**Folia Hort.** 25/1 (2013): 3-12

DOI: 10.2478/fhort-2013-0001

FOLIA HORTICULTURAE

Published by the Polish Society for Horticultural Science since 1989

ORIGINAL ARTICLE | Open access | http://www.foliahort.ogr.ur.krakow.pl

# The relationship between the diamondback moth, climatic factors, cabbage crops and natural enemies in a tropical area

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**ABSTRACT**

The impact of abiotic and biotic factors (rainfall, temperature, host plant and natural enemies) on population dynamics of the *Plutella xylostella* L. diamondback moth was investigated. The experiments were conducted during the rainy and dry seasons for two years (June 2009-April 2011) on unsprayed cabbage plots in Malika (Senegal). Every 10 days, 10 cabbages were randomly selected. *Plutella xylostella* larvae, pupae and parasitoid cocoons were recorded on each plant. Before each sampling, the diameters and ages of plants were recorded. Temperature and rainfall were also recorded during this study. Larvae and pupae of *P. xylstella* were higher for the dry season than the rainy season. There was a negative correlation between temperature and *P. xylostella* populations, and a strong relationship between *P. xylostella* populations and the age of cabbages. Females oviposited on young cabbages where the presence of young larvae was important, whereas older immature stages were mainly found in older cabbage plants. Parasitoid populations were higher for the dry season than the rainy season. High temperatures did not increase the pest populations and parasitism rate. There was no effect found on pest, plants and natural enemies due to rainfall. There was a positive correlation between pest populations and parasitism. Four Hymenoptera species were found: *Oomyzus sokolowskii*, *Apanteles litae*, *Cotesia plutellae* and *Brachymeria citrae*, but they were not efficient to control the *P. xylostella* populations. These results are important for understanding the factors that promote or inhibit pest populations and their natural enemies, and therefore essential for effective crop protection.

Key words: biological control, parasitoid, plant phenology, *Plutella xylostella*, rainfall, temperature

## INTRODUCTION

Cabbage, *Brassica oleracea* L., is an important vegetable crop playing a key role in the economy of many countries, particularly in Asia and Africa (Grzywacz et al. 2010). The diamondback moth *Plutella xylostella* L. (Lepidoptera: Plutellidae) is oligophagous and considered to be the most important pest for the Brassicaceae family (Talekar and Shelton 1993, Sarfraz et al. 2006). The proliferation of larvae pest populations is favoured by the short duration of the life cycle, with up to 20 generations per year under tropical conditions

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(Vickers et al. 2004) and a high reproductive potential of the females (Justus et al. 2000). The damage caused by this pest has been estimated globally to cost US$ 1 billion in direct losses and control costs (Grzywacz et al. 2010). The use of synthetic insecticides is the main control strategy (Kibata 1996). This pest has developed resistance against all major groups of pesticides, including *Bacillus thuringiensis* bacterial based bio-pesticides (Tabashnik et al. 1990, Zhou et al. 2011).

Several studies (Shelton et al. 1993, Hill and Foster 2000, Liu et al. 2000) have shown that the use of insecticides is not a sustainable pest management option for farmers, as it is fraught with problems such as the improper handling of pesticides, increased cost of pesticides, reduced control efficacy and contamination of the farming environment (Dobson et al. 2002). A possible alternative to pesticides in the development of an integrated management strategy against *P. xylostella* is biological conservation control using endemic parasitoids (Sarfraz et al. 2005). Parasitoids are particularly susceptible to chemical insecticides and understanding their role in the ecosystem is important for the implementation of an integrated pest management strategy (Shepard et al. 1999).

More than 90 insect parasitoids have been recorded, but less than 10 have bio-control potential for *P. xylostella* (Noyes 1994). Among these natural enemies, *Cotesia plutellae* Kurdjumov (Hymenoptera: Braconidae) is the most abundant larval parasitoid of *P. xylostella* in South Africa (Kfir 1997, Mosiane et al. 2003). In Ethiopia, *Oomyzus sokolowskii* Kurdjumov (Hymenoptera: Eulophidae), *Diadegma* sp. (Hymenoptera: Ichneumonidae) and *Cotesia plutellae* are the most important ones, accounting for more than 90% of the parasitoid complex (Ayalew et al. 2004). However, total parasitism of *P. xylostella* rarely exceeds 15% in East Africa (Kfir 2003). According to Löhr and Kfir (2004), the diversity of the parasitoid fauna associated with *P. xylostella* in West Africa is relatively poor. Most common were *C. plutellae* and *O. sokolowskii* in Benin and Senegal (Goudegnon et al. 2004, Sall-Sy et al. 2004), while *Apanteles litae* Nixon (Hymenoptera: Braconidae) was predominant in Ivory Coast (Löhr and Kfir 2004).

The agro-ecological concept, which integrates agriculture into the natural ecosystem, has been found useful for population management of *P. xylostella* (Vandermeer 1995). Population management of pests integrates cultivated plants, endemic flora, natural enemies and climatic factors (Regnault-Roger 2005). Temperature and humidity are among the most important climatic factors affecting the biology of the diamondback moth (Guo and Qin 2010). According to Ansari et al. (2010), the development of *P. xylostella* depends on the host plants and temperature. The development rate in relation to temperature plays an essential role in pest management, especially in helping to predict the timing of the development of pests and natural enemies in field conditions (Roy et al. 2002).

The biology and ecology of the pest population and its relationship with the host plant and natural enemies must also be studied (Campos et al. 2003). Brassica IPM depends on a good understanding of factors affecting *P. xylostella* population dynamics. In this study, the impact of abiotic and biotic factors (rainfall, temperature, host plant and natural enemies) on the population dynamics of *P. xylostella* was investigated on cabbage plants in the field.

## MATERIAL AND METHODS

### *Study site*

The study was conducted in Malika, a district in the Niayes of Dakar, Senegal (N: 14°47’552, W: 17°19’818 and 189 m above sea level). The area is characterised by a long dry season from November to June with a temperature range of 15-20°C and a short rainy season from July to October, with temperatures ranging between 25 to 35°C (Pereira 1963). The yearly precipitations do not exceed 500 mm between August and September. The experiments were conducted during the rainy and dry seasons for two years from June 2009 to April 2011.

### *Cabbage crops*

The host plants (*Brassica oleracea* L. var. *capitata* 'Copenhagen Market' were grown in a small farmers’ field and no insecticide was used. Thirty-day old seedlings were transplanted to seven replicate plots. Plot size was six rows of 5 m length, each with a spacing of 40 cm between plants and 60 cm between rows. Spacing between plots was 1 m. In order to protect the plants from nematodes, Furadan at 500 g was applied in the soil prior to planting. Poultry manure at 50 kg was applied 10 days later with intensive irrigation. Additional fertilizers NPK (10:10:20) at 5 kg and poultry manure at 75 kg were applied 15 days after planting. The crops were watered daily using sprinkler irrigation.

***Sampling methods***

The samplings started 10 days after transplanting and were performed every 10 days on unsprayed cabbage plots. Samples were collected randomly by selecting 10 cabbages in the central rows of each plot. Each plant selected was examined and numbers of *P. xylostella* larvae (second to fourth instar), pupae and parasitoid cocoons were recorded and left to develop in order to determine parasitism levels in the field (Nofemala and Kfir 2005). The eggs and larvae that were inside the leaves were not considered. The samples were taken to the laboratory where they were maintained at 25°C, 60% relative humidity and 12 h light/dark photoperiod. Emerging parasitoids were identified (by the taxonomy Laboratory from Cirad, Montpellier, France), and their incidence recorded.

The diameters and ages of cabbage plants collected during each sample were noted. The temperature of the air was recorded with the aid of an automatic tape recorder, "Tinytag", programmed via the software Tinytag Explorer 4.1 (Tinytag Explorer 2005). Parameters were recorded all 10 min and permitted to have a daily mean of temperature. Rainfall was also recorded daily using a rain gauge. The effects of these factors on the population dynamics of *P. xylostella* and parasitoid populations were assessed.

***Statistical analysis***

The data were normalised by logarithmic transformation before being subjected to an analysis of variance (ANOVA). The abundance of *P. xylostella* larvae and pupae, parasitoid populations, temperature and rainfall among the seasons were analysed using one-way ANOVA (XLSTAT). Means were separated using the Student Newman Keuls test. Correlation analyses were performed to determine relationships between the abundance of *P. xylostella* and rainfall, infestation levels and temperature, plant age and infestation levels, rainfall and parasitoid populations, temperature and parasitoid populations, plant age and parasitoid populations, and abundance of *P. xylostella* and parasitoid populations using XLSTAT version 2012.1.01. In all statistical analyses, $p = 0.05$ was considered significant.

**Table 1.** Overall relationship between the abundance of *Plutella xylostella* larvae and pupae, parasitism, adults of parasitoid species, temperature and rainfall from June 2009 to April 2011

| Parameter | Season | |
|---|---|---|
| | dry | rainy |
| *P. xylostella* larvae/pupae | 474.0 ± 71.4 a* | 29.1 ± 9.2 b |
| Parasitism (%) | 5.5 ± 1.6 a | 0.4 ± 0.1 b |
| *Oomyzus sokolowskii* | 7.7 ± 1.5 a | 0.9 ± 0.3 b |
| *Apanteles litae* | 10.3 ± 2.3 a | 0.6 ± 0.2 b |
| *Cotesia plutellae* | 3.9 ± 2.1 a | 1.1 ± 0.7 a |
| *Brachymeria citrae* | 0.0 a | 0.1 ± 0.1 a |
| Mean temperature (°C) | 23.8 ± 1.5 b | 29.7 ± 2.6 a |
| Total rainfall (mm) | 0.0 b | 498.0 ± 0.0 a |

*Values marked with the same letters do not differ significantly at $p = 0.05$

## RESULTS

***Relationships between P. xylostella populations and climatic factors***

*Effects of season*

The population density of the pest varied significantly between the dry and rainy seasons ($F = 11.17$, $p = 0.002$, Tab. 1). The abundance of *P. xylostella* was higher in the dry season than in the rainy season. Infestation levels by larvae and pupae were high at the middle of the dry season (February-April), fluctuating between 100 and 800 larvae and pupae per plant. The immature stages of *P. xylostella* were low in the rainy season (1 to 200 larvae and pupae per plant) and the beginning of the dry season (16 to 120 larvae and pupae per plant) (Fig. 1).

*Effects of rainfall and temperature*

No significant correlation was found between rainfall and infestation levels of *P. xylostella* ($r = -0.198$, $p = 0.247$). There was a significant difference between rainfall during the rainy and dry seasons ($F = 13.75$, $p = 0.001$, Tab. 1). Rainfall was higher during the rainy season than the dry season (Fig. 2). There was a significant correlation between temperature and *P. xylostella* populations ($r = -0.405$, $p = 0.014$). There was also a significant difference between temperatures during the rainy and dry seasons ($F = 65.37$, $p = 0.0001$, Tab. 1). Temperatures were higher (30 to 42°C) during the rainy season than the dry season (Fig. 2).

***Relationship between P. xylostella populations and the age of the cabbage***

There was a negative correlation between the young larval stages of *P. xylostella* with the cabbage age ($r = -0.340$, $p = 0.038$). These young stages (L2 and L3) decreased when the age of the cabbage was 50 to 55 days in the dry season. On the other hand, the number of old stage (L4 and pupae) increased

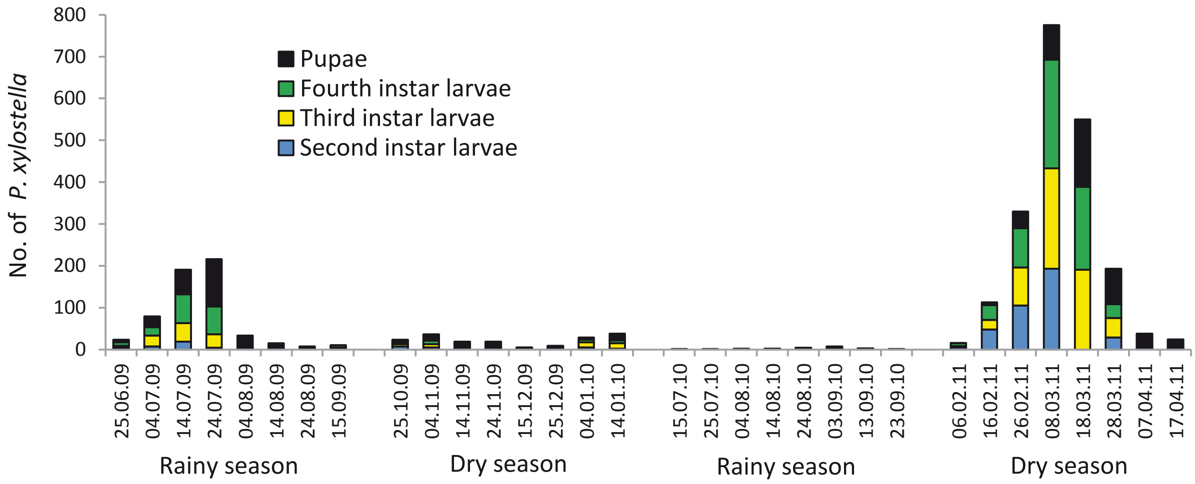


**Figure 1.** Abundance of *P. xylostella* larvae and pupae on unsprayed cabbage fields during the rainy and dry seasons from June 2009 to April 2011

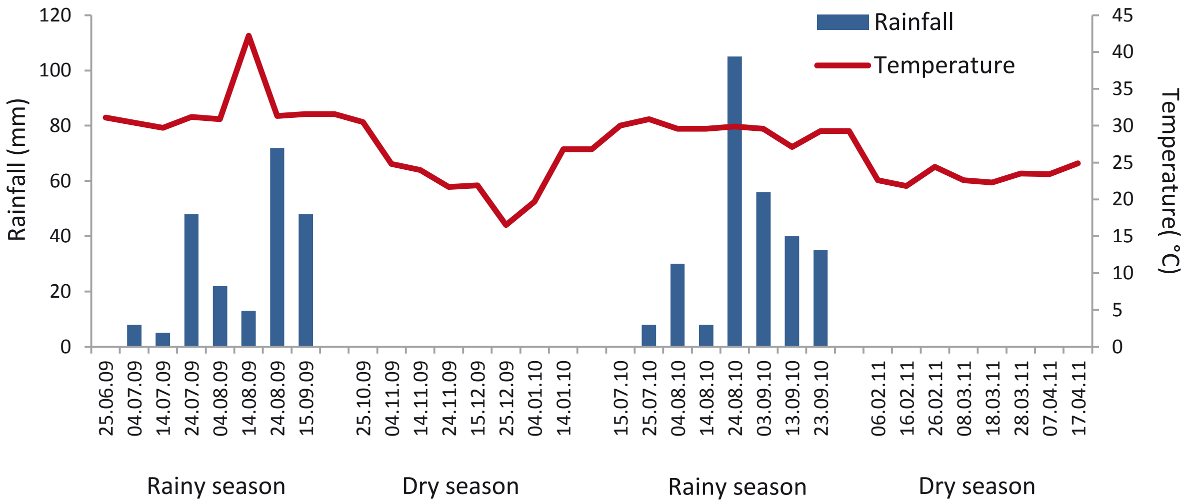


**Figure 2.** Total rainfall and mean temperature recorded at Malika (Senegal) during the rainy and dry seasons from June 2009 to April 2011

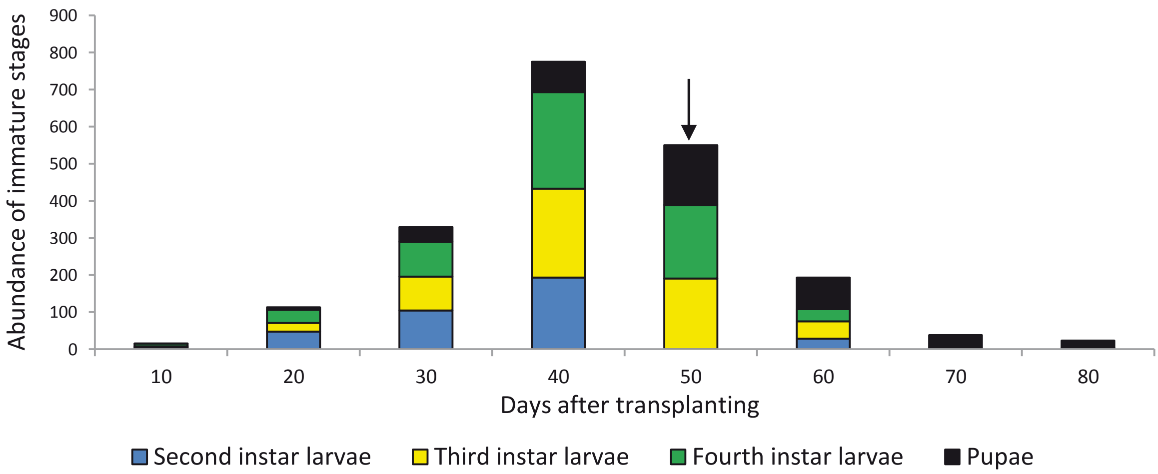


**Figure 3.** Relationship between the abundance of immature stages of *P. xylostella* and the age of the cabbage in the dry season. Arrow indicates the beginning of hearting (cabbage maturation)

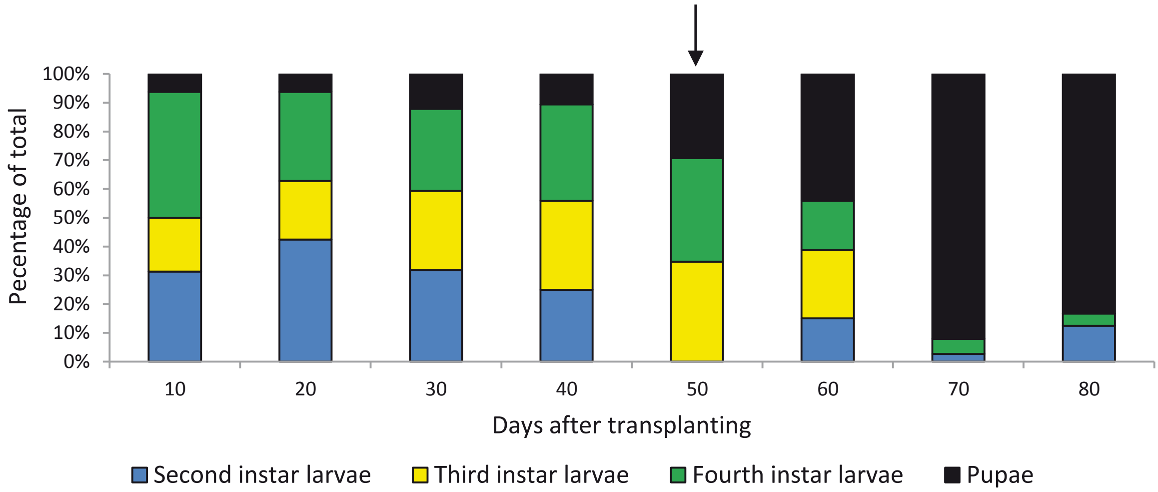


**Figure 4.** Relationship between the relative abundance of immature stages of *P. xylostella* and the age of the cabbage in the dry season. Arrow indicates the beginning of hearting (cabbage maturation)

with the age of the cabbage (r = 0.44, p = 0.007) (Figs 3 and 4). There was a significant correlation between the diameter of the cabbage plants and pest populations (r = 0.39, p = 0.018). The diameter of cabbage plants increased with plant age.

***Relationships between natural enemies and climatic factors***

*Effects of season*

Parasitoid populations were significantly different depending on the seasons (F = 29.81, p = 0.0001). The average parasitism varied significantly between seasons. It was high in the dry season, and very low in the rainy season (Tab. 1).

Four indigenous parasitic Hymenoptera were found in the pest populations (Fig. 5). *Oomyzus sokolowskii* Kurdjumov (Eulophidae), a larval-pupal, was active throughout the year and dominated the parasitoid complex (Fig. 5). It was the only gregarious parasitoid recorded during this study. The population density of *O. sokolowskii* varied significantly between the dry and rainy seasons (F = 14.49, p = 0.001, Tab. 1). *Apanteles litae* Dixon (Braconidae), a larval parasitoid, was most predominant in the dry season (F = 7.55, p = 0.009, Tab. 1). *Cotesia plutellae* Kurdjumov (Braconidae), a larval parasitoid, was also recorded throughout the year, but its activity was sporadic (Fig. 5). There was no significant difference between the seasons (F = 1.71, p = 0.19, Tab. 1). Only two specimens of *Brachymeria citrae* Westwood (Chalcididae), a pupal parasitoid, were recorded and there were no significant differences between the seasons (F = 0.23, p = 0.06, Tab. 1). Hyperparasitoids were not recorded.

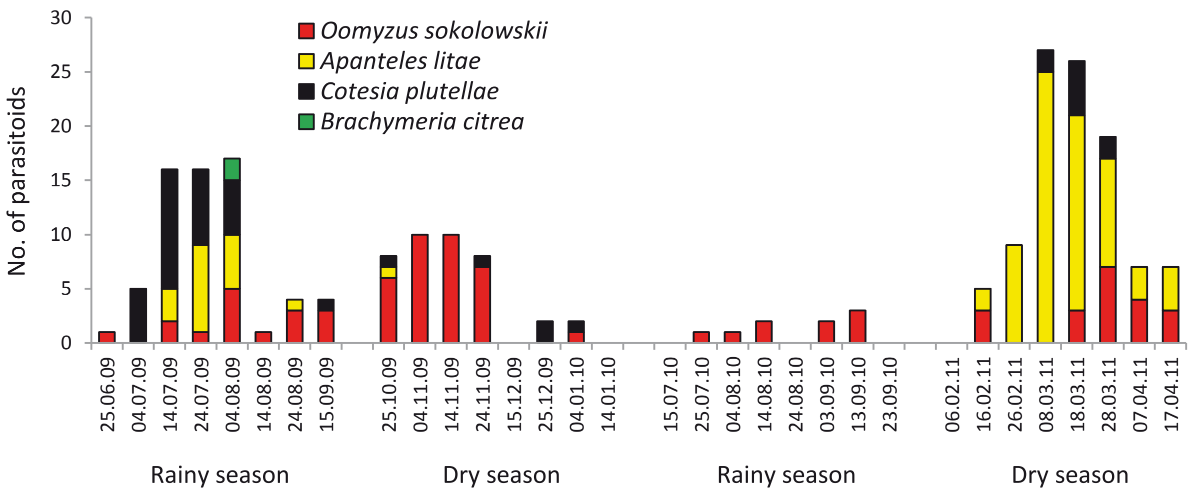


**Figure 5.** Abundance of parasitoids associated with *P. xylostella* on unsprayed cabbage fields during the rainy and dry seasons from June 2009 to April 2011

*Effects of rainfall and temperature*

No significant correlation was found between rainfall and parasitoid populations (r = –0.27, p = 0.1) (Fig. 2). There was a negative correlation between temperature and parasitoid populations (r = –0.34, p = 0.04). There was also a negative correlation between temperature and *A. litae* (r = –0.35, p = 0.032). There was a positive correlation between temperature and *B. citrae* (r = 0.36, p = 0.03). However, no significant correlation was found between temperature and *O. sokolowskii* (r = –0.29, p = 0.08). There was also no correlation between temperature and *C. plutellae* (r = –0.13, p = 0.4).

***Relationships between natural enemies and the age of the cabbage***

The correlation between the age of the cabbage and total parasitism was significant (r = –0.65, p = 0.0001, Fig. 6). There was a negative correlation between cabbage age and *O. sokolowskii* (r = –0.44, p = 0.007, Fig. 7). No significant correlation was found between the age of the cabbage and *A. litae* (r = –0.23, p = 0.16), *C. plutellae* (r = –0.32, p = 0.056) or *B. citrae* (r = –0.041, p = 0.8).

***Relationships between P. xylostella populations and natural enemies***

The correlation between pest populations and total parasitism was positive (r = 0.36, p = 0.003)(Figs 3 and 7). There was a positive correlation between *P. xylostella* populations and *O. sokolowskii* (r = 0.38, p = 0.02), *A. litae* (r = 0.98, p = 0.0001) and *C. plutellae* (r =0.77, p = 0.0001). No significant correlation was found between *P. xylostella* populations and *B. citrea* (r = 0.08, p = 0.6).

## DISCUSSION

The relationships between *P. xylostella* populations, climatic factors, cabbage phenology and the natural

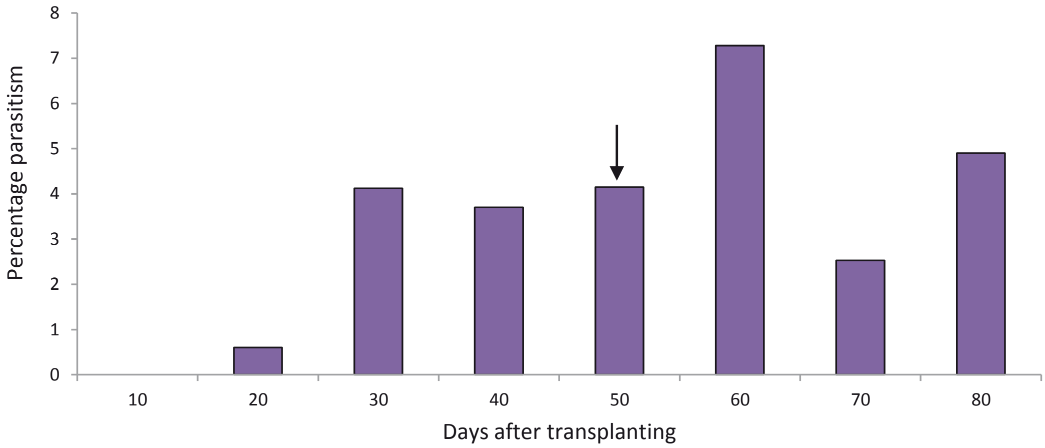


**Figure 6.** Relationship between *P. xylostella* parasitism and the age of the cabbage in the dry season. Arrow indicates the beginning of hearting (cabbage maturation)

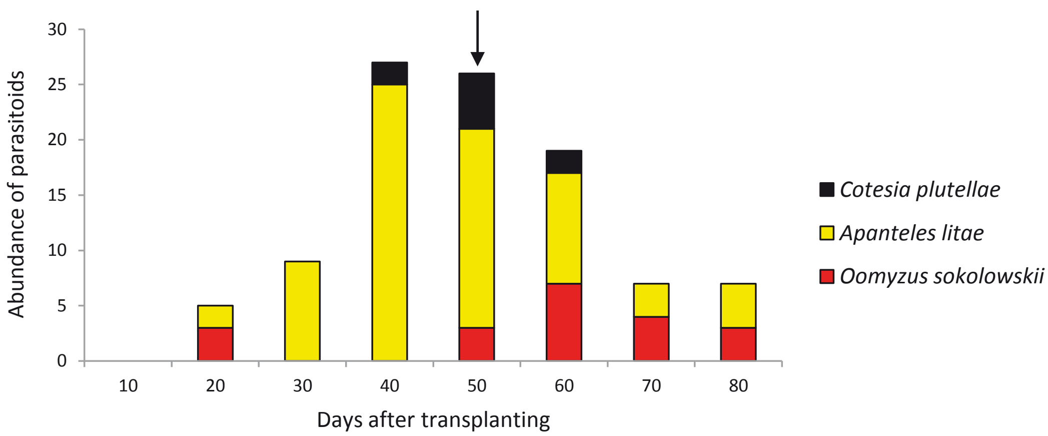


**Figure 7.** Relationship between the abundance of natural enemies and the age of the cabbage in the dry season. Arrow indicates the beginning of hearting (cabbage maturation)

enemy fauna were examined. The importance of climatic factors in the population dynamics of this pest has been emphasised by several authors (Cohen 1982, Vickers et al. 2004). The *P. xylostella* population was low in the rainy season. It is possible that rainfall may cause the mortality of immature stages of *P. xylostella*; but it is unlikely to be a major factor in the reduction of the pest populations during this period. The detrimental effect of rainfall and high temperature on pest populations has been reported by several authors (Wakisaka et al. 1992, Lui et al. 2000, Shirai 2000, Waladde et al. 2001). In the present study, we observed that the temperature influenced the dynamics of the *P. xylostella* population. The pest population increased when the temperature fell. In the rainy season, the mean temperature was 29.7°C, in the transient season it was 26.8°C and in the dry season it was 23.8°C. These data confirm Atwal (1955), where the optimal temperature for *P. xylostella* development was 17 to 25°C. However, several authors have reported that *P. xylostella* is a more important pest in tropical areas than in a temperate climate. This pest has a high number of generations per year in tropical areas; 20 in Taiwan and 28 in Malaysia (Miyata et al. 1986, Talekar and Shelton 1993). In Senegal (semi-urban Dakar area), *P. xylostella* larvae damage is most important in the dry season, probably due to many consecutive cabbage crops growing in this area for a long period of time. In the rainy season, vegetable farmers do not grow cabbages continuously.

A significant relationship was found between the immature stages of *P. xylostella* and the age of the cabbage. The number of young larval stages decreased on aged plants, whereas pupal stages increase considerably. According to Nofemela and Kfir (2005), the preponderance of younger individuals is an indication of a growing population, whereas the high incidence of older individuals is an indication of a declining population. This phenomenon is probably also due to the low attraction of old cabbages to ovipositing females because the glucosinolates produced by the cabbage decrease in concentration during tissue maturation (Hopkins et al. 1998, Spencer et al. 1999), and the effect of declining resource quality (Campos et al. 2006). According to Campos et al. (2003), plant ageing increased pre-imaginal mortality and reduced the larval development rate and fecundity.

Relationships were found between *P. xylostella* and parasitoid populations. Generally, the abundance of natural enemy populations increases with host populations (Elliott et al. 2002), and the parasitoid complexes develop more in relation to plant succession (Price 1973). Temperature can have considerable effects on host susceptibility and/or parasite virulence with parasitoids (Matthew and Blanford 2003). Our study showed that the temperatures in the dry season (20 to 25°C) were a favourable range for the development, survival, and reproduction of parasitoids particularly for *O. sokolowskii* (Wang et al. 1999).

However, the impact of parasitoids on *P. xylostella* populations was low. Parasitoid populations were not able to control this pest. Shepard et al. (1999) noted that in Southeast Asia, indigenous parasitoids of cabbage moth were not able to regulate populations of this pest. Many agro-ecosystems are unfavourable environments for natural enemies due to high levels of disturbance (Landis et al. 2000).

These results may be due to the particular location of the cabbage plots, but the importance of the selection pressures present in each agro-ecosystem and the effects of natural selection on the totality of viable species and the change in their behaviour during successive generations should be recognised. For example, *C. plutellae* populations control *P. xylostella* larval populations in South Africa (Smith and Villet 2002) and in some localities in Benin (Goudegnon et al. 2000), have decreased a few larval populations in Martinique Island (Smeralda 2000) and have had no incidence in Dakar Niayes.

Generally, the immediate environment of a cultivated plot is more influential (beneficial or not) on the population of pests than on natural enemy populations (Burel et al. 2000). Further studies in other environmental conditions in the field will be conducted to confirm the influence of the selection pressures on *P. xylostella* populations and their natural enemies in a cabbage crop agro-system. Despite four species of natural enemies, the low parasitism rates found on *P. xylostella* immature stages cannot control pest populations and may necessitate additional control measures.

## CONCLUSIONS

1. The present study showed that climatic factors influenced the dynamics of *P. xylostella* populations and their natural enemies. The density of pests increased when the temperature was low. Females of *P. xylostella* oviposit on relatively young cabbages where the presence of young larvae was important, whereas older

immature stages were mainly found in older cabbages.

2. Farmers can avoid chemical treatments 40 days after planting; the cabbages were not attractive to female pests. The limitation of these treatments promotes the survival of parasitoid fauna, despite its low observed incidence.
3. For treatments against larval populations, farmers should use bacterial insecticides, such as *Bacillus thuringiensis* (Bt) to control them. These products have no effect on natural enemies.

## ACKNOWLEDGEMENTS

The authors are grateful for the support of the AUF through the program “Horizons Francophones”. We would also like thank two anonymous reviewers for comments on the manuscript.

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Received August 15, 2012; accepted November 21, 2012