International Journal of Agricultural Sciences ISSN: 2167-0447 Vol. 5 (3), pp. 610-615, May, 2015. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Seasonal occurrence of *Plutella xylostella* (Lepidoptera: Plutellidae) and its associated natural enemies in major crucifer growing areas of Kenya

Moses G. Balala

Department of Crop Science, Faculty of Agriculture, Jomo Kenyatta University of Agriculture and Technology, Kenya.
E-mail: balala33@jkuat.ac.ke

Accepted 25 April, 2015

Seasonal incidences of *Plutella xylostella,* diamondback moth (DBM) and its associated natural enemies were investigated in two agro-ecological zones of the major crucifer growing areas of Kenya in 2005 and 2006. DBM larvae and pupae were collected from the cabbage and kale crops grown in farmers' field and maintained in the laboratory for the emergence of parasitoid or DBM. Four larval, one larval-pupal and one pupal parasitoid species were recorded from DBM. The parasitoids recovered were *Diadegma semiclausum, Diadegma mollipla, Itoplectis* spp., *Cotesia plutellae, Apanteles* spp., *Oomyzus sokolowskii* and *Brachymeria* species. *D. semiclausum* was the most dominant species throughout with highest parasitism rates of over 70% recorded in the highlands. *C. plutellae*, *Apanteles* and *Brachymeria* were recovered from mid-altitude semi-arid areas. Generally, parasitism was significantly higher on *Brassica oleracea* var. *capitata*. *D. semiclausum* displaced the indigenous parasitoids from *B. oleracea* var. *capitata.*

Key words: *Brassica oleracea*, parasitoids, diamondback moth, seasons, agro-ecological zones.

INTRODUCTION

Diamondback moth (DBM) *Plutella xylostella* Linnaeus is the most important pest of cultivated crucifers worldwide (Talekar and Shelton, 1993). Its exceptional pest status is due to the diversity and abundance of the host plants, most common disruption of its natural enemy's communities by application of broad-spectrum insecticides, its high reproductive potential and genetic elasticity facilitating rapid development of pesticide resistance (Mohan and Gujar, 2003; Vickers et al., 2004; Shelton, 2004). The pest has developed resistance to most chemical and bacterial insecticides (Kibata, 1996).In one of the recent classical biological control efforts, *Diadegma semiclausum* Hellén (Hymenoptera: Ichneumonidae) was imported from Taiwan and released in the highland areas of Kenya. In addition, a *Cotesia plutellae* (Kurdjumov) (Hymenoptera: Braconidae) biotype from South Africa was released in 2004 in mid-altitude semi-arid areas. *D. semiclausum* has successfully established and it is providing excellent control of DBM (Löhr et al., 2007). This has resulted in reducing insecticide application by farmers, while others have stopped spraying against DBM altogether in the highland areas where *D. semiclausum* was released. However, *C. plutellae* has not established in the mid-altitude semi arid areas, 2 years after the release since very few individuals were recovered. However, presence of other cabbage pests such as aphids during the dry season might necessitate pesticide application (Oruku and Ndung'u, 2001). The use of broad-spectrum insecticides may be detrimental to the introduced parasitoids and result in pest resurgence as observed in Asia (Verkerk and Wright, 1997). It is presumed that presence of wild crucifers in field margins can prevent large-scale elimination of parasitoids and thus, stabilize the crucifer growing system.

The alternate wild crucifers found harbouring DBM and its natural enemies were *Raphanus raphanistrum*, *Erucastrum arabicum*, *Rorippa micrantha, Rorippa nudiuscula, Brassica juncea* and *Sisymbrium officinale.* However, the numbers varied from one species to another.

MATERIALS AND METHODS

Study sites

Two sites each from highland and mid-altitude semi-arid crucifer growing areas were selected for DBM and parasitoid studies in 2005 and 2006. The highland sites were located in Central Province of Kenya and comprised of Naro Moru at an altitude of 1893 to 2293 m and Kinangop at 2343 to 2749 m. Maximum temperature ranged between 22 and 30°C and minimum temperature between 10 and 15°C. The areas receive bimodal rainfall, ranging from 1500 to 2000 mm per annum. The long rains occur between March and June and short rains between October and December. The soils are mostly of volcanic origin and relatively fertile. Both cabbage and kale are grown in the region with the former being the dominant crop.

The mid-altitude semi arid areas were located in Eastern Province of Kenya and comprised of Yatta at 1220 to 1290 m and Athi River at 1457 to 1527 m. Maximum temperature ranged between 25 and 32°C and minimum temperature between 5 and 20°C. The areas receive 500 to 900 mm rainfall per annum. Rainfall is unreliable and farmers supplement by irrigation. Black cotton soils are predominant in both areas. As temperature is usually too high for head cabbage, kale is the crop grown in both areas.

Sampling of *DBM* on cultivated crucifers

A total of 35 and 25 fields were sampled during each visit from the highland and mid-altitude semi-arid areas, respectively. The difference in number of fields was due to the low number of cultivated kale fields in the latter. In the highlands, sampling fields were selected at an interval of 2 to 4 km because of the large area under cabbage crop unlike in mid-altitude areas where most of the kale fields were located close to each other along the river valley of Athi River and irrigation canal of Yatta. DBM was sampled on cabbage *Brassica oleracea* var *capitata* L. in the highlands and on kale, *B. oleracea* var. *acephala* L. in the mid-altitude semi arid areas. Twenty (20) cabbage or kale crops were selected at random and physically checked for presence of DBM. The number of DBM larvae and pupae found on each plant were recorded. All 3^{rd} and 4^{th} instar DBM larvae and pupae collected from each field were kept in labelled plastic containers and taken to the laboratory. They were lined with tissue paper to absorb excess moisture and closed with cap containing a fine muslin cloth to facilitate ventilation. The larvae were kept at room temperature (23 ± 2°C), 50 to 70% Relative humidity and a photoperiod of 12:12 (L:D) h and fed on respective crop where necessary until pupation. The pupae were then placed individually in clean plastic vials, plugged with cotton wool and observed daily for DBM or parasitoid emergence. The parasitoids species were identified, adults sexed and recorded. The number of parasitoids emerging from single cocoon in gregarious species was recorded.

Data analysis

The data on DBM counts recorded from *B. oleracea* var. *capitata* and *B. oleracea* var. *acephala* was first transformed using SQRT (x + 1) before analysis and then subjected to Proc GLM linear model for analysis (SAS Institute, 2004). The means were separated using the Student Newman Keuls (SNK) test (Sokal and Rohlf, 1995). Parasitism rates for solitary parasitoids were calculated as the sum of parasitoids divided by total number of adults (DBM + parasitoids)*100, while that of gregarious parastoids as sum of parasitised cocoons/(DBM + cocoons)*100.

RESULTS

Incidence of DBM on cabbage and kale

DBM populations varied significantly between seasons in the highlands and mid-altitude semi-arid areas in 2005 and 2006 (Table 1). The population in Kinangop differed significantly (F = 169.2; df = 3, 1401; P < 0.0001 and F = 63.5; df = 3, 1391; P < 0.0001) between seasons in 2005 and 2006, respectively. The highest mean of 3.6 and 2.0 DBM/plant was recorded during the hot dry season in 2005 in Kinangop and Naro Moru, respectively, while the lowest during the short rains (0.24 DBM/plant) and cold dry season (0.27 DBM/plant) in Naro Moru and Kinangop, respectively. However, in 2006, a higher mean of 1.5 and 1.0 DBM/plant was recorded from Kinangop and Naro Moru during the hot dry and long rain seasons, respectively, while the lower mean was 0.4 and 0.3 DBM/plant during the short rain season in Kinangop and Naro Moru, respectively. When the data was pooled together, Kinangop had higher DBM population than Naro Moru in 2005, whereas there was no difference in population in 2006.

In the semi-arid areas, Athi River recorded significantly higher DBM populations than Yatta in both years (Table 2). The DBM population in Athi River differed significantly (F = 79.25; df = 3, 1016; P < 0.0001, and F = 53.24; df = 3, 986; P < 0.0001) between seasons in 2005 and 2006, respectively. Significant differences (F = 60.66; df = 3, 1016; P < 0.0001,and F = 72.48; df = 3, 1006; P < 0.0001) were also observed in Yatta in 2005 and 2006. The highest population of 5.2 DBM/plant was recorded in Athi River during the long rainy season of 2005, while the lowest was 0.6 DBM/plant during the hot dry season of 2006. In Yatta, the highest mean of 2.9 DBM/plant was recorded during the long rainy season of 2006, while the lowest was 0.6 DBM/plant during the short rain season of 2005. When the data on DBM population was pooled together in each year, higher DBM per plant were recorded in Kinangop than Naro Moru in both years. The population was significantly (F = 40.02; df = 1.2724; P <0.0001) higher in the former than the latter in 2006,

Table 1. Seasonal variation of DBM on *B. oleracea* var. *capitata* in the highland crucifer growing areas of Kenya.

Site	Seasons	2005	2006
		DBM/plant ± SE	DBM/plant ± SE
Naro Moru	Hot dry	1.99 ± 0.13[a]	0.66 ± 0.06[b]
	Long rains	0.76 ± 0.07[b]	1.01 ± 0.07[a]
	Cold dry	0.96 ± 0.09[b]	0.93 ± 0.07[a]
	Short rains	0.24 ± 0.04[c]	0.33 ± 0.03[c]
	Yearly average	0.98 ± 0.05[(b)]	0.72 ± 0.03[(a)]
Kinangop	Hot dry	3.62 ± 0.20[a]	1.52 ± 0.13[a]
	Long rains	0.55 ± 0.05[c]	0.27 ± 0.04[c]
	Cold dry	0.27 ± 0.03[d]	1.07 ± 0.08[b]
	Short rains	2.20 ± 0.04[b]	0.41 ± 0.04[c]
	Yearly average	1.66 ± 0.08[(a)]	0.82 ± 0.04[(a)]

For each site and year, means within a column followed by the same letter do not differ significantly at P < 0.05 (SNK). The means in brackets (between sites) within a column followed by the same letter do not differ significantly at P < 0.05 (SNK).

Table 2. Seasonal variation of DBM on *B. oleracea* var. *acephala* in mid-altitude semi-arid crucifer growing areas of Kenya.

Site	Seasons	2005	2006
		DBM/plant ± SE	DBM/plant ± SE
Athi River	Hot dry	1.39 ± 0.12[c]	2.50 ± 0.18[a]
	Long rains	5.20 ± 0.33[a]	2.25 ± 0.13[a]
	Cold dry	2.77 ± 0.18[b]	0.58 ± 0.10[c]
	Short rains	1.49 ± 0.11[c]	1.49 ± 0.13[b]
	Yearly average	2.75 ± 0.12[(a)]	1.72 ± 0.07[(a)]
Yatta	Hot dry	0.36 ± 0.02[d]	1.25 ± 0.12[b]
	Long rains	1.06 ± 0.12[b]	2.85 ± 0.19[a]
	Cold dry	2.05 ± 0.16[a]	0.73 ± 0.10[c]
	Short rains	0.60 ± 0.08[c]	0.72 ± 0.10[c]
	Yearly average	1.01 ± 0.06[(b)]	1.38 ± 0.07[(b)]

For each site and year, means within a column followed by the same letter do not differ significantly at P < 0.05 (SNK) test. The means in brackets (between sites) within a column followed by the same letter do not differ significantly at P < 0.05 (SNK) test.

while in 2005 it was not significantly different (F = 0.93; df = 1.2333; P = 0.34). Significantly (*F* = 225.8; df =1,2258; P < 0.0001, and *F* = 17.38; df = 1.1998; P < 0.0001). Higher DBM per plant was recorded in Athi River than at Yatta in 2005 and 2006, respecively. The means between Athi River and Yatta were 2.75 and 1.01, and 1.72 and 1.38 in 2005 and 2006, respectively.

Parasitoid fauna on cabbage and kale

Altogether, six primary parasitoid species consisting four larval parasitoids, *D. semiclausum* and *Diadegma mollipla* (Holmgren) (Ichneumonidae), *C. plutellae* (Kurdjumov) and *Apanteles* sp. (Braconidae), one larval-pupal, *Oomyzus sokolowskii* (Kurdjumov) (Eulophidae), and one pupal parasitoid, *Brachymeria* sp. (Chalcidae) were recovered from DBM (Tables 3 and 4). More parasitoid species were recovered in mid-altitude areas than in the highland areas. *D. semiclausum* was the dominant and abundant species in both highland and mid-altitude areas representing over 80% of the total number recorded.

D. semiclausum dominated in the highlands throughout the sampling period of 2005 and 2006 (Table 3). Parasitism in Naro Moru ranged between 70.1 and 84.5%, and 63.8 and 77.8% during the hot dry and short rain season in 2005 and 2006, respectively. However, in

Table 3. DBM parasitoids and seasonal variation (Mean ± SE) of parasitism on *B. oleracea* var. *capitata* in highland areas of Kenya.

Year	Parasitoid species	Naro Moru: Hot dry	Naro Moru: Long rains	Naro Moru: Cold dry	Naro Moru: Short rains	Kinangop: Hot dry	Kinangop: Long rains	Kinangop: Cold dry	Kinangop: Short rains
2005	*D. semiclausum*	70.1 ± 4.88^{a}	70.4± 3.42^{a}	71.7 ± 3.6^{a}	84.5 ± 4.6	45.2 ± 4.15^{a}	76.0 ± 4.0	63.3 ± 5.76	62.5 ± 4.01
	D. mollipla	0	0	0	0	3.1 ± 3.12^{b}	0	0	0
	Itoplectis sp.	3.2 ± 3.12^{b}	0	0	0	0	0	0	0
	O. sokolowskii	1.2 ± 1.12^{b}	0.4± 0.4^{b}	0.4 ± 04^{b}	0	0.2 ± 0.20^{b}	0	0	0
2006	*D. semiclausum*	68.9 ± 4.22	60.3± 4.05^{a}	63.8 ± 3.96^{a}	77.8 ± 4.15^{a}	56.5 ± 4.26	78.3 ± 5.79	51.1 ± 3.85^{a}	74.5 ± 4.68^{a}
	D. mollipla	0	0	0.57 ± 0.43^{b}	0.6 ± 0.59^{b}	0	0	3.6 ± 1.75^{b}	2.24 ± 1.57^{b}
	Itoplectis sp.	0	0.61± 0.61^{b}	0	0	0	0	0	0
	O. sokolowskii	0	0	0.91 ± 0.64^{b}	0	0	0	0.3 ± 0.26^{c}	0.5 ± 0.58^{c}

*Means within a column followed by the same letter do not differ significantly at P<0.05, PROC GLM (SNK test).

Table 4. DBM parasitoids and seasonal variation (Mean ± SE) of parasitism on *B. oleracea* var. *acephala* in mid-altitude semi-arid crucifer growing areas of Kenya.

Year	Parasitoid species	Athi River: Hot dry	Athi River: Long rains	Athi River: Cold dry	Athi River: Short rains	Yatta: Hot dry	Yatta: Long rains	Yatta: Cold dry	Yatta: Short rains
2005	*D. semiclausum*	0	0	25.5 ± 4.6^{a}	32.1 ± 5.8^{a}	0	0.4 ± 0.4^{b}	29.6 ± 6.2^{a}	40.3 ± 9.2^{a}
	D. mollipla	3.1 ± 2.9^{a}	7.2 ± 3.6^{a}	9.0 ± 2.3^{c}	0.8 ± 0.6^{b}	1.4 ± 1.4^{b}	10.4 ± 6.3^{ab}	9.1 ± 4.2^{b}	5.1 ± 4.4^{b}
	O. sokolowskii	7.2 ± 3.0^{a}	2.3 ± 1.2^{ab}	16.3 ± 2.9^{b}	10.2 ± 2.4^{b}	15.8 ± 6.3^{a}	21.2 ± 7.5^{a}	7.4 ± 2.2^{b}	2.6 ± 1.6^{b}
	Apanteles sp.	0	3.6 ± 1.6^{ab}	4.5 ± 1.6^{c}	4.2 ± 1.6^{b}	0	1.6 ± 0.9^{b}	0	0.4 ± 0.4^{b}
	C. plutellae	0		0	0	0	0	0	0
	Brachymeria sp	0	1.4 ± 1.0^{ab}	0	0	0	0.4 ± 0.4^{b}	0	0
2006	*D. semiclausum*	9.6 ± 3.4^{a}	30.4 ± 5.7^{a}	52.3 ± 8.2^{a}	63.8 ± 5.5^{a}	16.1 ± 5.3^{a}	33.0 ± 5.2^{a}	47.2 ± 8.0^{a}	42.7 ± 7.0^{a}
	D. mollipla	0.5 ± 0.5^{b}	5.1 ± 2.2^{b}	0	0	0	11.9 ± 2.8^{b}	3.1 ± 2.5^{b}	3.7 ± 1.6^{b}
	O. sokolowskii	1.8 ± 1.2^{b}	4.9 ± 2.1^{b}	7.7 ± 3.4^{b}	1.9 ± 1.1^{b}	1.8 ± 1.5^{b}	1.9 ± 0.7^{c}	3.3 ± 2.0^{b}	0
	Apanteles sp.	4.9 ± 2.3^{ab}	5.1 ± 1.5^{b}	0	0.2 ± 0.1^{b}	6.8 ± 4.7^{b}	4.0 ± 2.1^{c}	1.3 ± 0.9^{b}	0
	C. plutellae	1.1 ± 0.5^{b}	26.9 ± 7.1^{a}	0	1.3 ± 0.8^{b}	0	0.5 ± 0.3^{c}	0	0
	Brachymeria sp	0.1 ± 0.1^{b}	0.7 ± 0.5^{b}	0	1.1 ± 0.5^{b}	1.3 ± 0.8^{b}	2.0 ± 0.7^{c}	0	0.9 ± 0.6^{b}

Means within a column followed by the same letter do not differ significantly at P < 0.05, PROC GLM, (SNK test).

Kinangop, parasitism ranged between 45.2 and 76% during the hot dry and long rainy season, respectively in 2005, while in 2006, between 51.1 and 78.3% during the cold dry and long rainy seasons, respectively. In Kinangop, *D. semiclausum* was the only parasitoid recovered during the long rains,cold dry and short rain seasons of 2005. *D. mollipla* was recovered in both sites in 2006 during the cold dry and short rain seasons, while in 2005, it was only recovered in Kinangop during the hot dry season. *Itoplectis* sp. (Ichneumonidae) was recovered from Naro Moru during the hot dry and long rainy seasons of 2005 and 2006, respectively, while none in Kinangop. However, the numbers were relatively low. Parasitism by *O. sokolowskii*, a larval-pupal parasitoid was low and ranged between 0 and 1.2%. No parasitoid was recovered during the short rains in 2005, while in 2006 it was only there during the cold cry season in Naro Moru. In Kinangop, *O. sokolowskii* was recovered during the hot dry season of 2005 and cold dry and short rains of 2006.

Six primary parasitoid species viz., *D. semiclasusm, D. mollipla, O. sokolowskii, Apanteles* sp., *C. plutellae* and *Brachymeria* were collected from kale in Yatta and Athi River (Table 4). *D. mollipla* and *O. sokolowskii* were the dominant species in 2005. However, in 2006, *D. semiclasusm* became the most dominant species and recovery was throughout the year. Recovery of *D. semiclausum* started in Yatta during the long rainy season of 2005 followed by Athi River during the cold dry season. Parasitism ranged between 9.6 and 63.8% during hot dry and short rain seasons of 2006. *C. plutellae* was not recovered in 2005 from both Athi River and Yatta despite its initial release in March, 2005. The parasitoid was only recovered during the long rains of 2006 from Yatta with parasitism rates of 0.5%, while in Athi River, the parasitoid was recovered throughout except during the cold dry season with parasitism rates ranged between 0 and 26.9% during the cold dry and long rainy seasons. *O. sokolowskii* was recovered all through in Athi River and Yatta with an exception of shrt rain season of 2006 in Yatta. The parasitism rates were significantly higher in 2005 than 2006 in both sites. *Brachymeria* species, a pupal parasitoid was recovered during the long rains of 2005 in both sites, while in 2006, none was recovered during the cold dry season. *Apanteles* species was present in both sitesof the mid-altitude areas. Parasitism ranged between 3.6 and 4.5%, and 0.2 and 5.1% in Athi River and 0.4 and 1.6%, and 1.3 and 6.8% in Yatta in 2005 and 2006, respectively. Incidence of other parasitoids decreased with the increase in *D. semiclausum* parasitism.

Total parasitism for the 2 years combined was significantly higher in the highland areas than in the mid-altitude semi areas. Kinangop recorded the highest parasitism rates of 71% compared to 63% in Naro Moru on cabbage while in the mid-altitude semi arid areas, Yatta had 43% compared to 41% in Athi River. Overall, *D. semiclausum* accounted for highest parasitism rates in the four sites. The sex ratio of *O. sokolowskii* wasps that emerged from the parasitised pupae of DBM were female biased. Females constituted 70% of the total number of adults and very few pupae produced females only. The number of parasitoids per pupa ranged between 3 and 17 and a pupa had a mean of 9.2 adult wasps.

Other pests and diseases

Apart from DBM, a wide range of other pests and diseases were associated with *B. oleracea* var *capitata* and *B. oleracea* var. *acephala*. They were cabbage aphid *Brevicoryne brassicae* L., the false cabbage aphid *Lipaphis erysimi* Kaltenbach (both Homoptera: Aphididae), cabbage looper *Trichoplusia ni* Hubner. (Lepidoptera: Noctuidae), African bollworm *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae), cabbage sawfly *Athalia* sp. (Hymenoptera: Tenthredinidae), cabbage webworm *Hellula undalis* Fabricius (Lepidoptera: Pyralidae), whiteflies *Aleyrodes proletella* L. (Homoptera: Aleyrodidae), thrips *Frankliniella* spp. (Thysanoptera: Thripidae), leaf miner *Liriomyza brassicae* (Riley) (Diptera: Agromyzidae), flea beetles *Phyllotreta cruciferae* Goeze (Coleoptera: Chrysomelidae), red spider mite *Tetranychus urticae* Koch., bagrada bug *Bagrada cruciferarum* Kirkaldy (Hemiptera: Pentatomidae) and *Spodoptera exigua* Hubner (Lepidoptera: Noctuidae). The diseases *Erysiphe cruciferam* Opiz ex L. Junell and downy mildew, *Peronospora parasitica* (Pers.) Fr., were more prevalent during the cold season.

DISCUSSION

DBM population was generally lower in 2005 and 2006 than those reported earlier on cabbage in highland growing areas with similar growing conditions (Oruku and Ndung'u, 2001). The reason for the relatively lower DBM population in Naro Moru than Kinangop might have been the time difference in parasitoid release between the two sites. Parasitoids were released 8 months earlier in Naro Moru than Kinangop. The introduction of an exotic larval parasitoid, *D. semiclausum* into the areas about 2 years before the research was conducted and could have contributed to the low DBM numbers. DBM populations were higher on kale than on cabbage. This could have been the difference in the releasing of parasitoids in the two agro-ecological areas; *D. semiclausum* and *C. plutellae* were released in the highlands and mid altitude areas in 2003 and 2005, respectively. There was also a general decline in DBM numbers from 2005 to 2006 in the highland areas most probably it is still attributed to the faster establishment of the exotic parasitoids. Higher DBM numbers per plant in Yatta than Athi River could be due to the relatively lower parasitoid numbers recovered.

The number of parasitoids in the cabbage growing areas was significantly higher than in kale growing areas. These could be due to continuous cabbage growing all the year round and abundance of wild crucifer species. Parasitoids strongly respond to vegetation complexity (Marino and Landis, 1996). However, the difference in parasitoid numbers and assemblage may be related to climatic variations. The continuous cropping in the highlands may be partly offering a more stable environment where both DBM and its parasitoids co-exist for a long time. Large patches observed in the cabbage growing areas with wild crucifers may have contributed to high parasitoid numbers. Important effects of flowering weeds include increased attraction, retention, parasitism and efficiency of natural enemies in the fields. In Michigan, presence of wild flowers surrounding the field influenced parasitism rates by *Diadegma insulare* (Idris and Grafius, 1993).

Very low numbers of *D. mollipla* were recovered from kale, none from Naro Moru and only one wasp from Kinangop on cabbage. Some of the main reasons that could have led to include *D. mollipla* is considered relative generalist, the species is reported to be indigenous to eastern and southern Africa, and apart from attacking DBM, it is also a parasitoid of potato tuber moth *Pytothorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) on potato. It was observed that *D. mollipla* was the most abundant species of DBM in East African highlands. However, overall field parasitism was less than 20%, with *D. mollipla* accounting for 9%. The parasitoid was also recovered from DBM on snow peas, where it recorded significantly higher parasitism rates compared to that of DBM on cabbage. Lack of intrinsic cues to accept the host plant of DBM may also explain the generally low parasitism rates observed in the laboratory (Akol et al., 2003). *D. mollipla* was not attracted by the chemical odours produced by kale and this could have contributed to the low parasitism rates (Rossbach et al., 2005). Absence of *D. mollipla* on cabbage in the highlands 2 years after the introduction of *D. semiclausum* could be due to stiff competition the parasitoid is facing from *D. semiclausum*, which is known as a DBM specialist with a high searching efficiency (Wang and Keller, 2002). This could have forced *D. mollipla* to search for DBM from the wild crucifers, which are the alternative hosts.

O. sokolowskii is a gregarious larval-pupal parasitoid that attacks DBM and has been introduced in tropical and subtropical regions to control DBM where it is adapted to high temperature conditions (Fitton and Walker, 1990; Talekar and Hu, 1966). They were abundant in the mi-altitude semi-arid areas throughout the sampling period, while in the highlands their occurrence was mainly during the hot seasons. Parasitism rates ranged between 0 and 21.2% in the mid-altitude semi-arid areas and, 0 and 1.2% in the highlands. Parasitism by *O. sokolowskii* decreased with the increase in parasitism rates by *D. semiclausum*. This could be due to the low number of fourth instar DBM larvae and pupae available for *O. sokolowskii* to parasitize. Previous findings shows that *D. semiclausum* is very competitive and displaced or decimated the indigenous parasitoids from cabbage fields even before it had become firmly established in the highlands of Kenya. Overall higher parasitism rates by *D. semiclausum* could have been due to different responses to host defenses (Wang and Keller, 2002). It was observed that *D*. *semiclausum* displayed a wide-area searching behaviour around feeding and damaged leaf section of the crucifer and waited near the silk thread for the suspended DBM larvae to climb up to the leaf, then attacked it again, while *C. plutellae* displayed an area-restricted searching behaviour and usually pursued the host down the silk thread onto the ground. This might have led to the DBM larvae not finding its way onto the plant. *D. semiclausum* was also observed to show a relatively fixed behavioral pattern leading to oviposition, while *C. plutellae* exhibited a more plastic behavioral pattern. Wang and Keller (2002) observed that *D semiclausum* visited individual plants more frequently and spent more time than *C. plutellae* before it left the patch and stung hosts at more than twice the rate of *C. plutellae*, which could have contributed to the higher parasitism rates.

Much to our surprise, *D. semiclausum* considered a parasitoid for cool highland areas, and was recovered from the mid-altitude semi-arid areas that are hot and dry. The large numbers recovered show that the parasitoid can thrive under these conditions, even though their seasonality indicates their susceptibility to high temperature conditions. *C. plutellae* was released in March, 2005 in Yatta and Athi River. However, only very low numbers have been recovered since then. On the contrary, the parasitoid has become established within Lake Victoria region and spread over 200 km from the release sites in Uganda into western Kenya (ICIPE, unpublished data). Remarkably also, is the complete absence of hyper-parasitoids in both highland and mid-altitude semi-arid areas, which could have contributed to the successful establishment and spread of the exotic parasitoid *D. semiclausum.*

In conclusion, further research needs to be conducted to investigate the reasons for the poor establishment of *C*. *plutellae* in the semi-arid areas. Competition studies needs to be conducted to find out if presence of *D*. *semiclausum* in the mid-altitude areas has any impact on this. Otherwise the latter seems to control the DBM populations and there is need to reduce the regime of pesticide application. It is our opinion that average parasitism rates of about 60% have significant influence on the pest population dynamics and there is need to reduce pesticide application.

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