Chapter 4

Efficacy of pseudostem and pheromone seasonal trapping of the banana weevil *Cosmopolites sordidus* in South Africa

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Abstract

The banana weevil (*Cosmopolites sordidus*) is an important pest of bananas (Musaceae: *Musa* species) in South Africa. Adult trapping methods were compared in field trials using a randomised block design. Pseudostem traps, pitfall traps containing a pheromone (either Cosmolure® (Pheromone A) or Cosmolure+® (Pheromone B)), and unbaited pitfall traps (control), were compared over 5 weeks during all seasons along the Southeast coast of South Africa. Pseudostem traps treated with an insecticide, and rhizome traps were included as additional treatments in autumn. In summer two treatments were also added: individual suspension of both pheromones above a pitfall trap either in combination with or without a pseudostem trap. The adult beetles were sexed, and the number of internal eggs noted. Pheromone A proved to be the most effective of the different traps. Grouping of the pheromones resulted in a synergistic response, while combining the pseudostem did not enhance trap efficacy. The different plant material traps and the control were usually equally effective in catching weevils. Plant material traps caught greater numbers of fecund females, but pheromone traps captured a higher proportion of females. Treatment effects were much less pronounced in summer, and compared to a pseudostem trap, pitfall traps were the most efficacious during spring. Compared to conventional pseudostem trapping, Pheromone A pitfall traps should be optimally applied during spring in South Africa.

Keywords: Pheromone trap, pseudostem, sex, fecundity, season.

4.1 Introduction

Semiochemical trapping of the banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), has been employed since the early twentieth century and has been retained in modern recommendations for monitoring and control (Knowles and Jepson 1912, cited in Froggat 1928, Cuille 1950, Arleu 1982, Bujulu *et al*. 1983, Allen 1989, Ogenga-Latigo and Bakyalire 1993, Mestre and Rhino 1997). Historically, semiochemical trapping of the banana weevil was exclusively based on chemicals emitted by the host plant (serving as kairomones) (Cuille 1950, Budenberg *et al*. 1993a). These traps are still used today and are developed from residual pseudostems and rhizomes (Gold *et al*. 2003). Several trap designs are known, (Hord and Flippen 1956, Castrillon 1989, 1991, cited in Gold *et al*. 2003, Batista Filho *et al*. 1990, Collins *et al*. 1991, Treverrow *et al*. 1992, Price 1993, Raga and De Oliveira 1996, Aranzazu *et al*. 2000, cited in Gold *et al*. 2003), but disk-on-stump traps, pseudostem-disk traps and split-pseudostem traps are the most common (Yaringano and Van der Meer 1975, Mitchell 1978, Koppenhöfer 1992, Treverrow *et al*. 1992, Gold *et al*. 1999). Traps manufactured from different plant clones show great variation in weevil capture, although reports are inconsistent (Gold *et al*. 2003). Pseudostems (Cuille 1950, Sumani 1997) and rhizomes (Hord and Flippen 1956, Yaringano and Van der Meer 1975, Cerda *et al*. 1995) have been claimed to be the most effective trapping material. Fresh (Delattre 1980, Koppenhöfer *et al*. 1994) or decayed (Budenberg *et al*. 1993b) material may attract the most weevils. Rhizome trap preparations are laborious to perform and pseudostem traps are more common and preferred by most growers. Traps prepared from the proximal end of the pseudostem may be the most attractive (Mestre and Rhino 1997). Recently, dead banana leaves and other non-host plants were reported to potentially exceed the attractiveness of pseudostem and rhizome material (Braimah 1997, Braimah and Van Emden 1999). The major attractive kairomone substances are unknown (Budenberg *et al*. 1993b, Braimah 1997), but lipophilic plant and annalose-11 volatiles (Jones 1968), mono- and sesquiterpenes (Ndiege *et al*. 1991) and 1,8 cineole (Ndiege *et al*. 1996a) have been suggested as attractants.

The aggregation behaviour of *C. sordidus* is well known (Cuille 1950), but evidence of an aggregation pheromone was only recently obtained and it was suggested that it is produced by males via the hindgut (Budenberg *et al*. 1993a).

Females may also produce a pheromone responsible for initial attraction, while the male pheromone may cause the main aggregation (De Mendonca *et al*. 1999). Beauhaire *et al*. (1995) identified six male specific compounds, with 80% comprised of a single compound ($C_{11}H_{20}O_2$) with formula (1S, 3R, 5R, 7S) 2, 8-dioxa 1-ethyl 3, 5, 7 – trimethyl bicyclo (3, 2, 1) octane. This was synthesised and named sordidin (Beauhaire *et al*. 1995), a compound related to known ketal pheromones produced by scolytids (Gold *et al*. 2003). Large-scale synthesis of the four diastereoisomers (*exo-β*-sordidin, *endo-β*-sordidin, *exo-α*-sordidin and *endo-α*-sordidin) of sordidin made field testing possible (Ndiege *et al*. 1996b, Jayaraman *et al*. 1997). In field and laboratory trials, pheromones have been shown to attract significantly more weevils than plant material traps (Ndiege *et al*. 1996b, Jayaraman *et al*. 1997, Tinzaara *et al*. 2003).

The efficacy of trapping to control the banana weevil is disputed (Gold *et al*. 1993, Fogain *et al*. 2002, Gold *et al*. 2003) and appears to be affected by population density (Seshu Reddy *et al*. 1999), trapping intensity (Fogain *et al*. 2002), management and/or immigration (Gold *et al*. 2002). Nevertheless, intensive split-pseudostem trapping (one trap/mat/month) has been shown to significantly reduce *C. sordidus* damage after one year (Gold *et al*. 2002). Semiochemical-enhanced mass trapping has also been reported to exert effective control (Alpizar *et al*. 1998). The control potential of pheromone mass trapping compared to plant material may depend on climate, cultivation practices, proportion of the population attracted and the monetary cost of trapping. These factors may vary between areas and may also be influenced by the possible occurrence of weevil biotypes.

In South Africa, management of the banana weevil is based mainly on pseudostem trapping, a practice that is both labour intensive and costly. No research comparing pheromones to conventional traps has been conducted in the country, and the only reports available address pheromone efficacy in tropical countries (Ndiege *et al*. 1996b, Alpizar and Fallas 1997, Jayaraman *et al*. 1997, Alpizar *et al*. 1998, Tinzaara *et al*. 1999). In the framework of integrated pest management, the aim of the study was to quantify the efficacy of pheromone trapping under local conditions. Plant and pheromone traps were compared during different seasons in terms of the number and fecundity of the beetles attracted.

4.2 Material and methods

4.2.1 Research sites

Trials were conducted on different commercial banana farms in the South Coast of KwaZulu-Natal, South Africa. Farms were situated in Munster (31°01’44’’S; 30°12’30’’E), Leisure Bay (31°00’56’’S; 30°14’33’’E), and Ramsgate (two locations) (a: 30°53’20’’S; 30°18’38’’E) (b: 30°52’23’’S; 30°19’23’’E), ranging from 56 to 137 meters above sea level. Experiments were conducted during August 2002 (late winter), October/November 2003 (late spring), February/March 2004 (late summer) and April 2003 (late autumn), respectively.

The Cavendish subgroup of banana cultivars (AAA) was grown at all the trial localities. The cultivars Grand Nain, Chinese Cavendish, Williams and Chinese Cavendish were cultivated at the Munster, Ramsgate a, Leisure Bay and Ramsgate b location, respectively. Plantations were planted in November/December 1993, but the Ramsgate b site was planted in November 2000. The site at Munster and Ramsgate a utilized micro jet irrigation, whilst the Ramsgate b and Leisure Bay sites used sprinkler irrigation. Plants were irrigated with 20 mm water/week, a practise only suspended if rainfall exceeded that value in the particular week. The Munster, Ramsgate a, Ramsgate b and Leisure Bay sites were treated with the oxime carbamate, aldicarb (15% GR), at a rate of 2.025 g.a.i./mat at planting. The Ramsgate a site was also treated with aldicarb once a year up to the third ratoon. Pre-trial plant inspection at all sites revealed rhizome tunnel damage by *C. sordidus*.

4.2.2 Treatments

Treatments comprised of two aggregation pheromone lures, individually suspended above pitfall traps, untreated pseudostem traps and pitfall traps with no lure (control). Two additional treatments were included in the autumn and summer trials. The autumn trial included pseudostem traps treated with an insecticide and a rhizome disk trap. The summer trial included the two different pheromone lures individually suspended above a pitfall trap and a treatment combining the latter with a pseudostem trap placed next to the mat of the plant.

Pitfall trap designs were used because it was shown to be more effective than ramp traps in Uganda (Tinzaara *et al*. 1999), even though the contrary was concluded in Costa Rica (Alpizar and Fallas 1997). The commercially available aggregation pheromones, Cosmolure® (Pheromone A) and Cosmolure+® (Pheromone B), containing kairomone and four sordidin diastereoisomers, were imported from the producers, ChemTica Internacional S.A., situated in San José, Costa Rica. Pitfall traps were prepared by cutting four windows (200 × 200 mm) at the sides of rectangular prism-shaped containers (width:length:height: 250:300:350 mm) and suspending the pheromone with wire cable in the middle of the openings from the top end of the trap. Pitfall traps of the winter trial consisted of smaller cylindrical containers (radius: 70 mm; height: 200 mm) with the lid suspended by wire pillars 50 mm above the ground. Pitfall traps were filled with a mixture of ethylene glycol and water to reduce evaporation and lower the surface tension of the solution, to drown attracted beetles. The traps were placed in-line with the planting row at a constant direction to the mat. Pitfall traps were buried 150 mm in the soil (200 mm for the winter pitfall traps) at a distance of 300 mm from the pseudostem of the plant. Pseudostem trap material was randomly selected from plants harvested within 2 weeks before trap preparation at a plantation similar to but isolated (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 300 mm in length (pseudostem section 300-600 mm 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 autumn trial included pseudostem traps treated with a pyrethroid, cyfluthrin (trade name: Baythroid®, manufacturer: Bayer) (10% WP) at 0.02 g.a.i. per half pseudostem. Rhizome disk traps (selected from the widest part of the rhizome) were also prepared from plants used for pseudostem traps during the autumn trial series. The rhizomes used for traps had a circumference of at least 600 mm and were cut to a thickness of 50 mm. One rhizome trap was prepared from each plant and rhizomes with internal damage/necrosis/tunnels were discarded. The plant material traps were covered with mulch to delay desiccation and decomposition.

Ambient temperature at each trial site was measured using a waterproof WatchDog 100-Temp 2K data logger (Spectrum Technologies Inc. 2001) suspended next to a pheromone lure and set to record hourly temperature. Rainfall was measured on site and corrected with irrigation quantities.

4.2.3 Experimental design

The layout of all the trials was a randomised block design. Treatments were separated by 24 m and considered independent, as the attractive radius of pheromone pitfall traps were determined to range from 2.5 to 7.5 m (Alpizar *et al*. 1998) and the former value falls within the range recommended and used in previous studies (Ndiege *et al*. 1996b, Jayaraman *et al*. 1997, Alpizar *et al*. 1998, Tinzaara *et al*. 1999, Anonymous 2003). Plant material traps (pseudostems and rhizomes) were replaced once a week, when the samples per trap were collected and counted. Pheromones were replaced only during the autumn trial (on week 4). Adults were dissected, the sex determined by examining internal genitalia, and the percent of females with eggs and the number of eggs per female recorded. Oocytes were evaluated as eggs when covered by an egg shell (vitelline membrane and chorion). Unfortunately, beetles collected during the winter trial were destroyed before they could be dissected. Trials were monitored for 5 weeks. The winter, spring, summer and autumn trials had five, four, three and three replicates respectively, this being dependent on the size of the experimental block and number of treatments. To standardise for abiotic influences, replicates were orientated perpendicular to the sea/land breeze and moisture gradient in the field.

4.2.4 Statistical analysis

One-way ANOVA (Sokal and Rohlf 1997) was used to quantify differences between treatments and the dependent variables of total, female, male and percent female beetles attracted, eggs per female and percent of females containing eggs. The members of weevils caught between trials (seasons) were compared by converting these variables to fractions (indices of increase relative to the pseudostem trap). For each fraction, the interaction between season and treatment was determined by factorial ANOVA (Sokal and Rohlf 1997). The Tukey HSD test (Sokal and Rohlf 1997) was used for all post hoc analysis. Data for all the trials were not transformed, because it showed a normal distribution and homogeneity of variances in the linear scale. The ambient temperature and corrected rainfall values were averaged per week (corresponding to collection dates) and entered as covariates. The STATISTICA Version 7 (Statsoft Inc. 2004) software program was used for analysis.

4.3 Results

4.3.1 Winter trial

4.3.1.1 Weevils attracted

The winter trial ANOVA showed a significant difference between treatments and total number of beetles attracted ($F_{3,\ 96}$ = 15.56, P<0.001). The results of the post hoc comparisons are presented in figure 4.1.

Pheromones A and B were equally effective (P=0.990), and attracted a mean of 10.00 and 9.44 beetles per week, respectively. The pheromone-baited traps attracted significantly more beetles than the pseudostem (P<0.001) and control traps (P<0.001), whilst efficacy of pseudostems was not significantly different (P=0.666) than the control traps. During the trial the pseudostem traps attracted a mean of 2.08 weevils per week, while no weevils were collected in the control traps.

4.3.2 Spring trial

4.3.2.1 Weevils attracted

ANOVA of the spring trial indicated significant differences between treatments and total number ($F_{3,\ 76}$ = 18.13, P<0.001), female number ($F_{3,\ 76}$ = 18.13, P<0.001), male number ($F_{3,\ 76}$ = 6.46, P<0.001) and female percent ($F_{3,\ 66}$ = 5.59, P<0.002) of weevils attracted. Post ANOVA comparisons of attracted beetles, genders and female percent are illustrated in figure 4.2a.

Pheromone A was significantly more effective than any other treatment in the total number and number of female weevils attracted. Pheromone B attracted significantly more beetles and females than the control traps, but compared to pseudostem traps, only captured significantly more females. No significant difference was found between controls and pseudostem traps regarding weevil and female captures. The number of males collected was similar between all the traps, but significantly lower in the control traps. The pseudostem traps attracted 65.32% females, a value which was significantly lower than that of the two pheromone traps, which did not differ significantly. The percent of females attracted by the control pitfall trap was similar to the other treatments. The total number of beetles captured was similar between week 1 and 5, while the first week of collection captured significantly more beetles versus week 2 to 4 (data not shown). The number of females and males attracted showed a similar pattern, but collections on week 4 also showed no significant difference to week 1.

4.3.2.2 Fecundity variables

Treatments segregated significantly regarding the percent of females with eggs ($F_{3, 65}$ = 5.70, P<0.002) and mean eggs per female ($F_{3, 65}$ = 18.74, P<0.001). Figure 4.2b summarises the mean number of eggs per female and the percent of females with eggs during spring.

The number of eggs per female peaked at a mean of 5.07 for the pseudostem traps, which was significantly higher than any other trap; the values of the pheromone and control traps did not show a significant difference. The majority of females collected in all the treatments contained eggs, with the lowest percent of females with eggs recorded for Pheromone B at 90.24%, which was significantly lower than the 100% recorded for the pseudostem traps. Females with eggs captured in the Pheromone A trap were similar to the Pheromone B trap, but were significantly lower than the pseudostem traps. Values for the control traps were not significantly different to any treatment.

4.3.3 Summer trial

4.3.3.1 Weevils attracted

Analysis of the summer trial revealed significant disparity between treatments and total ($F_{5, 84}$ = 10.25, P<0.001), female ($F_{5, 84}$ = 7.33, P<0.001), male ($F_{5, 84}$ = 11.68, P<0.001) and female percent ($F_{4, 62}$ = 2.82, P=0.032) of weevils sampled. Figure 4.3a provides a significance summary for beetles collected and percent of females attracted between traps during the summer trial.

The control traps did not collect any weevils during the course of the trial and were excluded from the post hoc comparisons concerning proportions and eggs per female. Regarding the total number of weevils attracted, the grouping of the two pheromones and that of the latter with a pseudostem trap were similar, but both these treatments were significantly more effective than the control traps and the singular constituent treatments, which were not significantly different among themselves. The number of females collected in the Pheromone A traps was similar to all the other treatments; female number collected in the Pheromone B traps were only significantly lower than the combined pheromone traps, whilst the pseudostem trap collected a significantly lower proportion of females than both the grouping traps. The two grouping traps collected a similar number of females. The pseudostem trap collected a mean of 1.87 females per week, a value no different to the control trap. The number of males attracted was similar between the pheromone, pseudostem and control traps and also between the two grouping traps. The amount of male beetles collected from the pseudostem traps was no different to the number of males in the pheromone grouping trap. The percent of females collected in the traps ranged from 58.13% (pseudostem traps) to 87.35% (Pheromone A traps), with no statistical difference ($0.070<P<1.000$) found between the treatments by the Tukey HSD test. The total, female and male numbers were statistically similar between all the sampling dates (data not shown).

4.3.3.2 Fecundity variables

No significant difference was found between treatment and the percent of females with eggs ($F_{4,\,58} = 0.27$, P=0.900) and eggs per female ($F_{4,\,57} = 1.12$, P=0.358). Figure 4.3b presents differences of eggs per female and percent of females with eggs between traps during the summer trial.

The fecundity of females was similar for all the traps. The percent of females with eggs was very high for most treatments and peaked at 93.33% for pseudostem traps, but no significant differences between traps were found.

4.3.4 Autumn trial

4.3.4.1 Weevils attracted

The autumn trial revealed significant differences between treatments and total weevils ($F_{5,\,84} = 5.29$, $P<0.001$), female weevils ($F_{5,\,84} = 6.22$, $P<0.001$), male weevils ($F_{5,\,84} = 3.88$, $P<0.004$) and female percent ($F_{5,\,55} = 6.72$, $P<0.001$). Post hoc comparisons of the percent of females, the total, female and male number of *C. sordidus* attracted to the different traps are summarised in figure 4.4a.

The trial showed that Pheromone A and Pheromone B attracted a statistically similar number of weevils. Compared to the other traps, Pheromone A captured significantly more beetles, while the number captured in Pheromone B traps was not significantly different to any other treatment. The plant material and control traps did not show significant differences. A similar tendency was found for the number of females attracted. Pheromone A attracted significantly more males than the control, but showed no difference to the other treatments. The plant material traps were equally effective in attracting males and showed no difference to the Pheromone B trap, while the pseudostem trap also attracted more males than the control trap. The Pheromone A and Pheromone B traps attracted statistically similar and the highest percent of female *C. sordidus* (80.41% and 76.87%, respectively), only different significantly from the treated pseudostem (45.81%) and rhizome traps (39.91%), which were not significantly different among themselves. Values for the untreated pseudostems and control traps were not significantly different than any other trap. For all the different dependent variables, values for the pseudostems treated with the insecticide were similar to the other plant material traps. The total, female and male weevils attracted were similar between the sampling weeks (data not shown). The pheromone traps showed a significant decrease in weevil collections (relative to week one and two), with very low (statistically similar) numbers from the third to the fifth week (data not shown). The data from the trial were regarded as comparable with other seasons because the pheromone replacement (on the fourth week) did not cause any notable or significant change in the number of weevils, females or males attracted.

4.3.4.2 Fecundity variables

Significant differences were evident between treatments and the percent of females with eggs ($F_{5, 51}$ = 4.33, P=0.002) and eggs per female ($F_{5, 51}$ = 33.49, P<0.001) during the autumn trial. Autumn differences between traps regarding fecundity and percent of females with eggs are summarised in figure 4.4b.

Females in the insecticide treated pseudostem traps contained a mean of 7.52 eggs, which were different to the rhizome, but not the untreated pseudostem traps. Eggs per female were also significantly higher in the untreated pseudostem versus the rhizome traps. The control and pheromone treatments were not significantly different, but segregated significantly from the plant material traps. The percent of females with eggs peaked in the plant material traps, where all the females contained eggs. Between all the treatments, only Pheromone B was significantly different to the untreated pseudostem traps.

4.3.5 Seasonal comparison

4.3.5.1 Weevil attraction

Localities (representing specific seasons) were compared by linearly converting the total, female and male number of beetles attracted between treatments to indices of increase relative to the standard pseudostem trap, specific for each replicate. Linear conversion assumed no weevil density effects. Variables were therefore compared as fractions of corresponding treatments between seasons and cultivar influence was assumed negligible. Post hoc differences between the specific seasons and total fraction ($F_{2,\ 189}$ = 2.99, P=0.053), female fraction ($F_{2,\ 177}$ = 5.10, P=0.007), male fraction ($F_{2,\ 157}$ = 6.19, P=0.003) and female percent ($F_{2,\ 146}$ = 0.78, P=0.459) are indicated in figure 4.5a.

Relative to the pseudostem traps, the two individual pheromone and control traps had a strong tendency to attract almost three times the number of weevils in spring, while the values for summer and autumn were 1.22 and 1.36, respectively. The relative number of females and males attracted during spring was significantly more than in summer, while autumn values were no different to spring and summer. The percent of females of all the treatments (pseudostem, Pheromone A, Pheromone B and control) peaked in spring, but did not show significant differences.

4.3.5.2 Fecundity variables

The percent of females with eggs ($F_{2,\ 141}$ = 1.45, P=0.239) showed no significant seasonal effect, while eggs per female ($F_{2,\ 140}$ = 4.11, P=0.018) were significantly different between seasons. Seasonal differences of all the relevant traps regarding fecundity and percent of females with eggs are summarised in figure 4.5b.

The number of eggs per female was significantly higher in autumn than in summer, while the value for spring was similar to the other seasons, assuming density effects between trials were negligible. The percent of females containing eggs peaked in spring, but values between seasons were not significantly different.

4.3.6 Season and treatment

Management proposals require resolution on the efficacy of specific treatments between seasons. Table 4.1 summarises the post ANOVA interaction between season and treatment of the total fraction ($F_{6,\ 180}$ = 1.09, P=0.368), female fraction ($F_{6,\ 168}$ = 2.21, P=0.045) and male fraction ($F_{6,\ 148}$ = 2.34, P=0.035).

For the number of weevils, females and males, the pheromone efficacy (relative to pseudostem traps) generally peaked in spring, followed by autumn and then summer. The relative catches of the control trap peaked in autumn, followed by spring and summer. The Pheromone A trap was the most effective treatment tested between seasons, attracting a respective mean of 5.37, 6.97 and 1.84 times more of total, female and male weevils per week (over 5 weeks) than pseudostem traps during spring. The relative number of female and male weevils collected in the Pheromone A traps during spring was significantly higher than the corresponding values in summer. Pheromone B showed a similar pattern for male weevils. The late winter trial showed weevil indices of increase (standard error) relative to the pseudostem trap of 9.34 (3.10), 8.74 (1.98) and 0.00 (0.00) for the Pheromone A, Pheromone B and control traps, respectively (data not shown). Post-ANOVA the pheromone values were statistically similar among themselves, but significantly higher than the pseudostem and control values, which were not significantly different (data not shown). The indices of increase for total weevils, females and males attracted did not change over time (data not shown).

4.3.7 Relationship between biotic and abiotic variables

The dependent variables did not show a significant relation with ambient temperature and corrected rainfall (data not shown).

4.4 Discussion

Pheromones proved to be the most effective means of trapping *C. sordidus* in South Africa. The trial conducted in winter showed that the two pheromone traps were equally successful and the most effective means of trapping the banana weevil. The different dimensions of pitfall traps, however, prevented comparisons to other trials.

In the local subtropical climate, Pheromone A was the most effective lure regarding total and female weevils attracted during spring and autumn. This is consistent with studies conducted in the tropics that also found pheromone traps to be more effective than pseudostem traps (Ndiege *et al*. 1996b, Jayaraman *et al*. 1997, Tinzaara *et al*. 1999, 2003). During spring and autumn, the plant material traps attracted more fecund females, but higher proportions of females were captured in pheromone traps. The summer trial showed similar tendencies regarding these variables, but differences were much less pronounced and usually not significant. The sex ratio of adults attracted to pheromone and plant material traps is different to previous reports from tropical Costa Rica that concluded pseudostem traps and pseudostem traps baited with pheromone attract an equal sex ratio (Ndiege *et al*. 1996b, Jayaraman *et al*. 1997). A study in Uganda concluded Pheromone B pitfall traps to also attract an equal amount of males and females (Tinzaara *et al*. 1999), contrary to current findings. Detergent and water was added to the pitfalls in the tropical studies, standardising the influence of gender humidity preferences between trials (Roth and Willis 1963). The discrepancy of sex ratios between traps may be related to gender behavioural differences (Delattre 1980), reproduction physiology, plant variety, climate and/or weevil biotype.

Compared to pheromone traps, plant material traps collected a higher proportion of females with eggs. Rhizome traps generally desiccated at a higher rate than pseudostem traps, which may have attributed to pseudostems collecting more fecund females. If females also prefer rhizome material as an ovipositioning substrate (Cuille 1950, Masanza 2003) under local conditions, it then appears to be independent of fecundity. Previous research showed similar differences in electroantennogram response between the sexes of *C. sordidus*. Orientation is to food resources rather than oviposition sites (Budenberg *et al*. 1993b). Our results, however, suggest that (excluding density effects) chemoreception is possibly involved in host acceptance, as was reported by Cuille (1950).

The reduction in pheromone efficacy in autumn was unclear and although it did not result from ambient temperature or rainfall/irrigation, other abiotic factors, destructive sampling, pest density and/or activity may have been responsible. During the autumn trial, addition of cyfluthrin to pseudostem traps did not alter any of the tested variables. Treated pseudostems showed a weevil mortality rate of approximately 75% per week. Jayaraman *et al*. (1997) reported a comparable 80% mortality of weevils attracted to carbaryl-soaked (10 g.a.i.) sandwich traps. Equal efficacy of rhizome and pseudostem traps is in agreement with Masanza (2003). Grouping the two pheromones in summer produced a synergistic response in terms of total, female and male beetles attracted. The data of the pheromone grouping traps were no different from a similar trap combined with a pseudostem trap, in general agreement with Ndiege *et al*. (1996b).

Seasonal behavioural differences of *C. sordidus* were observed in pheromone and unbaited pitfall traps compared to pseudostem traps. Traps attracted more fecund females in autumn versus summer, while spring values were intermediate. Tendencies may be dependent on reproduction physiology and climate, but were not related to temperature and rainfall/irrigation. The conversion of variables to fractions effectively decreased sample size and values, especially when pseudostem numbers were low and treatment numbers high, showed relatively high variability. Compared to pseudostem traps, Pheromone A traps generally attracted the highest total, female and male numbers during all the seasons. The highest total values obtained during late winter and spring were, however, considerably lower than corresponding values of 18 reported for Pheromone B pitfall traps in Uganda (Tinzaara *et al*. 1999). In Costa Rica, pseudostem traps treated with Pheromone B increased attractiveness five to ten times and Pheromone B-baited pitfall traps are two and a half times more effective than baited pseudostems (Alpizar and Fallas 1997). Weevil biotype, plant variety and/or climate may be responsible for the lower relative efficacy of pheromones in South Africa.

The economic viability of pheromone traps can be calculated based on their linear equivalent to pseudostem traps, bearing in mind that pseudostems were replaced five times to produce the mean weekly indices of increase calculated in this study. In South Africa pheromone traps show potential as an economical monitoring and mass trapping technique that should entail the weekly movement of traps by 20 m during spring and autumn.

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Table 4.1. Mean total, female and male number of *Cosmopolites sordidus* (standardised as pseudostem trap indices of increase) collected in different traps per week over 5 weeks in southern KwaZulu-Natal. Standard errors are in parenthesis. For each dependent variable, means with letters in common indicate no significant difference (*P*>0.05).

Dependent variable (fractions)	**Season**	**Treatment**			
		Pheromone A	**Pheromone B**	**Control**	**Pseudostem**
Total	Spring	5.37 (1.46)^{b}	4.46 (1.95)^{bc}	0.20 (0.06)^{a}	1.00 (0.00)^{ac}
	Summer	2.47 (1.23)^{abc}	1.40 (0.45)^{abc}	0.00 (0.00)^{a}	1.00 (0.00)^{abc}
	Autumn	2.78 (0.80)^{abc}	1.36 (0.29)^{abc}	0.32 (0.28)^{ac}	1.00 (0.00)^{abc}
Female	Spring	6.97 (1.54)^{c}	5.08 (1.68)^{cd}	0.23 (0.08)^{b}	1.00 (0.00)^{ab}
	Summer	1.14 (0.24)^{abd}	1.17 (0.37)^{abd}	0.00 (0.00)^{ab}	1.00 (0.00)^{abd}
	Autumn	4.53 (1.34)^{acd}	2.30 (0.56)^{abd}	0.35 (0.28)^{ab}	1.00 (0.00)^{abd}
Male	Spring	1.84 (0.37)^{b}	1.53 (0.38)^{bc}	0.19 (0.07)^{a}	1.00 (0.00)^{abc}
	Summer	0.53 (0.26)^{ac}	0.22 (0.22)^{a}	0.00 (0.00)^{a}	1.00 (0.00)^{abc}
	Autumn	0.95 (0.30)^{abc}	0.54 (0.16)^{ac}	0.32 (0.31)^{a}	1.00 (0.00)^{abc}

Figure legends

Figure 4.1. The mean (+ standard error) number of *Cosmopolites sordidus* attracted per week to different traps during August 2002 (winter). Means with letters in common indicate no significant difference ($P > 0.05$).

Figure 4.2a. The mean (+ standard error) total, female, male and percent of females of *Cosmopolites sordidus* individuals attracted per week to different traps during October/November 2003 (spring). Percentage means are indicated by black dots and refer to the secondary y-axis. For each dependent variable, means with letters in common indicate no significant difference ($P > 0.05$).

Figure 4.2b. The mean (+ standard error) number of eggs per female and percent of females containing eggs of *Cosmopolites sordidus* individuals attracted per week to different traps during October/November 2003 (spring). Percentage means are indicated by black dots and refer to the secondary y-axis. For each dependent variable, means with letters in common indicate no significant difference ($P > 0.05$).

Figure 4.3a. The mean (+ standard error) total, female, male and percent of females of *Cosmopolites sordidus* attracted per week to different traps during February/March 2004 (summer). Percentage means are indicated by black dots and refer to the secondary y-axis. For each dependent variable, means with letters in common indicate no significant difference ($P > 0.05$). Ph, Pheromone; PS, Pseudostem.

Figure 4.3b. The mean (+ standard error) number of eggs per female and percent of females containing eggs of *Cosmopolites sordidus* attracted per week to different traps during February/March 2004 (summer). Percentage means are indicated by black dots and refer to the secondary y-axis. For each dependent variable, means with letters in common indicate no significant difference ($P > 0.05$). Ph, Pheromone; PS, Pseudostem.

Figure 4.4a. The mean (+ standard error) total, female, male and percent of females of *Cosmopolites sordidus* attracted per week to different traps during April 2003 (autumn). Percentage means are indicated by black dots and refer to the secondary y-axis. For each dependent variable, means with letters in common indicate no significant difference ($P > 0.05$). Ph, Pheromone; PS, Pseudostem.

Figure 4.4b. The mean (+ standard error) number of eggs per female and percent of females containing eggs of *Cosmopolites sordidus* attracted per week to different traps during April 2003 (autumn). Percentage means are indicated by black dots and refer to the secondary y-axis. For each dependent variable, means with letters in common indicate no significant difference ($P > 0.05$). Ph, Pheromone; PS, Pseudostem.

Figure 4.5a. The mean (+ standard error) total fraction, female fraction, male fraction and percent of females of *Cosmopolites sordidus* attracted per week to all seasonally corresponding traps during spring (October/November 2003), summer (February/March 2004) and autumn (April 2003). Fractions represent indices of increase relative to pseudostem traps. Percentage means are indicated by black dots and refer to the secondary y-axis. For each dependent variable, means with letters in common indicate no significant difference ($P > 0.05$).

Figure 4.5b. The mean (+ standard error) number of eggs per female and percent of females containing eggs of *Cosmopolites sordidus* attracted per week to all seasonally corresponding traps during spring (October/November 2003), summer (February/March 2004) and autumn (April 2003). Percentage means are indicated by black dots and refer to the secondary y-axis. For each dependent variable, means with letters in common indicate no significant difference ($P > 0.05$).

Figure 4.1

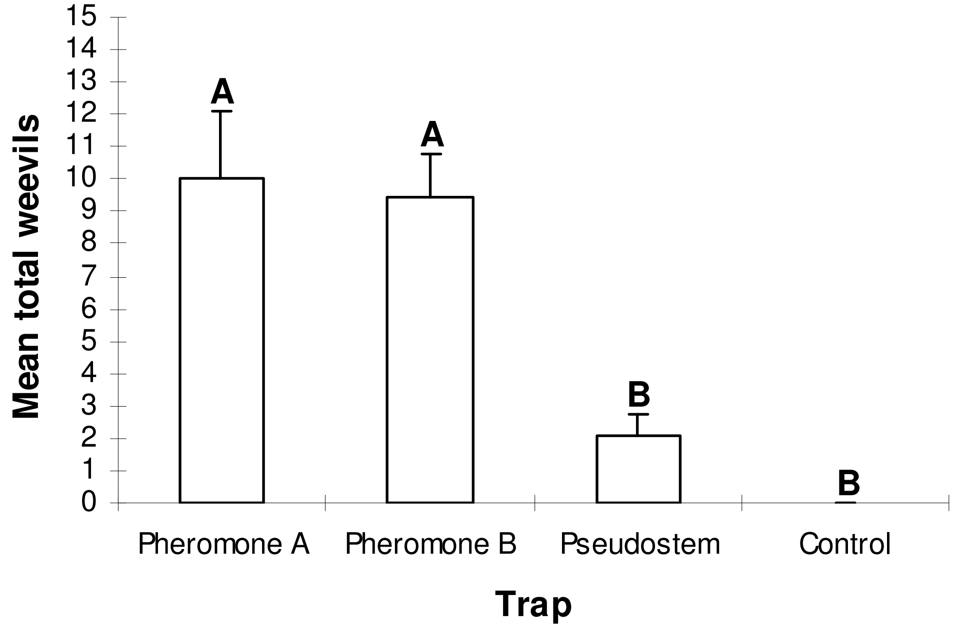

Mean total weevils
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
A
A
B
B
Pheromone A
Pheromone B
Pseudostem
Control
Trap

Figure 4.2a

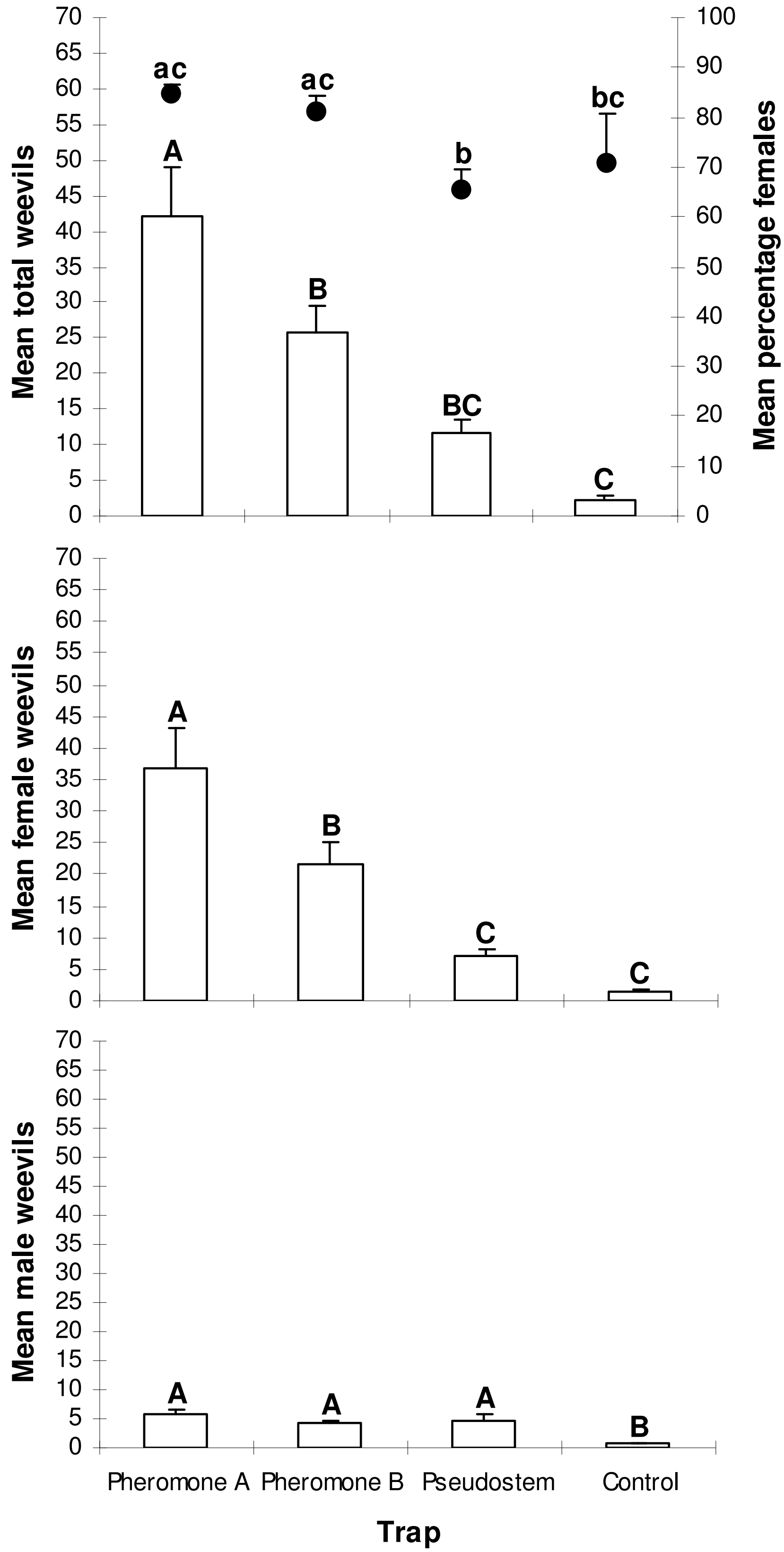

Mean total weevils
Mean percentage females
ac
ac
b
bc
A
B
BC
C
Mean female weevils
A
B
C
C
Mean male weevils
A
A
A
B
Pheromone A
Pheromone B
Pseudostem
Control
Trap

Figure 4.2b

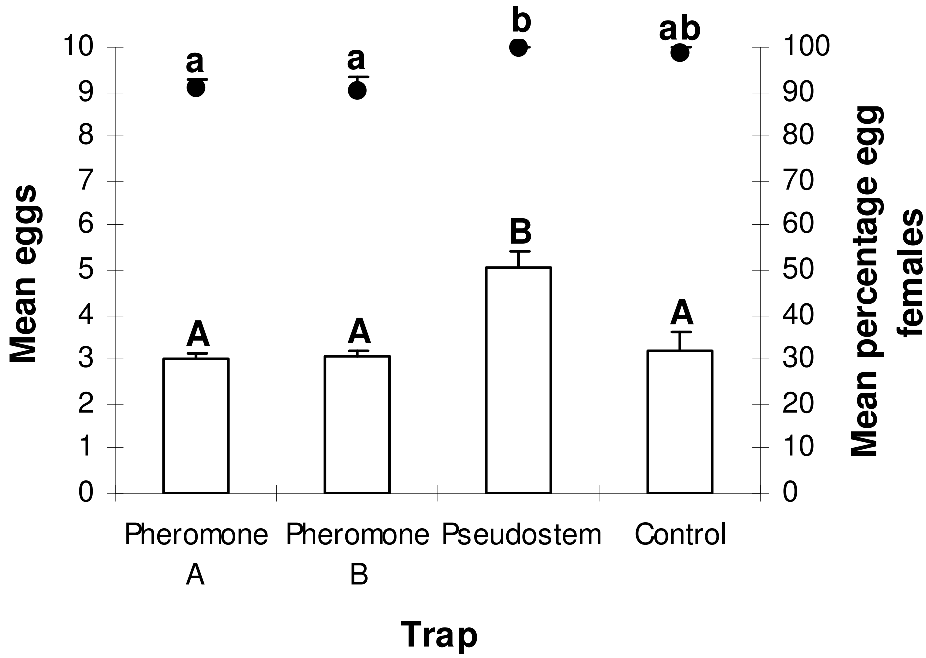

Mean eggs
Mean percentage egg females
10
9
8
7
6
5
4
3
2
1
0
100
90
80
70
60
50
40
30
20
10
0
a
a
b
ab
A
A
B
A
Pheromone A
Pheromone B
Pseudostem
Control
Trap

Figure 4.3a

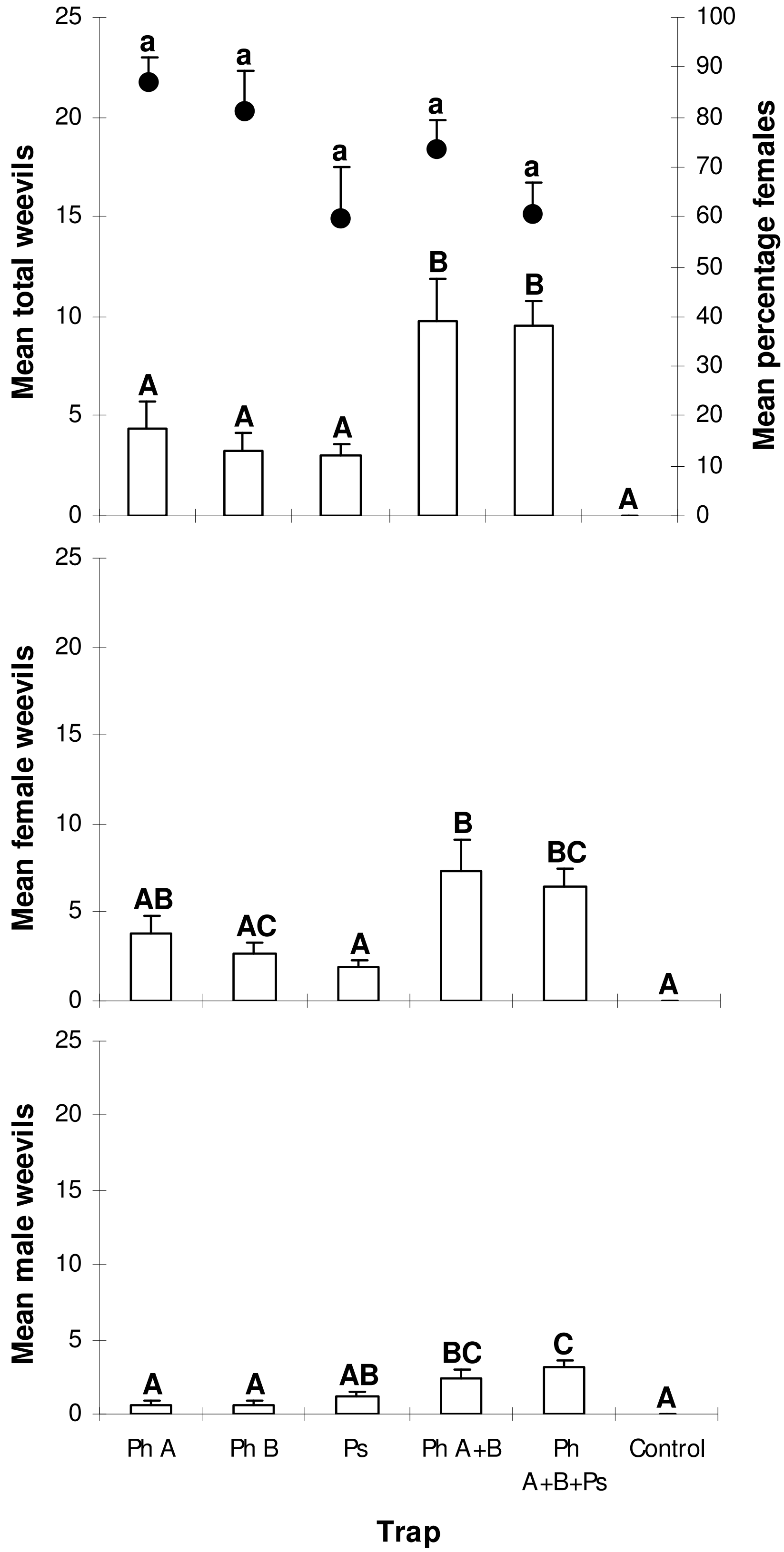
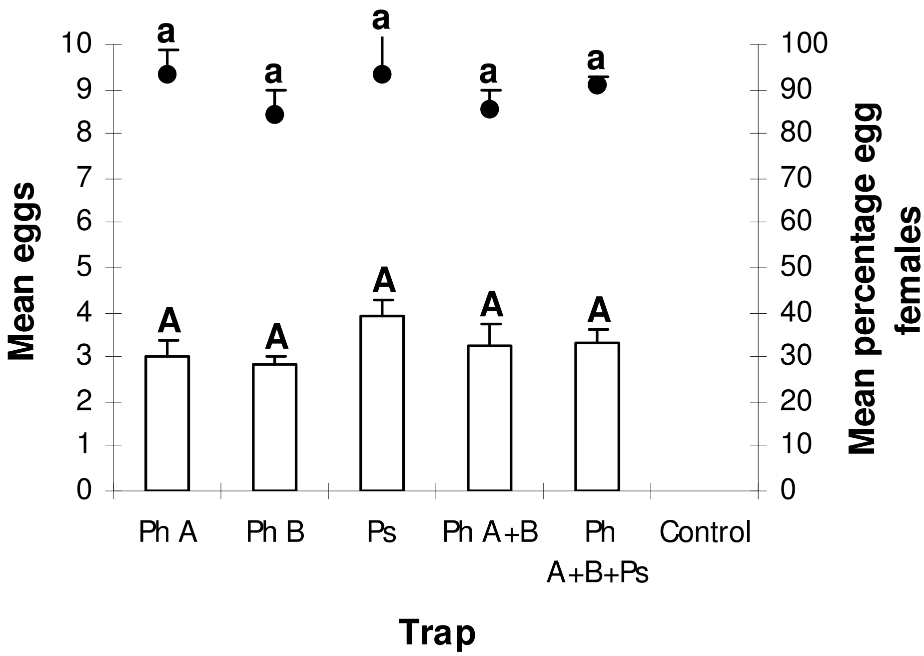

25
20
15
10
5
0
100
90
80
70
60
50
40
30
20
10
0
a
a
a
a
a
A
A
A
B
B
A
Mean total weevils
Mean percentage females
Mean female weevils
AB
AC
A
B
BC
A
Mean male weevils
A
A
AB
BC
C
A
Ph A
Ph B
Ps
Ph A+B
Ph A+B+Ps
Control
Trap

Figure 4.3b


Mean eggs
Mean percentage egg females
Trap
Ph A
Ph B
Ps
Ph A+B
Ph A+B+Ps
Control
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
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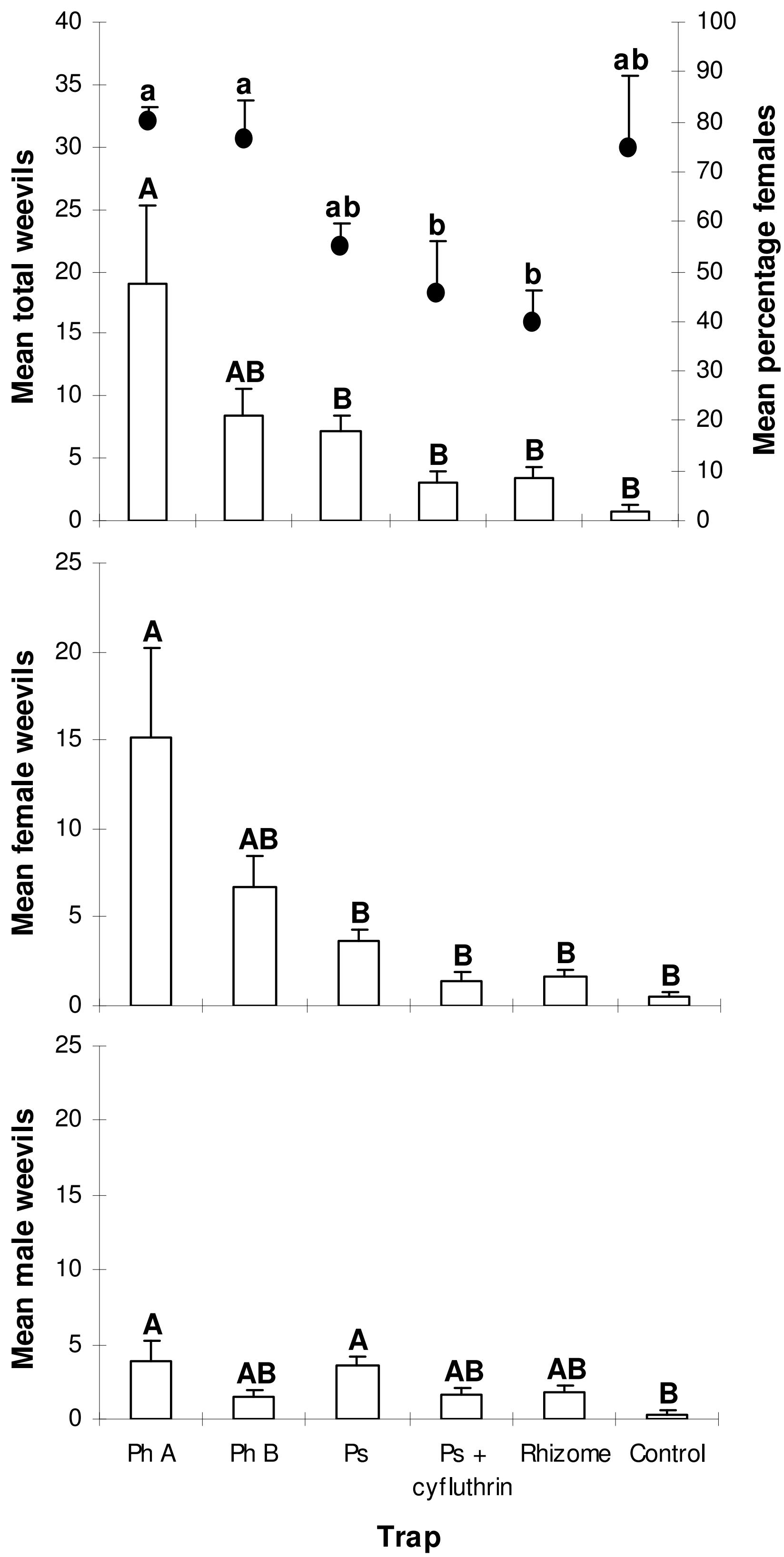
70
80
90
100
A
A
A
A
A
a
a
a
a
a

Figure 4.4a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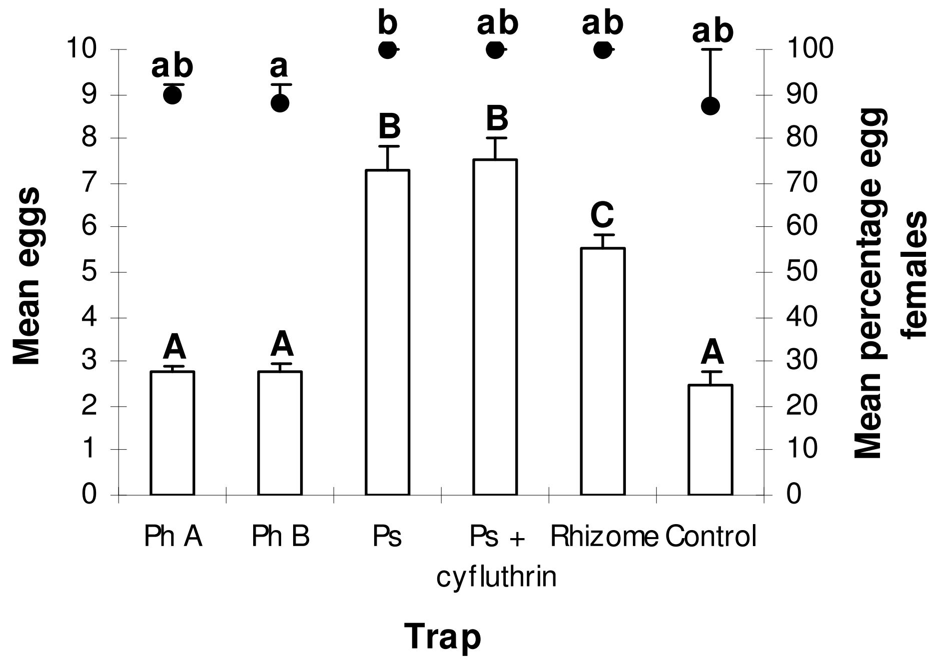
35
30
25
20
15
10
5
0
100
90
80
70
60
50
40
30
20
10
0
Mean total weevils
Mean percentage females
a
a
ab
b
b
ab
A
AB
B
B
B
B
25
20
15
10
5
0
Mean female weevils
A
AB
B
B
B
B
25
20
15
10
5
0
Mean male weevils
A
AB
A
AB
AB
B
Ph A
Ph B
Ps
Ps + cyfluthrin
Rhizome
Control
Trap

Figure 4.4b


Mean eggs
Mean percentage egg females
Trap
Ph A
Ph B
Ps
Ps + cyfluthrin
Rhizome
Control
A
A
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b
ab
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90
100

Figure 4.5a

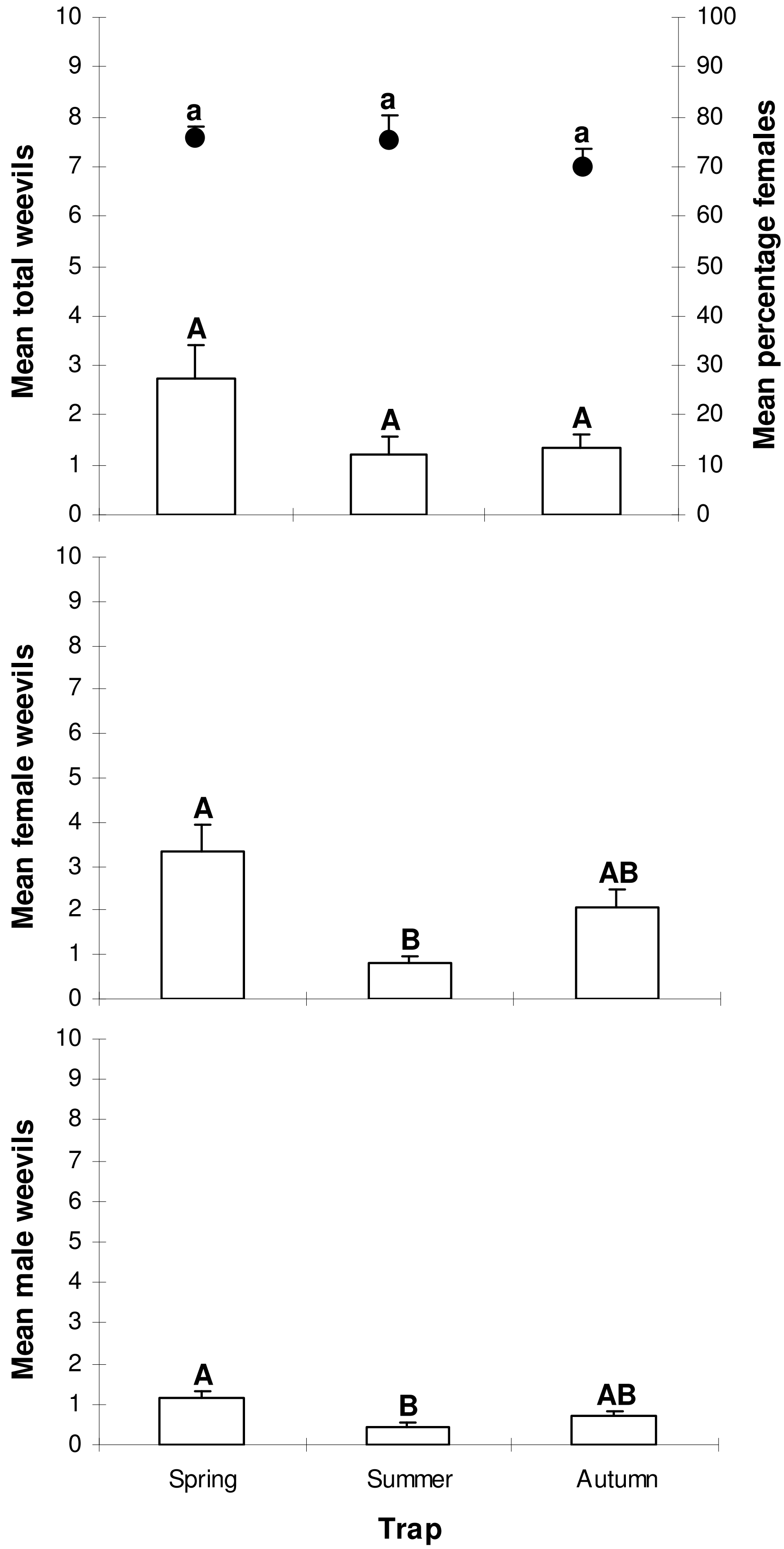
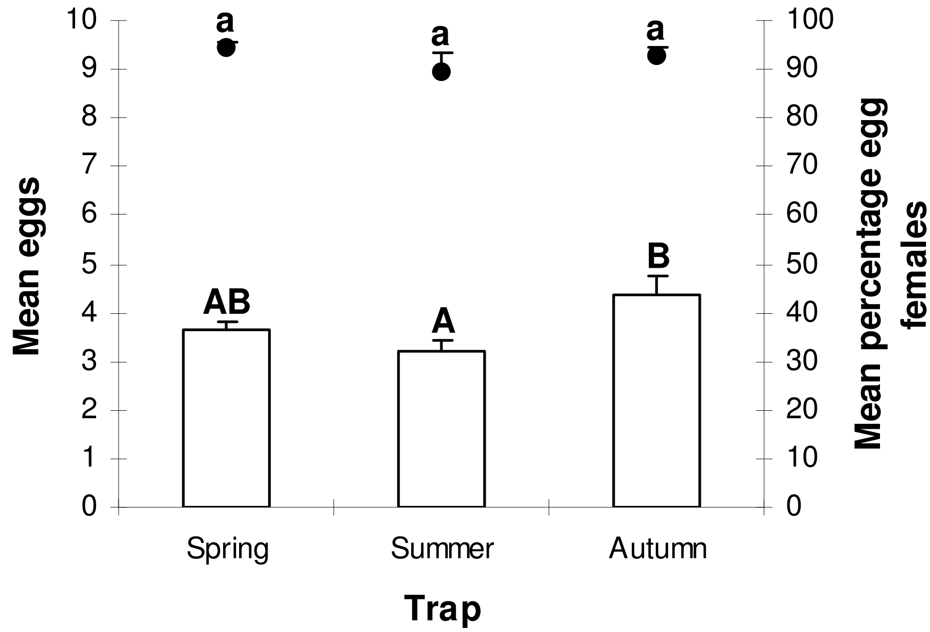

Mean total weevils
Mean percentage females
Mean female weevils
Mean male weevils
a
a
a
A
A
A
A
B
AB
A
B
AB
Spring
Summer
Autumn
Trap

Figure 4.5b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100
90
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70
60
50
40
30
20
10
0
Mean eggs
Mean percentage egg females
Spring
Summer
Autumn
Trap