Chapter 6

Chemical control of *Cosmopolites sordidus* in South Africa

Abstract

Cosmopolites sordidus (banana weevil) is a major production constraint in most areas where bananas are grown. The weevil is difficult to control, and chemical control arguably provides the best opportunity to manage the pest. The aim of this study was to determine the efficacy of injecting bifenthrin, chlorpyrifos, fipronil, imidacloprid, oxamyl and water (control) into residual banana plants. The chemicals were administered every even numbered month over 2 years at two locations in Southern KwaZulu-Natal, South Africa. Yield, weevil damage and pseudostem girth of plants felled from August to October were measured, while adult beetle densities were assessed over 4 weeks in October and April. Nematode samples were analysed in October every year. Damage parameters included the Coefficient of Infestation, the Percentage Coefficient of Infestation (PCI) at two intervals, the summed PCI value, the percentage cross sectional damage of the central cylinder and cortex, and the mean cross sectional damage percentage. Replicated block designs were used in the experiments. The parameters were similar before the onset of the trial. Fruit yield and plant girth, corrected by nematode densities, were not significantly increased after chemical applications, nor were the nematodes controlled. Fipronil and imidacloprid were highly effective against *C. sordidus*, minimising damage to the periphery, cortex and central cylinder of the rhizome and significantly reduced adult density. Fipronil caused a 95% and imidacloprid a 100% reduction in the cross sectional damage of the central cylinder, the damage parameter most closely related to yield. Injection of fipronil and imidacloprid provides an optimal chemical strategy in an integrated pest management programme for the banana weevil.

Keywords: Insecticide, injection, yield, damage, banana weevil

6.1 Introduction

The banana weevil, *Cosmopolites sordidus* (Germar), is an important pest of *Musa* and *Ensete* (Stover & Simmonds 1987, Gold & Messiaen 2000; Gold *et al*. 2003) and the dominant insect pest of bananas in South Africa. Adults feed on plant tissues or crop debris but the damage inflicted is negligible (Franzmann 1972; Treverrow *et al*. 1992). Females oviposit their eggs singularly (Froggatt 1925, Simmonds 1966; Franzmann 1972) in the crown of the rhizome and pseudostem base (Abera *et al*. 1999), favouring flowered plants (Treverrow *et al*. 1992; Abera *et al*. 1999). Upon emergence, the larvae tunnel into the rhizome, producing distinctive circular, debris-filled tunnels (Franzmann 1972). Interior corm damage affects nutrient transport and stem growth (Taylor 1991), while peripheral damage adversely affects root development (Gold *et al*. 1994). The pupa develops in a chamber at the corm periphery (Franzmann 1972) and eclosion produces a reddish, brown adult (teneral stage), which later becomes uniformly dull black (Pinese & Elder 2004). Infested plants show stunted growth, delayed maturation (Gold *et al*. 1998), reduced bunch weight, and can snap or topple (Batchelder 1954, Franzmann 1972; Koppenhöfer 1993). Infestation by banana root nematodes can show similar symptoms, including a reduction in vigour, leaf chlorosis, plant toppling and yield reduction (Bujulu *et al*. 1983, Smith 1995; Willers *et al*. 2001).

Chemical control of the beetle has been employed since the early 20th century. Pesticides consisted mainly of Paris Green, followed by the use of organochlorines like BHC and DDT (Froggatt 1925, Cuillé 1950, Simmonds 1966; Treverrow *et al*. 1992). The chemicals were usually applied with flour or other substances as baits (Froggatt 1925, Cuillé 1950, Simmonds 1966; Treverrow *et al*. 1992). The method was not very effective (Simmonds 1966) and the persistent cyclodienes, dieldrin and aldrin, showed high efficacy as a soil treatment against the banana weevil (Braithwaite 1958). Cyclodienes was used extensively around the world from the mid 1950's (Edge 1974) and was found to be effective for up to 2 years after application (Braithwaite 1967). Before 1970, however, resistance to cyclodienes was widely diagnosed (Vilardebó 1967, Anonymous 1969; Shanahan & Goodyer 1974).

Investigations into alternative chemicals (mainly organophosphates and carbamates) showed chlordecone (organochlorine), pirimiphos-ethyl, chlorpyrifos,

prothiophos and ethoprophos as viable for biannual applications, but diazinon was unsuitable because of its short residual action (Wright 1977, Collins *et al*. 1991; Smith 1995). Aldicarb, terbufos, carbofuran, carbosulfan, oxamyl, fenamiphos (Román *et al*. 1979, Cárdenas 1984, De Jager *et al*. 1991, Vittayaruk *et al*. 1994, Chavarria-Carvajal & Irizarry 1997; Fogain *et al*. 2002), isofenphos, isazofos (Bujulu *et al*. 1983), phoxim (Nuno & Ribeiro 2002) tebupirimiphos, cadusafos (Quilici 1993), fosthiazate (Chabrier *et al*. 2002), phorate, disulfoton, quinalphos (Viswanath 1977), acephate, diethyl, pada, monocrotophos, deltamethrin (pyrethroid) (Maolin 1994), fipronil (phenyl pyrazole) (Price 1995; Fogain *et al*. 2002) and bifenthrin (pyrethroid) (Smith 1995) were also found to be effective. Less than 10 years after widespread organophosphate use in Australia, resistance to pirimiphos-ethyl, prothiophos, chlorpyrifos and ethoprophos were reported in Queensland and New South Wales with evidence of cross resistance to oxamyl but not to carbofuran, isazofos or isofenphos (Collins *et al*. 1991). Subsequently soil applications of bifenthrin were found to be effective, but fipronil, carbosulfan and furathiocarb were similar to untreated controls in Southeast Queensland (Smith 1995). Resistance to carbofuran has not been found in Uganda or Australia (Collins *et al*. 1991; Gold *et al*. 1999). The high rate of resistance development was attributed to widespread, regular applications with no population monitoring (Collins *et al*. 1991).

Chemical control with non-systemic pesticides is mainly directed against adults (Simmonds 1966, Wright 1977; Collins *et al*. 1991). Dipping corms in insecticide solution were significantly more effective than hot water treatment in controlling the weevil in planting material (Cardenas Murillo *et al*. 1986). Chemical application is commonly recommended in planting holes (Franzmann 1972, Anitha *et al*. 1992; Fogain *et al*. 2002), to plant traps (bait spraying) (Treverrow *et al*. 1992) and to the bases of banana plants (butt sprays) (Braithwaite 1958, Bujulu *et al*. 1983, Collins *et al*. 1991, Smith 1995; Fogain *et al*. 2002). In Australia butt sprays are applied in spring and autumn and chemicals are injected into residual pseudostems during winter (Froggatt 1926, Treverrow 1985, Treverrow *et al*. 1992, Stanton 1994). Butt sprays are, however, detrimental to beneficial insects and only target adults in close vicinity of plants (Collins *et al*. 1991). Bait sprays are applied to fresh residues every 2nd or 4th week in spring and autumn. Poison traps save on insecticide, but are regarded as being relatively ineffective (Simmonds 1959), especially at high infestation levels (Treverrow *et al*. 1992).

Systemic chemicals (dimethoate, omethoate, aldicarb, carbofuran, carbosulfan, fenamiphos, fosthiazate, isazofos, monocrotophos, oxamyl, phorate and terbufos) can potentially control larvae following uptake by banana roots after soil application (Gold *et al*. 2003). These chemicals provide a protective treatment for plants, but have relatively shorter residual actions (Treverrow *et al*. 1992) and do not prevent attacks on plant residues after harvest (Treverrow pers. comm.). Dual action insecticide-nematicides with systemic action will be of value to treat moderate weevil infestations when nematode densities also require treatment (Treverrow *et al*. 1992).

In South Africa, late summer and early spring butt application of pirimiphos-ethyl and aldicarb has been recommended (Jones & Dieckmann 1982). Pirimiphos-ethyl was used until the mid 1990's (Schoeman 1996) and imidacloprid and prothiofos were used in 1999 (Schoeman *et al*. 1999). Locally the pesticides aldicarb, terbufos and oxamyl were also reported to be effective in controlling the banana weevil and the pratylenchid nematode, *Radopholus similis* (Cobb) (De Jager *et al*. 1991). Schoeman (1998) reported that fenamiphos and cadusafos showed promise to control the weevil in a field trial, yet Dochez (1998) showed that terbufos, fosthiazate, aldicarb and cadusafos did not reduce weevil damage locally. Only aldicarb is registered for control of the banana weevil and nematodes in South Africa (Nel *et al*. 2002; Anonymous 2005). The soil around the plants is treated and application is recommended at planting, during November (late spring) and March (late summer/early autumn). According to Quilici (1993) and Schoeman (1998), aldicarb does not provide sufficient control of the weevil and growers have also reported treatment failures. Some desperate growers have even resorted to illegal and unregistered chemical usage (Dochez 1998). The aim of this study was to determine the efficacy of injecting contact and systemic chemicals into residual banana material in South Africa throughout the year.

6.2 Material and methods

6.2.1 Research sites

Trials to evaluate the efficacy of chemicals against the banana weevil were conducted on two commercial farms at the South Coast of KwaZulu-Natal, South Africa. The trial sites were in Munster (30º59'29''S; 30º14'49''E) and Ramsgate (30º52'31''S; 30º19'29''E), 72 and 130 meters above sea level, respectively. Soil in the area is a

Glenrosa form, with an orthic A and lithocutanic B zone. It is a sandy loam soil with 16% clay, 30% loam and 54% sand (Dochez 1998). The experiments were conducted from August 2003 to October 2005. The locations were in a summer rainfall area (750-1000 mm per year), and during the trials the ambient temperature ranged from 12 to 25 °C.

The Cavendish cultivars Williams and Chinese Cavendish (AAA group) were grown at the Munster and Ramsgate trials, respectively. The former was planted in November 1995 and the latter in November 2000, both at a density of 2222 plants.ha^{-1} (300 × 150 cm). High mat was evident in the plantations, with the collar (junction between pseudostem and rhizome) commonly more than 10 cm above ground level. The Munster plantation was drip and the Ramsgate site sprinkler irrigated with 2 cm water/week, a practise only suspended if rainfall exceeded that value in the particular week. The sites were treated at planting with the oxime carbamate, aldicarb (Temik 15% GR), at the registered dosage of 2.025 g.a.i./mat, to provide nematode and weevil control. Regular chemical weed control with glyphosate (Roundup), leaf removal, desuckering and propping of bunch bearing plants were practised. Pre-trial plant inspections at all sites revealed rhizome tunnel damage by *C. sordidus*. No plantation hygiene was practised and at both sites accumulated residues were destroyed in January 2005. The sites were relatively similar, but compared to the Ramsgate location, the older Munster plantation had a lower plant density (less canopy cover) as a result of plant toppling, a higher rate of residue desiccation, more remnants present in the field and not all residues (approximately 65 to 70%) were attached to the mother plant.

6.2.2 Experimental design

Five different chemicals were evaluated, but imidacloprid was only included in the Ramsgate trial (Table 6.1). Control plants were injected with water. Treatments were applied by injecting 10 ml of chemical solution (or water) into residual banana pseudostems using a calibrated knapsack (Calibra stem applicator, Interlock CC, Pretoria, South Africa). The lance of the backpack was end-capped with a spear-shaped “dagger”, with three injector slits on opposite sides at the distal end (Interlock CC, Pretoria, South Africa). Moist tissue of softened, decayed pseudostems (or rhizomes), with at least a distal portion easily compressible by hand, were injected at a 100 cm height or less, depending on the level of decay. Chemicals were

administered at a 45° angle (downward) to the erect portion of the decayed plant, allowing introduction of the chemical dose with no leaching from the injection hole. Only the most recently harvested residual allowing injection, where possible still attached to the mother plant, was treated at each mat. The layout of the trials followed a randomised block design with three replicates. Plots had approximately 50 plants and were separated by a two-row barrier. To standardise for abiotic influences, replicates were orientated perpendicular to the sea/land breeze and moisture gradient in the field.

Application of pesticides (and water) was conducted every 2nd month from late October 2003 to late August 2005. Yield, damage parameters and pseudostem girth of plants felled during a 3-month period (August to October) in 2003 to 2005 were measured. Yield was determined at the pack-house by weighing of bananas (bunches excluding the peduncle). The plants were subjected to weevil damage and girth sampling within a week of harvest. The Coefficient of Infestation (CI) was determined by paring the corm and scoring the proportion of the rhizome circumference with weevil galleries (Vilardebó 1973). Intervals of 2.5% were included up to a level of 10% damage. Damage was also rated by the Percentage Coefficient of Infestation (PCI) (Mitchell 1978, 1980), which involved scoring the presence/absence of peripheral damage for ten sections, each covering 18° of the corm surface. The latter was determined at 5 cm (Gold *et al*. 1994) and between 5 and 20 cm from the collar. The two PCI values were summed to provide a total PCI value. A cross section of the corm was made at 10 cm from the collar and the percentage damage of the central cylinder and cortex scored in 10% intervals, using a transparent circular grid divided into 36° sections (modified from Gold *et al*. 1994, Kiggundu 2000). The two cross section values were averaged to provide the mean cross sectional damage (X mean). The circumference of harvested plants was measured at 100 cm from the collar.

Adult densities were assessed over 4 weeks in October (from 2003 to 2005) and April (from 2004 to 2005). Three split-pseudostem traps, placed individually next to three plants in the middle of each plot, were used to sample adult densities. Trap material was randomly selected from plants harvested within 2 weeks before trap preparation at a plantation similar to, but separated by a dirt road, from the specific trial sites. Only one trap was prepared from each plant and pseudostems with internal damage/necrosis/tunnels were discarded. Pseudostem traps were 30 cm in length

(pseudostem section 30-60 cm above the collar), bisected longitudinally and each half placed (with the cut surface ventrally) directly next to the mat of the plant. Two halves were placed on opposite sides of the mat and regarded as one trap. The split pseudostems were covered with mulch to delay desiccation and decomposition. Traps were replaced once a week, when the samples per trap were counted and destroyed.

Nematode samples were collected and analysed in October (from 2003 to 2005). Root samples were collected from three randomly selected mother plants per plot. Samples were sent to the ARC - Institute for Tropical and Subtropical Crops (Nelspruit, Mpumalanga), where 30 g of roots (randomly selected per plot) were examined for nematodes. The initial data were recorded before any of the treatments were applied.

6.2.3 Statistical analysis

Analysis of covariance (ANCOVA) (Sokal and Rohlf 1997) was used to quantify yield and girth over time, among treatments and between the interactions of time and treatment. The nematode number of all the species were combined and entered as a covariate. Nematode densities over time and between treatments were ascertained by factorial ANOVA, while the pre-treatment densities were compared by one-way ANOVA. The seven parameters used for damage estimation were compared over time, between treatments and among the interactions of time and treatment using repeated measures ANOVA. One-way ANOVA (Sokal and Rohlf 1997) was used to ascertain pre-trial differences in adult densities. Differences of adult densities over time, between treatments and between the interactions of the independent variables were determined by factorial ANOVA (Sokal and Rohlf 1997). The Tukey HSD test (Sokal and Rohlf 1997) was used for all *post hoc* analysis. Unless stated otherwise, the data were not transformed and showed a normal distribution and homogeneity of variances in the linear scale. The STATISTICA Version 7 (Statsoft Inc. 2004) software program was used for analysis.

6.3 Results

6.3.1 Munster trial

6.3.1.1 Yield, girth and nematodes

No differences were found in yield ($F_{4, 9} = 0.29$, $P = 0.876$) and plant girth ($F_{4, 9} =$

1.21, P = 0.372) between plots at the onset (spring 2003) of the trial. The initial nematode densities between plots were also similar ($F_{4, 10}$ = 0.52, P = 0.724).

Bunch yield was statistically similar in the spring of 2004 (24.80 ± 0.486 (SE) kg) and 2005 (26.59 ± 0.780 (SE) kg) ($F_{1, 19}$ = 0.57, P = 0.460), was no different between treatments (range: 24.9 to 26.81 kg) ($F_{4, 19}$ = 0.38, P = 0.822) and did not show a significant interaction between time and treatment ($F_{4, 19}$ = 0.57, P = 0.687). Similarly, plant girth also showed neither a significant temporal (2004: 66.257 ± 0.7912 (SE) cm, 2005: 65.889 ± 0.8694 (SE) cm) ($F_{1, 19}$ = 0.06, P = 0.813) or treatment effect (range: 64.725 to 66.728 cm) ($F_{4, 19}$ = 0.34, P = 0.845), nor an interaction between the independent variables ($F_{4, 19}$ = 1.43, P = 0.261).

The nematode-complex showed a significant difference between dates ($F_{1, 20}$ = 5.97, P = 0.024), while numbers between treatments and between interactions of time and treatment were similar ($F_{4, 20}$ = 0.12, P = 0.975 and $F_{4, 20}$ = 0.45, P = 0.771, respectively). Post ANOVA analysis showed that the average number of nematodes was significantly higher in 2005 (1770 nematodes per 30 g roots) compared to 2004 (1000 nematodes per 30 g roots). Analysis of samples in 2003 and 2004 showed that the spiral (*Helicotylenchus* spp.) and lesion nematodes (*Pratylenchus* spp.) were approximately of equal proportions. Root samples in 2005 were mainly infested with spiral nematodes, but lesion and root knot nematodes (*Meloidogyne* spp.) were also present. The burrowing nematode, *R. similis* was not found throughout the trial.

6.3.1.2 Damage parameters

The pre-trial plant damage estimations of the PCI (0-5 cm), PCI (5-20 cm), Total PCI, CI, XO, XI and X mean were similar between plots ($F_{4, 10}$ = 0.81, P = 0.548; $F_{4, 10}$ = 0.18, P = 0.943; $F_{4, 10}$ = 0.39, P = 0.810; $F_{4, 10}$ = 0.75, P = 0.580; $F_{4, 10}$ = 0.77, P = 0.567; $F_{4, 10}$ = 0.46, P = 0.764 and $F_{4, 10}$ = 0.43, P = 0.787, respectively).

The repeated measures ANOVA showed no significant difference between date (2004 and 2005) and any of the dependent variables (0.06 < $F_{1, 20}$ < 4.05, 0.06 < P < 0.805). Significant treatment effects were only found for PCI (5-20 cm) ($F_{4, 20}$ = 5.48, P = 0.004), Total PCI ($F_{4, 20}$ = 5.56, P = 0.004) and CI ($F_{4, 20}$ = 4.57, P = 0.009), but were minimised in the fipronil treatment for PCI (0-5 cm) (range: 0.63 to 1.94), XO (range: 19.42 to 34.03%), XI (range: 2.31 to 15.44%) and X mean (range: 10.86 to 23.89%). The analysis showed an interaction between date and treatment for X mean ($F_{4, 20}$ = 3.46, P = 0.027). Post ANOVA analysis found that the PCI (5-20)

parameter was significantly lower in chlorpyrifos and fipronil treated plants compared to control plants. Values for the remaining chemicals were statistically similar to all the other treatments (Fig. 6.1). Total PCI showed similar differences between means as the PCI (5-20) damage parameter. Compared to the control, the coefficient of variation (CI) was only significantly lower in fipronil treated plants (Fig. 6.1). The CI values for bifenthrin, chlorpyrifos and oxamyl treated plants were statistically similar to the fipronil treatment (Fig 6.1). The mean cross sectional damage was significantly lower in plants treated with fipronil in 2005 (7.94%) compared to control plants in 2004 (32.78%) (data not shown).

6.3.1.3 Adult densities

The one-way ANOVA showed that the pre-trial adult densities were similar between plots ($F_{4, 10} = 0.61$, $P = 0.666$). The number of adults varied significantly over time ($F_{3, 40} = 3.33$, $P = 0.029$) and between treatments ($F_{4, 40} = 5.36$, $P = 0.001$), but did not interact significantly between time and treatment ($F_{12, 40} = 0.83$, $P = 0.621$). Post ANOVA analysis showed that the mean of 1.45 adults collected (in three traps per week) in October 2004 was significantly less than 3.72 adults collected in April 2005. Values of the other months were statistically similar to October 2004 and April 2005 (data not shown). Fipronil treated plots had a significantly lower number of adults compared to the control (Fig. 6.2). The bifenthrin, chlorpyrifos and oxamyl treatment were similar to the control and fipronil treated plots (Fig. 6.2).

6.3.2 Ramsgate trial

6.3.2.1 Yield, girth and nematodes

No differences were found in yield or plant girth ($F_{5, 11} = 0.42$, $P = 0.825$ and $F_{5, 11} = 1.34$, $P = 0.316$, respectively) between plots at the onset of the trial. The initial nematode densities between plots were also similar ($F_{5, 12} = 2.06$, $P = 0.141$).

The yield in spring 2004 increased from a mean of 33.14 ± 0.801 (SE) to 35.23 ± 1.276 (SE) kg per bunch in spring 2005, but the difference was not significant ($F_{1, 23} = 1.06$, $P = 0.314$). There were no significant differences ($F_{5, 23} = 0.55$, $P = 0.740$) in yield between treatments, although the average yield per bunch increased by 11.29% in the fipronil (35.71 ± 1.497 (SE) kg) and 10.18% in the imidacloprid (35.27 ± 2.037 (SE) kg) treatments compared to the control treatment (31.68 ± 0.712 (SE) kg). The interaction between time and treatment also showed no significant

differences ($F_{5, 23}$ = 0.45, P = 0.808). Plant girth was similar between dates (2004: 72.037 ± 1.0576 (SE) cm, 2005: 69.487 ± 1.4916 (SE) cm) ($F_{1, 23}$ = 1.71, P = 0.204). Plant girth between treatments ranged from 65.875 cm in the control to 73.576 cm in the fipronil treatment (10.47% increase), but was not significantly different ($F_{5, 23}$ = 1.16, P = 0.359). There was no interaction between time and treatment ($F_{5, 23}$ = 0.43, P = 0.820).

The density of nematodes was significantly different between dates ($F_{1, 24}$ = 5.78, P = 0.024), but neither a significant treatment effect ($F_{5, 24}$ = 1.05, P = 0.414), nor an interaction between time and treatment was found ($F_{5, 24}$ = 1.52, P = 0.221). The Tukey HSD test showed that the nematode number was significantly higher in 2005 (1927.78 nematodes per 30 g roots) compared to 2004 (766.67 nematodes per 30 g roots). Spiral nematodes mainly comprised the nematode complex, but root knot and lesion nematodes were also present at relatively low densities in 2003 to 2005. Burrowing nematodes were present in two plots (averaging 975 individuals per 30 g roots) during 2005.

6.3.2.2 Damage parameters

The pre-trial plant damage estimations of PCI (0-5) ($F_{5, 12}$ = 2.59, P = 0.082), PCI (5-20) ($F_{5, 12}$ = 2.27, P = 0.113), CI ($F_{5, 12}$ = 0.93, P = 0.494), XO ($F_{5, 12}$ = 1.94, P = 0.161), XI ($F_{5, 12}$ = 1.46, P = 0.274) and X mean ($F_{5, 12}$ = 2.17, P = 0.126) showed no significant difference between plots. The Total PCI ranged from 9.44 (oxamyl treatment) to 13.67 (fipronil treatment) and was different in the ANOVA analysis ($F_{5, 12}$ = 3.66, P = 0.030), but not significantly differentiated in the *post hoc* analysis. The Tukey HSD test adopts a conservative approach by employing experimentwise error rates (based on the number of comparisons) for the type I error (Sokal & Rohlf 1997).

The ANOVA showed no significant difference between date (2004 and 2005) and any of the dependent variables ($0.01 < F_{1, 24} < 0.43$, $0.517 < P < 0.939$). Significant treatment effects were found for all the damage estimations; PCI (0-5) ($F_{5, 24}$ = 8.27, $P < 0.001$), PCI (5-20 cm) ($F_{5, 24}$ = 10.85, $P < 0.001$), Total PCI ($F_{5, 24}$ = 13.98, $P < 0.001$), CI ($F_{5, 24}$ = 12.61, $P < 0.001$), XO ($F_{5, 24}$ = 9.38, $P < 0.001$), XI ($F_{5, 24}$ = 3.81, P = 0.011) and X mean ($F_{5, 24}$ = 9.40, $P < 0.001$). The analysis showed an interaction between date and treatment for PCI (0-5) ($F_{5, 24}$ = 2.95, P = 0.032). The Tukey HSD test showed the PCI (0-5) parameter was only significantly lower in fipronil and imidacloprid treated plants compared to control plants. The oxamyl

treatment was similar to the fipronil and imidacloprid treatments, while bifenthrin was similar to fipronil treated plants (Fig. 6.3). PCI (5-20) showed that only the fipronil and imidacloprid treatments had significantly lower damage than the control plants, while the oxamyl treatment was similar to fipronil and imidacloprid. Relative to the control plants, the Total PCI was only significantly lower in oxamyl, fipronil and imidacloprid treated plants, while bifenthrin was similar to the oxamyl treatment. All the chemical treatments, except for chlorpyrifos, statistically reduced the CI parameter compared to untreated plants; imidacloprid showed the lowest value which was statistically similar to fipronil and oxamyl (Fig. 6.3). The XO was only statistically lower in the fipronil and imidacloprid treatments compared to the control; oxamyl was similar to fipronil and imidacloprid treated plants (Fig. 6.4). The imidacloprid treated plants reduced the XI damage by 100% and was the only treatment significantly lower than the control (Fig. 6.4). Fipronil caused a 95% reduction in XI. Imidacloprid, fipronil and oxamyl significantly reduced the X mean relative to untreated plants by 90.43, 81.91 and 63.48%, respectively. The bifenthrin treatment showed similar X mean values to oxamyl and fipronil (Fig. 6.4). The PCI (0-5) parameter was significantly lower in plants treated with imidacloprid in 2005 (0.00) compared to control plants in 2004 (1.83) and 2005 (2.00) (data not shown).

6.3.2.3 Adult densities

The distribution of adults between plots was similar before the trial started ($F_{5, 12}$ = 0.47, P = 0.794). Adult densities between subsequent collections ranged from 6.65 in April 2005 to 9.89 in October 2004 and were significantly different ($F_{3, 48}$ = 2.99, P = 0.040). Treatment effects were also significant ($F_{5, 48}$ = 19.96, P < 0.001), but no interaction between time and treatment was found ($F_{15, 48}$ = 1.08, P = 0.395). The Tukey HSD test did not show a difference between collection dates, because it adopts a conservative approach by employing experimentwise error rates (based on the number of comparisons) for the type I error (Sokal & Rohlf 1997). Fipronil, imidacloprid and chlorpyrifos treatment resulted in a significant decrease in adult density compared to the control (Fig. 6.5). Bifenthrin and oxamyl showed statistically similar values to the control, while the chlorpyrifos treatment was similar to the bifenthrin applications (Fig. 6.5).

6.4 Discussion

Fipronil and imidacloprid were highly effective chemicals against *C. sordidus*, minimising damage to the periphery, cortex and central cylinder of the rhizome and significantly reduced adult density. The damage parameter of Cavendish bananas most closely related to effective bunch weight is the percentage damage to the central cylinder (Chapter 7). Fipronil and imidacloprid virtually eliminated damage to this portion of the rhizome after six applications. Under certain conditions, the mean percentage damage to the cortex and central cylinder of the corm can be the best indicator of fruit yield (Chapter 7). This damage was also greatly reduced after six applications of fipronil and imidacloprid. The percentage reduction in these important damage parameters after chemical application should be considered as conservative measures. The measurement scale of the cross sectional damage estimates was crude, with an increment (and minimum) of 10% damage. The result was that slight damage (probably less than one percent) to some chemically treated plants, especially fipronil and imidacloprid, was scored as 10% damage, while extensive larval tunnels comprising a 10% area of the rhizome in control plants received a similar score. In future studies the estimate of percentage internal corm damage should therefore be refined, preferably to a one percent scale. Of the other chemical treatments, chlorpyrifos and oxamyl showed a reduction in peripheral damage, but results were inconsistent. Injection of bifenthrin was generally ineffective. In a previous study, a single injection of chlorpyrifos during winter did not reduce tunnels in the rhizome of mother plants after 10 weeks (Dochez 1998).

Banana fruit yield and plant girth, corrected by nematode densities, were not significantly increased after any of the chemical applications. Similar results have been reported after organophosphate and carbamate treatment (Román *et al.* 1983; Chavarria-Carvajal & Irizarry 1997). Nevertheless, the data showed (with nematode infestation constant) an increase of up to 11.29% in effective bunch weight and a 10.47% increase in plant girth in the fipronil and imidacloprid treatments. This increase probably would have been significant if the plot size was increased, thereby decreasing the variability. Moreover, plants were propped during the trail and plant loss, which can contribute more to yield loss than reduction in bunch weight (Rukazambuga 1996), was not considered. The Munster trial suggested that (assuming other variables were constant between the trials) if a portion of residues injected with

fipronil over an annual period is not attached to the mother plant, then an overall reduction in peripheral plant damage and adult densities can be expected, but a reduction in the more important internal damage estimates may only be evident after 2 years. The results suggested that fipronil and imidacloprid, both considered to be systemic chemicals (Potter 1998; Nel *et al.* 2002), provided a protective treatment when the injected residue is physically attached to the mother plant.

The application protocol used in this study is unique in that systemic pesticides are injected throughout the year. In Australia plants are also injected with chemicals, but it is limited to contact pesticides applied during winter (Treverrow pers. comm.). The high efficacy achieved after injection of fipronil and imidacloprid into plant residues provides an optimal chemical strategy in an integrated pest management programme for the banana weevil. Fipronil has been shown not to affect the viability of *Beauveria bassiana* Balsamo (Batista Filho *et al.* 1996). The pesticides belong to unique chemical groups and can be spatially and temporally altered to minimise resistance development. More importantly, the application is specific to the pest, targeting the residual plant, which can contain all the weevil life stages throughout the year, but where adults predominate (Chapter 3). These chemicals probably also provide control in the mother plant, which can contain all the life stages, but where weevil larvae predominate (Chapter 3).

The density of the nematode-complex increased during the trial and was not controlled by any of the chemical treatments. This is in general agreement with Pattison *et al.* (2002), who reported that oxamyl injection into harvested pseudostems was not effective in controlling burrowing nematodes. Injection of chlorpyrifos into post harvest residues during winter also provided no nematode control (Dochez 1998). In addition, no evidence of poisoning non-target species was observed during both field trials, although this aspect was not empirically evaluated.

In future, the action mechanism and residual activity of the pesticides under the application protocol should be specifically researched. Timing of applications can be optimised accordingly, and applied when larvae (November to December, February) and adults predominate (November, April/May and July) (Chapter 3).

6.5 Acknowledgements

Thank you to Quentin Elliott and Wayne Simpson for making their farms available for

experimental purposes and providing assistance in the weighing of banana bunches and the sampling of adult beetles. Mieke Daneel (ARC-ITSC) analysed the nematode samples. BASF South Africa (Pty) Ltd., Bayer (Pty) Ltd., Dow AgroSciences Southern Africa (Pty) Ltd., and DuPont Nemours Int. S.A. kindly provided chemicals. The project was financially supported by the Banana Growers Association of South Africa (BGASA), Technology and Human Resources for Industry Programme (THRIP), National Research Foundation (NRF) and the University of Pretoria (UP).

6.6 References

ABERA, A.M.K., GOLD, C.S. & KYAMANYWA, S. 1999. Timing and distribution of attack by the banana weevil (Coleoptera: Curculionidae) in East African highland banana (*Musa* spp.). *Florida Entomologist* 82: 631-641.

ANITHA, N., CHARLES, J.S.K. & RAJAMONY, L. 1992. Effect of sucker treatment with insecticides on incidence on banana rhizome weevil (*Cosmopolites sordidus*). *Indian Journal of Agricultural Sciences* 62: 572-573.

ANONYMOUS. 1969. Beetle borer studies. *Banana Bulletin* 33: 4.

ANONYMOUS. 2005. *Agricultural remedies*. National Department of Agriculture. World Wide Web: http://www.nda.agric.za/act36/AR/Insecticides.htm

BATCHELDER, C.H. 1954. Experimentos con insecticidas para combater el picudo negro, *Cosmopolites sordidus* (Germar), en plantaciones de abaca. *Turrialba* 4: 88-93.

BATISTA FILHO, A., LEITE, L.G., ALVES, E.B. & AGUIAR, J.C. 1996. Control of *Cosmopolites sordidus* by fipronil and its effect on *Beauveria bassiana*. *Arquivos do Instituto Biologico (Sao Paulo)* 63: 47-51.

BRAITHWAITE, B.M. 1958. Ground sprayed treatments for control of the banana beetle borer (*Cosmopolites sordidus*) (Germar). *Journal of the Australian Institute for Agricultural Science* 24: 27-34.

BRAITHWAITE, B.M. 1967. Banana beetle borer control investigations on the north coast of New South Wales. *The Agricultural Gazette of New South Wales* 78: 359-365.

BUJULU, J., URONU, B. & CUMMING, C.N.C. 1983. The control of banana weevils and parasitic nematodes in Tanzania. *East African Agricultural and Forestry Journal* 49: 1-13.

CÁRDENAS R. 1984. El picudo negro del plátano *Cosmopolites sordidus* (Germar). *Cenicafé* 120: 12.

CARDENAS MURILLO, R., ARROYAVE, R.F.P. & ARANGO BERNAL, L.G. 1986. Treatment of plantain (*Musa* AAB Simmonds) against the banana borer weevil (*Cosmopolites sordidus* Germar). *Cenicafé* 37: 61-71 (Abstract cited).

CHABRIER, C., HUBERVIC, J. & QUENEHERVE, P. 2002. Evaluation of fosthiazate (Nemathorin® 10G) for the control of nematodes in banana fields in Martinique. *Nematropica* 32: 137-147.

CHAVARRIA-CARVAJAL, J.A. & IRIZARRY, H. 1997. Rates, application intervals and rotation of four granular pesticides to control nematodes and the corm-weevil (*Cosmopolites sordidus* Germar) in plantain. *Journal of Agriculture of the University of Puerto Rico* 81: 43-52.

COLLINS, P.J., TREVERROW, N.L. & LAMBKIN, T.M. 1991. Organophosphorus insecticide resistance and its management in the banana weevil borer, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), in Australia. *Crop Protection* 10: 215-221.

CUILLÉ, J. 1950. *Recherches sur le Charancon du Bananier*. Institut des Fruits Agrumes Coloniaux; Serie Technique No 4, Paris.

DE JAGER, K., RABIE, E.C. & ANDERSON, S.H. 1991. Chemiese beheer van die piesangwortelboorder, *Cosmopolites sordidus* en aalwurms, veral die booraalwurm, *Radopholus similis*. *Inligtingsbulletin - Navorsingsinstituut vir Sitrus en Subtropiese Vrugte* 228: 17-20.

DOCHEZ, C. 1998. *Study on Pest Status and Control of* Cosmopolites sordidus *(Germar) in South Africa*. M.Sc. Thesis, Heriot-Watt University, Scotland.

EDGE, V.E. 1974. Cyclodiene-BHC resistance in *Cosmopolites sordidus* (Germ.) (Coleoptera: Curculionidae) in New South Wales, Australia. *Bulletin of Entomological Research* 64: 1-7.

FOGAIN, R., MESSIAEN, S. & FOURÉ, E. 2002. Studies on the banana borer weevil in Cameroon. *Infomusa* 11: 8-9.

FRANZMANN, B.A. 1972. Banana weevil borer in North Queensland. *Queensland Agricultural Journal* 98: 319-321.

FROGGATT, J.L. 1925. The banana weevil borer (*Cosmopolites sordidus*). *Queensland Agricultural Journal* 24: 558-593.

FROGGATT, J.L. 1926. *The Banana Weevil Borer*. Bulletin No. 4. Queensland Department of Agriculture and Stock, Brisbane, Australia.

GOLD, C.S., BAGABE, M.I. & SSENDEGE, R. 1999. Banana weevil (*Cosmopolites sordidus*) (Germar) (Coleoptera: Curculionidae) tests for suspected resistance to carbofuran and dieldrin in Masaka district, Uganda. *African Entomology* 7: 189-196.

GOLD, C.S. & MESSIAEN, S. 2000. *The Banana Weevil,* Cosmopolites sordidus. Musa Pest Fact Sheet No. 4, INIBAP.

GOLD, C.S., NIGHT, G., ABERA, A. & SPEIJER, P.R. 1998. Hot-water treatment for the control of the banana weevil, *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae), in Uganda. *African Entomology* 6: 215-221.

GOLD, C.S., PEÑA, J.E. & KARAMURA, E.B. 2003. Biology and integrated pest management for the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). *Integrated Pest Management Reviews* 6: 79-155.

GOLD, C.S., SPEIJER, P.R., KARAMURA, E.B., TUSHEMEREIRWE, W.K. & KASHAIJA, I.N. 1994. Survey methodologies for banana weevil and nematode damage assessment in Uganda. *African Crop Science Journal* 2: 309-321.

JONES, R.K. & DIECKMANN, F. 1982. Control of the banana root borer, *Cosmopolites sordidus* Germar. *Information Bulletin, Citrus and Subtropical Fruit Research Institute* 13-17.

KIGGUNDU, A. 2000. *Host Plant Reactions and Resistance Mechanisms to Banana Weevil, Cosmopolites sordidus (Germar) in Ugandan Musa Germplasm*. M.Sc. Thesis, Orange Free State University, South Africa.

KOPPENHÖFER, A.M. 1993. Observation on egg laying behaviour of the banana weevil, *Cosmopolites sordidus* (Germar). *Entomologia Experimentalis et Applicata* 68: 187-192.

MAOLIN, S. 1994. Status of nematode and weevil borer problems affecting banana in China. In: Valmayor, R.V., Davide, R.G, Stanton, J.M., Treverrow, N.L., & Roa, V.N. (Eds.) *Proceedings of Banana Nematode/Borer Weevil Conference in Los Banos, Philippines, INIBAP*. 57-62.

MITCHELL, G. 1978. *The Estimation of Banana Borer Population and Resistance levels*. Technical Bulletin 2, Windward Island Banana Growers Association (WINBAN), St. Lucia.

MITCHELL, G. 1980. *Banana Entomology in the Windward Islands. Final report 1974-1978*. Centre for Overseas Pest Research, London.

NEL, A., KRAUSE, M. & KHELAWANLALL, N. 2002. *A Guide for the Control of Plant Pests*. 39th Edition. Directorate, Agricultural Production Inputs, Department of Agriculture, South Africa.

NUNO, L. & RIBEIRO, V.P. 2002. *Cosmopolites sordidus* in the autonomous region of Madeira. *Infomusa* 11: 10.

PATTISON, A.B., VERSTEEG, C.A., MCQUINN, D.J., MATTHEWS, N.J., FARNSWORTH, W. & PIPER, R. 2002. Management of burrowing nematodes in bananas using pseudostem injection of Vydate L. DuPont, Australasia.

PINESE, B. & ELDER, R. 2004. *Banana Weevil Borer*. Queensland Government, Department of Primary Industries and Fisheries, Horticulture and Fresh Produce. World Wide Web: http://www.dpi.qld.gov.au/horticulture/2507.html

POTTER, D.A. 1998. *Destructive turfgrass pests*. Ann Arbor Press, Michigan.

PRICE, N.S. 1995. The use of a modified pseudostem trapping technique for assessing the efficacy of insecticides against the banana borer weevil. *Fruits* 50: 23-26.

QUILICI, S. 1993. Insect pests of banana. *Fruits* 48: 29-31.

ROMÁN, J., ORAMAS, D. & GREEN, J. 1979. Effect of rate and frequency of application of nematicides in plantain production. *Nematrópica* 9: 107-117.

ROMÁN, J., ORAMAS, D., GREEN, J. & TORRES, A. 1983. Control of nematodes and black weevils in plantains. *Journal of the Agricultural University of Puerto Rico* 67: 270-277.

RUKAZAMBUGA, N.D.T.M. 1996. *The Effects of Banana Weevil* (Cosmopolites sordidus *Germar) on the Growth and Productivity of Bananas* (Musa *AAA EA) and the Influence of Host Vigour on Weevil Attack*. Ph.D. Thesis, University of Reading, UK.

SCHOEMAN, P.S. 1996. Control of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). In: Robinson, J.C. (Ed.) *Banana Growers Association of South Africa* 1: 83-87.

SCHOEMAN, P.S. 1998. Chemical control of the banana root borer. *Neltropika* July: 28-30.

SCHOEMAN, P.S., SCHOEMAN, M.H. & DOCHEZ, C. 1999. Novel techniques for the control of the banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) in South Africa. *Yearbook of the Banana Growers Association of South Africa* 3: 78-82.

SHANAHAN, G.J. & GOODYER, G.J. 1974. Dieldrin resistance in *Cosmopolites sordidus* in New South Wales, Australia. *Journal of Economic Entomology* 67: 446.

SIMMONDS, N.W. 1959. *Bananas*. 1st Edition. Longmans Press, London.

SIMMONDS, N.W. 1966. *Bananas*. 2nd Edition. Longmans Press, London.

SMITH, D. 1995. Banana weevil borer control in south-eastern Queensland. *Australian Journal of Experimental Agriculture* 35: 1165-1172.

SOKAL, R.R. & ROHLF, F.J. 1997. *Biometry*. W.H. Freeman and Company, New York.

STANTON, J.M. 1994. Status of nematode and weevil borer problems affecting banana in Australia. In: Valmayor, R.V., Davide, R.G, Stanton, J.M., Treverrow, N.L., & Roa, V.N. (Eds.) *Proceedings of Banana Nematode/Borer Weevil Conference in Los Banos, Philippines: INIBAP*. 48-56.

STATSOFT INCORPORATED. 2004. *Statistica*. Version 7.

STOVER, R.H. & SIMMONDS, N.W. 1987. *Bananas*. Third Edition. 469. John Wiley and Sons, New York.

TAYLOR, B. 1991. Research field work on upland bananas, *Musa* spp., principally *acuminata* triploid AAA types, in the Kangera region of Tanzania with observations on growth and on the causes of decline in crop yield. *Revista di Agricultura Subtropicale e Tropicale* 85: 349-392.

TREVERROW, N.L. 1985. *Banana Weevil Borer.* Agfact H6.AE.1, 2nd edition. NSW Agriculture and Fisheries, Australia.

TREVERROW, N., PEASLEY, D. & IRELAND, G. 1992. *Banana Weevil Borer, A Pest Management Handbook for Banana Growers*. Banana Industry Committee, New South Wales Agriculture.

VILARDEBÓ, A. 1967. Resistance of the banana tree weevil *Cosmopolites sordidus* (Germar) to chlorinated hydrocarbon insecticides. *International Congress of Plant Protection* 586.

VILARDEBÓ, A. 1973. Le coefficient d'infestation, critere d' evaluation du degre d'attaques des bananeraies par *Cosmopolites sordidus* Germ. Le charancon noir du bananier. *Fruits* 28: 417-431.

VISWANATH, B.N. 1977. Studies on the biology, varietal response and control of banana rhizome weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). *Mysore Journal of Agricultural Sciences* 11: 597-598.

VITTAYARUK, W., WATTANACHAIYINGCHAROEN, W., CHUAYCHAROEN, T. & WATTANACHAIYINGCHAROEN, D. 1994. Status of weevil borer problems affecting banana in Thailand. In: Valmayor, R.V., Davide, R.G, Stanton, J.M., Treverrow, N.L., & Roa, V.N. (Eds.) *Proceedings of Banana Nematode/Borer Weevil Conference in, Los Banos, Philippines: INIBAP*. 106-114.

WILLERS, P., DANEEL, M.S. & DE JAGER, K. 2001. Banana. In: Van den Berg, M.A., De Villiers, E.A. & Joubert, P.H. (Eds.) *Pests and Beneficial Arthropods of Tropical and Non-citrus Subtropical Crops in South Africa*. 36. ARC – Institute for Tropical and Subtropical Crops. Ad Dynamics, Nelspruit.

WRIGHT, W.E. 1977. Insecticides for the control of dieldrin resistant banana weevil borer *Cosmopolites sordidus* Germar. *Australian Journal of Experimental Agriculture and Animal Husbandry* 17: 499-504.

Table 6.1. Chemical groups, trade names, formulations, active ingredients and gram active ingredient of chemicals evaluated against *Cosmopolites sordidus* at Ramsgate and Munster (KZN, South Africa) from October 2003 to October 2005. * Excluded from the Munster trial.

Chemical group	**Trade name (formulation)**	**Active ingredient (a.i.)**	**Gram active ingredient (g.a.i.)/plant**
Pyrethroid	Talstar (EC)	Bifenthrin ($100\ g.l^{-1}$)	0.015
Organophosphate	Dursban (WG)	Chlorpyrifos ($750\ g.kg^{-1}$)	0.125
Phenyl pyrazole	Regent (SC)	Fipronil ($200\ g.l^{-1}$)	0.01
Chloro-nicotinyl	Confidor (SC)	* Imidacloprid ($350\ g.l^{-1}$)	0.245
Oxime carbamate	Vydate (SL)	Oxamyl ($310\ g.l^{-1}$)	0.5

Figure legends

Figure 6.1. The mean values of the Percentage Coefficient of Infestation (PCI) and Coefficient of Infestation (secondary axis) damage parameters of untreated (control) plants and plants treated bimonthly with four chemicals at Munster (KZN, South Africa) from October 2003 to August 2005. For each dependent variable, means with letters in common are not significantly different (P>0.05) and upper case letters refer to the secondary axis. 20 = PCI from > 5 to 20 cm from the collar, To = Summed total PCI, Bifen = Bifenthrin, Chlor = Chlorpyrifos, Fip = Fipronil and Oxa = Oxamyl.

Figure 6.2. The mean adult banana weevil density values of untreated (control) plots and plots treated bimonthly with four chemicals at Munster (KZN, South Africa) from October 2003 to August 2005. For each dependent variable, means with letters in common are not significantly different (P>0.05). Bifen = Bifenthrin, Chlor = Chlorpyrifos, Fip = Fipronil and Oxa = Oxamyl.

Figure 6.3. The mean values of the Percentage Coefficient of Infestation (PCI) and Coefficient of Infestation (secondary axis) damage parameters of untreated (control) plants and plants treated bimonthly with five chemicals at Ramsgate (KZN, South Africa) from October 2003 to August 2005. For each dependent variable, means with letters in common are not significantly different (P>0.05) and upper case letters refer to the secondary axis. 05 = PCI from 0 to 5 cm from the collar, 20 = PCI from > 5 to 20 cm from the collar, To = Summed total PCI, Bifen = Bifenthrin, Chlor = Chlorpyrifos, Fip = Fipronil, Imi = Imidacloprid and Oxa = Oxamyl.

Figure 6.4. The mean values of the cross sectional damage parameters of untreated (control) plants and plants treated bimonthly with five chemicals at Ramsgate (KZN, South Africa) from October 2003 to August 2005. For each dependent variable, means with letters in common are not significantly different (P>0.05). XO = Cross section damage percentage of the cortex, XI = Cross section damage percentage of the central cylinder, X mean = Average cross sectional damage of the corm, Bifen = Bifenthrin, Chlor = Chlorpyrifos, Fip = Fipronil, Imi = Imidacloprid and Oxa = Oxamyl.

Figure 6.5. The mean adult banana weevil density values of untreated (control) plots and plots treated bimonthly with five chemicals at Ramsgate (KZN, South Africa) from October 2003 to August 2005. For each dependent variable, means with letters in common are not significantly different (P>0.05). Bifen = Bifenthrin, Chlor = Chlorpyrifos, Fip = Fipronil, Imi = Imidacloprid and Oxa = Oxamyl.

Figure 6.1

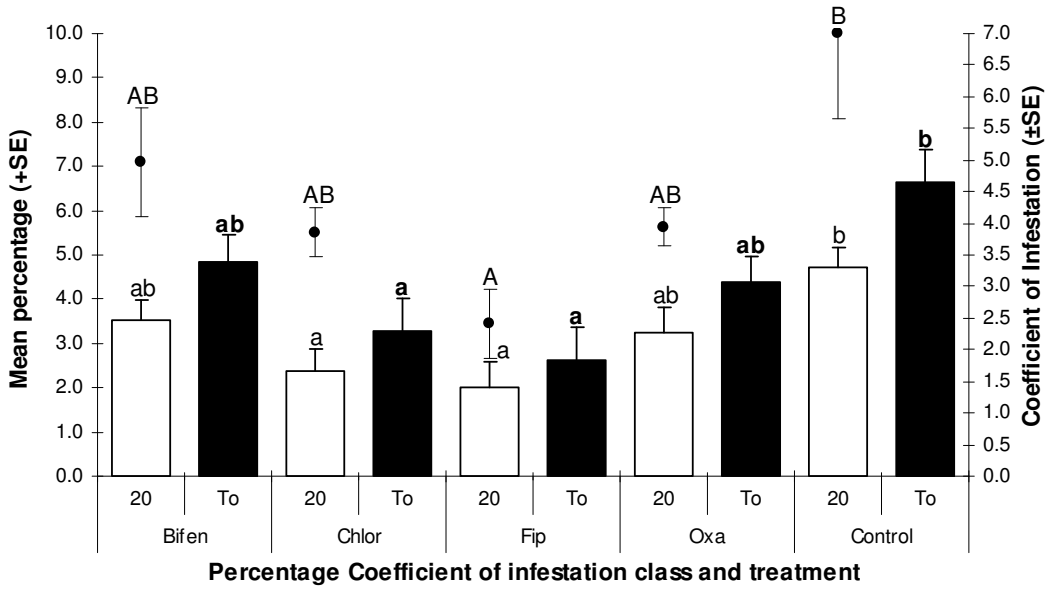

Mean percentage (+SE)
Coefficient of Infestation (±SE)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
AB
ab
ab
AB
a
a
A
a
a
AB
ab
ab
B
b
b
20
To
20
To
20
To
20
To
20
To
Bifen
Chlor
Fip
Oxa
Control
Percentage Coefficient of infestation class and treatment

Figure 6.2

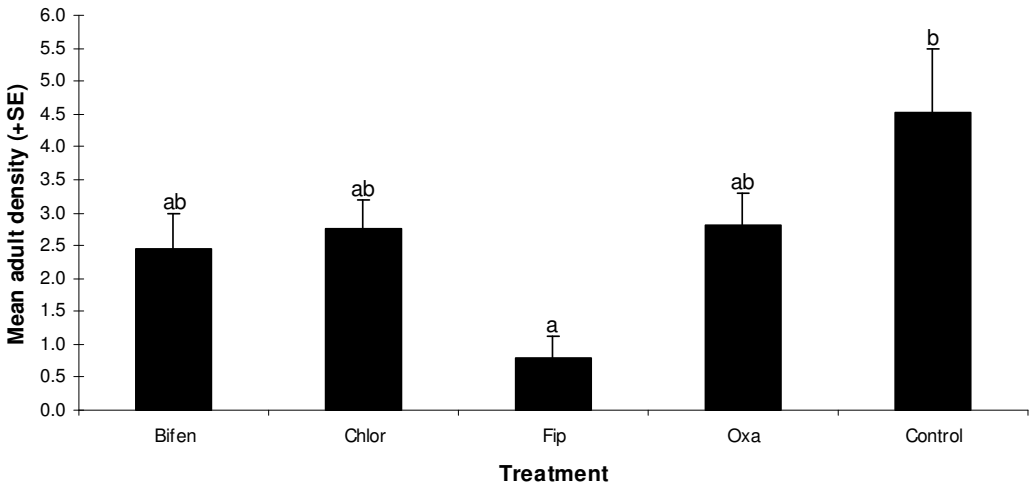

Mean adult density (+SE)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ab
ab
a
ab
b
Bifen
Chlor
Fip
Oxa
Control
Treatment

Figure 6.3

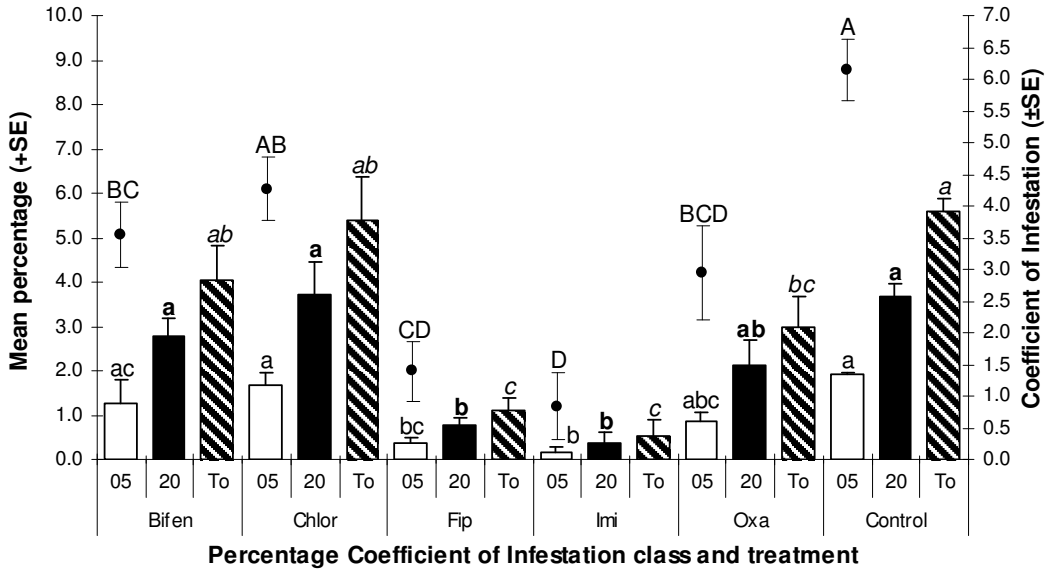

Mean percentage (+SE)
Coefficient of Infestation (±SE)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
BC
ac
a
ab
AB
a
a
ab
CD
bc
b
c
D
b
b
c
BCD
abc
ab
bc
A
a
a
a
05
20
To
Bifen
Chlor
Fip
Imi
Oxa
Control
Percentage Coefficient of Infestation class and treatment

Figure 6.4

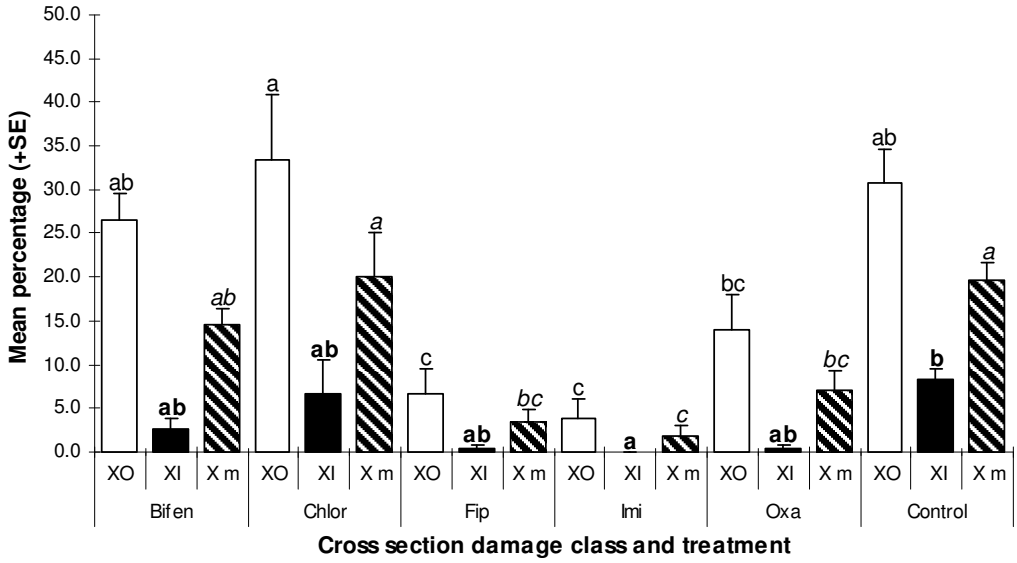
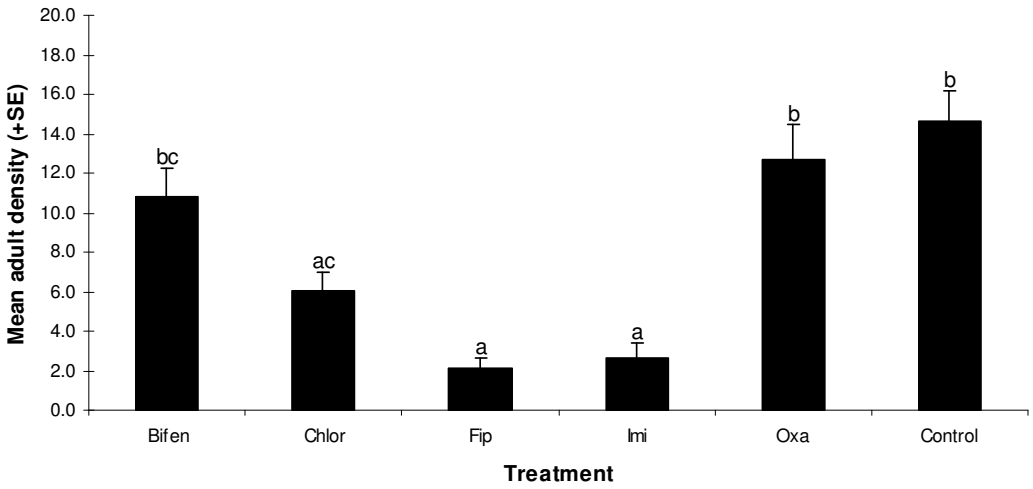

Mean percentage (+SE)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
ab
ab
ab
a
ab
a
c
ab
bc
c
a
c
bc
ab
bc
ab
b
a
XO
XI
X m
Bifen
Chlor
Fip
Imi
Oxa
Control
Cross section damage class and treatment

Figure 6.5


20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Mean adult density (+SE)
bc
ac
a
a
b
b
Bifen
Chlor
Fip
Imi
Oxa
Control
Treatment