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

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ABSTRACT
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' fields 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, D. 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 between 800 and 125 m above sea level (ASL) in the semi arid areas. Generally, parasitism was significantly higher on *B. oleracea* var. *capitata. D. semiclausum* displaced the indigenous parasitoids from *B. oleracea* var. *capitata.*
Keywords: *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 chemicals (Kibata, 1996).

In one of the recent classical biological control efforts which were initiate in 2000 by International Center of Insect Physiology and Ecology (ICIPE), *D. semiclausum* Hellén (Hymenoptera: Ichneumonidae) was imported from Taiwan and released in the highland areas of Kenya in May 2002. 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 in the highland areas of Kenya and Wundanyi and it is providing excellent control of DBM of up to 60% parasitism (Löhr et al., 2007). This has resulted in reduced insecticide application by farmers while others have stopped spraying against DBM altogether in the highland areas such as Naru Moru, Kinangop, and Wundanyi where *D. semiclausum* was released. However, *C. plutellae* has not established in the mid-altitude (1000-1500 m ASL) semi arid areas, two years after the release since very few individuals were recovered. 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 the field margins can provide refugia to parasitoids and thus prevent large-scale elimination of parasitoids and thus stabilize the crucifer growing system. Kahuthia-Gathu *et al*., (2009) observed DBM and its natural enemies on wild crucifers *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 in 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 - 2293 m and Kinangop at 2343 - 2749 m. Maximum temperature ranged between 22 and 30ºC and minimum temperature between 10 and 15 ºC. The areas receive bimodal rainfall, ranging from 1500 to 2000 mm per annum. The long rains occur between March-June and short rains from October to December. The soils are mostly of volcanic origin and relatively fertile. Both cabbage and kale are grown in the region for both commercial and subsistence use, with the former being the dominant crop.

The mid-altitude semi arid areas were located in Eastern Province and comprised of Yatta at 1220 - 1290 m and Athi River at 1457 - 1527m. Maximum temperature ranged between 25 and 32 ºC and minimum temperature between 5 and 20 ºC. The areas receive 500 to 900 mm rainfall per annum. Rainfall in this area is unreliable and farmers supplement water supply 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 for commercial and subsistence use.

Sampling of diamondback moth 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 - 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 valley at Athi River and irrigation canal of Yatta. DBM was sampled on cabbage *Brassica olearacea* var *capitata* L. (Photo 1) in the highlands and on kale, *B. olearacea* var. *acephala* L. (Photo 2) in the mid-altitude semi arid areas. Twenty cabbage or kale crops in each plot were selected at random and physically checked for presence of DBM. The number of DBM larvae (Photo 3) and pupae (Photo 4) found to have infested the kales on each plant were counted and recorded. All third and fourth 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 ºC), 50-70 % Relative Humidity and a photoperiod of 12:12 hours (Light: Darkness) cycle 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.

Photo 1 *Brassica olearacea* var *capitata*

Photo 2: *B. olearacea* var. *acephala*

Photo 3 Diamondback moth larva

Photo 4: Diamondback moth pupa

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: Diamondback moth 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 was 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 for the whole year, higher DBM per plant were recorded in Kinangop than Naro Moru for 2005 and 2006. The population was significantly (*F*=40.02; df= 1, 2724; P<0.0001) higher in the former than the latter in 2006 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.

Table 1: Seasonal variation of DBM on *B. oleracea* var. *capitata* in Naro Moru

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

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

Parasitoid fauna on cabbage and kale: Altogether six primary parasitoid species consisting four larval parasitoids, *D. semiclausum* and *Diadegma mollipla* (Holmgren) (Ichneumonidae), *Cotesia 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 & 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 per cent 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 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. *Diadegma 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) (Photo 8) was recovered from Naro Moru during the hot dry and long rainy seasons of 2005 and 2006, respectively while none was recovered in Kinangop. Parasitism by *O. sokolowskii*, a larval-pupal parasitoid was low and ranged between 0 and 1.2%. No *O. sokolowskii* was recovered during the short rains in 2005 while in 2006 the parasitoid 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* (Photo 5), *D. mollipla, O. sokolowskii* (Photo 7), *Apanteles* sp., *Cotesia plutellae* (Photo 6) 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 ranging 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 short 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 sites of 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 two years combined was significantly higher in the highland areas (Kinangop and Naro Moru) than in the mid-altitude semi areas (Yatta and Athi River). Parasitism rates were highest in Kinangop at 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 the highest parasitism rates in the four sites. The number of *O. sokolowskii* per pupa ranged between 3 and 17 and a pupa had a mean of 9.2 adult wasps with a sex ratio that was female biased. The females constituted 70% of the total number of the adults.

Table 3: Diamondback moth parasitoids and seasonal variation (Mean ± SE) of parasitism on *B. oleracea* var. *capitata* in Naro Moru and Kinangop

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

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

Table 4: Diamondback moth parasitoids and seasonal variation (Mean ± SE) of parasitism on *B. oleracea* var. *acephala* in mid-altitude of Athi River and YAatta

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

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

Photo 5: *Diadegma semiclausum*

Photo 6: *Cotesia plutellae*

Photo 7A: *Oomyzus sokolowskii* (female)

Photo 7B: *Oomyzus sokolowskii* (male)

Photo 8: *Itoplectis* species

DISCUSSION

Diamondback moth population was generally lower in 2005 and 2006 than those reported earlier on cabbage in highland areas of Kenya with similar growing conditions (Oruku and Ndung'u , 2001). The Parasitoids contributed to the low numbers by parasitizing the DBM and thereby reducing the pest populations on the cabbage crop. The reason for this relatively lower DBM population in Naro Moru than Kinangop might have been the time difference in parasitoid release between the two sites. The introduction of an exotic larval parasitoid, *D. semiclausum* into the areas about two years before the research was conducted could have contributed to the low DBM numbers. DBM populations were higher on kale than on cabbage. This could have been the due to different parasitoids species being released 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 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 in these areas. This could be due to lack of kale in the farms all year throughout the year to sustain their establishment, spread, reproduction and survival.

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 *D. 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 these include the following: *D. mollipla* is considered as a generalist parasitoid; 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 had 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 two years after the introduction of *D. semiclausum* could be due to stiff competition between the two parasitoid; *D. Semiclausum* 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.

Oomyzus 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 (Talekar and Hu, 1966; Fitton and Walker, 1990). They were abundant in Yatta and Athi River 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.

Findings by Kahuthia-Gathu et al. (2009) and Lohr et al., (2007) show 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, 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. *Cotesia plutellae* was released in March 2005 in Yatta and Athi River. However, only less than 1 % of the total parasitoid 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 of Kenya. Competition studies need to be conducted to investigate whether presence of *D. semiclausum* in the mid-altitude areas has any impact on the poor establishment and spread of *C. plutellae.*

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REFERENCES

Akol, A. M., Njagi, P. G. N., Sithanantham, S. and Mueke, J. M. (2003). Effects of two neem insecticide formulations on attractiveness, acceptability and suitability of diamondback moth larvae to parasitoid *Diadegma mollipla* (Holmgren) (Hymenoptera: Ichneumonidae). J. Appl. Entomol. 127: 325-331.

Fitton, M. and Walker, A. (1990). Hymenopterous parasitoids associated with diamondback moth: the taxonomic dilemma. In N.S. Talekar (ed.). Diamondback Moth and other Crucifer Pests. Proceedings of the 2nd International Workshop Tainan, Taiwan, 10th-14th December 1990. Asian Vegetable Research and Development Centre. AVDRC Publication No. 92-368.

Idris, A. B. and Grafius, E. (1993). Field studies on the effects of pesticides on the diamondback moth (Lepidoptera, Yponomeutidae) and parasitism by *Diadegma insulare* (Hymenoptera, Ichneumonidae). J. Econ. Entomol. 86: 1196-1202.

Kahuthia-gathu R., Löhr, B., Poehling, H-M. & Mbugua P.K. (2009). Diversity, distribution and role of wild crucifers in major cabbage and kale growing areas of Kenya. Bulletin of Entomological Research. 99 (3), 287-297.

Kibata, G. N. (1996). Diamondback moth *Plutella xylostella* L. (Lepidoptera: Yponomeutidae), a problem pest of Brassicae crops in Kenya. In: Farrell, G., Kibata, G.N. (eds.) *Proc. 1st Biennial Crop Protection Conference* 27th-28th March 1996, Nairobi, Kenya. 1-11.

Löhr, B, Gathu, R., Kariuki, C., Obiero, J. and Gichini, G. (2007). Impact of an exotic parasitoid on *Plutella xylostella* (Lepidoptera: Plutellidae) population dynamics, damage and indigenous natural enemies in Kenya. Bull. Entomol. Res. 97, 337-350.

Marino, P. C. and Landis, D. A. (1996). Effect of landscape structure on parasitoids diversity and parasitism in agroecosystems. Ecol. Applic. 6: 276-284.

Mohan, M. and Gujar, G. T. (2003). Characterization and comparison of midgut proteases of *Bacillus thuringiensis* susceptible and resistant diamondback moth (Plutellidae: Lepidoptera). J. Invert. Pathol. 83: 1-11.

Oruku, L. and Ndung'u, B. (2001). Final socio-economic report for the peri-urban vegetable IPM thematic cluster. CABI Africa Regional Centre Report, Nairobi. 49

Rossbach, A., Löhr, B. and Vidal, S. (2005). Generalism versus specialism: Responses of *Diadegma mollipla* (Holmgren) and *Diadegma semiclausum* (Hellen), to the host shift of the diamondback moth (*Plutella xylostella* L.) to peas. J. Insect Behav. 18: 491-503.

SAS Institute Inc. 2004. Version 9.1 SAS/STAT Users Guide. Vol. 1 and 2. Cary, N C., USA.

Shelton, A. M. (2004). Management of diamondback moth: déjà vu all over again? In: Endersby, N. M., Ridland, P.M. (eds.). The management of diamondback moth and other crucifer pests. Proceedings of the 4th International Workshop, 26-29 November 2001. Department of Natural

Resources and Environment, Melbourne, Australia, 3-8.

Sokal, R. R. and Rohlf, F. J. (1995). Biometry. The Principles and Practice of Statistics in Biological Research. W. H. Freeman & Company, New York.

Talekar, N. S. and Hu, W. J. (1966). Characteristics of parasitism of *Plutella xylostella* (Lepidoptera: Plutellidae) by *Oomyzus sokolowskii* (Hymenoptera: Eulophidae). Entomophaga. 41: 45-52.

Talekar, N. S. and Shelton, A. M. (1993). Biology, ecology and management of the diamondback moth. Ann.l Rev. Entomol. 38: 275-301.

Varela, A. M., Seif, A. A. and Löhr, B. (2003). A guide to IPM in crucifer production with emphasis on Kenya. International Centre of Insect Physiology and Ecology, Nairobi, Kenya.

Verkerk, R. H. J, and Wright, D. J. (1997). Field-based studies with diamondback moth tritrophic system in Cameron Highlands of Malaysia: Implications for pest management. Inter. J. Pest Management. 43: 27-33.

Vickers, R. A., Furlong, M. J., White, A. and Pell, J. K. (2004). Initiation of fungal epizootics in diamondback moth populations within a large field cage: proof of concept of auto-dissimination. Entomol. Expe. Applic. 111: 7-17.

Wang, X. G. and Keller, M. A. (2002). A comparison of host searching efficiency of two larval parasitoids of *Plutella xylostella*. Ecol. Entomol. 27: 105-114.