Effect of *Bt*-cotton cultivation on spider (Arachnida: Araneae) populations near Marble Hall, Mpumalanga, South Africa

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Bt-cotton, containing and expressing genes from the soil bacterium, *Bacillus thuringiensis* var. *kurstaki,* is toxic specifically to lepidopteran larvae, but little is known about the impact it could have on predators such as spiders. A survey to determine the effect of *Bt*-cotton and endosulfan application on spider populations was conducted over two cotton-growing seasons (2001/2002 and 2002/2003) on a farm near Marble Hall in South Africa. Plant-dwelling spiders (n = 227) were counted over the two seasons while scouting the plants, but were not identified. Ground-dwelling spiders (n = 3777) were collected with pitfall traps in both seasons and identified to species level. The ground dwellers were represented by 21 families, 49 genera and 54 species. During the first season a total of 2431 spiders was collected from the pitfall traps, 945 from *Bt*-cotton and 1486 from non-*Bt*-cotton (control) fields. In the second season a total of 781 was collected, 416 from *Bt*-cotton and 365 from non-*Bt*-cotton fields. A total of 565 spiders was collected from a non-*Bt*-cotton field sprayed with endosulfan during the second season. The Lycosidae (n = 2359) represented 62.5 % of all spiders collected in the pitfall traps, followed by the Theridiidae (n = 757) with 20.0 % and Linyphiidae (n = 342) with 9.1 %. *Steatoda erigoniformis* (Theridiidae) (n = 744) was the most abundant species, representing 19.7 % of all the spiders collected, followed by *Pardosa clavipalpis* (Lycosidae) (n = 624) with 16.5 %, an undetermined *Trabea* sp. (Lycosidae) (n = 592) with 15.7 % and another lycosid, *Pardosa crassipalpis* (n = 543), with 14.4 %. Neither *Bt*-cotton nor the application of endosulfan had a marked or persistent negative impact on ground- or plant-dwelling spiders in the field.

Key words: Araneae, *Bacillus thuringiensis, Bt*-cotton, endosulfan, South Africa, spiders, transgenic cotton.

Cotton (*Gossypium* spp.) is one of South Africa's five major field crops, with the production increasing annually. Several pests that attack cotton have a wide range of natural enemies, of which spiders are one (Van den Berg & Dippenaar-Schoeman 1991b). Observations have shown that spiders are amongst the first predacious arthropods to colonise newly planted cotton fields and their numbers build up gradually as plant density and prey numbers increase (Dinkins et al. 1970; Van den Berg 1989; Van den Berg & Dippenaar-Schoeman 1991b). Spiders are common on cotton in South Africa and 127 species from 31 families have thus far been recorded (Dippenaar-Schoeman et al. 1999). They are abundant throughout the season, representing up to 76 % of all predacious arthropods in some cotton fields (Van den Berg & Dippenaar-Schoeman 1991b).

Most spiders are polyphagous and feed on a variety of available prey (Nyffeler et al. 1994). Predation is not limited to adult insects only, but includes the egg and larval or nymphal stages as well (Whitcomb 1974; Nyffeler et al. 1990). Spiders play an important role in biological control, not only through direct killing of prey, but also through indirect effects such as triggering cessation of feeding on the host plant and superfluous killing, i.e. prey dropping from the host plant to escape spiders and as a consequence die of starvation or are captured by other soil-dwelling predators (Riechert 1999). In Israel, wandering spiders have been observed to cause a disturbance effect in apple (*Malus domestica* Baumg.) orchards while wandering around and a larval mortality of about 30 % in Egyptian leaf worm (*Spodoptera littoralis* (Boisduval)), was attributed to this effect (Mansour et al. 1980). Prey specialists, i.e. spiders with a narrow feeding niche in a particular environment, tend to specialise on abundant prey species (Nyffeler & Sterling 1994; Riechert 1999), while prey generalists such as *Cheiracanthium* spp. (Miturgidae) (Dippenaar-Schoeman et al. 1999) and *Oxyopes salticus* Hentz (Oxyopidae) (Nyffeler & Sterling 1994) can switch their diets to feed on the most abundant species, thus playing an important role in biological control. A laboratory study conducted by Samu & Bíró (1993) indicated that *Pardosa hortensis* Thorell (Lycosidae) could also play a role in controlling agricultural pests in a density-sensitive way.

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Bt-cotton, i.e. transgenic cotton containing a gene of *Bacillus thuringiensis* var. *kurstaki* (Hilder & Boulter 1999), was introduced to South Africa during the 1998/1999 cotton-growing season (Edge et al. 2001; Carpenter et al. 2002). Three years later, 40 % of the total area under cotton in South Africa comprised *Bt*-varieties (Galanopoulou-Sendouca & Oosterhuis 2003). Although *Bt*-cotton is lepidopteran-specific and direct mortality of natural enemies therefore not expected (Head et al. 2001; Soomro et al. 2003; Udikeri et al. 2003), concerns have been expressed regarding the safety of *Bt*-crops to upper trophic level non-target organisms (Head et al. 2001). The consumption of prey that survive the ingestion of *Bt*-toxin and thus contain traces of the toxin, for example, could indirectly affect natural enemies occurring in cotton fields (Schuler et al. 1999; Dutton et al. 2002; Sisterson et al. 2004; Meissle & Lang 2005). This is, however, highly unlikely to occur in non-susceptible predators at field level endotoxin expression (Head et al. 2001). *Bt*-cotton could adversely affect predatory populations if numbers of bollworm larvae and pupae that serve as prey items for predators are reduced (Men et al. 2003), or if the quality of non-lepidopterous prey is decreased (Head et al. 2001). A reduction in the number of insecticidal sprays per season through the use of *Bt*-cotton can lead to an increase in the number of natural enemies that are not dependent on bollworm, and minor pest species of which the numbers have previously been kept in check by insecticidal sprays directed at bollworm (Men et al. 2003).

Spiders seem to be less susceptible to insecticides than other predatory insects in cotton (Van den Berg & Dippenaar-Schoeman 1991b). Van den Berg et al. (1990) reported that endosulfan application reduced the spider population on cotton plants by 40.6 %. The spider population initially showed a significant reduction in numbers, but recovered soon after the endosulfan application. Insecticide susceptibility can, however, be influenced by spider behaviour and the niche they occupy (Van den Berg & Dippenaar-Schoeman 1991b).

Despite the importance of spiders as biological control agents in cotton, no laboratory data are currently available on the effect of *Bt*-crops on spiders (Lövei & Arpaia 2005). Field data on the effect of *Bt*-crops on spiders are also limited (Meissle & Lang 2005). The aim of this study was to determine if the cultivation of *Bt*-cotton in South Africa has an impact on spider populations (numbers, species, families, sex and developmental stage) occurring in these fields.

Materials and methods

Study area and cotton cultivation

The study formed part of a comprehensive two-year trial conducted on a commercial, irrigated, cotton farm near Marble Hall in the Mpumalanga province of South Africa (24°59′S, 29°18′E; alt. 901 m asl). *Bt*-cotton was introduced to the farm during the first year of the trial. Mean rainfall over the study period was 38 mm/month (first season) and 24 mm/month (second season). Mean minimum and maximum temperatures were 16 °C and 29 °C (first season) and 18 °C and 34 °C (second season).

First season. During the first cotton-growing season (2001/2002; planting date 7 January 2002), two NuOpal (referred to as *Bt*-cotton in text) fields and two Delta Opal (unsprayed non-*Bt*-cotton, referred to as control in text) fields were studied. Each field consisted of 100 × 52 m rows, with a corridor of at least 5 m separating the different fields. No pesticides were applied during this season.

Second season. During the second cotton-growing season (2002/2003; planting date 14 November 2002), an insecticide-sprayed Delta Opal field (referred to as sprayed non-*Bt*-cotton in text) was also included in the study. Field size was 36 × 180 m rows for the control and sprayed non-*Bt*-cotton fields and 140 × 180 m rows for the *Bt*-cotton, again with corridors of at least 5 m between the different fields. The sprayed non-*Bt*-cotton field was sprayed when threshold levels of insects were noted. Endosulfan was applied three times against bollworm (*Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae)) at the recommended rate 76, 91 and 102 days after planting (DAP). Chlorpyrifos was applied at the recommended rate 26 DAP against syagrus beetle (*Syagrus* spp. (Coleoptera: Chrysomelidae)) adults in all fields. No other pesticide applications were required.

Scouting

During both seasons, scouting was conducted by MAM on a weekly basis according to procedures recommended by the Agricultural Research Council's (ARC) Institute for Industrial Crops

(Anon. 1996), from 53 DAP (2001/2002) and 54 DAP (2002/2003) for eight and ten weeks, respectively. The presence of spiders in the field was determined through visual observation and specimens were not collected for identification. In the first season, 24 plants per field were thoroughly inspected per week, but were reduced to 12 plants on three occasions when rain interfered with the scouting process. During the second season, 48 plants per field were scouted and as the plants matured and the search time per plant increased, the number of plants inspected per field was first reduced to 30 (82 DAP) and then to 24 (89 DAP).

Pitfall trapping

During both seasons, 60 pitfall traps were set per field. Plastic honey jars (volume 350 ml, diameter 52 mm) were used and ten pitfall traps were set per row in six adjacent rows with three metres between each trap. The first pitfall trap in each row was placed three metres from the edge of the field. Fifty millilitres of Glauber's salt solution (333 g l^{-1} water) was added to each pitfall trap to kill and preserve trapped arthropods. The traps were removed from the fields and replaced on a weekly basis (i.e. assessment interval = one week). Trapping commenced on 53 DAP (2001/2002) and 54 DAP (2002/2003) and continued for nine and twelve weeks, respectively. In the laboratory, arthropods were removed by sieving and the spiders transferred to 70 % ethanol. Specimens were sorted by sex and development stages and identified to species level by ASD-S. Voucher specimens were deposited in the National Collection of Arachnida (NCA) at the ARC-Plant Protection Research Institute in Pretoria. A number of specimens could not be identified to species level due to unresolved taxonomy of some families or the absence of adult specimens.

Statistical analysis

A repeated measures ANOVA was used to determine if time (weekly sampling) had a significant influence on spider numbers within seasons. If time had a significant effect on the spider species or family, least square means were calculated for ANOVA and Student's t-test analysis (parametric data) or Kruskal-Wallis ANOVA and the Mann-Whitney *U*-test (non-parametric data). If time had no effect on spider numbers, unconverted data were used for the relevant analysis. Each time interval constituted a replicate. Student's *t*-test or Mann-Whitney *U*-test was used to analyse differences between seasons. The computer program STATISTICA 6 (StatSoft Inc 2002) was used for the statistical analyses. Actual mean values per time interval are presented unless indicated otherwise.

Results

Plant-dwelling species

A total of 138 spiders was counted during the first season while scouting, 73 in the control fields and 65 in the *Bt*-cotton. During the second season the numbers were lower and only 89 spiders were recorded, 39 from the control fields, 27 from the *Bt*-cotton and 23 from sprayed non-*Bt*-cotton. The difference in numbers between the two seasons was, however, not statistically significant. Time (weekly sampling) did not have a significant effect on the visual observation data, and numbers were therefore not converted to least square means for statistical purposes. No significant difference in mean number of spiders per plant was found between control, *Bt*- and sprayed non-*Bt*-cotton fields with visual observations (Fig. 1).

Ground-dwelling species

During the first season a total of 2431 spiders was collected by pitfall trapping, 1486 from the control fields and 945 from the *Bt*-cotton fields. No significant difference was evident between the number of spiders collected in the control and *Bt*-cotton (t = 1.14, P = 0.27) (Fig. 2). During the second season, a total of 1346 spiders was collected, 365 from the control, 416 from the *Bt*-cotton and 565 from the sprayed non-*Bt*-cotton fields. Again no significant differences were found between the number of spiders collected in the control, *Bt*- and sprayed non-*Bt*-cotton fields (U = 0.86, P = 0.65) (Fig. 2). Significantly higher numbers of spiders were collected during the first than the second season in both the control (t = 3.40, $P \leq$ 0.01) and *Bt*-cotton (t = 3.48, $P \leq$ 0.01) (Fig. 2).

Time (weekly sampling) had a significant effect on *Castianeira* sp. (Corinnidae) (F = 2.46, $P \leq$ 0.05), Corinnidae (F = 3.18, $P \leq$ 0.01) and *Pardosa clavipalpis* Purcell (Lycosidae) (F = 3.50, $P \leq$ 0.01) in the first season's pitfall trapping and on Gnaphosidae (F = 2.60, $P \leq$ 0.001), *Steatoda erigoniformis* O P-Cambridge (Theridiidae) (F = 3.49, $P \leq$ 0.001), Theridiidae (F = 4.31, $P \leq$ 0.001) and male numbers (F = 2.31, $P \leq$ 0.01) in the

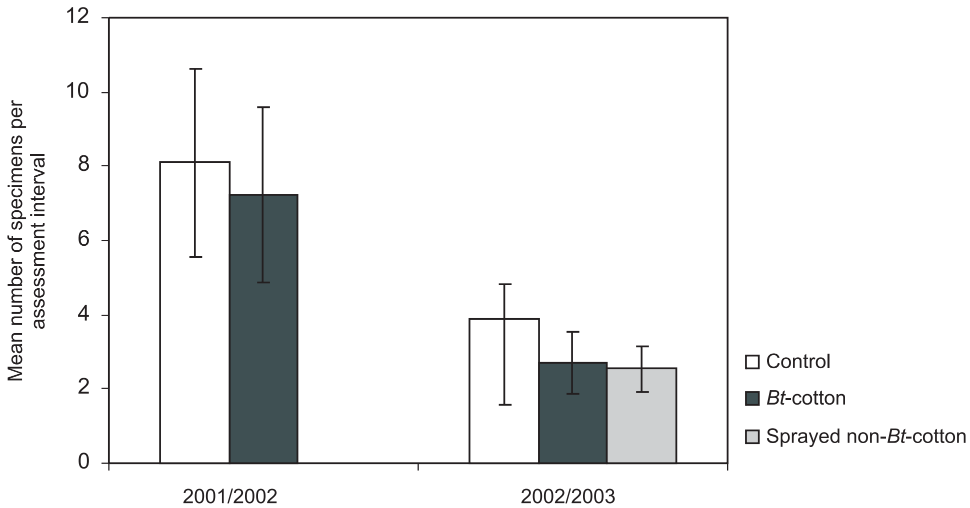

Fig. 1. Mean number of visually counted spiders per assessment interval on cotton plants in control (unsprayed non-*Bt*-cotton), *Bt*-cotton and endosulfan-sprayed non-*Bt*-cotton fields over two seasons at Marble Hall, South Africa. SE bars are included. No significant differences in numbers were evident between cotton types within seasons.

second season's pitfall trapping. The data were therefore converted to least square means for statistical analysis.

During the first season, 18 families and 39 species were recorded in total from the pitfall traps, 16 families and 34 species from the control plots and 15 families and 31 species from the *Bt*-cotton plots. During the second season a total of 16 families representing 40 species was collected, 12 families and 25 species from the control plots, 14 families and 29 species from the *Bt*-cotton plots, and 11 families and 25 species from the sprayed non-*Bt*-cotton plots (Table 1).

Lycosidae (n = 2359, 62.5 %) was the most abundant family collected over the two seasons, followed by the Theridiidae (n = 757, 20.0 %) and Linyphiidae (n = 342, 9.1 %) (Figs 3, 4). No significant differences in numbers of spiders per family

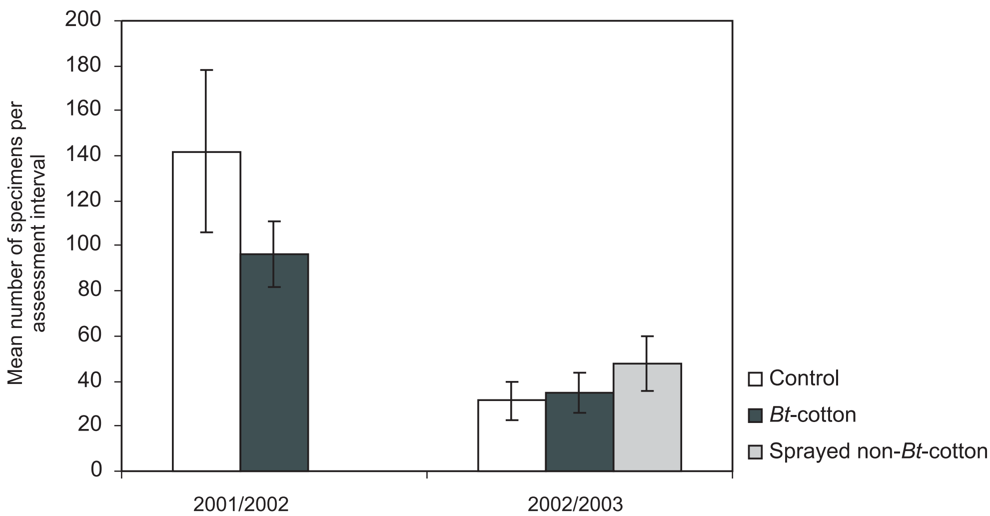

Fig. 2. Mean number of spiders collected per assessment interval over two seasons at Marble Hall, South Africa, by pitfall trapping in control (unsprayed non-*Bt*-cotton), *Bt*-cotton and endosulfan-sprayed non-*Bt*-cotton fields. SE bars are included. No significant differences in numbers were evident between cotton types within seasons.

Table 1. Diversity and abundance of spiders collected by pitfall trapping in non-*Bt*-cotton (control), *Bt*-cotton and endosulfan-sprayed non-*Bt*-cotton fields over two seasons (2001–2003) at Marble Hall, South Africa.

Taxon	Number of specimens collected[a]						
	First season			Second season			
	Control	*Bt*-cotton	Total	Control	*Bt*-cotton	Total	Sprayed non-*Bt*-cotton
Ammoxenidae							
Ammoxenus amphalodes Dippenaar & Meyer, 1980*	2	2	4	7	2	9	8
Araneidae							
Nemoscolus sp.	0	0	0	0	1	1	0
Neoscona blondeli (Simon, 1885)	0	0	0	1	0	1	0
TOTAL	0	0	0	1	1	2	0
Corinnidae							
Castianeira sp.	26	11	37	3	1	4	7
Copa flavoplumosa Simon, 1885*	0	0	0	0	2	2	0
TOTAL	26	11	37	3	3	6	7
Dictynidae							
Dictyna sp.	1	2	3	0	0	0	2
Gnaphosidae							
Asemesthes ceresicola Tucker, 1923*	0	0	0	1	0	1	0
Camillina cordifera Tullgren, 1923	2	1	3	9	9	18	5
Odontodrassus sp.	0	1	1	0	1	1	1
Scotophaeus sp.	1	1	2	0	0	0	0
Setaphis subtilis (Simon, 1897)	10	6	16	0	0	0	0
Trachyzelotes jaxartensis (Kronenberg, 1875)*	0	3	3	0	0	0	0
Upognampa sp.	0	0	0	1	5	6	1
Urozelotes rusticus (L Koch, 1872)*	4	2	6	0	0	0	2
Zelotes pallidipes Tucker, 1923*	0	0	0	0	0	0	2
Zelotes vespertilionis Tucker, 1923*	5	4	9	0	0	0	0
TOTAL	22	18	40	11	15	26	11
Hahniidae							
Hahnia tabulicola Simon, 1898	0	0	0	0	1	1	0
Hersiliidae							
Tyrotama australis (Simon, 1893)*	0	0	0	1	0	1	0
Linyphiidae							
Undetermined genus	80	72	152	31	14	45	18
Eperigone fradeorum (Berland, 1932)*	12	11	23	29	40	69	18
Microlinphia sp.	1	1	2	0	0	0	0
Ostearius melanopygius (O P-Cambridge, 1879)	4	2	6	3	4	7	2
TOTAL	97	86	183	63	58	121	38
Lycosidae							
Hogna sp.	31	24	55	3	2	5	1
Lycosa sp.	131	1	132	4	9	13	9
Pardosa clavipalpis Purcell, 1903	209	84	293	119	85	204	127
Pardosa crassipalpis Purcell, 1903	279	202	481	14	17	31	31
Pardosa sp.	213	87	300	33	29	62	23
Trabea sp.	340	252	592	0	0	0	0
TOTAL	1203	650	1853	173	142	315	191
Miturgidae							
Cheiracanthium furculatum Karsch, 1879	1	1	2	0	1	1	0

Continued on p. 45

Table 1 (*continued*)

Taxon	Number of specimens collected[a]						
	First season			Second season			
	Control	*Bt*-cotton	Total	Control	*Bt*-cotton	Total	Sprayed non-*Bt*-cotton
Oonopidae							
Gamasomorpha sp.	1	0	1	0	0	0	0
Oxyopidae							
Oxyopes sp.	6	7	13	0	0	0	0
Philodromidae							
Suemus punctatus Lawrence, 1938*	1	0	1	0	0	0	1
Thanatus vulgaris Simon, 1870	3	3	6	2[b]	16	18	20
Tibellus minor Lessert, 1919	0	0	0	1	0	1	0
TOTAL	4	3	7	3	16	19	21
Pholcidae							
Smeringopus sp.	0	1	1	0	1	1	0
Phyxelididae							
Vidole sothoana Griswold, 1990	1	0	1	0	0	0	0
Salticidae							
Undetermined genus	2	0	2	2	1	3	1
Aelurillus sp.	0	0	0	0	1	1	0
Brancus bevisi Lessert, 1925	0	0	0	0	1	1	0
Heliophanus insperatus Wesolowska, 1986	2	0	2	2	1	3	0
Langona sp.	0	0	0	0	1	1	3
Myrmarachne sp.	4	1	5	0	0	0	0
Stenaelurillus sp.	16	9	25	3	4	7	5
TOTAL	24	10	34	7	9	16	9
Scytodidae							
Scytodes sp.	0	4	4	0	0	0	0
Sicariidae							
Loxosceles spiniceps Lawrence, 1952	4	0	4	2	1	3	3
Theridiidae							
Enoplognatha molesta O P-Cambridge, 1904	3	5	8	0	1	1	0
Latrodectus geometricus C L Koch, 1841	2	0	2	0	0	0	0
Latrodectus renivulvatus Dahl, 1902	0	0	0	1	0	1	0
Steatoda grossa (C L Koch, 1838)*	0	0	0	1	0	1	0
Steatoda erigoniformis (O P-Cambridge, 1872)*	80	139	219	91	164	255	270
TOTAL	85	144	229	93	165	258	270
Thomisidae							
Synema decens (Karsch, 1878)	0	1	1	0	0	0	0
Thomisus kalaharinus Lawrence, 1936	1	0	1	0	0	0	0
TOTAL	1	1	2	0	0	0	0
Zodariidae							
Diores recurvatus Jocqué, 1990	8	5	13	1	0	1	2
Ranops sp.	0	0	0	0	1	1	1
TOTAL	8	5	13	1	1	2	3
TOTAL NO. SPECIMENS	1486	945	2431	365	416	781	565

[a]Data were only analysed statistically if at least 20 species of a specimen were collected within a particular season.

[b]*Thanatus vulgaris* numbers were significantly lower in the control than in *Bt*-cotton ($U = 36.5$, $P \leq 0.05$) and sprayed non-*Bt*-cotton fields ($U = 35.0$, $P \leq 0.05$).

*New records for Marble Hall.

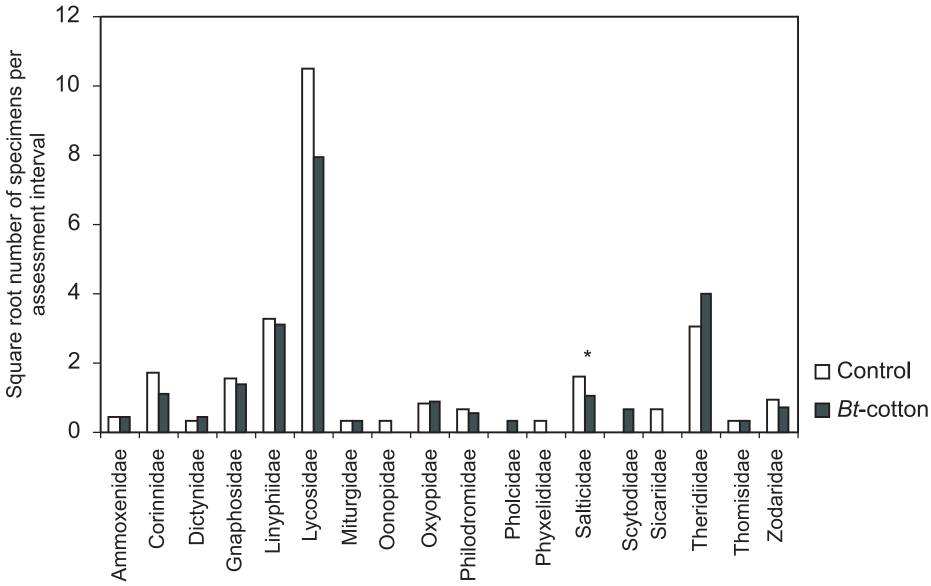

Fig. 3. Mean number (converted to square root) of spiders per family per assessment interval collected during the 2001/2002 season at Marble Hall, South African, by pitfall trapping in control (unsprayed non-*Bt*-cotton) and *Bt*-cotton fields. *Significantly higher numbers of Salticidae were collected in the control than in *Bt*-cotton.

were evident between the various plots, except for the Salticidae which were significantly more abundant in the control (n = 24) than in the *Bt*-cotton (n = 10) during the first season (t = 2.23, $P \leq 0.05$) (Fig. 3).

During the first season, an undetermined *Trabea* sp. (n = 592) was the most abundant species, representing 24.4 % of the total collected that season, followed by *Pardosa crassipalpis* Purcell (Lycosidae) (n = 481) with 19.8 % (Table 1). No

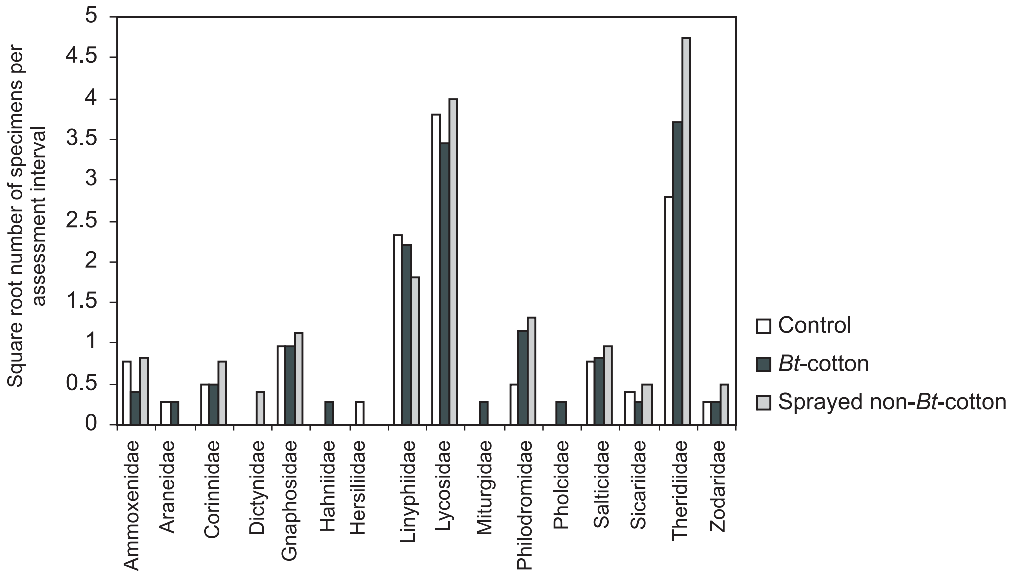

Fig. 4. Number (converted to square root) of spiders per family per assessment interval collected during the 2002/2003 season at Marble Hall, South Africa, by pitfall trapping in control (unsprayed non-*Bt*-cotton), *Bt*-cotton and endosulfan-sprayed non-*Bt*-cotton fields. No significant differences in numbers were evident between cotton types within spider families.

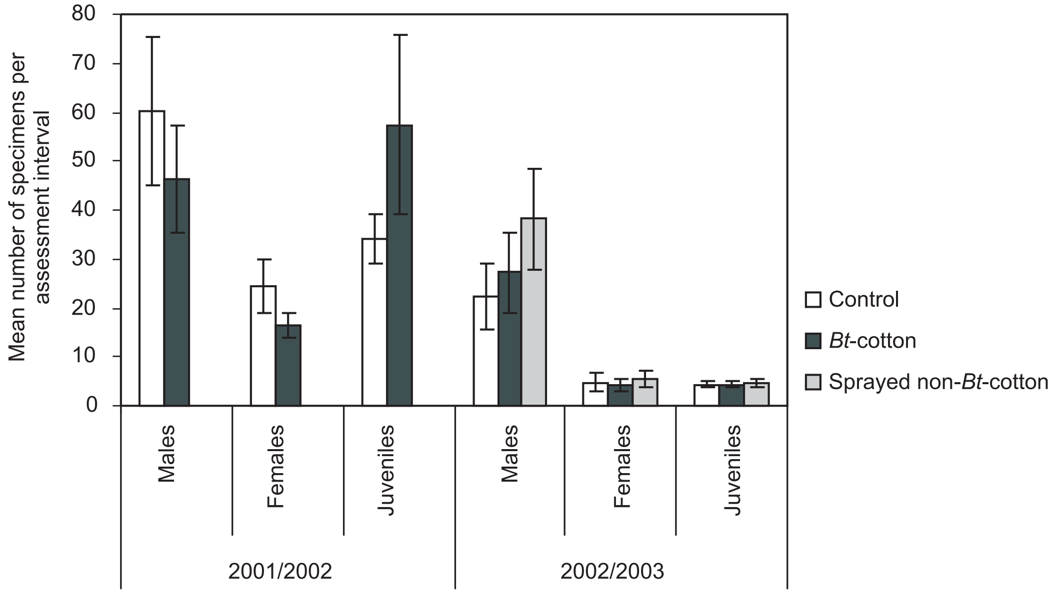

Fig. 5. Mean number of spider males, females and juveniles per assessment interval collected by pitfall trapping in control (unsprayed non-*Bt*-cotton), *Bt*-cotton and endosulfan-sprayed non-*Bt*-cotton fields at Marble Hall, South Africa, over two seasons. SE bars are included. No significant differences in numbers were evident between cotton types within seasons.

Trabea sp. individuals were collected during the second season, while the numbers of *P. crassipalpis* declined to a low of 31. *S. erigoniformis* (n = 255) was the most abundant species in the second season, representing 32.7 % of the total number of specimens collected from control and *Bt*-cotton fields, followed by *P. clavipalpis* (n = 204) with 26.1 %. No significant differences in abundance of individual species were found between fields in the first season. During the second season, *Thanatus vulgaris* Simon (Philodromidae) occurred in significantly lower numbers in the control than in *Bt*-cotton (U = 36.5, $P \leq 0.05$) and sprayed non-*Bt*-cotton fields (U = 35.0, $P \leq 0.05$). No other significant differences were evident.

The number of males, females and juveniles did not differ significantly between control, *Bt*-cotton and sprayed non-*Bt*-cotton fields (Fig. 5).

Discussion

In a previous study in Arizona, USA, Sisterson et al. (2004) found no significant difference in the number of Clubionidae collected by whole-plant sampling from *Bt*- and non-*Bt*-cotton fields, whereas Hagerty et al. (2005) observed that *Bt*-cotton had no effect on spider populations collected with beating sheets. Similar results have been reported for other crops. Jasinski et al. (2003), for instance, found no significant difference in numbers of spiders collected by sweepnet sampling and unbaited Pherocon AM yellow sticky traps from *Bt*- and non-*Bt*-maize (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) fields in Ohio. Meissle & Lang (2005) used four trapping methods (beating sheets, suction sampling, plant removal and stem eclectors (transparent plastic funnels attached to the stalks with adhesive tape)) in Bavaria, southern Germany, to determine if *Bt*-maize and/or use of the pyrethroid insecticide cyfluthrin have an effect on spider populations. *Bt*-maize had no marked effect on species richness or spider abundance, but application of cyfluthrin reduced spider densities substantially after one application. The paucity of significant differences and inconsistent trends observed in the present study support the view that cultivation of *Bt*-cotton has little, if any, negative impact on spider populations. The apparent insensitivity of the spider community towards endosulfan in sprayed non-*Bt*-cotton plots is also in accordance with existing literature. Van den Berg et al. (1990) found that although endosulfan spraying on cotton in South Africa initially greatly reduced spider numbers, the final population densities were not significantly lower than in the untreated plots. It should, however, be emphasised that observations were made over two seasons only and that additional field and laboratory studies are needed to determine if adverse effects, not apparent in the present investigation, can be expected over a longer period.

The fluctuation in spider numbers and family and species abundance between the two seasons observed in this study is difficult to explain. However, it corresponds with other long-term surveys which showed spider populations to fluctuate from year to year. Dippenaar-Schoeman et al. (1989) found that spider abundance varied annually during a four-year survey in a nature reserve in Gauteng Province, South Africa. Very high numbers (34 % of the total) Tetragnathidae were recorded the first year, but declined to a low (5 %) the next year. A similar pattern was observed in a three-year grassland survey in Gauteng where the incidence of Ammoxenidae declined from 50.1 % of the total number sampled in the first year to 10.5 % the second year and a low of 3.2 % the third year (Van den Berg & Dippenaar-Schoeman 1991a). During the same period the Gnaphosidae numbers increased from 18.8 % of the total collected the first year to 78 % the third year. The decrease in spider numbers during the second season in the present study could have been due to normal fluctuation or an increase in the number of other predatory insects and thus higher competition levels or interpredatory effects. Higher numbers of predatory beetles such as carabids (Coleoptera: Carabidae) and earwigs (Dermaptera) were observed in the cotton fields during the second than the first season (Mellet 2005).

Numerically, Lycosidae, Theridiidae and Linyphiidae were the dominant families in the ground layer of the cotton fields during both seasons. A study by Dippenaar-Schoeman et al. (1999), showed the Linyphiidae, Theridiidae and Araneidae to be the most common families in five cotton-growing areas in South Africa, including Marble Hall. Van den Berg et al. (1990), using a whole-plant bagging method, found Lycosidae, Clubionidae, Theridiidae and Linyphiidae to predominate numerically in cotton fields in the Hartebeespoort Dam area in North West Province. This skew distribution corresponds with other studies. Angeli et al. (1996) reported that three species constituted more than 50 % of all spiders collected from pear (*Pyrus communis* L.) and apple orchards in Italy. Haddad et al. (2004) found a salticid to represent 52.8 % of the spider fauna in pistachio (*Pistacia vera* L.) orchards in the Prieska district of South Africa, whereas Dippenaar-Schoeman et al. (2001, 2005) reported that four and three salticid species represented 61 % and 44.7 % of the fauna in macadamia (*Macadamia integrifolia* Maiden & Betcke) and avocado (*Persea americana* Mill.) orchards in the Mpumalanga Lowveld, respectively.

The total number of families (21) and species (54) collected between 2001 and 2003 by pitfall trapping corresponded with the 20 families and 72 species of ground- and plant-dwelling spiders recorded in the study by Dippenaar-Schoeman et al. (1999) from the Marble Hall area during the 1995–1997 cotton-growing seasons. Thirteen of the families identified in the present study were also found by Dippenaar-Schoeman et al. (1999) in the Marble Hall district, but the Ammoxenidae, Hahniidae, Hersiliidae, Oonopidae, Pholcidae, Phyxelididae, Scytodidae and Sicariidae are new recordings on cotton in this region. They did, however, occur in small numbers and was each represented by a single species. Twelve species marked with an asterisk in Table 1 are new records for Marble Hall.

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References

Angeli G, Forti D & Pesarini C 1996. Epigeic spiders (Araneae) in apple and pear orchards in Trentino. *Redia* **79**: 113–121.

Anon. 1996. *Management guide for the cotton producer.* Volume 1. Agricultural Research Council, Tobacco and Cotton Research Institute, Rustenburg.

Carpenter J, Felsot A, Goode T, Hammig M, Onstad D & Sankula S 2002. *Comparative environmental impacts of biotechnology-derived and traditional soybean, corn, and cotton crops.* Council for Agricultural Science and Technology, Ames, Iowa.

Dinkins R L, Brazzel J R & Wilson C A 1970. Seasonal incidence of major predaceous arthropods in Mississippi cotton fields. *Journal of Economic Entomology* **63**: 814–817.

Dippenaar-Schoeman A S 1979. Spider communities in strawberry beds: seasonal changes in numbers and species composition. *Phytophylactica* **11**: 1–4.

Dippenaar-Schoeman A S, Van den Berg A M & Van den Berg A 1989. Species composition and relative seasonal abundance of spiders from the field and tree layers of the Roodeplaat Dam Nature Reserve. *Koedoe* **32**: 51–60.

Dippenaar-Schoeman A S, Van den Berg A M & Van den Berg A 1999. Spiders in South African cotton fields: species diversity and abundance (Arachnida: Araneae). *African Plant Protection* **5**: 93–103.

Dippenaar-Schoeman A S, Van den Berg M A & Van den Berg A M 2001. Spiders in macadamia orchards in the Mpumalanga Lowveld of South Africa: species diversity and abundance (Arachnida: Araneae). *African Plant Protection* **7**: 36–46.

Dippenaar-Schoeman A S, Van den Berg A M, Van den Berg M A & Foord S H 2005. Spiders in avocado orchards in the Mpumalanga Lowveld of South Africa: species diversity and abundance (Arachnida: Araneae). *African Plant Protection* **11**: 8–16.

Dutton A, Klein H, Romeis J & Bigler F 2002. Uptake of BT-toxin by herbivores feeding on transgenic maize and consequences for the predator *Chrysoperla carnea. Ecological Entomology* **27**: 441–447.

Edge J M, Benedict J H, Carroll J P & Reding H K 2001. Bollgard cotton: an assessment of global economic, environmental, and social benefits. *Journal of Cotton Science* **5**: 1–8.

Galanopoulou-Sendouca S & Oosterhuis D 2003. Agronomic concepts and approaches for sustainable cotton production. *World cotton research conference proceedings – 3: Cotton production for the new millennium,* 507–522. Cape Town.

Haddad C R, Louw S Vd M & Dippenaar-Schoeman A S 2004. An assessment of the biological control potential of *Heliophanus pistaciae* (Araneae: Salticidae) on *Nysius natalensis* (Hemiptera: Lygaeidae), a pest of pistachio nuts. *Biological Control* **31**: 83–90.

Hagerty A M, Kilpatrick A L, Turnipseed S G, Sullivan M J & Bridges W C 2005. Predaceous arthropods and lepidopteran pests on conventional, Bollgard, and Bollgard II cotton under untreated and disrupted conditions. *Environmental Entomology* **34**: 105–114.

Head G, Brown C R, Groth M E & Duan J J 2001. Cry1Ab protein levels in phytophagous insects feeding on transgenic corn: implications for secondary exposure risk assessment. *Entomologia Experimentalis et Applicata* **99**: 37–45.

Hilder V A & Boulter D 1999. Genetic engineering of crop plants for insect resistance – a critical review. *Crop Protection* **18**: 177–191.

Jasinski J R, Eisley J B, Young C E , Kovach J & Willson H 2003. Select nontarget arthropod abundance in transgenic and nontransgenic field crops in Ohio. *Environmental Entomology* **32**: 407–413.

Lövei G L & Arpaia S 2005. The impact of transgenic plants on natural enemies: a critical review of laboratory studies. *Entomologia Experimentalis et Applicata* **114**: 1–14.

Mansour F, Rosen D & Shulov A 1980. A survey of spider populations (Araneae) in sprayed and unsprayed apple orchards in Israel and their ability to feed on larvae of *Spodoptera littoralis* (Boisd.). *Acta Oecologica* **1**: 189–197.

Meissle M & Lang A 2005. Comparing methods to evaluate the effects of BT maize and insecticides on spider assemblages. *Agriculture, Ecosystem and Environment* 107: 359–370.

Mellet M A 2005. Cotton cultivation practices with special reference to the effect of BT-cotton on Arthropoda populations. PhD thesis, University of Pretoria, Pretoria.

Men X, Ge F, Liu X & Yardim E N 2003. Diversity of arthropod communities in transgenic BT cotton and nontransgenic cotton agroecosystems. *Environmental Entomology* **32**: 270–275.

Nyffeler M, Breene R G, Dean D A & Sterling W L 1990. Spiders as predators of arthropod eggs. *Journal of Applied Entomology* **109**: 490–501.

Nyffeler M & Sterling W L 1994. Comparison of the feeding niche of polyphagous insectivores (Araneae) in a Texas cotton plantation: estimates of niche breadth overlap. *Environmental Entomology* **23**: 1294–1303.

Nyffeler M, Sterling W L & Dean D A 1994. Insectivorous activities of spiders in United States field crops. *Journal of Applied Entomology* **118**: 113–128.

Riechert S E 1999. The hows and whys of successful pest suppression by spiders: insights from case studies. *Journal of Arachnology* **27**: 387–396.

Samu F & Bíró Z 1993. Functional response, multiple feeding and wasteful killing in a wolf spider (Araneae: Lycosidae). *European Journal of Entomology* **90**: 471–476.

Samu F & Szinetár C 2002. On the nature of agrobiont spiders. *Journal of Arachnology* **30**: 389–402.

Schuler T H, Potting R P J, Denholm I & Poppy G M 1999. Parasitoid behavior and BT plants. *Nature* **400**: 825.

Sisterson M S, Biggs R W, Olson C, Carrière Y, Dennehy T J & Tabashnik B E 2004. Arthropod abundance and diversity in BT and non-BT cotton fields. *Environmental Entomology* **33**: 921–929.

Soomro A R, Anjum R & Bano S 2003. Reduced use of insecticides against cotton bollworms with F1 cotton hybrids possessing BT-gene: A myth or reality? *World cotton research conference proceedings – 3: Cotton production for the new millennium,* 1097–1102. Cape Town.

Statsoft Inc. 2002. *Electronic statistics textbook.* Tulsa, OK. http://www.statsoft.com.

Udikeri S S, Patil S B, Nadaf A M & Khadi B M 2003. Performance of BT-cotton genotypes under unprotected conditions. *World cotton research conference proceedings – 3: Cotton production for the new millennium,* 1281–1286. Cape Town.

Van den Berg A & Dippenaar-Schoeman A S 1991a. Ground-living spiders from an area where the harvester termite *Hodotermes mossambicus* occurs in South Africa. *Phytophylactica* **23**: 247–253

Van den Berg A M 1989. An investigation into the effects of two commonly used pesticides on spider mite predator populations in cotton with special reference to spiders. MSc dissertation, Rand Afrikaans University, Johannesburg.

Van den Berg A M & Dippenaar-Schoeman A S 1991b. Spiders, predacious insects and mites on South African cotton. *Phytophylactica* **23**: 85–86.

Van den Berg A M, Dippenaar-Schoeman A S & Schoonbee H J 1990. The effect of two pesticides on spiders in South African cotton fields. *Phytophylactica* **22**: 435–441.

Whitcomb W H 1974. Natural populations of entomophagous arthropods and their effect on the agroecosystem. In: *Proceedings of the Summer Institute on biological control of plant insects and diseases,* 150–169 (Eds F G Maxwell & F A Harris). University Press of Mississippi, Jackson.

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