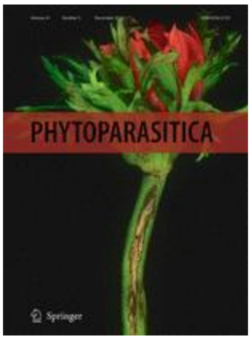

Biological control of the millet head miner *Heliocheilus albipunctella* in the Sahelian region by augmentative releases of the parasitoid wasp *Habrobracon hebetor:* effectiveness and farmers' perceptions

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Phytoparasitica
December 2013, Volume 41, Issue 5, pp 569-576

DOI: http://dx.doi.org/10.1007/s12600-013-0317-x

Biological control of the millet head miner *Heliocheilus albipunctella* (de Joannis) (Lepidoptera: Noctuidae) in the Sahelian region by augmentative releases of the parasitoid wasp *Habrobracon hebetor* (Say) (Hymenoptera: Braconidae): effectiveness and farmers' perceptions.

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Short title: Biocontrol of *Heliocheilus albipunctella*

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Abstract

On-farm augmentative releases of the parasitoid *Habrobracon hebetor* (Say) for controlling the millet head miner (MHM) *Heliocheilus albipunctella* (de Joannis) was experimented in Burkina Faso, Mali and Niger from 2007 to 2009. In addition, a survey of farmers' perceptions of insect pests, with particular focus on MHM, and the biological control program (BCP) was carried out. Our findings indicate a significant increase of MHM parasitization rate after the releases with up to 97% mortality. The survey on farmer's perceptions revealed a fair knowledge of the MHM and the ability of farmers to describe the pest and its damage. Farmers claimed that the biocontrol agent *H. hebetor* is effective and perceived a significant gain in grain yield due to this control strategy. Implications of these findings for a large extension of the MHM biocontrol program are discussed.

Keywords: millet head miner; farmer perceptions; biological control; *Habrobracon hebetor*

Introduction

Pearl millet, *Pennisetum glaucum* (L.) R. Br., is the only cereal crop adapted to the Sahelian arid region in Burkina Faso, Mali and Niger. Despite the extreme climatic conditions, the millet crop suffers from many biotic constraints including insect pests (Nwanze and Harris 1992). The millet head miner (MHM), *Heliocheilus albipunctella* (de Joannis) (Lepidoptera: Noctuidae), is one of the most important of them in Sub-Saharan Africa. Its immature larval stages feed on the panicle and prevent grain formation (Ndoye 1991). Yield losses range from 40 to 85% (Gahukar et al. 1986; Krall et al. 1995; Youm and Owusu 1998).

Biological control relying on indigenous natural enemies has been perceived as one of the most promising management strategies for this pest (Gahukar et al. 1986; Bhatnagar 1987; Youm and Gilstrap 1993). In the early 80s a natural parasitism of 64-95% due to

Habrobracon hebetor (Say) (Hymenoptera: Braconidae) was reported in Senegal and Niger (Gahukar et al. 1986; Bhatnagar 1987; Nwanze and Harris 1992), but it was effective only after the crop damage has occurred (Bhatnagar 1987; Nwanze and Harris 1992). Moreover, large-scale insecticide use to combat the desert locust plague at the end of 1990 in the Sahelian region, causing substantial non-target effects on wildlife (Rowley and Bennet 1993) may have interfered with the biocontrol agents and reduced the natural parasitism of MHM. However, our biocontrol strategy is based on releasing parasitoids in the field at the beginning of MHM infestation to enhance the natural parasitism and prevent panicle damage.

Since the target pest developed only one generation per year, there was a need to identify an alternate host for the parasitoid rearing. Based on the polyphagous behaviour of *H. hebetor* attacking many lepidopterous species of stored grain (Richards and Thomson 1932), the parasitoid was first reared on the alternate host *Cadra cautella* (Walker) (Lepidoptera: Pyralidae) (Bathnagar 1989). First experimental releases of parasitoids were carried out in 1985 in Senegal (Bathnagar 1989). At the same time, studies of the life cycle of this parasitoid (Youm and Gilstrap 1993) provided the basis for developing a very simple mass rearing technique of *H. hebetor* (Bal et al. 2002). Release techniques for this parasitoid were subsequently refined (Baoua et al. (2002), leading to experimental on-farm releases of *H. hebetor* from 2007 to 2009 in Burkina Faso, Mali and Niger (Payne et al. 2011). While Payne *et al.* (2011) focused their study on institutional and financial arrangement of the BCP, the present study aims to assess its technical aspects.

In addition to the releases of parasitoids, we evaluate farmers' perceptions because the success of pest management program could depend on pest recognition (Fujisaka 1992; Litsinger et al. 1980) and farmers practices (Heong 1985; Teng 1987; Morse and Buhler 1997).

Moreover, the degree to which farmers adopt new pest control technology depends on their understanding of the control techniques. Therefore, program included also the training of farmers through the Farmer Field School (FFS) on millet production and the BCP of the MHM.

The present study was aimed at evaluating the effectiveness of on-farm augmentative releases of *H. hebetor* to control the MHM in the Sahelian Region; and the farmers' perceptions on the BCP of this pest was also carried out.

Material and Methods

Description of the study sites

The study was carried out in Burkina Faso, Mali and Niger within a millet cropping area, which has a monomodal rainfall pattern (300 to 400 mm annual). The experiment was conducted in the districts of Pobe-Mengao and Dori in north-western Burkina Faso, Segou and Mopti in south-eastern Mali and Zinder and Maradi in south-eastern Niger. In the three countries, the farmer household size ranged from 3 to 20 people with an average of 9. Farm size ranged from 7 ha in Burkina Faso to more than 10 ha in Mali. Millet is the main crop covering 68 to 80% of the land and farmers planted at least two different local landraces and the main purpose of the production is for household consumption.

Establishment of H. hebetor colony

Since *H. albipunctella* is a univoltine species diapausing from October to June, a colony of *H. hebetor* was established and maintained in the laboratory on an alternate host, the rice moth *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae). The rearing technique was adapted from that developed by Bal *et al.* (2002). Wooden cages (20 x 20 x 13 cm) with muslin cloth on three lateral sides were used for *C. cephalonica* mass rearing. A mixture of

1.2 kg of millet flour and 1.8 kg of millet grains was introduced into the cages and inoculated with about 3000 eggs of *C. cephalonica*. Subsequent generations were regularly obtained after 30 days at room temperature (average 26 °C). Third and fourth instars larvae of *C. cephalonica* were used for mass rearing of *H. hebetor*. For this purpose 25 *C. cephalonica* larvae were confined within a petri dish for 48h with 2 mated *H. hebetor* females. Subsequent generation of *H. hebetor* emerged 7 to 14 days after confinement.

On-farm parasitoid release technique

Parasitoids were released in "jute kit bags" as follows; 200 g of millet grains and 200 g of millet flour were placed into a jute bag of 15 cm x 25 cm, together with 25 larvae of *C. cephalonica* and 2-mated *H. hebetor* females. Bags were suspended to the ceiling of traditional straw granaries. Parasitoids were allowed to reproduce and multiply in those bags from which their offspring was able to escape through the jute meshes and dispersed to parasitize the MHM larvae in millet fields. Twenty villages were selected every year for the experiment from 2007 to 2009. The villages were selected on the basis of an endemic occurrence of the MHM and every year new villages different from the previous year were selected. The experimental design included two treatments: i) 10 villages were supplied each with 15 parasitoid bags, these villages were 5km away from each other; ii) 10 control villages did not receive any parasitoids bag; these villages were located 10km away from villages receiving the parasitoids. The distance between the villages was chosen based on preliminary studies demonstrating that the parasitoid can travel up to 5 km from the release point (Garba and Gaoh 2008).

Assessing MHM parasitization rates after releases

MMH parasitization rates by *H. hebetor* were assessed at harvest on 500 millet panicles randomly collected in 5 millet farms. The panicles were dissected and the number of alive (not parasitized) and parasitized larvae was recorded. The larvae parasitized by *H. hebetor* were easily distinguished by the presence of the cocoons (Garba and Gaoh 2008).

Survey on farmers' perceptions

The survey was carried out in two steps using a structured questionnaire. Before the implementation of the biocontrol program (BCP) in 2006, farmers were questioned about their perception of MHM. Three years after the implementation of the program in 2009, farmers were interviewed about their perceptions of BCP. The questionnaire was submitted to 100 farmers in each country. These farmers were men or women leading the farm responsibilities. Farmers were randomly selected from 20 villages. To cater for any variation in responses owing to the position of an interviewee in the social set-up, only farmers capable of taking independent decisions regarding their farm activities were interviewed. The interviews were conducted with individual farmers, the questions were asked orally to farmers in appropriate local languages (*More* and *Fulfulde* in Burkina Faso, *Bambara* in Mali and *Hausa* in Niger).

The 2006 survey addressed the various constraints on millet cropping (social, economic, abiotic and biotic constraints). Subsequently, data were recorded on insect pest identity and damage. With regard to MHM, more detailed questions were asked: farmers' perceptions of the insect, details of its life cycle, the levels of yield losses, and the control measures (if any) they used. The 2009 questionnaire was submitted to a new set of randomly selected farmers and included: farmer knowledge about the biological control agent, the biological control technique and views on its impact. On average, the interview took one hour.

Data analysis

For each country and each year the percentage of parasitism was subjected to ANOVA using SAS Version 8 software (PROC GLM; SAS, 2001). When ANOVAs were significant, means were separated by the Student – Newman – Keuls test at the 5% level.

For farmers' perception survey, responses were quantified for each question. The percentage of farmers giving similar responses was calculated per country based on the total number of farmers responding to the given question.

Results

Effectiveness of H. hebetor parasitism upon the MHM

Regardless of the year and the country the releases of the parasitoids significantly increased the natural parasitism of the millet head miner (Figs 1-3). Parasitism by *H. hebetor* was significantly higher in villages where the parasitoid bags were placed than the control villages in 2007 and in the all countries (Burkina Faso $F=15.23$ $P<0.05$; Mali $F=22.97$ $P<0.05$; Niger $F=26.07$ $P<0.05$). The highest percentage of parasitism was recorded in Niger and Burkina Faso (Fig. 1). In 2008 the highest percentage of parasitism was recorded in Burkina Faso (Fig. 2); and for all countries parasitism was significantly higher in villages covered by the BCP than control villages (Burkina Faso $F=17.52$ $P<0.05$; Mali $F=34.18$; $P<0.05$; Niger $F=22.54$ $P<0.05$). In 2009, parasitism was lower in Burkina Faso and Mali but still very high in Niger (Fig. 3). However, it was still significantly higher than in the control villages for all countries (Burkina Faso $F=5.34$; $P<0.05$; Mali $F=8.27$ $P<0.05$; Niger $F=9.82$ $P<0.001$).

Farmers' perceptions of production constraints and BCP

Farmers ranked soil fertility and drought as most important constraints limiting millet production. Insect pests were ranked third major constraint in Burkina Faso and Niger and fourth in Mali (Table 1). Among them, MHM was ranked first major insect damaging millet in the three countries (Table 2). Farmers identified *H. albipunctella* as the caterpillar that destroys the millet panicle and recognized damaged panicles by the presence of the characteristic spiral mines on the earhead. Farmers described very well the different colours of the ageing larvae: yellow, green and red. A large proportion of farmers were able to describe MHM life cycle from egg to adult (Table 3). Farmers noted that their worst infestations were in years of severe drought. The majority of farmers estimated yield losses from MHM ranging between 42 and 48%. Some farmers in Burkina Faso mentioned that earlier maturing varieties were less damaged and therefore effective as an endogenous control strategy (Table 3). None of the farmers were aware of endogenous biological control agent before the implementation of BCP.

During the 2009 survey, most farmers were aware of BCP that was deployed in their region (Table 4). They were informed by attending the FFS sessions or learned about it from farmers involved in the program. The majority of farmers mentioned that BCP was effective and estimated that the parasitoid *H. hebetor* inflicted up to 52% mortality to MHM larvae in the field. Farmers estimated average yield gain of 42 to 57% due to the implementation of BCP in their region. Finally farmers expressed a strong willingness to buy the parasitoid release bags (Table 4).

Discussion

Augmentative aerial releases of Braconidae parasitoids for controlling insect pests were successful in many cases (Sivinski et al. 1996; Obrycki et al. 1997; Montoya et al. 2000). In our case we developed an "on-farm parasitoid rearing facility" from which the parasitoid escaped and parasitized MHM in millet fields in the Sahelian Region. An average of 70 parasitoids can emerge from each jute bag within a period of 10 days (Baoua et al. 2002). An estimate of at least one thousand parasitoids may be released with the total of 15 bags supplied in each village. Considering the demographic parameters of *H. hebetor* - 8 days from egg to adult (Garba and Gaoh 2008; Farag et al. 2012), 173 progeny per female and sex ratio 1:1 (Youm and Gilstrap 1993) - our release technique should produce several thousand of parasitoids within few weeks. After three years of experimental releases, we clearly demonstrated a significant increase of the parasitism of MHM by *H. hebetor*. Up to 97% mortality due to *H. hebetor* was recorded in Niger. In Senegal much lower percentage of parasitism was recorded with previous attempts of augmentative releases of *H. hebetor* (Bathnagar 1989). This indicates that the method we used for releases of the parasitoid was more effective. The level of parasitism in Niger was similar to the natural parasitism recorded at the end of the season in the early 80s (Nwanze and Harris 1992). But, as indicated by the very low parasitization rates observed in the control villages, natural parasitism is no longer significant in Niger. However, in Burkina Faso and Mali the natural parasitism was still important (up to 38%). The differences between the three countries may be due to agro-ecological variability and cultural practices (extended use of pesticides). Despite the already substantial natural parasitism in Burkina Faso and Mali, the augmentative release of *H. hebetor* significantly increases the mortality of MHM.

The second objective of the study was to document farmer's knowledge before and after BCP implementation. The survey revealed insect pests along with drought and soil fertility as the main constraints for millet production in the Sahelian region. Farmers had a fair knowledge of millet pests and easily provided local names. They accurately perceived the millet head miner, as the most important insect pest of millet in the Sahel region. A large number of farmers were able to describe the pest, particularly its larva, based on size and colour and accurately describe damage symptoms. The ability of farmers to describe crop insect pests has been documented by several previous surveys in Africa (Tanzubil and Yakubu 1997; Ochou et al. 1998; Tefera 2004; Poubom et al. 2005). But, according to Ooi (1996), generally, farmers do not pay attention to natural enemies of insect pests or are not able to distinguish between pest and beneficial arthropods. In addition, the majority of farmers recognized losses caused by MHM, similarly to earlier reports (Krall et al. 1995; Youm and Owusu 1998). Before the implementation of this biocontrol program farmers were unaware of MHM natural enemies.

Although several biological control programs involving augmentative release of parasitoids have been carried out in Africa (Neuenschwander 2003; Overholt et al. 2003; Tamò et al. 2003) most of them were implemented without farmers' involvement. The innovative approach of our program was the full involvement of farmers during the whole process. Although our study did not attempt to estimate the increase in millet grain yield due to the proposed innovation, farmers themselves already perceived an important yield gain. Farmers positively assessed their experience with the biological control approach, and they expressed sustained interest in using it. Similar positive perception of farmers experimenting biological control programs with parasitoid wasp were reported in Europe and China (Moser et al. 2008; Yang et al. 2009)

Although belonging to one of the poorest regions of the world, farmers consistently expressed a significant willingness to pay for parasitoid rearing kit bags. Similar willingness of farmers to pay for biocontrol of insect pests was reported with the locust and grasshopper BCP in the same region (De-Groote et al. 2001). However in this case, the microbial control agent (fungus) was provided for spraying. Consequently, this is the first time the commitment of farmers to buy parasitoids for biocontrol purpose is reported for this region.

The releases of *H. hebetor* showed great promise for controlling MHM, but long-term effectiveness is challenging. Our earlier investigations indicate that new releases of parasitoids need to be done every two years. In addition ecological and economic assessment of the BCP need to be addressed.

Acknowledgments

This study was made possible through the support provided to INERA, IER and INRAN by the Collaborative Crop Research Program (CCRP) of the McKnight Foundation under the terms of grants No. 06-011 and No. 09-036 thru 039. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the CCRP/ McKnight Foundation. The authors are also thankful to farmers who graciously gave their time to answer and discuss questions and to our collaborators, Adama Bonkoungou, Simon Tarpidiga, Mayaki Gaya, Laouali Amadou, Maimouna Abdourahamane, Ibrahim Ouattara and Amadou Tembely. We also thank Dr David Onstad of University of Illinois at Urbana-Champaign, USA for his helpful edits.

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Table 1. Constraints upon millet production in Burkina Faso, Mali and Niger (figures are % of farmers mentioning the constraint)

Constraints	Burkina Faso	Mali	Niger
Soil fertility	100	100	100
Drought	100	100	100
Insects pests	75	60	80
Mildew	47	85	5
Weeds	7	15	33
Birds	4	15	8

Table 2. Major insect pests constraints faced by farmers in millet production in Burkina Faso, Mali and Niger

	Local names			% Farmers mentioning as the main insect pest of millet		
	Burkina Faso	Mali	Niger	Burkina Faso	Mali	Niger
Millet head miner	*Rouga/ kiendougou*	*Kolosogo tumu*	Zuzzuda	74	60	50
Stem borers	*Pidel/ tiondré*	*Kalasogo tumu*	Birin bissa	11	20	20
Blister beetles	*Borboro*	*Minan*	*Hangara*	14	15	24
Others	-	-	-	1	5	6

Table 3. Farmers' perceptions of the Millet head miner in Burkina Faso, Mali and Niger

	Burkina Faso	Mali	Niger
% describing MHM damages	100	100	100
% farmers listing eggs-larvae-moth as development stage of the MHM	46	35	36
Year of severe infestation	Year of severe drought		
Date of first outbreak of the insect	unknown		
% farmers perceiving high damages	96	65	91
Average millet yield losses (%)	48	42	40
Endogenous control method	Earlier maturing varieties	None	None
Knowledge of biocontrol agent (%)	0	0	0

Tableau 4. Farmers' perception of the biological control program of the MHM

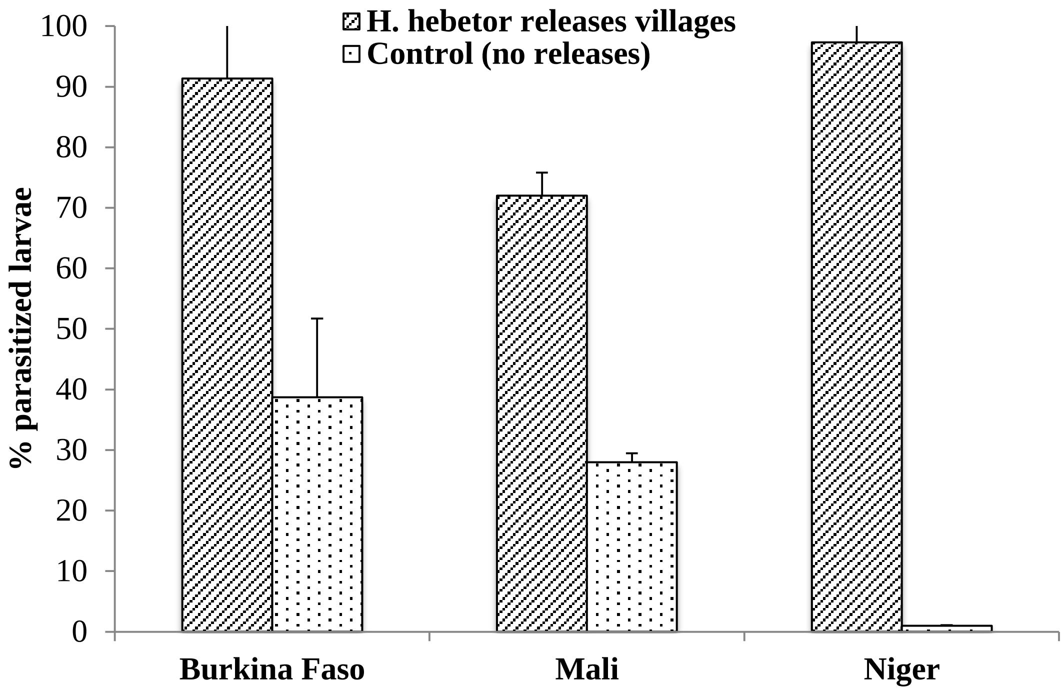
	Burkina Faso	Mali	Niger
% farmers aware of the biological control program	100	88.6	91.7
Source of information	FFS, pilot farmer	FFS, pilot farmer	FFS, pilot farmer
% farmers perceiving an effectiveness of the biocontrol agent *H. hebetor*	100	83	98
% farmers able to recognize *H. hebetor*	42	48	42
% of MHM killed by *H. hebetor*	77	53	37
Yield gain due to the biocontrol program	57	42	56
Local name of the parasitoid	*Songdba, boubi Nguildi*	*Dondolini*	*Mayaki*
Willingness price to buy parasitoids kit bags (USD)	1.34	1.50	2

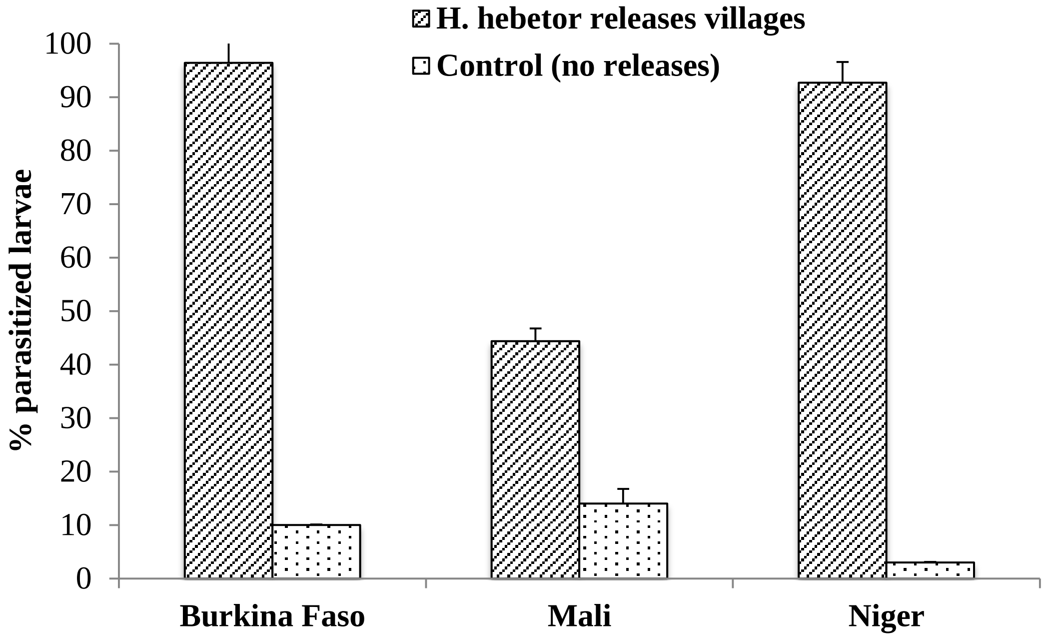
Figures titles

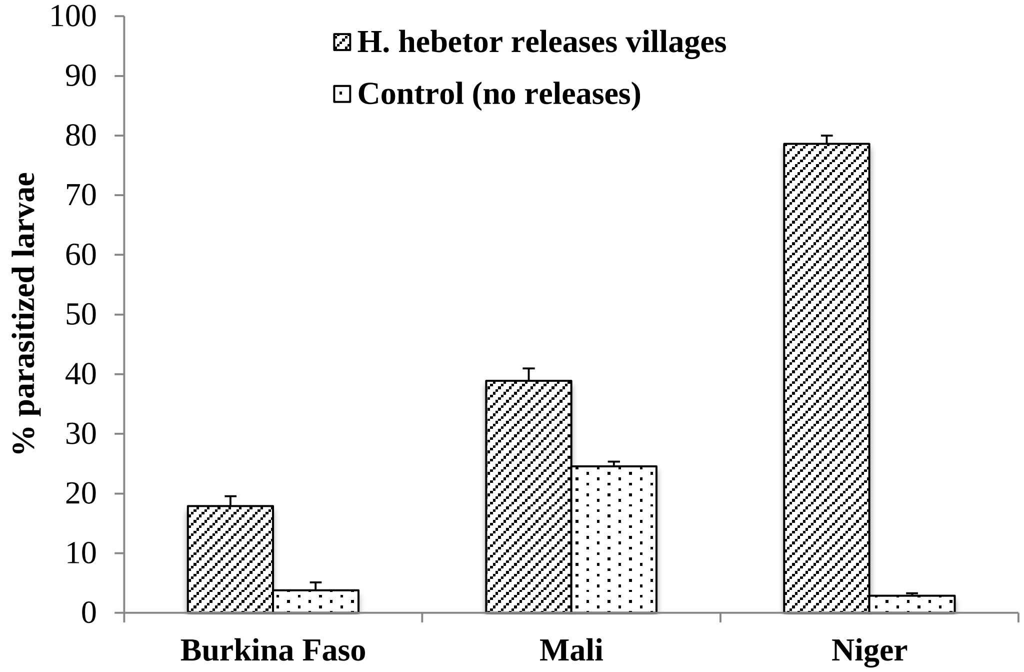
Fig.1 Parasitized larvae of *H. albinpuctella* (%means ± SE) due to *H. hebetor* in Burkina Faso, Mali and Niger in villages covered by augmentative releases of *H. hebetor* and control villages in 2007

Fig.2 Parasitized larvae of *H. albinpuctella* (%means ± SE) due to *H. hebetor* in Burkina Faso, Mali and Niger in villages covered by augmentative releases of *H. hebetor* and control villages in 2008

Fig.3 Parasitized larvae of *H. albinpuctella* (%means ± SE) due to *H. hebetor* in Burkina Faso, Mali and Niger in villages covered by augmentative releases of *H. hebetor* and control villages in 2009


H. hebetor releases villages
Control (no releases)
% parasitized larvae
100
90
80
70
60
50
40
30
20
10
0
Burkina Faso
Mali
Niger


H. hebetor releases villages
Control (no releases)
% parasitized larvae
100
90
80
70
60
50
40
30
20
10
0
Burkina Faso
Mali
Niger


100
90
80
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30
20
10
0
% parasitized larvae
H. hebetor releases villages
Control (no releases)
Burkina Faso
Mali
Niger