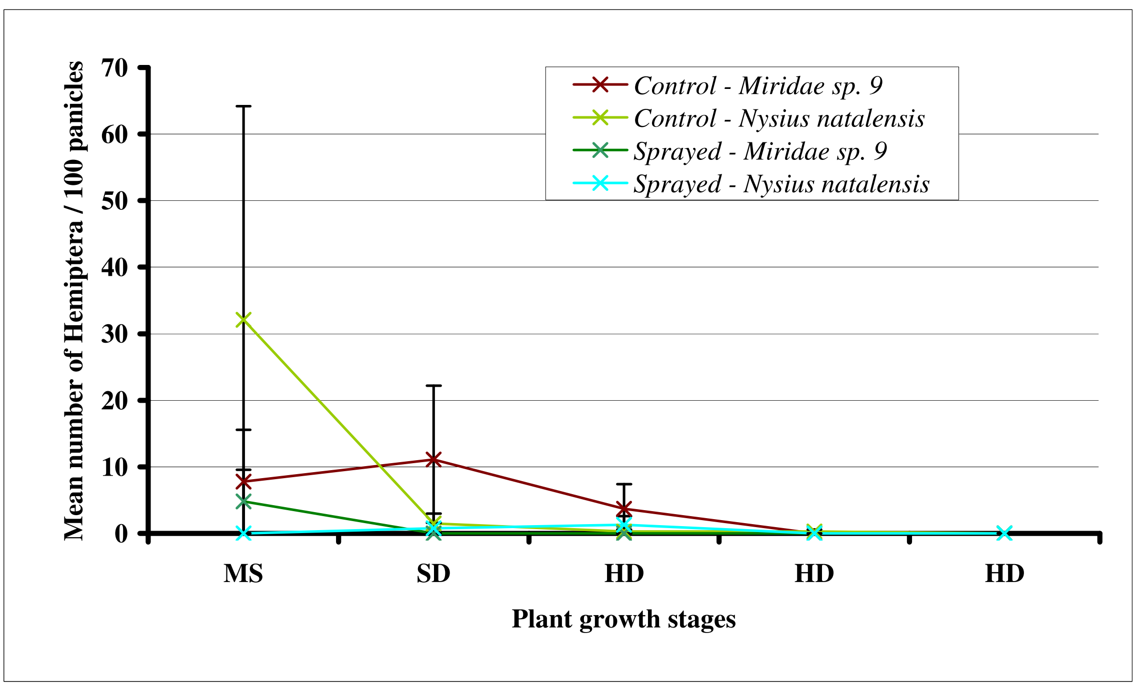

Fig. 3.14. Occurrence of adult Hemiptera during the different plant growth stages of insecticide treated and untreated sorghum fields at Nylstroom (Bars = Standard errors) (MS – Milk stage, SD – Soft dough stage, HD – Hard dough stage).

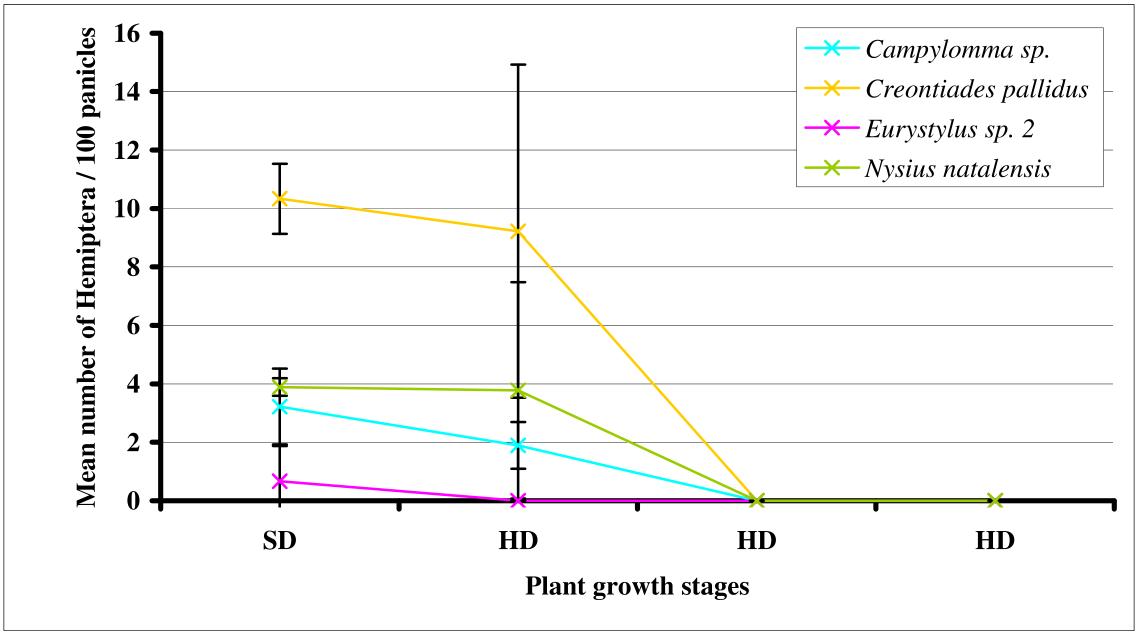

Fig. 3.15. Occurrence of adult Hemiptera during the different plant growth stages of sorghum at Settlers (field one) (Bars = Standard errors) (SD – Soft dough stage, HD – Hard dough stage).

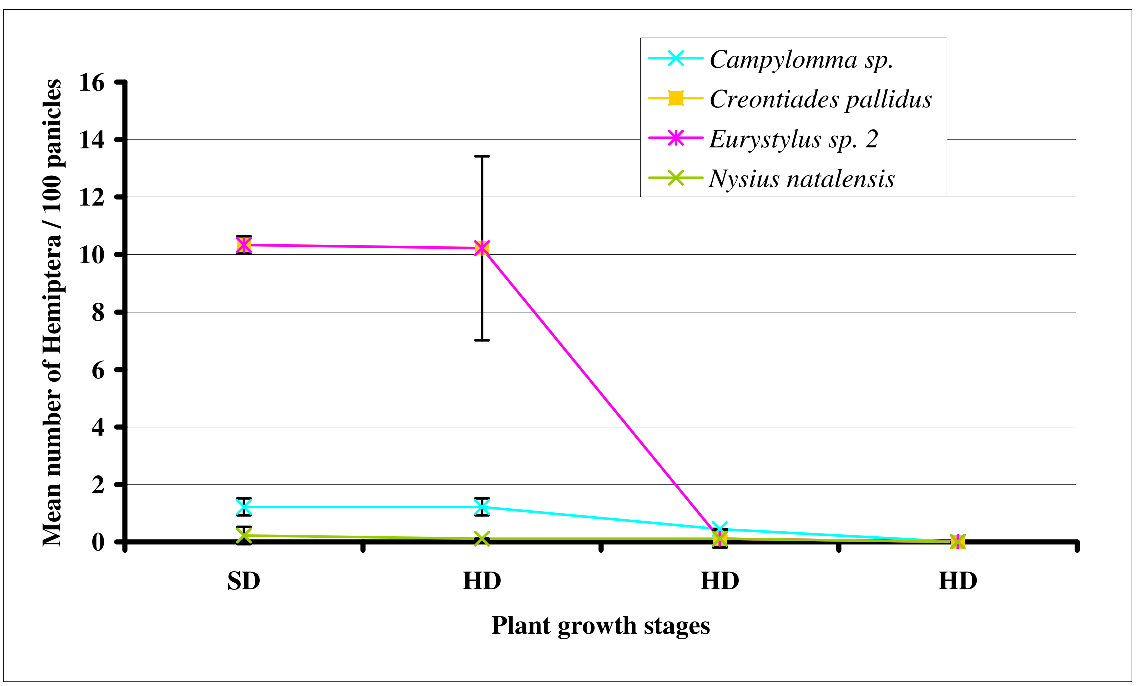

Fig. 3.16. Occurrence of adult Hemiptera during different plant growth stages insecticide treated of sorghum fields at Settlers (field two) (Bars = Standard errors) (SD – Soft dough stage, HD – Hard dough stage).

Table 3.1 Sampling date and plant growth stages in the 2005 production season.

Province	Sampling site	Date of sampling	Growth stage
North-West Province	Modderdam	25 February	FS
		10 March	MS
		24 March	SD
		7 April	SD
		14 April	HD
		22 April	HD
		27 April	HD
		5 May	HD
	Potchefstroom field 1	21 January	FS
		24 January	FS
		27 January	FS
		1 February	MS
		7 February	MS
		10 February	SD
		14 February	SD
		17 February	SD
	Potchefstroom field 2	21 January	FS
		24 January	FS
		27 January	FS
		1 February	MS
		7 February	MS
		10 February	MS
		14 February	SD
		17 February	SD
		21 February	SD
		25 February	SD
		28 February	SD
		3 March	SD
		8 March	SD
		10 March	SD
		14 March	SD
		18 March	SD

		21 March	HD
		24 March	HD
		29 March	HD
		1 April	HD
		4 April	HD
		7 April	HD
		11 April	HD
		14 April	HD
		18 April	HD

FS = Flowering stage, MS = Milk stage, SD = Soft dough stage, HD = Hard dough stage

Table 3.2 Sampling date and plant growth stages in the 2006 production season.

Province	Sampling site	Date of sampling	Growth stage
Free State Province	Heilbron field 1, 2 & 3	8 March	MS
		3 April	SD
		9 May	HS
Limpopo Province	Lebowakgomo field 1 & 2	3 March	FS
		23 March	MS
		19 April	SD
		11 May	HD
		7 June	HD
	Lebowakgomo field 3	3 March	FS
		23 March	SD
		19 April	SD
		11 May	HD
		7 June	HD
	Lebowakgomo field 4 & 5	3 March	FS
		23 March	MS
		19 April	SD
		11 May	HD
		7 June	HD
	Lebowakgomo field 6	3 March	MS
		23 March	SD
		19 April	HD
		11 May	HD
		7 June	HD
	Nylstroom field 1 & 2	10 May	MS
		24 May	SD
		6 June	HD
		15 June	HD
		22 June	HD
	Settlers field 1 & 2	22 March	SD
		19 April	HD
		10 May	HD
		6 June	HD

FS = Flowering stage, MS = Milk stage, SD = Soft dough stage, HD = Hard dough stage

Chapter 4

Resistance of sorghum varieties to head bugs and the relationships between feeding damage, grain mould and discoloured kernels.

4.1 Introduction

Grain moulds are becoming a major disease problem in sorghum production throughout the tropical regions of Africa, particularly where agricultural intensification is leading to the substitution of traditional varieties with more productive improved varieties (Chantereau & Nicou, 1994). Whereas local sorghum varieties escape mould infection by maturing late, normally at the beginning of the dry season, modern cultivars have been developed to flower early (Young & Teetes, 1977). Marley & Malgwi (1999) reported an increase in the incidence and severity of grain mould on sorghum that previously had a very low incidence and noticed that grain with insect punctures caused by Hemiptera (head bugs), had a higher fungal incidence than the same grain without punctures. Head bugs suck the sap out of developing grains, which then become tanned, shrivelled and under severe infestation, become completely invisible outside the glumes. Head bug injured grains are more prone to damage by mould fungi (Sharma *et al*., 2000) since feeding-injuries provide sites for entry of mould fungi and further colonization inside grains. As a result, bug injury makes most mould-resistant sorghum genotypes susceptible by breaching their resistance to the fungus (Sharma *et al*., 2000).

Head bug species with which association with grain mould fungi has been observed are *Nezara viridula* (Pentatomidae) (Hall *et al*., 1982) and the Miridae complex, particularly *Eurystylus* spp. (Ratnadass *et al*., 2003) and *Nysius* spp. (Orsillidae) (Hall *et al*., 1982). Sorghum may be infected by a large number of diseases. The fungi, which vary according to region, are mainly *Fusarium* sp. (notably *Fusarium moniliforme*), *Curvularia* sp., *Alternaria* sp. and *Helminthosporium* sp. (Chantereau & Nicou, 1994).

The aims of the study were to determine if there are varietal differences in resistance to head bug feeding, and if there is a correlation between field rating of grain mould severity and Hemiptera feeding damage to sorghum.

4.2 Materials and methods

A trial was established at Potchefstroom to determine the effect of insect feeding damage on grain mould development. Plots consisted of single row plots 6 m in length with a 10 cm intra-row and 1.2 m inter-row spacing with three replications. Standard agronomic practices were applied throughout the season. Fifteen entries from the Sugarcane Aphid Nursery obtained from Texas A&M Agricultural experiment station, at Lubbock, Texas (courtesy of Dr. G. C. Peterson) were used in the assessment. These varieties were mostly red and tan food-type sorghums.

At maturity, five panicles from each entry were scored visually for grain mould severity on the panicle surface. Scoring was based on a 1-5 scale following the methods of Audilakshmi *et al.* (1999), where 1 = no mould visible on the panicle; 2 = scant superficial mould growth up to 10% of the panicle surface covered by mould; 3 = moderate mould growth and 11-15% of the panicle moulded; 4 = considerable mould growth with 26-50% of the panicle surface moulded; and 5 = extensive mould growth with more than 50% of the surface moulded. This 1-5 rating scale is also used by sorghum pathologists in the INTSORMIL-programme, in the USA. Since this study was done using INTSORMIL sorghum varieties, the ICRISAT 1-9 rating (Sharma *et al.*, 1992) was not used.

After the average rating was determined for each variety, five varieties from each group were selected that received high, intermediate and low grain mould damage ratings. The genetic background of these selected varieties is provided in Table 4.1. Three replications, each consisting of fifty sorghum seeds collected from each of the replications of the field experiment were investigated for Hemiptera feeding damage. The number of punctures caused by Hemiptera feeding was determined on each seed using a stereomicroscope (30 X magnification). Only one side of the seed was observed. The total number of feeding lesions on each seed was then calculated by multiplying the number of visible symptoms by two. The number of seeds of which the germ was discoloured was also determined. The mean number of feeding lesions per kernel and percentage of seeds with discoloured germ for each variety was determined.

Linear regressions were used to determine the correlations between visual rating values and insect damage parameters using STATGRAPHIC Plus 5 (2000). Data on the number of feeding lesions and discoloured germ was analysed by means of ANOVA.

4.3 Results and discussion

The Hemiptera complex on panicles was dominated by *Eurystylus* sp., *Creontiades pallidus* and *N. natalensis* (Chapter 3). *Liorhyssus hyalinus* (Rhopalidae), and *N. viridula* were also recorded but at low numbers.

Feeding lesions caused by Hemiptera were visible on the seeds (Fig. 4.1). Visual grain mould rating values ranged between 2.3 and 4.8, while the number of feeding lesions per seed varied between 0.67 and 6.03 (Table 4.2). Based on the number of feeding lesions entry numbers 2, 3, 5, 10, 12 and 15 were the most resistant varieties, while entry numbers 1 and 4 were the most susceptible. The percentage seed with discoloured germ did not differ significantly between any of the varieties, except for entry 1 which had 20 % seeds with discoloured germ (Table 4.2).

No significant ($F_{(1\text{-}13)} = 2.54$; $P = 0.13$) relationship existed between visual rating values and the number of feeding lesions per seed (Fig. 4.2) or percentage seed with discoloured germ ($F_{(1\text{-}13)} = 0.02$; $P = 0.87$) (Fig. 4.3). According to Frederiksen *et al*. (1991), accurate visual ratings can only be made after the sample has been threshed.

A significant relationship was however observed between the number of feeding lesions per seed and percentage seed with discoloured germ ($F_{(1\text{-}13)} = 11.25$; $P = 0.005$) (Fig.

4.4). This result indicated that Hemiptera feeding damage contributed significantly to degradation of seed. The presence of discoloured germ cannot be detected unless grain has been threshed. The germ of the seed is covered by the glume and this parameter is therefore not accounted for during visual ratings in the field. The number of feeding lesions per seed most likely depends on the level of resistance of the variety to head bug damage, the number of Hemiptera per panicle and the feeding behaviour of the Hemiptera. The feeding lesions and the oviposition punctures that are sometimes observed on developing grains can lead to secondary fungal infection on the seed that in turn could lead to higher percentage of discoloured germ.

Development of fungal growth tended to be more extensive on panicles infested from milk to maturity (28 days) than on panicles infested from soft dough to maturity (20 days) (Hall *et al*., 1982). Differential infections (*Alternaria alternata* and *Fusarium semitectum*) of grain moulds may develop when infestations of *Ne*. *viridula* and *Ny*. *raphanus* occur on sorghum (Hall *et al*., 1982). Both feeding and oviposition punctures caused by *E*. *oldi* in maturing sorghum caryopses result in severe quantitative and qualitative losses and favour secondary infection by grain mould, particularly in improved compact-headed caudatum types (Ratnadass *et al*., 1995).

Grain mould damage can be accentuated to a large extent due to mild injury by head bugs. Some factors that are associated with grain mould resistance also confer resistance to head bugs. For example, grain hardness contributes resistance to grain mould as well as to head bug. It should therefore be possible to develop combined resistance to grain mould and head bugs in the same cultivar (Sharma *et al*., 2000).

4.4 Conclusions

This study indicated that Hemiptera feeding damage resulted in an increase in incidence of seeds with discoloured germ and therefore contributed significantly to reduction in grain quality. This aspect of Hemiptera damage cannot be accounted for by the visual grain mould damage rating method. Varietal differences in levels of resistance to head bug feeding were observed. Future studies should be directed at elucidating the relationship between different Hemiptera and fungi species and to assess the importance of the head bug complex as sorghum pests in South Africa.

4.5 References

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Fig. 4.1. Feeding lesions caused by Hemiptera to a sorghum seed.

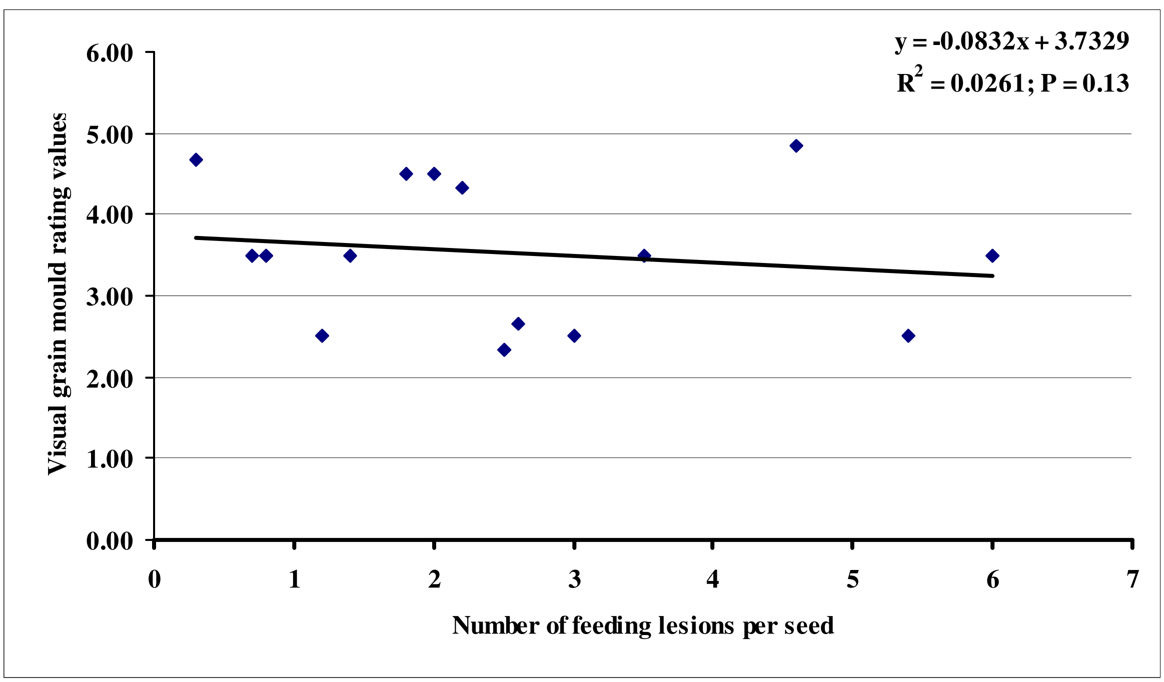

Fig. 4.2. The relationship between grain mould rating values and the number of feeding lesions per seed.

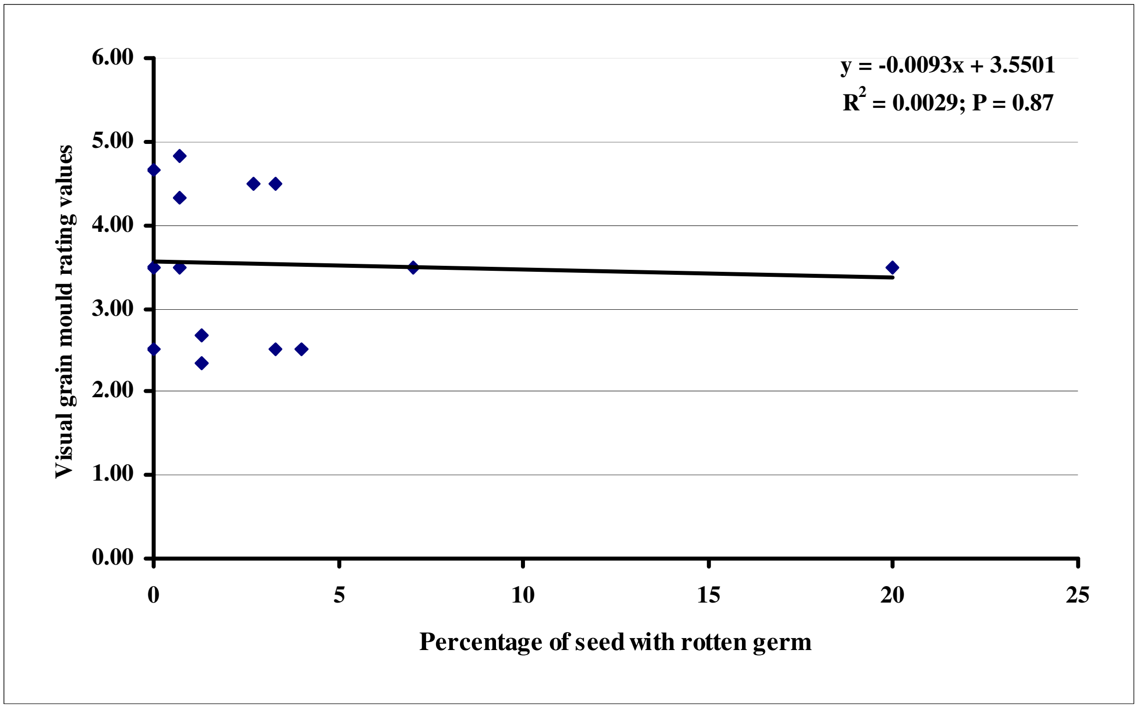

Fig. 4.3. The relationship between grain mould rating values and the percentage of seed with discoloured germ.

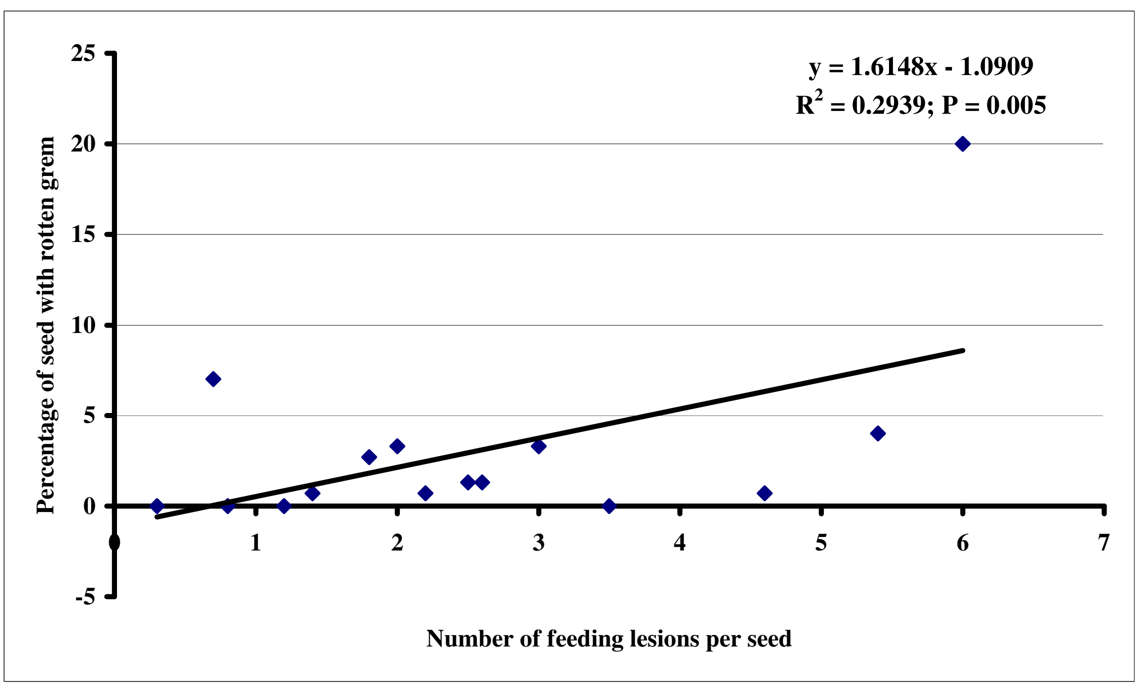

Fig. 4.4. The relationship between percentage of seed with discoloured germ and the number of feeding lesions per seed.

Table 4.1. Genetic background of sorghum varieties used for evaluation of head bug and grain mould resistance.

Entry number	Pedigree
1	WM#177
2	PRGC/E#222878
3	(Macia*TAM428)-LL9
4	(Segaolane*WM#322)-CG1-BGBK-CCBK
5	(6OB128/(Tx2862*6EO361)*CE151)-LG25-CG1-BGBK-CCBK
6	(SV1*Sima/IS23250)-LG15-CG1-BG2-BGBK
7	(6OBS124/94CE81-3/GR134B-LG56-*WM#177)-LG1-LG1-BG3-BGBK
8	(6OBS128/94CE88-3/(Tx2862*6EO361)*EPSON2-40/E#15/SADC)-LG15-CG2-BG2-BGBK
9	(6BRON161/(7EO366*Tx2783)*EPSON2040/E#15/SADC)-CG2-BG2-BGBK
10	(6BRON126/5BRON154/(87BH8606-14*GR107-90M46)*EPSON2-40/E#14/SADC)-LG2-LG1-BG2
11	(CE151*A964)-CG1-BG2-BG3
12	(6BRON161/(7EO366*Tx2783)-HG54-*CE151)-CG3-BG2-BG2-CG1
13	(96AD34/6BRON116/5BRON131/(80C2241*GR108-90M30)-HG46-*WM#177)-CG2-BG1-LG1
14	(Macia*GR128-92M12)-LG41-BG1-CG1
15	(Macia*GR128-92M12)-HM16-CM1-CG1

Table 4.2. Grain mould evaluation and mean number of Hemiptera feeding lesions on different sorghum varieties.

Entry	**Grain mould resistance classification**	**Visual grain mould rating values**	**Number of feeding lesions per seed ***	**Percentage of seeds with discoloured germ**
5	Medium	4.7 ab	0.67 a	0.0 a
3	Medium	3.5 ab	0.73 ab	0.67 a
2	Medium	3.5 ab	0.87 abc	0.0 a
15	Low	4.3 ab	1.0 abcd	0.67 a
12	High	2.5 ab	1.17 abcd	0.0 a
10	Low	3.5 ab	1.43 abcde	0.67 a
8	Low	4.5 ab	1.83 bcdef	2.67 a
13	High	3.5 ab	2.04 cdef	0.0 a
9	High	4.5 ab	2.04 cdef	3.33 a
11	Medium	4.3 ab	2.2 def	0.67 a
7	High	2.3 b	2.53 ef	1.33 a
14	Low	2.7 ab	2.7 f	1.33 a
6	Medium	2.5 ab	3.0 f	3.33 a
4	Low	2.5 ab	5.47 g	4.0 a
1	High	3.58 ab	6.03 g	20.0 b

* Means within columns followed by the same letter do not differ significantly at P = 0.05 (Tukey test for Honestly Significant Differences).

Chapter 5

Conclusions

Very little attention has been paid to panicle feeding insects on sorghum in South Africa. The panicle-feeding bug complex is important on sorghum in Central and West Africa. Prior to this study it was not known whether the species complex or damage caused by these pests differed between the two regions and a gap in knowledge exited on whether these pest are actually not present, or whether they are present, but not recognised as pests by farmers, due to their small size and colouration, or alternatively, whether they are present but cannot be considered as pests, because of trivial crop losses caused. A study was therefore conducted to investigate the diversity of the panicle feeding Hemiptera complex in South Africa and to address the shortage of information on these insects in sorghum. The objectives of this study were:

- to determine the abundance and diversity of sorghum panicle-feeding Hemiptera.
- to compile a check list of Hemiptera that occur on sorghum panicles in South Africa.
- to determine the temporal distribution of different Hemiptera species on panicles and to evaluate the effect of insecticide application on Hemiptera numbers.
- to assess resistance levels of sorghum varieties to head bug and determine the relationship between grain mould severity and Hemiptera feeding damage.

In order to determine the diversity and abundance of Hemiptera on sorghum panicles, field surveys were conducted between November 2004 and June 2006 at 26 sites in four provinces in South Africa (Chapter 2). Two methods of collection were used in this study. Whole panicles were sampled by closing them with plastic bags and removing it from the field, while a D-Vac was used to sample insects from large numbers of panicles in fields without removing panicles. Results from a study in which the efficacy of the two collection methods was compared showed that there was no significant difference in numbers collected between the two methods. These two sampling methods can therefore be considered to be equally efficient for collection of panicle feeding Hemiptera on sorghum. Due to the lack of Hemiptera identification expertise in South Africa, many species could only be identified to family level.

The total number of adults and nymphs collected during this study was 23 798 (14 590 adults and 9 208 nymphs). Forty-three species of herbivorous Hemiptera were collected. This diversity is surprisingly high compared to the 57 species of panicle-feeding Hemiptera which Harris (1995) reported to occur in the world and the 42 species reported on sorghum in Central and West Africa. In this study the majority of species did however occur at very low infestation levels (<8 individuals / 100 panicles) and can therefore not be classified as pests of sorghum in South Africa. However, many of these species commonly reach pest status on sorghum in West Africa, North- and South America and India. In only a few instances were infestation levels of 12-30 / 100 panicles recorded. Six species occurred in relatively high numbers but cannot be considered to have pest status since damage was not recorded. These were *Nezara viridula*, *Eurystylus* sp. 5, *Campylomma* sp., Miridae sp. 9, *Nysius natalensis* and *Eurystylus* sp. 2 (Chapter 2). The *Eurystylus* complex that was collected during this study consisted of five different species. *Eurystylus* sp. 2 and *Eurystylus* sp. 5 were the most abundant (Chapter 2) at mean infestation levels of 164.4 and 11.9 / 100 panicles respectively. Some of the *Eurystylus* species have the possibility to become pests of sorghum in South Africa. The head bud complex on sorghum in Africa is dominated by the genus *Eurystylus*, of which several species have been reported (Ratnadass *et al*., 1994). *Eurystylus oldi* is the most abundant and injurious of the species (Ratnadass *et al*., 1994). Studies in West Africa showed that *E. oldi* can cause economic damage at infestation levels of 3-11 / panicle during the milk stage and 9-100 during the dough stage (Ajayi *et al*., 2001).

Sorghum panicles are infested by a wide range of insect pests from flowering to grain maturity. However, only a few species have been reported to cause severe damage. Studies on the population dynamics of head bugs in the sorghum production areas (Chapter 3) showed no clear distinctions between species and the plant growth stage during which panicles were infested. The general tendency was that nearly all species were present during the period from flowering onwards and that numbers declined when grain became hard. *Nezara viridula* however seemed to infest panicles at slightly later stages and it was never recorded before the soft dough stage. *Campylomma* sp. and *C. pallidus* numbers usually peaked during the flowering stage and *Eurystylus* spp. and *N. natalensis* during the milk stage. Numbers of *Campylomma* sp., *C. pallidus*, *Eurystylus* spp., *N. viridula* and *N. natalensis* peaked during the soft dough stage. According to the literature *Campylomma* species occurred on panicles during the first weeks after panicle emergence (Nwanze, 1985), while *N. viridula* feeds on sorghum from the soft dough stage until maturity (Meksongsee & Chawanapong, 1985).

Wild host plants have been reported to be important in the biology of head bugs (Panizzi *et al*., 1997; Ratnadass *et al*., 2001). In South Africa, *Eurystylus* spp. feed on male and female flowers of *Ricinus communis*, causing them to shrivel and die, in some cases, the entire stem dies (Boyes, 1964, cited by Wheeler, 2001). Du Plessis (2004) recorded 27 plant species as hosts of *Nysius natalensis* in the sunflower production area of South Africa. While *Spilostethus pandurus* attacks more than 40 different host plant species in the world, the most commonly attacked species are sorghum, pearl millet, cotton and groundnuts (Sweet, 2000). A survey conducted on indigenous host plants of sorghum head bugs in Mali showed that *C. pallidus*, *Campylomma angustior* and *E. oldi* occurred on several plant species (Table 1.4) (Ratnadass *et al*., 1997).

Although no infestation-yield loss studies were conducted during this project, it can be concluded that the Hemiptera complex is not of great importance on sorghum in South Africa. However, many of the species that are reported to be serious pests of sorghum in other parts of the world were commonly found during this study. Based on regression model data and the infestation level – yield loss relationship for *N. viridula*, Hall and Teetes (1982) calculated the economic injury level (EIL) for this pest in Texas, USA. Based on this regression model, the EIL for *N. viridula* in South Africa is approximately 4.3 / panicle depending on yield and input costs. In this study *N. viridula* was recorded at a mean infestation level of 0.37 / panicle which indicated that it cannot be considered to be of general importance on sorghum in South Africa.

Economic injury levels (EILs) have been determined for relatively few sorghum pests, although these are central issues in decision-making in pest management. This can be ascribed to difficulties in calculating actual yield losses, the variation in input costs and the associated saving in yield. In sorghum, EILs have been reported for shoot fly (*Atherigona soccata*), midge (*Stenodiplosis sorghicola*), armyworm (*Spodoptera exigua*), some Coreidae, Pentatomidae and *Calocoris angustatus* (Miridae) (Sharma & Lopez, 1989). Knowledge of pests that could result in development of Integrated Pest Management strategies for these pests in which host plant resistance, cultural practices, biological control and chemical control methods can be used. Once EILs are determined for individual species, studies can be conducted to determine the efficacy of different insecticides for control of these pests under outbreak conditions. In the present study it was shown that parathion could possibly be used for control of head bugs (Chapter 3). There is however no insecticides registered for control of panicle-feeding bugs in high-input commercial farming systems in South Africa and chemical control is beyond the scope of resource-poor farmers that also plant this crop.

The relationship between the incidence of Hemiptera infestation and sorghum yield or quality has not yet been studied in South Africa. This study indicated that Hemiptera feeding damage resulted in an increase in incidence of seeds with discoloured germ, therefore contributing significantly to reduction in grain quality (Chapter 4). This aspect of Hemiptera damage is not accounted for in the visual grain mould damage rating system that is commonly used to do field ratings of mould infections. Discoloured germ cannot be detected unless grain has been threshed. This part of the seed is covered by the glume and this parameter is therefore not accounted for during visual ratings in the field. The feeding lesions that are sometimes observed on developing grains, can lead to secondary fungal infection of the seed and result in a higher percentage discoloured germ. The levels of resistance to head bug damage, based on the numbers of feeding lesions on kernels, differed significantly between varieties. Head bug damage correlated significantly with the incidence of discoloured germ but not with grain mould severity ratings. This result indicated that head bug feeding damage contribute to the accessibility of sorghum kernels to fungal infection.

Future studies should be aimed at establishing the interactions between head bugs and their winter and early-season host plants, since this could lead to development of environmentally friendly habitat management systems for these insects. The relationship between different Hemiptera and fungi species should also be elucidated in future research to assess the importance of direct damage caused by the head bug complex, as well as its role in grain mould infection of sorghum in South Africa.

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