Available online at http://www.ifgdg.org

Int. J. Biol. Chem. Sci. 11(3): 1288-1298, June 2017

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://ajol.info/index.php/ijbcs http://indexmedicus.afro.who.int

Spatiotemporal distribution and impact of diamondback moth parasitoids in the Dakar Niayes in Senegal

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ACKNOWLEDGEMENTS

We would like to thank E. Tendeng and A. Dia, and the FPMN (Fédération des Producteurs Maraîchers de la zone des Niayes) for helping us with the farmers' survey, the field monitoring and the insect collection. This work was supported by IRD (AIRD) under Grant PEERS-BIOBIO 2013.

ABSTRACT

Conservation biological control, which fosters the optimal use of indigenous natural enemies, is a promising way for reducing pesticide reliance in horticultural systems. The objective of this study is to determine the distribution of parasitoid species, their parasitism rates on pest populations in relation to environmental conditions in the main Senegalese market garden area (Niayes). To do this, one hundred and sixteen cabbage plots, distributed in the Niaye segmented into three areas, along a South-North transect, are chosen. These plots were observed during four crop seasons from October 2012 to May 2014. Pest larvae were counted every three weeks using 24 randomly chosen cabbage plants per plot. Four hymenopteran parasitoid species were identified; *Oomyzus sololowskii* (Kurdjumov), (Eulophidae), *Brachymeria* sp. (Chalcididae), *Apanteles litae* Nixon and *Cotesia vestalis* (Haliday) both Braconidae. The percentage of parasitism varied between the plots, the geographical locations and the sampling period. *O. sokolowskii* and *A. litae* species were predominant and were affected by the growing season. The species distribution in the three sampling areas revealed that *O. Sokolowskii* was more efficient during the cold dry season, whereas *A. litae* was more efficient during the hot dry season. These results aim at identifying conditions favorable to the regulation of populations of cabbage moth by natural enemies. Parasitoids can play a promising role as biological control agents in Senegal. In order to do this, studies such as these must be carried out and the results communicated to farmers who often misunderstand the primordial role that natural enemies can play in pest control.

Keywords: Cabbage, parasitism percentage, dry season, West Africa, *Plutella xylostella.*

INTRODUCTION

The increase of the worldwide population and the incessant urbanisation currently reducing farmable lands are issues behind problems affecting the population comestible supplies. On an international basis, vegetables have a vital role in safe dietaries programmers. The Brassicaceae crops represent an important dietary with, in 2001, an annual production of 152 million tons of cabbages, cauliflowers and rape seeds (FAOSTAT, 2013). The Brassicaceae family is very diversified and being composed of 350 genera and 3500 wild and cultivated species (Warwick et al., 2003). Africa has only 5.8% of the worldwide Brassicaceae production

DOI : https://dx.doi.org/10.4314/ijbcs.v11i3.28

(FAOSTAT, 2013), but most countries depend on these crops. In Senegal, cabbage is among the most cultivated vegetables and constitutes, with its short biological cycle (60-90 days after transplanting), an important revenue and work source for rural populations. In 2013, Senegal produced nearly 60000 tons of cabbage grown on 3500 hectares (FAOSTAT, 2013).

Pest attacks are limiting factors for productivity and results in deficit soft populations food supply. *Plutella xylostella* (L.) (Lepidoptera, Plutellidae). The Diamondback moth (DBM) constitute an important threat for this food supply because it can cause yield losses higher than 90% (Verkerk and Wright, 1996; Sarfraz et al., 2005; Mondédji, 2010). This insect species is a problem in the tropical and subtropical countries where cabbage is grown all year round. Weather conditions hightly favourable for its biological development, associated with a high reproduction rate, result in more than 20 generations of DBM per year (Vickers et al., 2004).

DBM has been controlled for a long time using pesticides which are very expensive, and pesticide application cost can represent 30 to 50% of the cultural spending (Zalucki et al., 2012). Additionally, pesticides may have a negative impact on insect biodiversity with a reduction of natural enemies (Furlong et al., 2012), an impact on the healf of users and consumers an increase of production costs (Chilcutt and Tabashnik, 1997) and a risk of appearance of resistant strains (Hooks and Johnson, 2003; Macharia et al., 2005; Sarfraz and Keddie, 2005; Shelton et al., 2007; Huang et al., 2010). Because of the negative aspects, alternative methods are needed. Among them, the biological control constitutes the most efficient method to control DBM larval populations (Lim, 1992). This biological control includes agents such as viruses, bacteria, fungi and entomophage insects (predators and parasitoids). All these agents show efficacy against DBM species (Delvare, 2004), but parasitoids are the most studied, the most efficient and therefore the most used.

In West Africa, the DBM control by parasitoids remains a major issue (Lörh and Kfir, 2004). In Senegal, numerous farmers are not familiar with this control method and their cultural practices (including the use of pesticides) prevent efficient control by auxiliary insects (Furlong et al., 2012). This observation prompted us to carry out this study with the following objectives: (i) to inventory the various species of parasitoids in the Niayes and to evaluate their parasitism rates on populations of *P. xylostella*; (ii) to know their spatial and temporal variability according to environmental conditions and the abundance of the pest populations; (iii) to propose more appropriate and ecological methods of control.

MATERIALS AND METHODS

Sampling area sampled

This study was carried out in the Niayes area, a coastal strip, that is 180 km long and up to 30 km wide located between Dakar and Saint Louis between the latitudes 14°37 North and 16°02 North. This area has soil, water and climate characteristics that are favorable for horticultural production, especially for vegetables and fruit trees. This area has inter-dune dips with soil rich in organic matter, where the water table is less deep (wells), but also tropical iron rich soils no washed less rich where water is accessible by drilling.

Selected plots

A total of 116 cabbages (*Brassica oleracea* L. var. *capitata*) plots were selected in three agro-ecological areas; 41 in the south, 41 in the center and 34 in the north, according to a transect Dakar - Saint-Louis. Sampling was carried out during four crop cycles. The cold dry season 1 (CDS1) from October 2012 to January 2013 (32 plots), the hot dry season 1 (HDS1) from February to June 2013 (27 plots), the cold dry season 2 (CDS2) from October 2013 to January 2014 (26 plots) and the hot dry season 2 (HDS2) from February to May 2014 (31 plots) (Figure 1). Consecutive plots were separated from each other by less than two kilometers. Each plot was geo-reference using GPS coordinates. Temperature and humidity were recorder using Hobo weather station date loggers installed in six plots (two plots in each of the three agro-ecological areas).

Insect sampling

Insect larvae were sampled every 21 days from cabbage transplanting to first cabbage harvest, and 24 plants were randomly collected per plot. All larvae and pupae present on each cabbage plant were identified and counted. For webworm (*Hellula undalis,* Lepidoptera Crambidae), the characteristic damages (cabbage with several little heads) were also recorded.

Statistical analyses

Data were analyzed using XLSTAT (Version 7.5.2, Addinsoft). A logistical decrease considering a binomial distribution of data (GLM, logit function) was used to determine the effects of year, geographical area, and season affecting the percentage of parasitism. Explicative variable effects were evaluated by type II analyses using the maximum likelihood report.

The number and the species of parasitoids in relation to their host larvae were classified by geographical area using the test of Kruskal Wallis. Parasitism dependence levels between the three agro-ecological areas and the seasons were compared by the khi-2 test.

Graphics with plot box were used to determine central value tendency, value variability, distribution symmetry and presence of atypical values (Principal component analysis with Hierarchical Clustering on Principle Components (HCPC), R Core, Package 'Facto Mine R').

The rate of parasitism is calculated by the formula:

Parasitism rate = number of individuals (larvae + pupe) parasitized x 100 / total number of individuals (larvae + pupe) of *P. xylostella.*

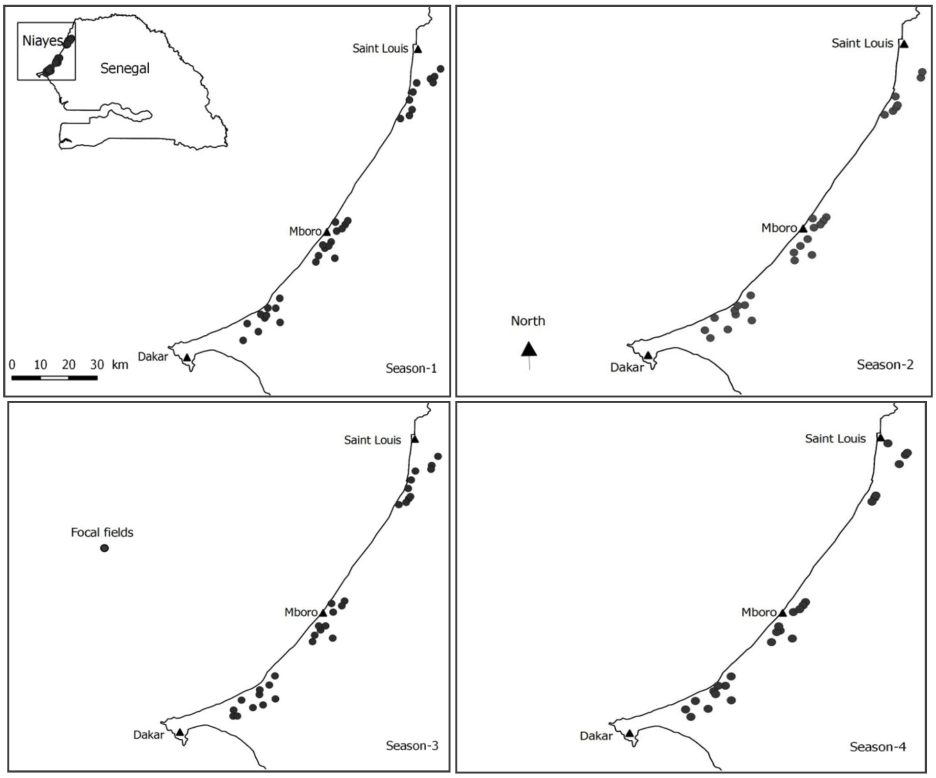

Figure 1: Geographical distribution of observation plots in Niayes area.

RESULTS

The parasitoid species

Four hymenopteran parasitoids species were found on the DBM immature stages during our sampling period; *Apanteles litae* Nixon and *Cotesia vestalis* (Haliday) which are two larval endoparasitoids Braconidae, *Oomyzus sokolowskii* (Kurdjumov) which is an Eulophidae larvo nymphal species and *Brachymeria* sp which is a pupal parasitoid Chalcididae.

The number of *O. sokolowskii* individuals represents DBM pupae that were parasitized by these species and not *O. sokolowskii* individuals per se, because unlike for the three others species which were solitary insect species, several adults (2 to 17) of *O. sokolowskii* emerged from a single parasitized DBM pupa.

DBM larvae parasitism in three different agro-ecological areas

The parasitoid distribution showed that south area was the most parasitized. This parasitism percentage vary (0 to 40%) with an average of 15%. This rate is significant in relation to those of the others areas, (χ^2 =23.8, df = 1, P < 0.0001). The parasitism rate between the two others areas respectively 6% and 5% is no different significantly (Figure 2). However, the plot parasitism percentage is very variable (one plot in the north area have a parasitism rate of 50%).

Parasitism rate of the four parasitoids species collected

The parasitism rate of each collected parasitoid varied between the three areas. However, in each area, *O. sokolowskii* and *A. litae* had significantly higher average rates (45% and 40%, respectively) than *C. vestalis* and *Brachymeria* sp (average of about 10% for each of the two species) (Figure 3).

Parasitism rate in DBM larvae according to growth seasons (CDS and HDS)

A significant season effect was found for the parasitism rate in DBM larvae (χ^2 =118,042, df = 3, P < 0.0001) and this rate was always higher during the second season of each year (15% for HDS 1 and 10% for HDS2). However, large variations were also observed between plots, some of which reaching 50% (HDS2). The weakest parasitism rate was found in CDS 2 with an average of 3% of parasitized larvae, although some plots had about 40% (Figure 4).

Variation of parasitism rate by crop seasons, geographical area and plot

Figure 5 showed the parasitism rates during season 1 (October 2012 to January 2013), season 2 (February to June 2013), season 3 (October 2013 to January 2014) and season 4 (February to May 2014). The south area showed most often plots with a parasitism rate higher than 20%. In contrast, the parasitism rate of the plots in the center area (season 3) was lower than 10%.

Seasonal parasitism rate of the four parasitoids species

During CDS and for the two years of insect collection, the populations of *O. sokolowskii* (76 to 84% of parasitism) were significantly higher than those of the others species. During HDS 1, average populations of all species varied between 10 and 42%, but these differences were not significantly different. During HDS 2, the populations of *A. litae* were higher (63 to 82% of parasitism) than those of the two others species. During this season, no individuals of *C. vestalis* were found (Figure 6).

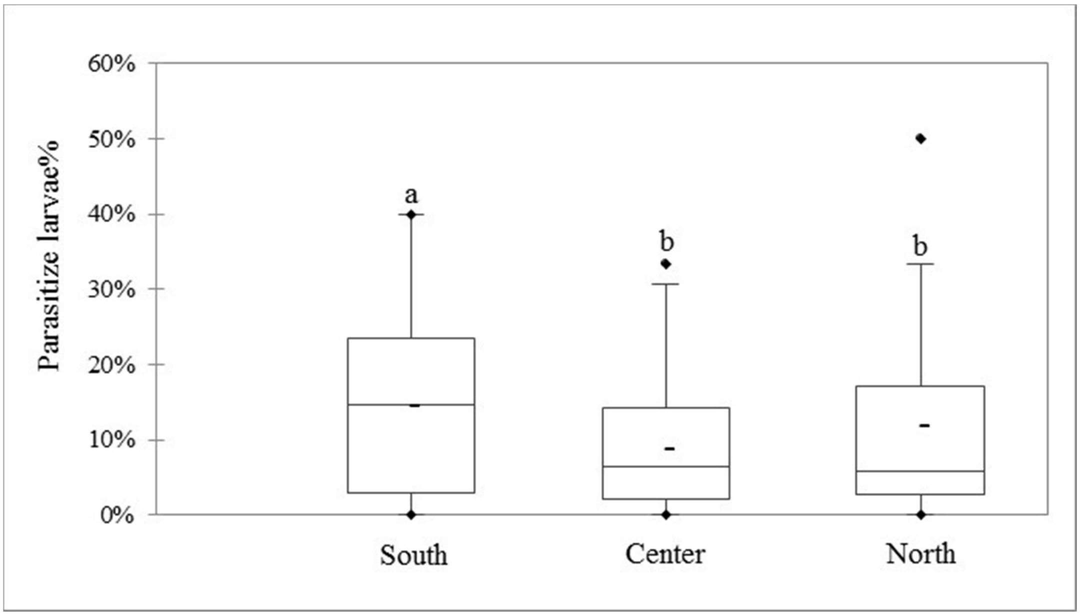

Figure 2: Percentage of *P. xylostella* larvae parasitized in agro-ecological areas. a & b indicate the significant difference in the percentages of parasitism between the zones: $\chi^2 = 23.8$, df = 1, P < 0.0001.

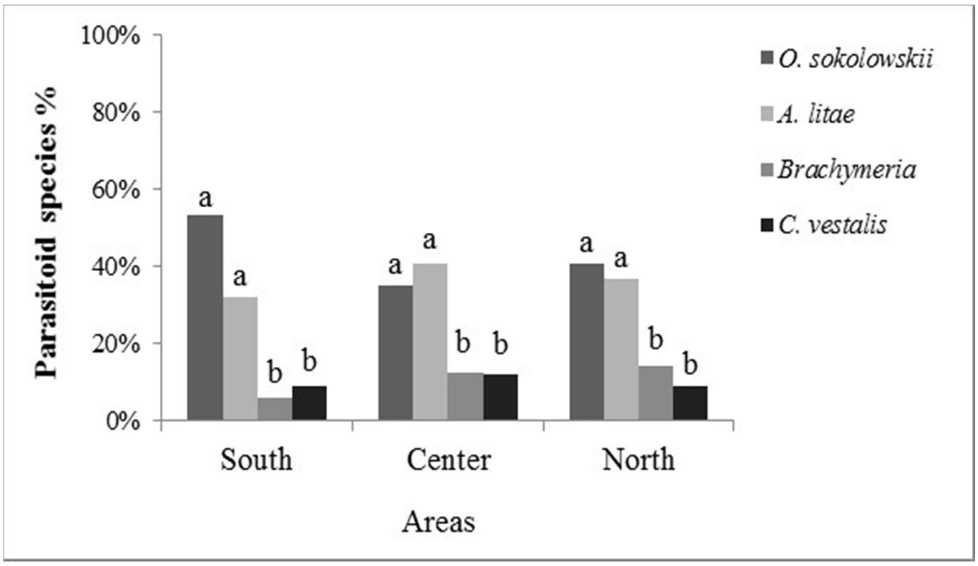

Figure 3: Percentage of parasitism from parasitoid species present in agro-ecological areas. a & b indicate the significant difference in the percentages of parasitism between the parasitoids species.

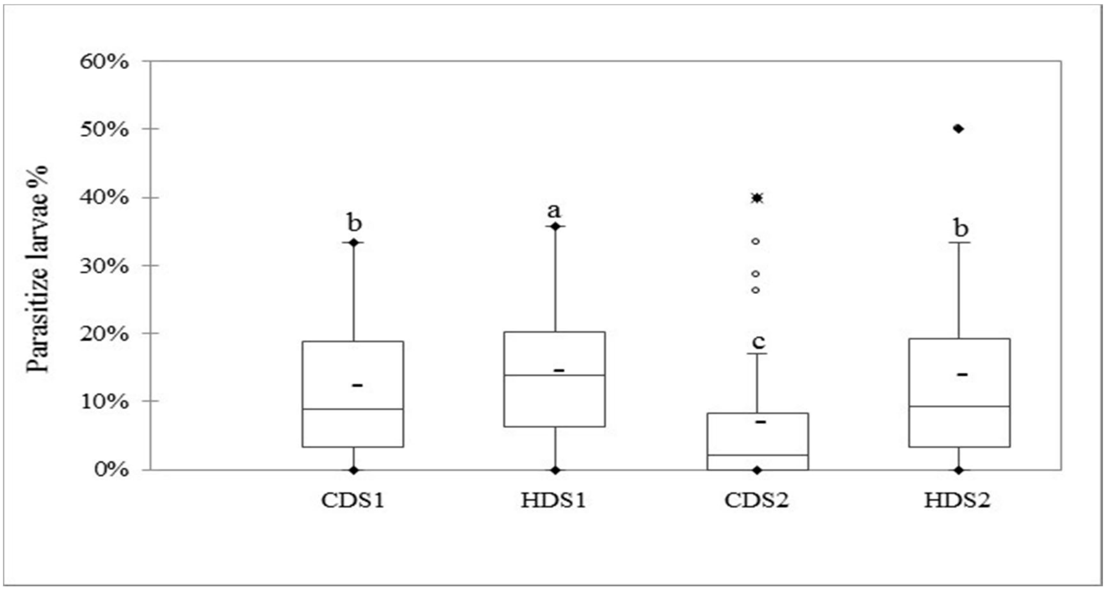

Figure 4: Percentage of parasitized larvae by the four hymenopteran species on the four seasons. a, b & c indicate the significant difference in the percentages of parasitism between the seasons: (χ^2 =118,042, df = 3, P < 0.0001).

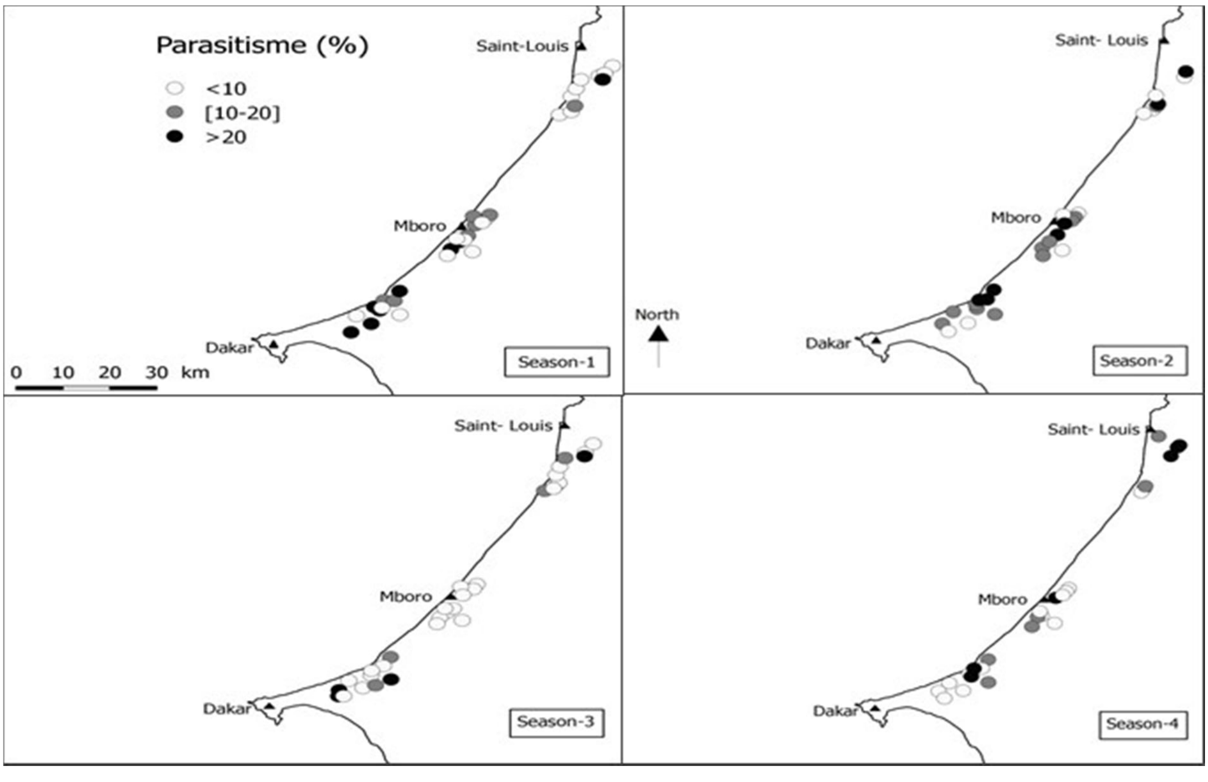

Figure 5: Percentage of parasitism obtained in the Niayes area during the sampling seasons (2012-2013 and 2013-2014).

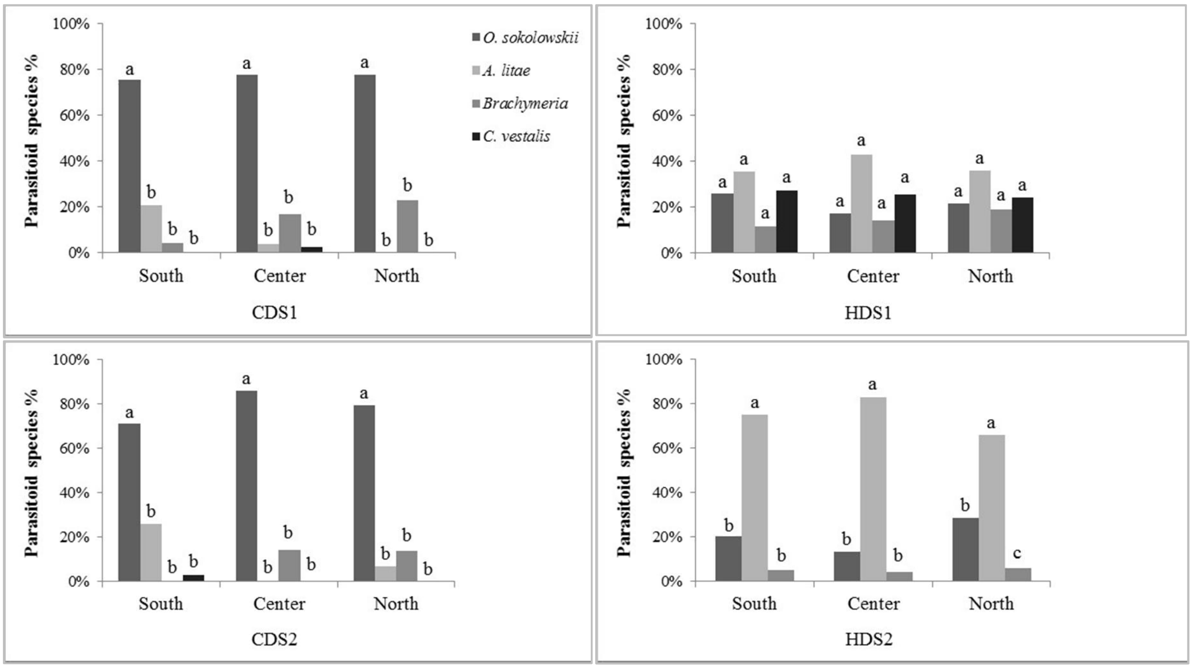

Figure 6: Distribution of collected parasitoids during sampling. a & b indicate the significant difference in the percentages of parasitism between the parasitoid species according to the seasons.

DISCUSSION

The rate of DBM larvae parasitism by the four hymenopteran species was higher in the south area. Parasitoid populations are usually larger when the host populations are bigger and when cabbages are more infested, because they attract more auxiliaries (Sow et al., 2013a). Additionally, cabbage damages caused by DBM larvae populations appear to have an attractive effect on specific parasitoids. Previous studies have highlighted parasitoid attractions by Brassicaceae plants attacked by pests (Reed et al., 1995; Bukovinszky et al., 2005; Girling et al., 2006). Cabbage damaged by DBM larvae produce a detectable smell retained by parasitoid females, which then easily find their hosts to lay their eggs (Bogahawatte and van Emden, 1996; Potting et al.,1999). This phenomenon is fundamental for of a highly specialized tri-trophic complex. In our study, we noticed that cabbage crops are much more abundant in the south area compared with the other areas. Generally, size of pest populations is related to availability of environmental resources, abundance resources are favorable for pests (Altieri and Nicholls, 2004; Rusch et al., 2012). In the south area farmers produce cabbages all year unlike to the north area where they prefer to grown onion. However, despite the relative lack of resources for pests, parasitism exists in the weak host larvae population of the north area. When host resources decrease by brief interruptions of the crop, a pest population control effect will occur which will be favourable for auxiliaries (Keller and Häni, 2000). The north area of the Dakar Niayes has good growing conditions for several Brassicaceae crops but several sites are not cultivated. This type of environment seems to offer favourable conditions to parasitoids. According to Keller and Häni (2000), nine auxiliary species out of ten need a non-cultivated environment during their life cycle. This cultural practice will also favor parasitoid species cohabitation on the host pest and four parasitoid species were found here in on DBM. Parasitoid cohabitation on a same pest will also prevent super-parasitism effect, and weak parasitism (5%) for each parasitoid does not disrupt the ecological niche for each species.

During this study, we noticed that the distribution for the four parasitoid species increased in consecutive years, in the three investigated ecological areas and during all seasons (cold dry and hot dry). Additionally, the parasitism rate was always higher during the hot dry seasons. Larger areas grown with cabbage during the cold dry seasons may explain this result (Altieri and Nicholls, 2004; Rusch et al., 2012). On the other hand, temperatures of the hot dry season are also very similar to the optimum temperature for DBM (Marchioro and Foerster, 2011; Sow et al., 2013a).

The species *O. sokolowskii* was more frequent during the cold dry seasons in 2013 and 2014. Parasitoid adaptability to temperatures varying between 22 to 28 °C may favor this behavior (Wang et al., 1999; Suêrda et al., 2003). Worldwide distribution of *O. sokolowskii*, reflects the large adaptation capacity of this species according to temperatures, a characteristic that is necessary for efficient biological control (Gruarin, 1998). However, *O. sokolowskii* is also a gregarious endoparasitoiod (several adults in a same pupa), and these parasitic performances are linked to the number of adults, the age of females, and rapid development (Sow et al., 2013b). Additionally, this species attacks all DBM larval stages (Sow et al., 2013b), resulting in high efficacy during the host larval cycle duration. However, *O. sokolowskii* can be a facultative hyperparasitoid of *C. vestalis* (Liu et al., 2000) and therefore harm to the population development of this latter species which were very low during the two cold dry seasons.

During the 2013 hot dry season, the population sizes of the four parasitoid species were similar. The populations of *C. vestalis* were very low if not absent during the cold dry season but the parasitism rate of this species was near 30% during the hot dry season. Humidity during the hot dry season appears to be critical for this behavior (Arvanitakis et al., 2014). During this same season, *A. litae* showed a parasitism rate of 75% in the three areas (south, center and north), which was higher than the one, observed for the other three parasitoids. During this period, climate was favorable for this species whose optimum development occurs at 25 °C and low humidity (Sow et al., 2013a). *Brachymeria* sp the DBM pupal parasitoid identified in this study, is a facultative generalist hyperparasitoid attacking hymenopteran (Liu et al., 2000). This insect had a low parasitism rate during all seasons, whatever the agro-ecological areas and the sampling year, with the exception of the 2013 cold dry season when its parasitism rate reached 20%. The north area of the Niayes has more semi-naturals habitats, wilderness, hedges and non-cultivated lands, than the south and center areas. These semi-naturals habitats contain a lot of beneficial arthropod species and supply a more stable environment than the monocultures environments (Altieri and Nicholls 2004; Bianchi*et* al., 2006; Médiène et al., 2011).

However, in our study *C. vestalis* and *Brachymeria* sp had the lowest parasitism rate among the four parasitoids species and their presence in the Niayes area is uncertain (Sow et al., 2013a). However, a new DBM larval parasitoid species was reported for the first time in Senegal in 2014: *Diadegma insulare* (Cresson) Hymenoptera; Ichneumonidae. This species was initially collected in the Dakar area (at Dalifort and Maristes) in 2015 at Gorom, and in 2016 at Mboro (Labou et al., 2016). A survey of this species will soon be undertaken to investigate its acclimation and distribution in Senegal.

Conclusion

Data described in this paper clearly showed that DBM parasitoid species play a critical role in control of this pest of cabbage. Because parasitism rates could reach up to

50% per plot, parasitoids are the best solution for biological control of this pest in an agricultural area where use of pesticides is the most common control method. However, the parasitoid species have a few effect on the DBM larval populations. Consequently, biological control by preservation is needed to protect natural local enemies. The farmers must have a protective behavior regarding these auxiliaries, which play a key role in the natural pest regulation and which are often the first victims of pesticides treatments. Therefore, the farmers need to promote cultural diversification to avoid monoculture and take advantage of biodiversity in a stable ecological environment.

COMPETING INTERESTS

The authors state that they have no conflict of interest.

AUTHORS' CONTRIBUTIONS

BL wrote the experimental protocol, contributed to the surveys, contributed to data statistical analysis and the writing of the first draft of the article; DB wrote the experimental protocol, contributed to data statistical analysis and the writing of the first draft of the article; TB, wrote the experimental protocol, participated to the logistics management, contributed to data statistical analysis and the writing of the first draft of the article; KD supervised the surveys.

ACKNOWLEDGEMENTS

We would like to thank E. Tendeng and A. Dia, and the FPMN (*Fédération des Producteurs Maraîchers de la zone des Niayes*) for helping us with the farmers' survey, the field monitoring and the insect collection.

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