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ORIGINAL PAPER

Annual cycle of the legume pod borer *Maruca vitrata* Fabricius (Lepidoptera: Crambidae) in southwestern Burkina Faso

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Abstract *Maruca vitrata* is an economically significant insect pest of cowpea in sub-Saharan Africa. Understanding the seasonal population patterns of *M. vitrata* is essential for the establishment of effective pest management strategies. *M. vitrata* larval populations on cultivated cowpea and adult flying activities were monitored in addition to scouting for host plants and parasitoids during 2 consecutive years in 2010 and 2011 in southwestern Burkina Faso. Our data suggest that *M. vitrata* populations overlapped on cultivated cowpea and alternate host plants during the rainy season. During the cowpea off-season, *M. vitrata* maintained a permanent population on the wild host plants *Mucuna poggei* and *Daniella oliveri*. The parasitoid fauna include three species, *Phanerotoma leucobasis* Kri., *Braunsia kriegeri* End. and *Bracon* sp. Implications of these finding for pest management strategies are discussed.

Keywords Cowpea · *Maruca vitrata* · *Mucuna poggei* · *Daniella oliveri* · Parasitoids

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Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) is a grain legume of vital importance to people in West Africa and in many parts of the tropics (Murdock et al. 2008). In Burkina Faso, cowpea is the major legume crop with an average production of over 450,000 tons per year (DPSAA 2013). The average yield is slightly over 450 kg/ha (FAOSTAT 2013) compared with the potential of 2 tons/ha (Singh et al. 1997). This gap is due to several limiting factors including abiotic and biotic stresses. Insect pests are the major biotic constraint for cowpea production in sub-Saharan Africa (Singh and Allen 1980; Singh et al. 1990). These include the legume pod borer, *Maruca vitrata* Fab. (Lepidoptera, Crambidae), one of the most devastating insect pests of cowpea in sub-Saharan Africa (Taylor 1967, 1978; Okeyo-Owuor et al. 1983). The *M. vitrata* larvae cause economic losses on cowpea by feeding on the tender parts of the stem, peduncles, flower buds, flowers and pods (Singh and Jackai 1988). The yield losses range between 20 and 80 % (Singh et al. 1990). *M. vitrata* damage has been reported in all agro-ecological zones of Burkina Faso (Ba et al. 2009); however, losses due to this pest species are highest in the southwestern part of the country (Ba et al. 2009; Baoua et al. 2011).

A variety of approaches have been developed for the control of *M. vitrata* including host plant resistance, cultural management, biological control and biopesticides (Adati et al. 2008) with limited success and applicability (Bottenberg and Singh 1996; Fatokun 2002; Asiwe et al. 2005; Asiwe 2009). Consequently, the West Africa region is seeking other strategies for managing *M. vitrata*. These include biological control using exotic parasitoids (Dannon et al. 2010, 2012) as well as development and deployment of Bt-cowpea expressing the Cry1Ab toxin of *Bacillus thuringiensis* Berliner (Huesing et al. 2011). However, regardless of the management practices to be deployed, it is essential to have a better understanding of the bioecology of *M. vitrata*, especially the annual cycle with regard to host plants and natural enemies. Comprehensive data on the annual cycle of *M. vitrata* are available for the humid zones of West Africa (Bottenberg et al. 1997; Tamò et al. 2002; Arodokoun et al. 2003, 2006), but very little work has, so far, been conducted in the Sahelian zone (Ba et al. 2009; Margam et al. 2010). Thus, the current study is focused on a better understanding of the pest dynamics and identification of the alternate host plants on which *M. vitrata* survives during season(s) when cowpea is not grown in the area. In addition, we also investigated the parasitoid fauna associated with *M. vitrata* in southwestern Burkina Faso.

Materials and methods

Study environment

The experiments were conducted on the research station of the Institute of Environment and Agricultural Research (INERA) at Farkoba in southwestern Burkina Faso (latitude: 11°11′N, longitude: 04°18′W) during 2 successive years, 2010 and 2011. Burkina Faso has a unimodal rainfall pattern, and the rainy season lasts from June to October. Total rainfalls of 1,289.5 and 831 mm were recorded respectively in 2010 and 2011 in the location of Farako-ba. For both years, average relative humidity reached 80 % during the rainy season and dropped to 19 % during the dry season.

Adult *M. vitrata* light trap catches

The monitoring of the *M. vitrata* adult population was carried out over 2 consecutive years in 2010 and 2011 using a light trap. The light traps utilized a 500-W mercury vapor white incandescent bulb positioned above a wire mesh cage (1.38 m width × 1.93 m height), which rested on a metal support set 2.43 m above ground level. The light was turned on daily from 6 p.m. to 6 a.m. The trap was emptied daily, and all *M. vitrata* adults were collected and placed into plastic vials containing 70 % ethanol. The insects were counted and sexed. Subsamples of females ($n = 600$), captured on different dates over the flying period, were dissected to check the presence of spermatophores, which are signs of mating experience. The insects were segregated by date of collection.

Monitoring of larval populations of *M. vitrata* on cultivated cowpea and *M. vitrata* larvae and pupae parasitism levels

We monitored *M. vitrata* larval populations on cultivated cowpeas using a randomized complete block design including four treatments and four replications. The treatments included the four most commonly used varieties in Burkina Faso of early, intermediate and late cowpea flowering plants. The varieties used included (1) KVx 404-8-1 (60 days; early flowering), (2) KVx 61-1 (70 days; intermediate flowering), (3) KVx 396-4-5-2D (70 days; intermediate flowering) and (4) Moussa local (85 days; late flowering). The four varieties are all sensitive to *M. vitrata*. Replicates for each treatment were planted in an 8 m × 4.4 m plot, using two seeds in each planting spot with an intra-row spacing of 0.4 m and inter-row spacing of 0.8 m. A total of ten rows of ten spots were planted per treatment for each replication. A space of 1.5 m was left between the treatments and between adjacent blocks. Mineral fertilizers NPK 15-15-15 were applied to the entire plot 2 weeks after planting at a dose of 100 kg per ha. The herbicide glyphosate was applied (at a rate of 360 g/hectare) to the plots immediately after planting of seeds. All the plots were kept free of any insecticide application.

At flowering, 20 flowers were randomly collected in each plot every 4 days and placed into plastic vials containing 70 % ethanol. The flowers were examined for the presence or absence of *M. vitrata* larvae. Data on flower infestation rates, by *M. vitrata* larvae, were recorded until the harvest of the cowpeas occurred.

A second set of flowers and pods, with visible signs of infestation by *M. vitrata* larvae, was collected weekly and placed in plastic vials. The flowers and pods were dissected in the laboratory; live larvae were reared on artificial diet, and the dead larvae incubated in petri dishes. Both type of larvae were monitored until the emergence of the parasitoids or *M. vitrata* moths. A total number of over 2,800 larvae were checked for parasitism in both years. In addition, *M. vitrata* pupae were collected at the pod filling stage and incubated in petri dishes for emergence of parasitoids according to the methods described by Adango (1994). Specimens of emerged parasitoids were identified at the Centre for Biological Control at the International Institute of Tropical Agriculture (IITA) in Cotonou, Benin.

Scouting for *M. vitrata* larvae on alternate host plants

From 2010 to 2011, plant species reported as alternative hosts in Benin and Nigeria (Bottenberg et al. 1997; Atachi and Djihou 1994; Arodokoun et al. 2003) were visually examined for the presence of *M. vitrata* larvae. Once a month, all flowering plants, in the families Cesalpiniaceae, Mimosaceae, Fabaceae and Combretaceae, were randomly sampled along an East–West direction chosen 36-km transects from the research stations. This transect has a permanent river and a forest preserve. All flowers, flower buds and young pods, shoot-tips bearing holes were collected and the larvae then reared until adult emergence to confirm their identity as *M. vitrata*. Emerging parasitoids were also collected. The host plants were identified at the Department of Forestry of the Burkina Faso National Research Centre for Science and Technology (CNRST).

Data analysis

An ANOVA was performed for the number of *M. vitrata* larvae on each of the cowpea varieties using SAS software (version 8, 2001). For each sampling date, a comparison was made between the varieties, and the separation of the means was done using the Student-Newman-Keuls test at the 5 % significance level.

Results

Maruca vitrata adult flights and larval population on cultivated cowpea

The number of *M. vitrata* adults captured in the light trap showed inter-year variability (Fig. 1). The duration of the flight period extended from mid-June to late October. A total of 5,323 moths were caught in 2010 and 872 in 2011. The highest flying activity of adults, as observed in the light traps, occurred from late August to mid-October (Fig. 1). The sex ratio was female biased with a proportion of up to 61 and 65 %, respectively, in 2010 and 2011 (Table 1). Mated females were captured in the light trap since the beginning of the flying activity until the end of the season with higher figures in 2010 than 2011 (Table 1).

In 2010, *M. vitrata* larvae were observed from 49 up to 65 days after planting (DAP), but on the late maturing variety, Moussa local, the first larva was observed only on the 57th DAP (Fig. 2a). The overall population of *M. vitrata* larvae was significantly lower on the Moussa local variety as compared to the three other varieties ($F = 10.2$; df $= 3$; $P < 0.001$). The same trend was observed in 2011 ($F = 4.77$; $df = 3$; $P < 0.0004$), but the larval population was recorded earlier than in 2010, and they overlapped on the four varieties from 43 up to 61 DAP (Fig. 2b).

Maruca vitrata alternate host plants

We recorded 14 alternate host plants for *M. vitrata* in southwestern Burkina Faso, all from the Fabaceae family (Table 2). The larvae were mainly found on the host plants' flowers or on the pods. On *Daniella oliveri*, the larvae were only found on the shoot-tips (Table 2). Larvae of *M. vitrata* were recorded on the alternate host either during or outside the cowpea-growing season (Fig. 3). Out of the 14 host plants, except *Dolichos lablab* and *Cajanus cajan*, which are cultivated plants, the 12 other host plants were all wild species.

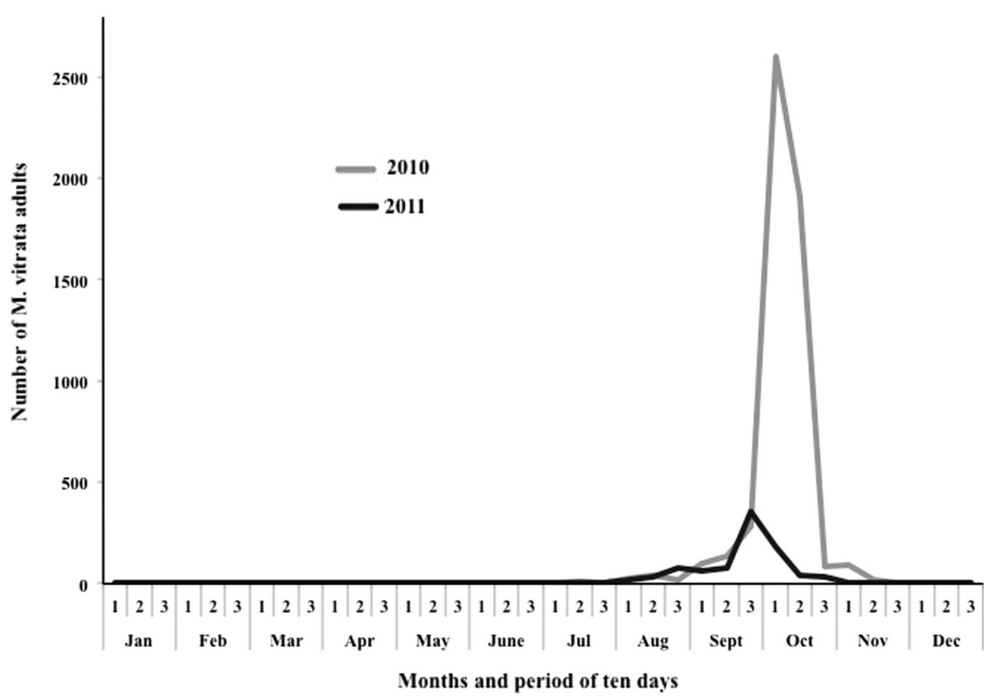

Fig. 1 Adult *Maruca vitrata* catches in the light trap in 2010 and 2011 in Farako-ba, southwestern Burkina Faso. (*Numbers* indicate total 10-day catches)

Table 1 Proportion of female *M. vitrata* caught in the light trap in southwestern Burkina Faso in 2010 and 2011 and their mating status

	2010		2011	
	Female proportion (%)	Mated female (% ±SE)	Female proportion (%)	Mated female (% ±SE)
August	53	73.68 ± 1.19	65	12.35 ± 0.58
September	61	65.00 ± 0.58	60	07.90 ± 0.07
October	55	43.83 ± 0.6	52	10.00 ± 0.56
	–	$F = 256.63$; $P < 0.05$	–	$F = 14.41$; $P < 0.05$

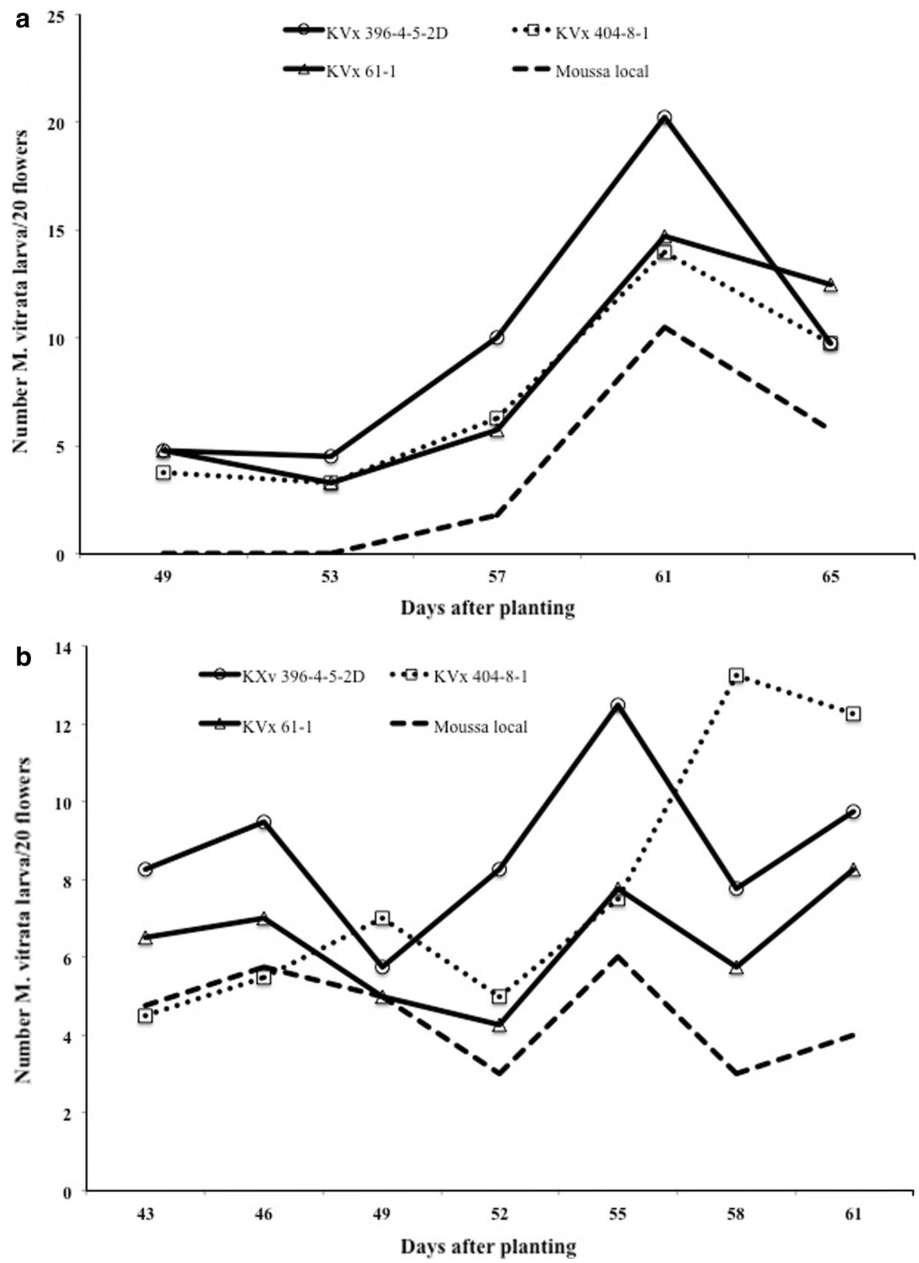

Fig. 2 **a** *Maruca vitrata* larvae infestation on four cowpea varieties during the 2010 rainy season in Farako-ba, southwestern Burkina Faso. **b** *Maruca vitrata* larvae infestation on four cowpea varieties during the 2011 rainy season in Farako-ba, southwestern Burkina Faso

Table 2 Alternative host plants of *M. vitrata* in southwestern Burkina Faso

Plant species	Families	Cycle	Number of larvae per flower/pods (mean ± SE)
Cajanus cajan Millsp.	*Fabaceae*	Annual	1.00 ± 0.01
Crotalaria naragutensis[a] Hutch.	*Fabaceae*	Annual	0.83 ± 0.03
Crotalaria ochroleuca[a] G. Don	*Fabaceae*	Annual	0.75 ± 0.25
Daniella oliveri (Rolfe.) Hutch & Dalz	*Fabaceae*	Perennial	1.00 ± 0.01
Dolicos lablab L.	*Fabaceae*	Annual	1.00 ± 0.01
Mucuna poggei Taub.[a]	*Fabaceae*	Annual	7.66 ± 0.15
Rhynchosia hirta[a] (Andrews) Meikle and Verdc.	*Fabaceae*	Annual	2.40 ± 0.50
Rhynchosia pycnostachya[a] (DC) Meikle	*Fabaceae*	Annual	2.00 ± 0.01
Sesbania pachycarpa D.C.	*Fabaceae*	Annual	9.27 ± 0.32
Tephrosia candida (Roxb.) DC.	*Fabaceae*	Annual	7.83 ± 0.16
Tephrosia nana Schweinf[a]	*Fabaceae*	Annual	8.20 ± 0.20
Tephrosia bracteolata Guill. & Perr.	*Fabaceae*	Annual	8.45 ± 0.41
Vigna gracilis[a] Guill. & Perr. Hook.f.	*Fabaceae*	Annual	2.67 ± 0.33
Vigna nigritia Hook.f.[a]	*Fabaceae*	Annual	2.46 ± 0.11
			$F = 200.43$; $P < 0.05$

[a] Species recorded for the first time

Parasitism of *M. vitrata* on cultivated cowpea and alternate host plants

An overall parasitism rate of 4.7 and 5.7 % on *M. vitrata* larvae was recorded, respectively, in 2010 and 2011 (Table 3). Three species of parasitoid were observed on the larvae of *M. vitrata* on cultivated cowpea, *Phanerotoma leucobasis* Kri., *Braunsia kriegeri* End. and *Bracon* sp (Table 3). The level of parasitism inflicted on *M. vitrata* larvae by each of the species was not significantly different for both years (Table 3).

Of the 14 alternate host plants of *M. vitrata*, parasitoids were recorded only on *Tephrosia nana* with only one species, *B. kriegeri* (Table 3).

No parasitoids were observed on the pupae of *M. vitrata* on either cultivated cowpea or the alternate host plants.

Discussion

In southwestern Burkina Faso, adult flights of *M. vitrata* coincided with the rainy season, and flight activity ceased during the dry season. Similar observations were made in Central and Northern Benin and Nigeria and southern Niger for locations above 09° N latitude (Bottenberg et al. 1997; Adati et al. 2012). This has lead previous researchers to conclude that *M. vitrata* do not maintain a permanent population in areas above the southern coastal zone of West Africa (Bottenberg et al. 1997; Margam et al. 2010; Adati et al. 2012). Those authors clearly failed to find any residual population of *M. vitrata* in the cowpea off-season in locations above 09° N latitude. The Adati et al. (2012) findings were only based on light trap catches, while the Bottenberg et al. (1997) and Margam et al. (2010) combined this with scouting for larva populations on wild leguminous plants. However our findings suggest that in southwestern Burkina Faso, even though no adult flight was noticed during the dry season, *M. vitrata* larvae were recorded on wild alternate host plants. Thus, we hypothesize that *M. vitrata* may have endemic populations in southwestern Burkina Faso. This is the first evidence of year-round presence of *M. vitrata* in the area above 09° N latitude. The location in southwestern Burkina Faso is the home of several rivers and preserved forest that may have created a microclimate favorable for *M. vitrata*'s year-round presence. Although *M. vitrata* larvae were found on wild host plants in the dry season, the moths could not be caught in the light trap. Several reasons may explain why *M. vitrata* moths could not be caught in the light trap: (1) low larvae population, (2) scarcity of host plants and (3) dry weather (19 % relative humidity) unfavorable for population buildup as *M. vitrata* moths need high relative humidity for reproduction (Jackai et al. 1990). Finally, our light trap was not located in the vicinity of the host plants. All these factors may explain why *M. vitrata* larvae could be recorded with no adult flight activity.

Despite strong evidence of a year-round presence of *M. vitrata* in southwestern Burkina Faso, we cannot rule out the possibility of migrant populations coming in during the rainy season as suggested for Northern Nigeria (Bottenberg et al. 1997; Adati et al. 2012). Mating status of females and the sex ratio of moths caught in the light trap can support this hypothesis. As observed in Northern Nigeria with a migrant population (Adati et al. 2012), in southwestern Burkina Faso the sex ratio of moths caught in the light trap was female biased, and the majority of females were mated. However, the proportion of mated females was

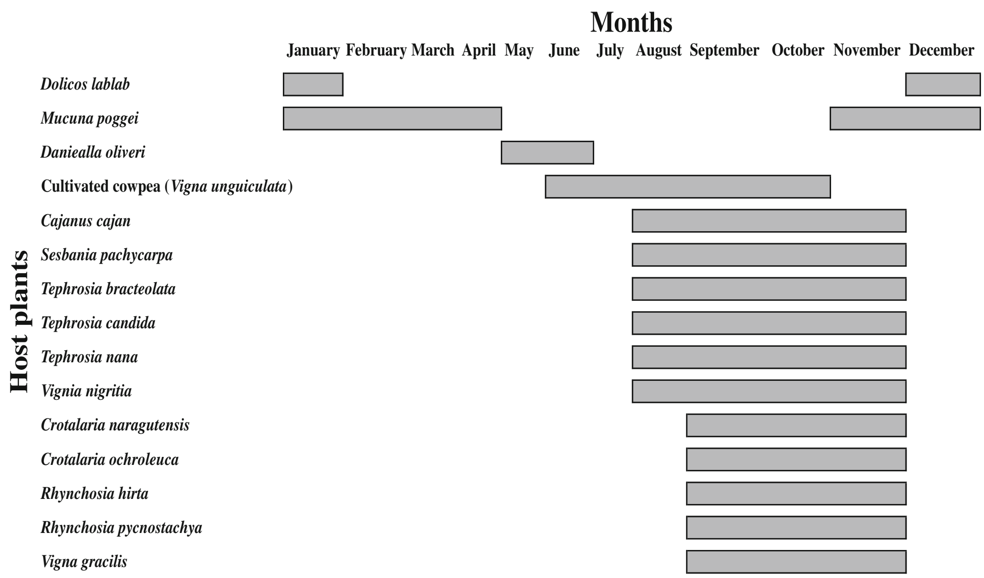

Fig. 3 Annual cycle of *Maruca vitrata* in southwestern Burkina Faso

Table 3 Parasitism of *M. vitrata* larvae on cultivated cowpea and alternate host plants in southwestern Burkina Faso

Parasitoid species	Mortality inflicted on *M. vitrata* larvae (% ± SE)		
	On cowpea in 2010	On cowpea in 2011	On *Tephrosia nana* in 2011
Phanerotoma leucobasis	2.62 ± 0.37	1.07 ± 0.17	–
Braunsia kriegeri	0.57 ± 0.12	1.07 ± 0.20	4.90 ± 1.19
Bracon sp.	1.56 ± 0.24	3.51 ± 0.74	–
	$F = 6.31$; $P > 0.05$	$F = 5.35$; $P > 0.05$	–

much higher in 2010 than 2011. This may suggest that in 2011 a more important proportion of the endogenous population was caught in the light trap. The lower rainfall in 2011 may have been unfavorable for population migration. This may explain why the overall population caught was lower in 2011. Further investigation needs to be undertaken to better understand the *M. vitrata* population structure.

While *M. vitrata* adults were caught in the light traps and larvae were observed on cultivated cowpeas during the rainy season, some wild alternate plants also hosted *M. vitrata* larvae, indicating an overlapping of the population on different host plants. Overlapping populations of *Maruca*, on cultivated cowpeas and wild alternative hosts, was also reported in southern Benin (Atachi and Djihou 1994; Tamò et al. 2002; Arodokoun et al. 2003). In our study, we observed that *Sesbania pachycarpa*, *Tephrosia bracteolata*, *Tephrosia candida* and *T. nana* were the most important wild alternative host plants during the rainy season, while *Mucuna poggei* and *D. oliveri* were likely the important host plant during the long dry season. In this study, we identified 14 alternate host plants for *M. vitrata*. So far, this is the highest number of alternative host plants to be reported in Burkina Faso. This number was, however, lower than the 23 host plants reported in southern Benin by Arodokoun et al. (2003). Of the 14 host plants, 8 species are reported for the first time as host plants of *M. vitrata* in Africa including *Vigna gracilis, Vigna nigritia, T. nana, Rhynchosia hirta, Rhynchosia pycnostachya, Crotalaria naragutensis, Crotalaria ochroleuca* and *M. poggei.* In our case, all the host plants are herbaceous legumes with the exception of *D. oliveri*, which is a perennial tree. In Benin, the major host plants were perennial trees (Arodokoun et al. 2003). All of the host plants that we observed *M. vitrata* feeding upon were from the Fabacea family, which confirms the stenophagous behavior of *M. vitrata* as reported by Tamò et al. (2002). *M. vitrata* larvae mainly fed upon the floral parts of the host plants, but for some of the host plant species, the larvae also fed on the pods or shoot-tips. This is in contradiction to Tamò et al. (2002), indicating that on wild host plants in Benin *M. vitrata* feeds only on floral parts.

To the authors' knowledge, natural enemies associated with *M. vitrata* have not previously been investigated in Burkina Faso. Thus, we identified three parasitoid species associated with *M. vitrata* larvae on cultivated cowpea, *P. leucobasis* Kri., *B. kriegeri* End. and *Bracon* sp. All three of the parasitoid species were from the same genus that has been reported also to occur at other locations in Africa

(Arodokoun et al. 2006; Taylor 1967; Usua and Singh 1978; Okeyo-Owuor et al. 1991; Ezueh 1991). In addition to cowpea, the parasitoid *B. kriegeri* was also observed on the wild host plant, *T. nana.* The parasitoid species diversity in Burkina Faso is less rich than the six to eight species reported respectively in Kenya and Benin (Okeyo-Owuor et al. 1991; Arodokoun et al. 2006). However, the overall mortality inflicted by the parasitoids on *M. vitrata* on cultivated cowpea in Burkina Faso is comparable to what has been observed in southern Benin (Arodokoun et al. 2006). This natural parasitism is too low for the parasitoids to be used for biological control. As indicated in Benin (Arodokoun et al. 2006), endogenous parasitoids are not effective for biological control of *M. vitrata*. This has led to investigations on the uses of exotic parasitoids (Dannon et al. 2010; 2012). However, for effective use of exotic parasitoids, it is crucial to identify nursery plots of *M. vitrata* host plants on which the parasitoid could be released and established (especially during the dry season) to control the population of *M. vitrata* in a way that could limit population buildup (Tamò et al. 2002; Tamò et al. 2012). Thus, the availability of wild host plants of *M. vitrata* in the off-season of cowpea in southwestern Burkina Faso makes this region suitable for the release of exotic parasitoids for conservative biological control. However, further investigations are needed to identify the ecological importance of the wild host plants in terms of distribution and abundance in southwestern Burkina Faso.

As stated previously, the current efforts for controlling *M. vitrata* include deployment of Bt-cowpea (Huesing et al. 2011). However, environmental risk assessments are needed to pave the way for Bt-cowpea to be extended safely and sustainably and commercialized. This includes an insect resistance management (IRM) strategy. In this regard, the availability of alternate host-plants of *M. vitrata* in southwestern Burkina Faso is highly valuable in terms of IRM. Several studies reported the utilization of wild host refuge for resistance management in transgenic crops (Tan et al. 2001; Abney et al. 2007; Jackson et al. 2008). Since the *M. vitrata* populations overlapped on cultivated cowpea and wild host plants, these alternative host plants may be used as a natural unstructured refuge to provide susceptible individuals a place to escape selection pressure by the treatments by lowering the proportion of homozygous-resistant genotypes in the population. Hence, again, further studies are needed to identify the wild host plant distribution and abundance in southwestern Burkina Faso. Finally, molecular studies still need to be performed to verify that these represent a common population.

In summary, our findings showed evidence of an uninterrupted cycle of *M. vitrata* in southwestern Burkina Faso, sustained by the year-round presence of cultivated cowpeas and wild host plants, all belonging to the Fabaceae. It appears that *M. poggei* and *D. oliveri* are the major host plants for *M. vitrata* during the dry season. Furthermore, releases of parasitoids for a biocontrol program of *M. vitrata* could be carried out earlier in the rainy season on the alternate host plants to prevent build up of the pest population.

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