Crop Protection 89 (2016) 6–11

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Determinants of parasitoid assemblages of the diamondback moth, *Plutella xylostella*, in cabbage farmer fields in Senegal

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ARTICLE INFO

Article history:
Received 18 February 2016
Received in revised form
20 June 2016
Accepted 22 June 2016

Keywords:
Parasitism
Biological control
Brassicaceae
Oomyzus sokolowskii
Cotesia vestalis
Apanteles litae
Brachymeria sp.
Africa

ABSTRACT

Conservation biological control, which fosters the optimal use of indigenous natural enemies, is a promising way for reducing pesticide reliance in horticultural systems. A two-year field survey was conducted in the main cabbage-producing area in Senegal (Niayes) to assess the potential of indigenous parasitoids to control populations of *Plutella xylostella* (Lepidoptera, Plutellidae). Results showed an overall low level of parasitism (11.7%) which was independent of host abundance, but was highly variable among fields (0–50%). Parasitism was predominant in the late part of dry season. Insecticide use, mostly relying on broad-spectrum insecticides, had a negative effect on the overall parasitism rate. Observations conducted throughout the cabbage crop cycle showed that parasitism unexpectedly decreased with crop aging (from 41 to 60 days post transplanting), likely due to repeated insecticide applications. Four main parasitoid species including *Oomyzus sokolowskii* (Kurdjumov) (Eulophidae) (48.8%), *Apanteles litae* Nixon (Braconidae) (32.5%), *Brachymeria* sp. (Chalcididae) (11.3%), and *Cotesia vestalis* Haliday (Braconidae) (7.3%) were identified. Parasitism due to *O. sokolowskii* was greater during the first part of the dry season whereas parasitism due to *A. litae* was greater during the second part of the dry season. Parasitism due to *Brachymeria* sp. was not affected by time of season but was greater in the Centre and North than in the South of Niayes. Parasitism due to *C. vestalis* was equal in the three zones but was higher in the late part of the dry season. The diversity of parasitoids was constant across zones but was greater during the second part of dry season. A positive relationship between diversity (Shannon diversity index H′) and parasitism rate was observed, suggesting a positive effect of parasitoid diversity on natural pest control. Parasitoids have a promising role to play as biocontrol agents of *P. xylostella* populations in Senegal, provided significant changes to current insecticide use are made. Better knowledge of their resource requirements including crop and non-crop habitats, and provision of these in and around crops is also needed.

1. Introduction

In the tropics and subtropics, damage caused by insect pests is a major obstacle to seasonal stability and overall increase of cabbage production. The diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera, Plutellidae), is by far the most destructive pest, which considerably increases the cost and uncertainty of production for smallholder farmers (Grzywacz et al., 2010). In Senegal, *P. xylostella* populations can persist year-round in the main brassica-producing area (Western Senegal, Niayes), resulting in a continuous threat to cabbage crops (Sow et al., 2013). Strategies deployed by farmers to control this pest rely on routine applications and sometimes overuse of broad-spectrum synthetic insecticides (mostly organophosphates and pyrethroids). Such intensive use of insecticides is a serious source of risk for ecosystems and human health (Barzman et al., 2015). In addition, it dramatically impacts biodiversity and related ecosystem services such as pest regulation provided by natural enemies (Furlong et al., 2004; Bommarco et al., 2011; Ayalew, 2011). The need for more insecticides often leads to increases in production costs and field-evolved resistance in pest populations (Li et al., 2012; reviewed in Furlong et al., 2013).

Finding biorational alternatives to synthetic pesticides is a major challenge to design productive and environmentally-sound

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http://dx.doi.org/10.1016/j.cropro.2016.06.018
0261-2194/© 2016 Published by Elsevier Ltd.

agricultural systems. Conservation biological control, which fosters the optimal use of indigenous natural enemies (Landis et al., 2000; Tscharntke et al., 2007), is a promising way towards sustainable pest management (Bale et al., 2008; Barzman et al., 2015). In Senegal, parasitoid wasps have been shown to have great potential for controlling field populations of *P. xylostella* (Sall-Sy et al., 2004; Sow et al., 2013a). However, only five hymenopteran parasitoid species have been documented to date - including larval parasitoids such as *Apanteles litae* Nixon and *Cotesia vestalis* Haliday (Braconidae), and more recently *Diadegma insulare* (Cresson) (Ichneumonidae) (Labou et al., 2016), but also larval-pupal and pupal parasitoids such as *Oomyzus sokolowskii* (Kurdjumov) (Eulophidae) and *Brachymeria* sp. (Chalcididae), respectively – and observed parasitism rates in the Dakar area were low (Sow et al., 2013b). On a worldwide scale, the parasitoid complex that attacks DBM is approximately equal to 60 species (Delvare, 2004). However, only around a dozen species are frequently recovered and egg parasitoids appear to be underrepresented (Liu et al., 2004; Furlong et al., 2013). There is a gap in knowledge on egg parasitoids (particularly *Trichogramma* species), which can have a great role to play in biological control, as evidenced by Liu et al. (2004) in Australia. In Africa, the most common and effective larval parasitoids belong to three major genera, *Apanteles*, *Cotesia* (Braconidae) and *Diadegma* (Ichneumonidae) and pupal parasitoids belong to the genus *Diadromus* (Ichneumonidae) (Kfir, 2003). According to Lohr and Kfir (2004), diversity of the parasitoid fauna associated with *P. xylostella* in Africa is relatively poor.

More information is needed on the spatio-temporal variation of biological control of DBM populations and parasitoid assemblages during the dry season, the main period for cabbage production. The present study was carried out (i) to assess the importance of larval and pupal parasitism of DBM larvae and pupae in cabbage farmer fields across the main cabbage-producing area in Senegal (Niayes), (ii) to update records of field-collected parasitoid species, and (iii) to map diversity, seasonality and relative abundance of *P. xylostella* parasitoids in the studied area. Results are discussed in the light of the potential of conservation biological control as a key component of a 'systems approach'to integrated management of the DBM in cabbage production in Senegal.

2. Material and methods

2.1. Study sites

The study was carried out during the dry season in the main vegetable-producing area in Senegal (Niayes). This area is a 180 km long and 10–30 km wide coastal strip that runs from Dakar to Saint Louis (Fig. 1). The environment is characterized by dunes and depressions that are often flooded, and the alternation of a short rainy season (July–September, 400–500 mm rainfall) and a long dry season (October–June) during which most cabbage crops are grown under irrigation. A set of 116 farmer fields (mean size 0.4 ha, 0.01–3.6 ha) were selected in three zones (South, n = 40; Centre, n = 42; North, n = 34) in the Niayes area (Fig. 1). These zones are situated along a rainfall gradient (from 450 mm in the South to 250 mm in the North) which shapes the landscape structure, from large patches of irrigated vegetable crops next to orchards (mango and citrus) and semi-natural vegetation (gallery forest, bush savannah) in the South, to small and isolated patches of irrigated vegetable crops in savannah in the North (Brévault et al., 2014). Temperature was recorded by placing data loggers (Hobo, Prosensor) in two randomly selected fields per zone. Mean temperature during field monitoring was 24.3, 22.4, 22.7 and 21.7 °C for crop cycles 1, 2, 3 and 4, respectively. The first part of the dry season was warmer (+1.3 °C) than the late part of dry season, but no significant temperature difference was recorded among zones.

2.2. Parasitism monitoring

In each field, 24 tomato plants were randomly selected and observed for fruit damage due to *H. armigera*. Parasitism of *P. xylostella* larvae and pupae was monitored over two dry seasons (Season 1, October 2012 to May 2013; Season 2, October 2013 to May 2014), namely four cabbage crop cycles (cycle 1 from October 2012 to January 2013; cycle 2 from February 2013 to May 2013; cycle 3 from October 2013 to January, 2014; cycle 4 from February 2014 to May 2014, with cycles 1–3 positioned in the early dry season and cycles 2–4 in the late dry season). For one given crop cycle, fields were separated from each other by at least two kilometers. Every three weeks from transplanting to harvest (3–5 observations), 20–40 third and fourth instar larvae were randomly collected from cabbage plants and individually incubated in the laboratory in 12-well culture plates (Thermo Fisher Scientific, France), with sections of fresh cabbage leaves. Samples of parasitized and apparently unparasitized *P. xylostella* pupae were confined individually in small pillboxes (2 × 2 cm). Emerging parasitoids were identified and the parasitism rate calculated for each field as the percentage of emergent parasitoids out of the total number of *P. xylostella* larvae and pupae collected from each cabbage field. Parasitism by gregarious parasitoid species was not an issue as larvae and pupae were kept individually. Larvae or pupae that died of unknown causes were not excluded from calculation, in contrast to some other studies that may overestimate parasitism rates (Ayalew et al., 2006; Bopape et al., 2014). A farmer's survey of insecticide applications (date, trade mark, active ingredient) was conducted for each cabbage field during the entire crop cycle.

The Shannon diversity index $H' = \sum_{i=1}^{s} (pi)*\ln(pi)$, where pi = probability of meeting a taxon i on a field, and s = total number of taxa encountered on the field, was calculated to assess the effect of zone and time of season on parasitoid diversity. H' = 0 when there is only one taxon and its value is at a maximum value when all taxa are of equal abundance.

2.3. Statistical analyses

Linear mixed effect models were used to examine the effects of zone (South, Centre, North of Niayes), time of season (early vs. late season), insecticide use (number of applications) and host abundance (number of *P. xylostella* larvae per plant) on overall parasitism rate, species-specific parasitism rate, and Shannon diversity index. Each model was fitted using the appropriate distribution type and link function: binomial for parasitism (proportion of parasitized larvae or pupae over the sampling dates) and quasi-poisson for Shannon index. For each model, year was considered as random effect because parasitism was different and some fields were selected on both years. Linear effect models were used to examine the relationship between crop phenology and parasitism rate. Models were fitted by maximum likelihood (ML) and their suitability was assessed by checking normality and randomness of residuals. Results were displayed as analysis of deviance tables with type II errors (Wald Chi-square or F tests). Mean comparisons were done using Tukey pair-wise comparisons. Chi-square tests were used to compare parasitoid assemblages depending upon zone and time of season. Pearson's r was used to test correlations between Shannon diversity and parasitism rates (after arc-sin square root transformation). All statistical analyses were carried out using 'lme4' and 'car' packages for mixed models, 'multcomp' for multiple