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Comparative effects of a selective insecticide, *Bacillus thuringiensis* var. *kurstaki* and the broad-spectrum insecticide cypermethrin on diamondback moth and its parasitoid *Cotesia vestalis* (Hymenoptera; Braconidae)

M.A. Stemele

Department of Zoology, University of Fort Hare, Private Bag X1314, Alice 5700, Eastern Cape Province, South Africa

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ABSTRACT

Cotesia vestalis (Haliday) (Hymenoptera: Braconidae) (= *plutellae*) is an important parasitoid of *Plutella xylostella* L. (Lepidoptera: Plutellidae) consistently accounting for high field mortality. However, indiscriminate use of broad-spectrum insecticides is reported to undermine this parasitoid's impact. To investigate the implications of selective and broad-spectrum insecticides on *C. vestalis,* trials were conducted in Eastern Cape Province, South Africa. *Plutella xylostella* infestation, *C. vestalis* parasitism, and yield variables were measured over three growing seasons on unsprayed cabbage, and cabbage treated with selective Biobit® (*B. thuringiensis* var. *kurstaki*, 32000 IU/mg) or broad-spectrum Cypermethrin® (cypermethrin, 200 g/l). *Plutella xylostella* infestation was higher in control compared to treated cabbage during winter and spring but not summer. However, parasitism was consistently higher in the control (≥55%) compared to the Biobit (≤45%) and Cypermethrin (≤25%) treatments throughout the study period. Consistent with higher parasitism, the *C. vestalis* yield loss abatement function was highest in the control followed by Biobit and least in Cypermethrin during winter (42 > 24 > 10%), spring (36 > 35 > 22%) and summer (41 > 36 > 23%). These results demonstrate that Biobit reduces *P. xylostella* field density and crop damage with minimal impact on the *C. vestalis* yield loss abatement function.

1. Introduction

Diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) is an important insect pest of brassica crops including cabbage, *Brassica oleracea* var. *capitata* (Mosiane et al., 2003; Talekar and Shelton, 1993; Zalucki et al., 2012). *Plutella xylostella* damage on cabbage is unpredictable and varies from minimal to vast yield losses (Ayalew, 2011; Omar and Mamat, 1997; Srinivasan and Krishnamoorthy, 1992; Verkerk and Wright, 1996). Worldwide crop losses and the cost of *P. xylostella* management is estimated to be billions of dollars annually (Grzywacz et al., 2010; Zalucki et al., 2012). To alleviate *P. xylostella* damage and subsequent crop losses, farmers often apply insecticides prophylactically. Insecticides are an important damage reducing input in agricultural production systems (Lansink and Silva, 2014; Trdan et al., 2007).

Under field condition, different life stages of *P. xylostella* are attacked by more than 130 parasitoid species worldwide (Sarfraz et al., 2005). However, the most effective species belong to family Ichneumonidae (*Diadegma* and *Diadromus* genera), Braconidae (*Microplitis* and *Cotesia* genera) and the Eulophidae (*Oomyzus* genus) (Sarfraz et al., 2005). In South Africa, Kfir (1997) recorded a total of 21 parasitoids species associated with *P. xylostella*. Among these parasitoids, the widely distributed solitary koinobont species (Furlong et al., 2013), *Cotesia vestalis* (Haliday) (Hymenoptera: Braconidae) (= *plutellae*) is often responsible for higher levels of parasitism than other hymenopteran parasitoids. In South Africa, *C. vestalis* is dominant and active all year round (Denill and Pretorius, 1995; Nofemela, 2010). However, *C. vestalis* occasionally fail to achieve top-down control of *P. xylostella* which demands for the integration of insecticides in cabbage production systems (Stemele, 2016).

In South Africa, insecticides recommended in cabbage production systems include *B. thuringiensis* formulations, Dedevap (dichlorvos 76 g/kg and p+6yrethrum 7.3 g/kg; Bayer AG, Germany), Cypermethrin (cypermethrin 200 g/l; Arysta Life Science, South Africa), Endosulfan (endosulfan 350 g/l; Universal Crop Protection (Pty) Ltd., South Africa), Metamidofos (methamidophos:

E-mail address: mstemele@ufh.ac.za.

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585 g/l; Villa Crop Protection, South Africa) and Dursban (chlorpyrifos 480 g/litre; Dow AgroScience, South Africa) (Whitehead and Archer, 2011). Since *P. xylostella* thresholds are not available, farmers have no decision making supporting tools and apply insecticides based on calendar sprays.

Selective insecticides such as *Bacillus thuringiensis* Berliner (*Bt*) based formulations are also widely adopted in many countries because they are assumed to have no direct effects on non-target species (Glare and O'callaghan, 2000). Although *P. xylostella* strains around the world had been reported to have developed resistance to *B. thuringiensis* products as early as the early 90's (Shelton et al., 1993; Tabashnik et al., 1990), there are no reports of *P. xylostella* resistance to *B. thuringiensis* in South Africa. The mechanism of *P. xylostella* resistance to *B. thuringiensis* products is reported to include both genetic and biochemical pathways (Ferré et al., 1995). However, Zago et al. (2014) recently demonstrated behavioural avoidance of plants treated with *B. thuringiensis* as an additional adaptation. Ability of *P. xylostella* to develop resistance to effectively any insecticide group is a major threat even in the African context where *B. thuringiensis* formulations are not as intensively adopted as in other continents.

Adoption of the IPM for cabbage production systems in South Africa would require extensive grower's training about IPM strategies in a way that encourages phasing out of the current pest management practises by providing alternatives. Therefore, the first step in promoting IPM in this context is to provide evidence showcasing the benefits of the IPM strategies. Biological control is an important component of IPM but its benefits are a multi-dimensional product of multiple biological control agents acting simultaneously which complicate its direct assessment. The contribution of the solitary parasitoid species however, can be isolated from other biological control agents (Mcfadyen et al., 2015) since the emergence of a parasitoid from field samples signifies a dead insect host (Nofemela, 2013). Several efforts has been made to assess the benefits of the parasitoids including those based on inferences made from farmer's interviews (Bokonon-Ganta et al., 2002), natural enemy exclusion (Kipkoech et al., 2010), yield loss assessments (Macharia et al., 2005) and the rates of parasitism (Kfir, 2011). Just as the impact of the natural enemies on the pest population can be quantified, the impact of the insecticides on natural enemies (Laznik and Trdan, 2014; Poorjavad et al., 2014) and the interactions between multiple natural enemies (Rojht et al., 2009) can be quantified.

Successful implementation of biological control based IPM program requires critical evaluation and monitoring of the practices by farmers to determine compliance with procedures of insecticide use in agroecosystems. The IPM approach as defined by Stern et al. (1959) requires regular inspection of crops for pest larval infestations and plant damage, application of selective insecticides based on need and the conservation of the natural enemies (Biever et al., 1994). Therefore careful selection of insecticide type is critical to the viability of the biological control based IPM. This study was therefore conducted to generate the baseline evidence that the farmers need to consider in decision making with regard to insecticide choice and its impact in agroecosystems. Insecticides that complement the action of the parasitoids in IPM programmes are more likely to improve pest control and the framework used here can be extended to other agroecosystem.

2. Materials and methods

2.1. Trial plots and treatments

Three experiments were conducted in Alice, Eastern Cape, South Africa (32°48′S 26°51′E, altitude 540 m.a.s.l). The objective was to investigate the direct implications of a selective and broad-spectrum insecticide on the *C. vestalis* yield loss abatement function. Cabbage seedlings were planted in a field consisting of 60 m × 10 m block replicated three times, each separated by 2.5 m from the adjacent. Each block was divided into three 18 × 10 m plots separated by 1 m. In each plot, twenty rows of cabbage seedlings were transplanted lengthwise at 90 cm intra-row spacing and twelve rows along the width at 80 cm inter-row spacing so that each plot contained 240 cabbage plants. The cabbage variety STAR 3301 (Starke Ayres, South Africa) adaptable to warm-cool conditions was planted for spring/summer crops and Green Coronet (Starke Ayres, South Africa) with good cold tolerance was used for winter crops. The field was irrigated twice a week or as required by means of overhead sprinklers. Seedlings for the respective seasons were transplanted during 2014 on 26 May, 21 August and 10 November as winter, spring and summer crops respectively.

The treatments were assigned as a Biobit (Trade name, Biobit® HP WP; active ingredient, *B. thuringiensis* var. *kurstaki* [32000 IU/mg]; Manufacturer, Valent BioSciences Philagro PTY Ltd, South Africa; Recommended application rate, 500 g in 600 L per ha adjusted to 10 g in 10 L per plot) and Cypermethrin (Trade name, Cypermethrin®; active ingredient, cypermethrin 200 g/l; Manufacturer, Arysta Life Sciences, South Africa; Recommended application rate, 10 ml in 100 L of water adjusted to 1 ml in 10 L per plot). Both, the Cypermethrin and the Biobit were acquired locally (Farmarama Mica Hardware, South Africa) and applied at fortnightly intervals using a manual flat-fan nozzle GS0341 knapsack sprayer (Green Industrial Supplies, South Africa).

2.2. The abundance of the P. xylostella and C. vestalis

Sampling for *P. xylostella* and *C. vestalis* was conducted from 03 June - 19 August 2014, 27 August - 11 November 2014 and 07 November 2014–26 January 2015. Twenty randomly selected cabbage heads per treatment per block were examined for *P. xylostella* larvae, pupae, and parasitoid cocoons once a week. A record of sampled plants was kept to prevent sampling the same plant twice within two weeks, roughly the developmental time of *P. xylostella* (Talekar and Shelton, 1993). The two border rows around each plot were considered guard rows and excluded from sampling. *Plutella xylostella* larvae (2nd to 4 the instar), pupae and the parasitoid cocoons recovered from the respective treatments were transported to the laboratory in plastic cages containing rape seedlings (*Brassica napus*), growing in vermiculite for continuous feeding. In the laboratory, the insects were reared in Perspex cages at 25 ± 2 °C and 16:8 h light: dark regime. *Plutella xylostella* life stages were used to calculate field density. Emerging adult moths and parasitoids were recorded twice a day and parasitism was calculated as a ratio of emerging *C. vestalis* in relation to *P. xylostella* 2nd to 4th instar larvae collected from the field. *Cotesia vestalis* preferentially oviposit on 2nd to 4th instar larvae (Shi et al., 2002) and including 1st instar larvae would underestimate parasitism (Van Driesche et al., 1991). This procedure was repeated for a period of 12 weeks during each season.

2.3. The impact of the P. xylostella infestation on cabbage yield

Mature cabbage was harvested on 22 August 2014, 13 November 2014 and 29 January 2015. The weight (w) of 40 randomly selected cabbage heads per plot, the total number of cabbage heads per treatment per plot (N) and the area (A) of each plot were recorded to calculate the effective yield (Y) using the equation modified from Subramanian et al. (2010) conveniently expressed as:

$$Y = [(w \times N) \div 1000] \div (A \times 1000) \quad (1)$$