Combined Effect of Millet-Cowpea Intercropping and Application of Aqueous Neem Seed Extract on the Management of the Millet Head Miner, *Heliocheilus albipunctella* De Joannis (Lepidoptera: Noctuidae), in Burkina Faso

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Abstract

Pearl millet, *Pennisetum glaucum* L. R. Br. (Poales: Poaceae) , the main cereal crop in the Sahelian zone of Burkina Faso, is attacked by several insect pests, among which is the millet head miner, *Heliocheilus albipunctella* De Joannis (Lepidoptera: Noctuidae). Damage and yield losses caused by *H. albipunctella* on millet range from 30.00% to 85.00%. Control and management of *H. albipunctella* currently rely on synthetic insecticides, which are harmful to human and environmental health. Hence, there is a need to explore and develop alternative management strategies. Consequently the current research which was held; ~~we~~ explored the use of millet-cowpea intercropping a very common practice in the Sahelian zone of Burkina Faso together with the application of a plant-based biopesticides ~~made~~ of Neem (*Azadirachta indica* A. Juss. (Sapindales: Meliaceae) seed kernels aqueous extracts.

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The obtained results ~~We~~ found that the application of neem extracts on cowpea plants at the flowering stage, synchronized with the heading stage of millet, significantly reduced the incidence of *H. albipunctella*. When millet was intercropped with cowpea, the application of aqueous extracts of neem indirectly led to a significant reduction of about 50.00% in the number of larvae per spike. Additionally, a reduction in the percentage of millet spikes attacked, a decrease in mine length, and a gain in grain yield of more than 40.00% were observed. Thus, the findings from the application of this agricultral practice used ~~cultivation of millet in association with cowpea, combined with the application of aqueous extract of neem~~ could be a promising control option against *H. albipunctella*.

Keywords: Pearl millet, Cultural control, Aqueous neem seed extract, *Heliocheilus albipunctella*, Burkina Faso

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1. Introduction

Pearl millet, , is an ancestral cereal of critical importance in agriculture and nutrition for the Sahelian populations of West Africa (Gahukar & Ba, 2019; Dupuy, 2017). It is cultivated in the arid and semi-arid climatic conditions of the continent millet is a vital resource for many rural communities (Shelke and Chavan, 2010). In Burkina Faso, Pearl millet is the third most produced cereal after maize and sorghum with an estimated production of 907,745.00 tons (DGESS, 2023). Its high-protein content, energy value, vitamin and mineral composition are higher than those from other cereals such as wheat and maize (Parthasarathy-Rao et al., 2006). In the Sahelian region of Burkina Faso, millet is the most widely cultivated crop, covering almost 80.00% of areas under cultivation due to its resistance to extreme climatic conditions and the dietary habits of the population (Saidou, 2011; Gahukar and Ba, 2019). *H. albipunctella*, is the insect pest that causes enormous damage to millet spikes in many sub-Saharan African countries, particularly Burkina Faso (Ndoye, 1991; Amadou et al., 2017; Gahukar and Ba, 2019). Damage is observed every year and is caused by larvae with a grain yield losses of between 30.00 and 85.00% (Kaboré et al., 2017; Gahukar and Ba 2019; Oumarou et al., 2019). Depending on the agroecological zones, millet is generally grown in association with several legumes, in particular cowpea, *Vigna unguiculata* L.Walp. (Fabales: Fabaceae) (Boly et al., 2022). This type of intercropping system is practiced by farmers to control diseases, weeds, and pests (Lawane et al., 2010; Guo et al., 2020). Likewise, it is used to increase the yield of cereals (Zoundi et al., 2007, Trail et al., 2016; Namatsheve et al., 2020). This intercropping is sometimes used in combination with other phytosanitary treatments of cowpea, including the use of synthetic chemicals to control insect pests. However, the use of pesticides comes with the risks it poses to human, ecosystems, the environment, and loss of biodiversity (Carpentier, 2010, Barzman et al., 2015). Beyond the economic and environmental consequences, the massive and prolonged use of synthetic insecticides has also led to the development of resistance in several insect' pests (Martin et al., 2000; Siddiqui et al., 2023). Considering all these reasons, research in Burkina Faso like in most part of the world, has over the last decade being geared towards the search for more ecofriendly strategies for managing insect pests, namely; biological control through the use of parasitoids (Ba et al., 2014; Kaboré et al., 2017), bio-pesticides and cultural practices. Thus, biopesticides associated with cultural practices could constitute an effective and promising alternative in the management of insect pests. Among the common biopesticides available, extracts from neem, *Azadirachta indica* A. Juss, containing Azadirachtin (Shafiq et al., 2012; Kpindou et al., 2013) as its active ingredient

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has emerged as one of the most commonly used repellent due to its antifeedant effects on insects (Ngom et al., 2018; Bonni et al., 2018). In addition to its repellent and insecticidal effect, it also has little or no effect on non-target species and has a low impact on the environment and biodiversity (Haseeb et al., 2004; Sanon et al., 2005). Indeed, it is used to control and manage more than 400.00 insect pest species associated with crops (Tanzubil, 2000; Malick et al., 2008; Younoussou et al., 2021). However, it has not been used indirectly or in combination with other management strategies for cowpea or against *H. albipunctella*. Hence the reasons for this study were to evaluate the effectiveness of cultural control specifically intercropping in association with the biopesticide neem extract for the control and management of *H. albipunctella* in Burkina-Faso/, With the specific aims of evaluating the indirect effect of cowpea treatment on the number of larvae per spike, *H. albipunctella* incidence and the grain yield of millet. It is in this logic that the present study, which aims

2. Material and methods

2.1. Study location

The study was conducted in Burkina Faso, in the communes of Djibasso (alt: 1191; N: 13°05'34.0; W: 004°12'57.2) and Dori (alt: 932; N: 14°01'41.8; W: 000°00'34.9), during the 2021 rainy season. These two communes, Djibasso and Dori, are located in the Kossi and Seno provinces, respectively. Pearl millet is the main cereal crop in these two provinces and covers almost 78.00 and 80.00% of the cultivated area, respectively (DGESS, 2023), and it is often intercropped with cowpea (Boly et al., 2022). The experimental plots were established in the villages of Bouakuy, located about 10 km from Djibasso, and Hoggo Sambowel, located about 10.00 km from Dori (Fig. 1). The cumulative rainfall from May to December was 827.00 mm in Djibasso and 557.00 mm in Dori. The relative humidity fluctuated between 53.16 - 91.44% in Djibasso and between 44.25-83.00% in Dori. While average monthly temperatures fluctuated between 25.00 and 32.00 °C. The vegetation is mostly covered with annual grass species, with areas of woodland and shrubland in which the dominant trees are Acacia species, *Balanites aegyptiaca* (Zygophyllales: Zygophyllaceae), *Faidherbia albida* (Fabales: Fabaceae), *Combretum glutinosum* (Myrtales: Combretaceae), *Guiera senegalensis* (Myrtales: Combretaceae), and *Piliostigma reticulatum* (Fabales: Fabaceae), (Lykke et al., 2004). The soil in both communes is sandy (Fontès and Guinko, 1995).

2.2. Experimental design

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The experimental design is composed of a divided plot (= Split Plot) made up of three sub-blocks (= Large plots). Each sub-block is composed of twelve (12.00) sub-plots (= Small plot). The sub-plots were each a 9.60 m × 9.60 m in dimension. This type of design provides the possibility of evaluating two factors in the system namely, the type of cropping association (primary factor) and the phytosanitary treatment (secondary factor). The cropping system consists of four combinations (i) millet (MP), (ii) cowpea monocultures i.e. as single main crop (NP), (iii) an intercrop consisting of two rows of millet and a single row of cowpea (2M-1N) and (iv) farmers' practices (PP, one planting of cowpea between four plantings of millet). The four cropping systems form the main plot (Σ MP + NP+ 2M-1N+ PP). The phytosanitary treatment assigned to each main plot (Σ MP + NP + 2M-1N + PP) at each large plot level consisted of three combinations: (i) an aqueous neem seed extract, which contains a variety of bioactive compounds. Among these, azadirachtin (Tetranortriterpenoid limonoid, $C_{35}H_{44}O_{16}$) meliantriol (Triterpenoid limonoid, $C_{32}H_{50}O_{8}$), and salannin (Triterpenoid limonoid, $C_{34}H_{44}O_{9}$) play key roles in the tree's insecticidal and repellent properties (Saxena, 1989); (ii) a synthetic insecticide (Lambda-Cyhalothrin 15.00 g/l + Acetamiprid 20.00 g/l); and (iii) a no-treatment control. Each of the cropping systems was replicated three times in each of the sub-blocks. The spacings between rows and pockets in each cropping system were 0.80 m × 0.80 m for millet and 0.80 × 0.40 m for cowpea. A distance of 2 m and 6 m was allowed between two sets of cropping systems and between sub-blocks, respectively in order to prevent effects of treatments. For the millet, we used the local variety that the farmers use in each locality was used, while the cowpea variety Komcallé was sown 20 days after the millet was sown, mullein order to synchronize the cowpea (45 days after sowing) with the millet heading stage. It is at this stage that *H. albipunctella* females prefer to lay their eggs on the spikes (Gahukar et al., 1986). The sub-plots were thinned to two (2.00) millet plants per pocket at the first weeding, three weeks after sowing. A microdose of fertilizer consisting of 5.00 g of NPK (14/23/14; 100Kg/ha) per pocket was applied to both millet and cowpea after weeding followed by an application of urea (46% N; 50Kg/ha) to 3.00 g / pocket of millet at the time of the millet bolting.

To prepare the neem aqueous extract, the neem seeds were collected under the trees, stored, and dried in the shade for 4 to 5 weeks. Next, they were ground into a fine powder, and this powder was macerated in water for 24 hours. Finally, the macerated material was filtered to obtain the extracts (Dabiré-Binso et al., 2008).

For the neem seeds extract treatment subplots, a formulation made up of 500.00 g per ten (10) L (w/v) of water per 400.00 m^2 was applied three times weekly (Dabiré-Binso et al., 2008).

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While the plots for treatments with synthetic insecticide, a mixture of Lambda-cyhalothrin, 15.00 g/l, and Acetamiprid, 20.00 g/l was applied twice at a concentration of one (1) liter/ha, two weeks apart.

2.3. Data collection

Data collection started at the doughy grain stage of millet from each sub-plot and sub-block until harvest (time in weeks). The number of *H. albipunctella* larvae per spike, the damage caused by *H. albipunctella* (number and length of mines per spike and number of spikes attacked) and the grain yield were recorded. To determine the number of larvae per spike, an area of 1 m^2 was delimited in each sub-plot and the number of larvae is counted on each spike contained in each surface and repeated four times. while the number of attacked spikes (spike bearing at least one mine), the number and length of mines per spike and the grain yield, an area of 9.00 m^2 was determined at each sub-plot. Thus, the number of attacked spikes, the number, and length of mines per spike and the grain yield were determined. The length of each mine was measured using a measuring tape. At harvest, the millet spikes from each area were threshed and weighed. The percentage of attacked spikes (PAE) and the grain yield (GY) were calculated for each sub-plot of each sub-block using equations 1 and 2:

$\boldsymbol{PAE}\,(\%) = (\boldsymbol{NSA/TNS}) \times \mathbf{100.00}$; where NSA: Number of spikes attacked per delimited area and TNS: Total number of spikes. Equation (1)

$\boldsymbol{GY}\,\left(\frac{\boldsymbol{kg}}{\boldsymbol{ha}}\right) = \left(\frac{\boldsymbol{GW}}{\boldsymbol{S}}\right) \times \mathbf{10,000.00}$ **;** where GW: Grain weight of millet in kg per delimited area and S: delimited area in m^2. Equation (2).

2.4. Data analyses

The data collected were analyzed using a two-way analysis of variance (Factorial ANOVA) to examine the influence of the phytosanitary treatments and the cropping systems (two independent variables) on the studied parameters. Post hoc tests were performed using the 'lsmeans' package in RStudio (Lenth, 2016) when factorial ANOVA was significant between groups. The visualize the data, box plots and figure were plotted using R and Excel, respectively. All statistical analyses were carried out using R (software version) and level of significance set at 5% for all statistical analyses.

3. Results

3.1. Influence of cropping system and phytosanitary treatment on the parameters studied

We found that phytosanitary treatment has a significant influence on the number of larvae per spike, *H. albipunctella* damage and grain yield (Table I). The average percentage of damaged and the average number of damaged per spike were influenced by the cropping system (Table I). On the other hand, the interaction between cropping system and phytosanitary treatments did not affect these parameters (Table I).

3.2.Number of *H. albipunctella* larvae per spike according to phytosanitary treatments

The average number of larvae per spike of millet varied significantly depending on the location of the treatment (Djibasso ANOVA, $F_{2.439} =2.94; P=0.003$; and Dori ANOVA, $F_{2.416} =2.39; P = 0.01;$ Fig 2). Regardless of the commune, it was greater in the sub-block that received no treatment (Fig 2). In Djibasso, the average number of larvae per spike obtained with neem aqueous extract (1.33 larvae/spike) was significantly lower compared to treatment with Synthetic insecticide (where to find the result ie which figure and then the statistics, see above (ANOVA, $F_{2.439} =2.94; P=0.003$). In contrast, no significant difference was observed between the neem aqueous extract treatment and Synthetic insecticide in the commune of Dori (Fig 2).

3.3.Damage by *H. albipunctella* according to phytosanitary treatments

The average percentage of millet spike attacked by *H. albipunctella* was significantly greater at the level of the control treatment compared to those of the aqueous extract of neem and Synthetic insecticide in the communes of Djibasso (ANOVA, $F_{2.26} = 6.26; P = 0.0006$) and Dori (ANOVA, $F_{2.26} = 6.95; P = 0.0003$) (Table II). In addition, treatments with aqueous neem extract and Synthetic insecticide reduced the average percentage of millet spike attacks by about 50.00% in both study sites. Regarding the average number of mines per spike, it varied significantly with location (Djibasso, ANOVA, $F_{2.404} = 8.21; P < 0.0001$) and Dori (ANOVA, $F_{2.90} =1.28; P = 0.2666$) (Table II). In Djibasso and Dori, the average number of mines per spike was lower from neem aqueous extract treatments in comparison to those from Synthetic insecticide and the control (Table II). The mean length of mines, which reflects the extent of *H. albipunctella* damage, varied significantly at the level both communes (Djibasso ANOVA: $F_{2.404} =8.06; P < 0.0001$; Dori ANOVA: $F_{2.90} =2.33; P = 0.0394;$ Table II). In addition, in Djibasso and Dori, the mean length of mines per spike was lower at the level in the neem aqueous extract treatment than those of the Synthetic insecticide and the control (Table II).

3.4. Effect of the cropping system on the percentage millet per spike attacked and the number of mines per spike in the commune of Djibasso

The percentage of millet spikes attacked and the number of mines per millet spike were significantly influenced by the cropping association system in the commune of Djibasso (Table III).

The highest and lowest significantly different percentages of damaged millet spike were observed on millet grown alone and on the combination of two rows of millet and one row of cowpea (ANOVA, $F_{2,\ 24}$= 6,16; P=0,01; Table III).

The average number of mines per spike was significantly higher in the farmer's practice compared with millet grown alone and the combination of two rows of millet and one row of cowpea (ANOVA, $F_{2,\ 132}$= 6,16; P=0,002; Table III).

3.5. millet grain yield by phytosanitary treatments

Grain yield of millet varied significantly at the level of commune of Djibasso (ANOVA, $F_{2.24} =3.53; P= 0.0096$; and Dori: $F_{2.24} = 2.34; P = 0.00473$; Fig 3). In contrast, regardless of the commune, millet grain yield was statistically similar between the neem aqueous extract and Synthetic insecticide treatments (Fig 3). The phytosanitary treatment, in both communes, made it possible to obtain more than one ton of millet per hectare compared to the control treatment which was less than one ton (Fig 3).

4. Discussion

Millet cultivation, whether in monoculture or in association with cowpea, is a recurrent practice in Burkina Faso (Zoundi et al., 2007; Boly et al., 2022). This combination is sometimes accompanied by treatment of the cowpea with a synthetic insecticide or biopesticides to control insect pests of the cowpea crop. In contrast, the indirect effect of cowpea treatment on cereal insect pests associated with cowpea is sometimes overlooked.

In this study, we evaluated the indirect effect of cowpea treatment when intercropped with millet on the main pest of millet, *H. albipunctella,* in the field conditions. Our results show that the application of the aqueous extract of neem seeds on cowpea grown in association with millet at the time of heading gives similar results to those treated with the synthetic pesticide (Lambda-Cyhalothrin 15 g/l + Acetamiprid 20 g/l). These findings show a significant reduction in the number of *H. albipunctella* larvae per millet spike, the percentage of spikes attacked, and the length of mines in treated plots compared to the control. Synchronization cowpea treatment with the millet heading stage significantly reduced the activity of *H. albipunctella* females on treated sub-plots. This reduction in female activity led to lower infestations of millet spikes. Indeed, infestation of millet by *H. albipunctella* is conditioned by a synchronization between the period of heavy outbreaks of *H. albipunctella* and the sensitive stage of millet corresponding to the beginning heading stage (Vercambre, 1978; Bal, 1988; Kaboré, 2018). Likewise, *H. albipunctella* females prefer to lay their eggs at the heading stage, precisely at the top of millet spikes, with hatching occurring 3 to 4 days after oviposition (Ndoye, 1991; Gahukar, 1984). The reduced infestation observed in the treated sub-plots may be attributed to the bioactive compounds in neem extract, such as azadirachtin, meliantriol, and salannin, which possess repellent, insecticidal, and fertility-reducing properties (Jacobson and al., 1978; Ascher, 1993; Rembold, 1989). These compounds, with their repellent properties, can disrupt insect communication and disorient pest insects. They also regulate insect growth by affecting egg-laying behavior (Strickman, et al., 2009; Guèye et al., 2011). The efficacy of neem extracts against insect pests, particularly Lepidoptera, has been widely documented (Cherry et al., 2010; Boni et al., 2018; Ngom et al., 2018; Yao et al., 2022). Similarly, the repellent properties of neem extract against insect pests have also been demonstrated in beekeeping. Spraying neem leaf extracts around hives within a radius of five (5) meters, both before and after insect colonization, resulted in a significant reduction in the number of insects colonizing the hives (Gbedomon et al., 2012). Indeed, the repellent property observed with the treatment of neem extract could be attributed to the volatile compounds contained in *A. indica* (Belder Den et al., 1998). These volatile compounds, present in neem seed extract, can deter females from locating their egg-laying sites, especially as their effect can last in the fields for 4 to 8 days depending on environmental conditions and the plant species treated (Schmutterer, 1990). The volatile compounds of neem are believed to act as an inhibitor, blocking the stimuli emitted by millet spikes, thereby deterring female *H. albipunctella*. Similar results were observed in Mali by Passerini in 1991. These authors reported a significant reduction in the number of eggs and mines of *H. albipunctella* after treating millet fields with an aqueous neem powder extract

(Passerini, 1991). Moreover, volatile compounds are used in locating oviposition sites by females of *H. albipunctella* (Hall et al., 2001; Green et al., 2004). Where the females prefer to lay eggs on spikes that have only emerged at 30.00% (Ndoye, 1991) which release high amounts of volatile compounds such as borneol that attract females. Thus, the mixture of volatile compounds from neem extracts with those emitted by the spikes in the same field of millet must have confused the females, who could no longer locate the spikes of millet for oviposition. This would explain the low number of larvae observed in the treated plots. Heavy rainfall can also reduce the density of *H. albipunctella* larvae, especially 1st and 2nd instars, which walk on the spikes. Indeed, the application of neem extract in the field resulted in a considerable reduction in the population density of *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae)*, Earias spp., Diparopsis watersi,* Roths. (Lepidoptera :Noctuidae) *Spodoptera littoralis* (Lepidoptera :Noctuidae)*,* and *Syllepte derogata* Fabricius (Lepidoptera : Crambidae) (Misra et al., 2002; Nboyine et al., 2013; Douro et al., 2013).

We also found a significant reduction in the incidence of *H. albipunctella*, which were lower in the treated sub-plots than in the untreated ones. This reduction could also be explained by a low infestation of spikes observed in these sub-plots at the time of heading. Damage by *H. albipunctella* is mainly caused by larvae feeding on the floral organs, perforating the glumes, cutting the floral and fruit peduncles causing them to dry out (Vercambre, 1978). This result corroborates those of Ndoye (1979), who stipulates that the extent of damage caused by *H. albipunctella* on the millet crop would strongly depend on the coincidence between the flight of the adults and the period when earing begins in millet and the density of the larval population. making the effectiveness of phytosanitary treatment at the early heading stage against *H. albipunctella* very critical. Which is why the application of endosulfan, Decis ULV (dimethoate + deltamethrin) and trichlorfon (dipterex + SI 8514) at early heading were effective against the *H. albipunctella* (Vercambre, 1978; Gahukar, 1984; Guevremont, 1982). However, considering the harmful effects of these synthetic chemicals on humans, the environment, and biodiversity, it is advisable to use these products only if there is no alternative solution. Other groups of insect pests have been the subject of similar study. According to Adda et al. (2011), sowing *Hyptis suaveolens* (L) on the edges of maize fields halved the percentage of plants infested by *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae).

In terms of the cropping system, the combination of two rows of millet and one row of cowpea resulted in a significant reduction in the percentage of millet spikes that were attacked and the average number of mines per spike. This reduction can be attributed to the diversity of the landscape, which not only disorients females in finding oviposition sites, but also provides a refuge for natural enemies. Indeed, pests may lose the ability to locate host plants when confronted with a mixture of several volatiles from non-host plants. This hypothesis supports the assertion that volatile compounds are important for the location of oviposition sites of the MEM (Hall et al., 2001; Green et al., 2004).

The results of the present study also showed the effectiveness of neem extract in increasing grain yield of millet by more than 40.00%. The increase in grain yield observed in the treated plots could be explained by a low number of *H. albipunctella* larvae. Indeed, according to Gahukar and Ba (2019), Oumarou et al. (2019), yield losses due to *H. albipunctella* larvae attacks without any external intervention in the Sahelian zone are estimated between 30.00 and 80.00%. The results of this study show that, in the context of integrated pest management, treating cowpea in association with millet using neem seed extract can protect the millet crop against *H. albipunctella*.

Conclusion

This study on the efficacy of the crop association associated with neem extract in the control of the millet head miner, *H. albipunctella* showed a particular interest in the importance of treating cowpea in association with millet in the field. Indeed, the use of aqueous neem seed extract on cowpea in combination with millet significantly reduced the infestation of millet by *H. albipunctella*. This resulted in a significant reduction in the percentage of millet ears attacked, the number and length of mines, and an increase in productivity. For these reasons, the use of this biopesticides in the treatment of cowpea in association with millet could constitute an alternative control method for the control of the millet head miner in the Sahelian zone.

References

Adda, C., Atachi, P., Hell, K., & Tamò, M (2011). Potential use of the bushmint, *Hyptis suaveolens*, for the control of infestation by the pink stalk borer, *Sesamia calamistis* on maize in southern Benin, West Africa. Journal of Insect Science, 11(1). https://doi.org/10.1673/031.011.0133

Amadou L, Baoua IB, Ba MN, Haussmann B, Altiné M (2017) Gestion de la chenille mineuse de l'épi du mil par des lâchers du parasitoïde *Habrobracon hebetor* Say au Niger. *Cah. Agric*. 26 : 55003. https://doi.org/10.1051/cagri/2017045

Ascher KRS (1993) Nonconventional insecticidal effects of pesticides available from the Neem tree, *Azadirachta indica*. Archives of Insect Biochemistry and Physiology, *22*(3-4), **https://doi.org/10.1002/arch.940220311**

Ba MN, Baoua I, Kaboré A, Amadou L, Oumarou N, Dabire-Binso C, Sanon A (2014) Augmentative on-farm delivery methods for the parasitoid *Habrobracon hebetor* Say (Hymenoptera: Braconidae) to control the millet head miner *Heliocheilus albipunctella* (de Joannis) (Lepidoptera: Noctuidae) in Burkina Faso and Niger. BioControl 59, 689–696. https://doi.org/10.1007/s10526-014-9613-8

Bal AB (1988) *Acigona ignefusalis* HMPS et *Raghuva albipunctella* de Joanis, ravageurs du mil au Sénégal : dynamique des populations imaginales et infestations au champ. Atelier Régional sur le mil 15-19 Aout 1988 - I.A.R., A.B.U, ZARIA, Nigeria. Pp 1- 21.

Barzman M, Lamichhane JR, Booij K, Boonekamp P, Desneux N, Huber L, Kudsk P, Langrell SRH, Ratnadass A, Ricci P, Sarah JL, et Messean A (2015) Eight principles of integrated pest management. Agronomy for sustainable development, 35, 1199-1215. https://doi.org/10.1007/s13593-015-0327-9

Belder Den E, Elderson J, Agca I (1998) Host finding of *thrips tabaci* disrupted by volatiles. Department of Crop Production Ecology, Wageningen University, 19p.

Boly A, Waongo A, Kaboré A, Traore F, Ba MN, & Sanon A (2022) Perception des producteurs sur les insectes ravageurs du mil au Burkina Faso : Place de la mineuse de l'épi de mil, *Heliocheilus albipunctella* De Joannis (Lepidoptera : Noctuidae). Journal of Applied Biosciences, 176(1), 18322-18341. https://doi.org/10.35759/JABs.176.10

Bonni G, Azonkpin S, & Paraïso A (2018) Efficacité des programmes de traitement phytosanitaire à base de kaolin, de neem et d'insecticide dans la gestion des chenilles endocarpiques du cotonnier dans la zone Centre du Bénin. 40 (1), 12. http://www.ijisr.issr-journals.org/

Carpentier A (2010) Economie de la production agricole et régulation de l'utilisation des pesticides : une synthèse critique de la littérature. INRA-UMR Smart et ENSAI, Rennes, 48 p. https://hal.inrae.fr/hal-02821066

Cherry R, & Nuessly G (2010) Repellency of the biopesticide, azadirachtin, to wireworms (Coleoptera: Elateridae). Florida Entomologist, *93*(1), 52-55. https://doi.org/10.1653/024.093.0107

Dabiré-Binso C, Ba NM, et Sanon A (2008) Module de formation sur les insectes ravageurs du niébé en culture. 9p

DGESS (2023) Résultats définitifs de la campagne agricole et de la situation alimentaire et nutritionnelle 2020/2021. Mars 2021. 95 p.

Douro KOK, Paraïso A, Djegui DA, Maffon S, Glitho IA, Tamo M (2013) Comparative study of the efficacy of entomopathogenic fungi, chemicals and botanical pesticides management of cotton pest and their natural enemies in Benin. International Journal of Science and advanced Technology. 3 (1) : 21-33. http://www.ijsat.com

Dupuy C (2017) De la domestication du mil aux récoltes de grains excédentaires : Données archéologiques associées. Bulletin mensuel de la Société linnéenne de Lyon. Année 2017 86-1-2 pp. 3-18

Fontès J, et Guinko S (1995). Carte de la végétation et de l'occupation du sol au Burkina Faso ; Notice explicative. 67p

Ruparao TG, Malick N (2019) Une revue actualisée des recherches sur *Heliocheilus albipunctella* (Lepidoptera : Noctuidae), en Afrique de l'Ouest sahélienne, Journal of Integrated Pest Management , Volume 10, Numéro 1, 2019, 3, https://doi.org/10.1093/jipm/pmz003

Gahukar RT (1984) Insect pests of pearl millet in West Africa: a review. Int J Pest Manage 30 :142–147. https://doi.org/10.1080/09670878409370867

Gbedomon CR, Sikirou R, Zannou E, Pomalegni SCB, Goergen G, Bokonon-Ganta AH, Atachi P, Mensah GA (2012) Extraits botaniques utilisés contre les arthropodes associés aux abeilles et produits de la ruche inventoriés au centre du Bénin. In Actes du 3ème Colloque des Sciences, Cultures et technologies de l'UAC-Benin (pp. 573-588).

Green SV, Owusu EO, & Youm O (2004) Egg-laying behaviour in the millet head miner moth, *Heliocheilus albipunctella* (De Joannis)*:* A preliminary assessment of the role of chemical cues in oviposition site selection.

Guèvremont H (1982) Études de la mineuse de l'épi et autres insectes du mil : Rapport annuel de recherche pour l'année 1981. CNRA de Tarna, Maradi, Niger, pp.57.

Guèye MT, Seck D, Wathelet JP, et al. (2011) Lutte contre les ravageurs des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : Synthèse bibliographique. Biotechnol. Agron. Soc. Environ., 12. **https://hdl.handle.net/2268/89355**

Guo Z, Dong Y, Dong K, et al. (2020) Effects of nitrogen management and intercropping on faba bean chocolate spot disease development. Crop Prot. 127, 104972. https://doi.org/10.1016/j.cropro.2019.104972

Hall DR, Farman DI, Green SV, et al. (2001) Analysis of volatiles from millet panicles as potential factors affecting oviposition by the millet head miner moth, *Heliocheilus albipunctella* de Joannis (Lepidoptera: Noctuidae).

Haseeb M, Liu TX, & Jones WA (2004) Effects of selected insecticides on *Cotesia plutellae*, endoparasitoid of *Plutella xylostella*. BioControl, 49(1), 33-46. https://doi.org/10.1023/B:BICO.0000009377.75941.d7

Kaboré A (2018) Optimisation de la lutte biologique contre la mineuse de l'épi de mil, *Heliocheilus albipunctella* De Joannis (Lepidoptera : Noctuidae) au Burkina Faso : Techniques d'élevage de masse et de lâchers du parasitoïde *Habrobracon hebetor* Say (Hymenoptera : Braconidae). Thèse de Doctorat, Université Joseph KI ZERBO. Pp.136

Kaboré A, Ba MN, Dabire-Binso CL, et al. (2017) Field persistence of *Habrobracon hebetor* Say (Hymenoptera: Braconidae) following augmentative releases against the millet head miner, *Heliocheilus albipunctella* (de Joannis) (Lepidoptera: Noctuidae), in the Sahel. Biol. Control. 108: 64–69. https://doi.org/10.1016/j.biocontrol.2017.03.001

Kpindou OD, Paraïso A, Djegui DA, et al. (2013) Comparative study of the efficacy of entomopathogenic fungi, chemicals and botanical pesticides in the management of cotton pests and their natural enemies in Benin. International Journal of Science and AdvanceTechnology, 3, 21-33. http://www.ijsat.com

Lawane G, Sougnabe SP, Lendzemo V, Gnokreo F, Djimasbeye N, et Ndoutamia G (2010) "Efficacité de l'association des céréales et du niébé pour la production de grains et la lutte contre *Striga hermonthica* (Del.)". Savanes africaines en développement : innover pour durer, 8 p. http://hal.cirad.fr/cirad-00471450.

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Lenth RV, (2016) Moindres carrés signifient : le paquet R lsmeans. Journal des logiciels statistiques, *69*, 1-33.

Lykke AM, Kristensen MK, Ganaba S (2004) Valuation of local use and dynamics of 56 woody species in the Sahel. Biodivers. Conserv. 13, 1961–1990. https://doi.org/10.1023/B:BIOC.0000035876.39587.1a

Malick N, Dabire CB, Drabo I, et al. (2008) Combinaison de la résistance variétale et d'insecticides à base de neem pour contrôler les principaux insectes ravageurs du niébé dans la région centrale du Burkina Faso. Sciences Naturelles et Appliquées, 30(1). https://revuesciences-

Martin T, Ochou GO, N'klo FH, et al. (2000) Pyrethroid resistance in the cotton bollworm, *Helicoverpa armigera* (Hubner), in West Africa. Pest Management Science, 56: 549-554. https://doi.org/10.1002/(SICI)1526-4998(200006)56:6<549::AID-PS160>3.0.CO;2-Y

Misra HP, Dash DD, & Mahapatra D (2002) Efficacité de certains insecticides contre la pyrale du gombo, Earias spp. et la tordeuse des feuilles, *Sylepta derogata* Fab. Annals of Plant Protection Sciences, 10(1), 51-54.

Namatsheve T, Cardinael R, Corbeels M, et al. (2020) Data from: productivity and biological N2-fixation in cereal-cowpea intercropping systems in sub-Saharan Africa. A review. CIRAD Dataverse, V1 1. https://doi.org/10.18167/DVN1/DXDR1R

Nboyine JA., Abudulai M, & Opare-Atakora DY (2013) Field efficacy of neem (*Azadirachta indica* A. Juss) for managing soil arthropods and Cercospora leaf pots damage for increased yield in peanut. http://csirspace.csirgh.com:80/handle/123456789/321

Ndoye M (1991) Biologie et dynamique des populations de *Heliocheilus albipunctella* (De Joannis) ravageur de la chandelle de mil dans le Sahel. Sahel PV Info 39 :11–20. http://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=6487349

Ngom S, Perez RC, Mbow MA, et al. (2018) Larvicidal activity of Neem oil and three plant essential oils from Senegal against *Chrysodeixis chalcites (Esper, 1789)*.

Oumarou N, Baoua I, Saidou AA, et al. (2019) Perception des paysans sur la contrainte de la mineuse de l'épi *Heliocheilus albipunctella* De Joannis, ravageur important du mil en zone sahélienne. Tropicultura, Volume 37, Numéro 1. https://doi.rog/10.25518/2295-8010.255

Passerini J (1991) Field and laboratory trials in Mali to determine the effects of neem extracts on three millet pests; *Heliocheilus albipunctella* De Joannis (lepidoptera: noctuidae), *Coniesta ignefusalis* Hampson (lepidoptera: pyralidae) and *Kraussaria angulifera* Krauss (orthoptera: acrididae). Master of Science (M.Sc.), Department of Entomology McGill University, Montreal Québec, Canada, Pp: 183

Parthasarathy Rao P, Birthal PS, Reddy BV, et al. (2006) Diagnostics of sorghum and pearl millet grains-based nutrition in India. International Sorghum Millets Newsletter (ISMN) 2006; 47:93-96. http://oar.icrisat.org/id/eprint/1119

R Core Team (2022) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Saïdou AA (2011) Etude moléculaire, évolution et caractérisation de gènes impliqués dans l'adaptation du mil (Pennisetum glaucum [L.] R. Br.) aux changements climatiques. Montpellier : Montpellier SupAgro, 236 p. Thèse de doctorat : Evolution, écologie, ressources génétiques, paléontologie : Montpellier SupAgro

Sanon A, Sou S, Dabiré C, et al. (2005) Combining *Boscia senegalensis* Lamarck (Capparaceae) Leaves and Augmentation of the Larval Parasitoid *Dinarmus basalis* Rondani (Hymenoptera: Pteromalidae) for Bruchid Control in Stored Cowpeas. Journal of Entomology, 2 (1): 40-45.

Saxena, R.C (1989) Insecticides from Neem. In: Insecticides of Plant Origine ACS Society, Toronto Conf. pp. 110-131

Schmutterer H (1990) Properties and potential of natural pesticides from the neem tree, *Azadirachta indica*. Ann. Rev. Entomol. 35, 271–297.

Shafiq MA, Nadeem A, & Fazil H (2012) Potential of Biopepticides in Sustainable Agriculture, Strategies for Sustainability. Environmental Protection Strategies for Sustainable Development, 529-595.

Shelke GV, et Chavan AM (2010) Improvement of agronomicaly desirable genotype for downy mildew disease resistance in Pearl millet [(*Pennisetum glaucum* (L.) R. Br.] By recombination breeding. Journal of Ecobiotechnology, vol. 2, no. 1, Jan. 2010, https://updatepublishing.com/journal/index.php/jebt/article/view/14.

Siddiqui JA, Fan R, Naz H, et al. (2023) Insights into insecticide-resistance mechanisms in invasive species: Challenges and control strategies. Frontiers in Physiology, 13, 1112278. https://doi.org/10.3389/fphys.2022.1112278

Strickman D, Frances SP, Debboun M (2009) Prevention of Bug Bites, Stings, and Disease. Oxford University Press: New York, 323 p.

Tanzubil PB, Zakariah M, & Alem A (2004) Effect of nitrogen and farmyard manure on insect pests of pearl millet in northern Ghana, Trop. Sci., 44, 1, 35-39. **https://doi.org/10.1002/ts.129**

Trail P, Abaye O, Thomason WE, et al. (2016) Evaluating intercropping (living cover) and mulching (desiccated cover) practices for increasing millet yields in Senegal. Agron J 108:1742–1752. https://doi.org/10.2134/agronj2015.0422

Vercambre B (1978) Raghuva spp. et Massalia sp., Chenilles des Chandelles de mil en zone sahélienne. Agronomie Tropicale 33 : 62-79. http://agritrop.cirad.fr/421402/

Yao BL, Gogoue DO, Nando PMN, et al. (2022) Etude comparée de l'efficacité des extraits aqueux de feuilles d'eucalyptus (*Eucalyptus camaldulensis*) et des graines de neem (*Azadirachta indica* Juss) contre les principaux ravageurs de chou. International Journal of Biological and Chemical Sciences, *16*(2), 581-592. 10.4314/ijbcs.v16i2.6

Younoussou R, Abdou MA, Abdou L, et al. (2021) Effets comparés de quelques biopesticides et d'un pesticide chimique (cyperméthrine 10 EC) sur les insectes ravageurs et maladies parasitaires du Niébé, *Vigna unguiculata* (L.) Walp (Fabaceae). Revue Marocaine des Sciences Agronomiques et Vétérinaires, 9(4), 710-717. www.agrimaroc.org

Zoundi JS, Lalaba A, Tiendrébéogo JP, et al. (2007) Systèmes de cultures améliorés à base de niébé (*Vigna unguiculata* (L.) Walp) pour une meilleure gestion de la sécurité alimentaire et des ressources naturelles en zone semi-aride du Burkina Faso. TROPICULTURA, 2007, 25,2, 87-96.http://hdl.handle.net/10625/44281