Impact of aqueous extracts of *Cassia occidentalis*, *Eucalyptus camaldulensis* and *Hyptis suaveolens* on the entomofauna and the seed yield of *Gossypium hirsutum* at Boklé (Garoua, Cameroon)

Moïse Adamou a,b,*, Daniel Kosini b, Abraham Tchoumbou-Salé a, Odette Dabole Massah a, Tchepegni Fernande Cadette Tchognia a, Mokhtar Mohammadou a, Ousmana Youssoufa a, Elias Nchiwan Nukeninea

a Laboratory of Applied Zoology, Department of Biological Sciences, Faculty of Science, University of Ngaoundéré, PO Box 454, Ngaoundéré, Cameroon
b Faculty of Medicine and Biomedical Sciences, University of Garoua, PO Box 317, Garoua, Cameroon

ARTICLE INFO

Keywords:
Amegilla sp. 1
Gossypium hirsutum
Cassia occidentalis
Eucalyptus camaldulensis
Hyptis suaveolens
Plant extracts
Yield
Bocklé

ABSTRACT

There is a frightening decline in the population pollinators around the world due to the over usage of synthetic pesticides, leading to the directly reduce of plant production. Plant extracts with insecticidal properties could be eco-friendly alternatives to synthetic pesticides in maintaining the pollinator population and the diversity of the ecosystem. The impact of aqueous extracts of *Cassia occidentalis* L., *Eucalyptus camaldulensis* Dehnh. and *Hyptis suaveolens* L. was investigated on the entomofauna and the seed yield of *Gossypium hirsutum* L. cotton. The study was carried out in RCBD, four times replicated: 3 extracts x 1 standard synthetic insecticide (TEMA) x 1 control x 4 groups of flowers (group 1: flowers free to insect visits, group 2: flowers protected from insects using gauze bags, group 3: protected flowers and opened exclusively to *Amegilla* sp. and group 4: protected flowers opened from time to time without any visit of insect). *Gossypium hirsutum* was found to be visited by the insects belonging to five orders, 10 families and 18 species. *Amegilla* sp.1 and *Apis mellifera* were the major pollinators during the rainy and dry seasons, respectively. The number and quality of seeds visited exclusively by *Amegilla* sp.1 were significantly improved by *H. suaveolens* extract. During the dry season, *E. camaldulensis* and *H. suaveolens* extracts as well as the standard insecticide improved the number of seeds and the percentage of normal seeds harvested from the flowers allowed to be visited by insects; that was probably due to their insecticidal effects which protected plants from pest damage. Therefore, aqueous extracts of *E. camaldulensis* and *H. suaveolens* are good candidates for incorporation in integrated pest management programs to minimize the risk of synthetic pesticides to pollinators, hence to increase the yield and the quality of seeds.

1. Introduction

In Cameroon, agriculture is the main activity in countryside and the main provider of jobs, since it employs around 60% of the working population (INS, 2017). One of the key objectives of agricultural research in Cameroon is the optimisation of agricultural yields to achieve a balanced diet (MINADER/DESA, 2010). The qualities of seeds and varieties have enabled farms to have yields of nearly 70% (MINADER, 2017). Cotton cultivation plays an important role in food self-sufficiency. In fact, the FAO estimates that nearly 100 million rural African families depend directly on cotton production, including more than 6 million rural African households (Abdoulaye et al., 2008). Cotton is the main lint crop in the world, its global production declining 3% to 25.8 million tons in 2018 (OECD/FAO, 2016). Although more than 50% of its production is intended for clothing; it also produces various derivatives, including vegetable oil and 20–30% protein (Abdoulaye et al., 2008). In Cameroon, the demand for cotton seeds and fiber (350,000 tons) is greater than its production (250,000 tons) because of pests, which represent the main cause of destruction of cotton crops (MINADER/DESA, 2010). The insect pests of cotton are grouped into four main categories, namely carphopagous caterpillars, phylophagous caterpillars, sucker and mites. Crop losses due to attacks by these pests are greater than 30% and can reach total destruction of the production potential (SODECOTON, 2019).

* Corresponding author.

E-mail address: adamou.moise@yahoo.fr (M. Adamou).

https://doi.org/10.1016/j.heliyon.2022.e10937
Received 29 April 2022; Received in revised form 23 June 2022; Accepted 29 September 2022
2405-8440/© 2022 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Thus, in order to boost yields and meet up the ever-increasing market demand, farmers resort to the use of synthetic pesticides which has caused more damages than it has solved (Bambara and Tiemtòre, 2008). Africa uses less than 10% of global pesticide production but accounts for 75% of pesticide fatalities (Guye et al., 2011). Indeed, they aren’t just expensive, but they also acidify the soil when misuse and their residues are toxic to non-target fauna. They cause resistance in pest insects (Immaraju et al., 1992; Margni et al., 2002), and pollute surface water and groundwater (Ouedraogo, 2004). Considering the harmful effects of synthetic insecticides, it is necessary to develop and recommend alternative environmentally friendly methods to control insect pests of cotton while preserving pollinating insects. Pollinators such as bees are often involved in increasing the yield of fruits and seeds of several plants (Fluri and Frick, 2005; Djonwangwe et al., 2017).

Botanical insecticides are naturally occurring insecticides derived from plants that possess repellent, sterilant, antifeedant and toxicant properties and are environment friendly (Issan, 2000; Ayyas et al., 2009). In fact, plants through their derivatives such as powders, crude extracts, oil, essential oils and semi-purified or purified compounds provide natural insecticides for the protection of field crops and can be therefore used as a substitute for synthetic insecticides (Bambara and Tiemtòre, 2008; Cheikh et al., 2015; Barry et al., 2017, 2019). Essential oils from the leaves of C. occidentalis, E. camaldulensis and H. suaveolens have been reported to possess insecticidal efficacy against insect pests (Conti et al., 2012; Chibuzor and Obioma, 2018; Rezaei et al., 2019). To provide farmers with quick and cheap access to crop pest control solutions, the present study was undertaken to investigate the impact of aqueous extracts of C. occidentalis, E. camaldulensis and H. suaveolens on the entomofauna and the seed yield of G. hirsutum.

2. Materials and methods

2.1. Study area and biological materials

The study was carried out over two seasons from 08 July to 17 December, 2019 and from 22 December, 2019 to 17 June, 2020 in Bocklé, 3rd district of Garoua Northern Region of Cameroon (latitude: 9°17'29.814"N; longitude: 13°25'4.38636"E; altitude: 169 masl). This area belongs to the Sudano-Sahelian zone of Cameroon characterized by unimodal rainfall. The rainy season lasts 4 months from June to September with two intermediate months of unreliable rainfall in May and October. Mean total annual rainfall is approximately 1000 mm and mean annual temperature varied between 25.5 to 32.5 °C. Mean relative humidity varied between 42 to 83% (data recorded in 2018 by the Garoua international airport: unpublished).

The floristic species of vegetation encountered are consisting of Hyparrhenia rufa along rivers, Borassus aethiopium, Boswellia dalzielii, Commiphora africana, Lannea microcarpa, Bombax costatum, Prosopis africana, Vittellaria paradoxa and plantations of Asadraeha indica. Eucalyptus camaldulensis, Cassia occidentalis and Hyptis suaveolens is used in several traditional medicines to cure various diseases can be also naturally present in the environment of the study area.

The experimental plot covered a surface area of 494 m² (26.0 m length × 19.0 m broad). It was cleared and excavated using machetes and pickaxes, and then 4 blocks of 5 experimental units each were established. Each experimental unit consisted of one row of 3.5 m broad × 4.0 m length spaced 1.0 m apart. Five cotton Gossypium hirsutum seeds, variety QR, 302 supplied by SODECOTON were sown at an intra-row and inter-row spacing of 36.36 cm and 50 cm respectively, and thinned to two per hill two weeks after sowing. The plot was manually weeded every two weeks.

2.2. Collection and processing of plant materials

Fresh leaves of C. occidentalis, E. camaldulensis and H. suaveolens were collected in the Djamboutou district at Garoua (latitude 9°310’N and longitude 13°410’E). Collection was done each two weeks on the eve of a treatment during the entire period. The aqueous plant extracts were obtained by using the method described by Sheekhan (2013): 400 g of each these leaves were weighed using a DIAMAN brand electronic balance (Capacity 3 kg, Precision 0.1 g), pounded separately using a wooden mortar and pestle before being put in a bucket containing 4L of water. Thereafter, the mixture was left to stand for 12 h. After maceration, the mixture was sifted through a 0.2mm mesh sieve into another bucket. The solutions obtained were each put into the sprayers.

2.3. Treatments

The study was carried out in a randomized complete block design (RCBD): 3 aqueous plant extracts × 1 standard synthetic insecticide (TEMA) × 1 control × 4 groups of flowers (group 1: flowers free to insect visits, group 2: flowers protected from insects using gauze bags, group 3: protected flowers and opened exclusively to Amegilla sp. and group 4: protected flowers opened from time to time without any visit of insect) × 4 replications. TEMA is a synthetic chemical insecticide containing 60 g of emamectin benzoate per kg and 75 g of teflubenzuron per kg. It is recommended at the rate of 200 g/ha to protect G. hirsutum at its different developmental stages against insect pests. In our study, 2 g was diluted in 3 L of water. Insecticide formulations were sprayed using five distinct manual gauge sprayers, each corresponding to a specific insecticidal product including the water used as control. Extracts and water at the rate of 714 L/ha and TEMA solution at the rate of 300 L/ha were applied in the evening between 5 and 6 p.m., two weeks interval, starting from the germination to the maturation of capsules. At bud stage, flowers were grouped as previously described and labelled: groups 1 and 2 = 120 flowers each, group 3 = 200 flowers and group 4 = 100 flowers.

2.4. Data collection

Flowers of group 1 were observed at the peak of flowering period and the foraging behaviour and insect species were recorded. The number of insects morphospecies visiting 120 G hirsutum flowers were counted every day between 6.00 a.m. and 5.00 p.m., with six time periods per day (6:00–7:00 a.m., 7:00–8:00 a.m., 8:00–9:00 a.m., 9:00–10:00 a.m., 10:00–11:00 a.m., 11:00–12:00 p.m., 12:00–1:00 p.m., 1:00–2:00 p.m., 2:00–3:00 p.m. and 4:00–5:00 p.m.). Since the insects were not marked, the cumulative data were expressed as the number of visits. Except A. mellifera and Amegilla sp., other insects visiting G. hirsutum were captured by hand/entomology forceps (larvae) or using entomological net (adults). Specimens were stored in glass vials containing 70% ethanol, except Lepidoptera that was preserved in papillotes as recommended by Borror and White (1991). Each glass vial was labelled according to the different treatments where insects were captured. At the end of the study, insects were identified by using insect keys (Delvare and Arbelenc, 1989; Borror and White, 1991; Cuilloud, 1993; Eardley et al., 2010).

The number of A. mellifera and Amegilla sp.1 simultaneously foraging one and 1000 flowers was assessed according to the method described by Tchuenguem et al. (2005). The frequency of each insect species (Fi) was determined using the following formula: 

\[ F1/F2 \times 100\]  

where \( F1 \) is the number of boll formed and \( F2 \) the number of flowers initially labeled.

- \( FR = (F1/F2) \times 100\): \( FR \) is the average number of seeds (ANS) and normal seed percent (%NS) were recorded for each group as follow:

- FR = (F1/F2) × 100: F1 is the number of boll formed and F2 the number of flowers initially labeled.
- ANS: dried capsules were opened manually and seeds were harvested and counted.
- %NS = (Number of normal seeds/Total seeds) * 100.

The mode of reproduction of *G. hirsutum* was determined from group 1 (not protected flowers) and group 2 (protected flowers). Ten days after the last flower wilted, the number of bolls formed in each group was counted. For each group, the fruiting index (Ifr) was calculated using the following formula: Frx = (g1 + g2 + g3 + g4) * 100, where g1, g2, g3 and g4 are the fruiting indexes of four free flowers (group 1) and protected flowers (group 2), respectively (Demarly, 1977). The rate of self-pollination in the broad sense (TA) was calculated using the formula: TA = (100 – TC).

The impact of flower insects and insecticide treatments on the fruiting rate (Frx) was evaluated using the following formula: Frx = ([(g1 + g2 + g3 + g4) * 100]) / g1, g2, g3 and g4 are the average number of seeds per capsule in groups 1, 2 and 4, respectively (Dijur et al., 2020).

The percentage of the number of seeds per capsule (Pg) attributable to the impact of flower insects and insecticide treatments was calculated as follows: Pg = (g1 + g2 + g3 + g4) * 100) where g1, g2, g3 and g4 are the average number of seeds per capsule in groups 1, 2, 3 and 4, respectively (Dijur et al., 2020).

The percentage of normal seeds (Pn) attributable to the impact of flower insects and insecticide treatments was calculated using the following formula: Pn = (([Pn1 – Pn4]/Pn1 + Pn2 – Pn4) * 100); where Pn1, Pn2, and Pn4 are the percentages of normal seeds from groups 1, 2, 3 and 4, respectively (Dijur et al., 2020).

The yield was assessed for each treatment by weighting the harvested corresponding seeds.

### 2.5. Statistical analysis

Data on insect abundance, fruiting rate, average number of seeds per capsule, normal seeds percent, weight of seeds and seed yield were log-transformed (x + 1). The transformed data were subjected to the ANOVA procedure of SPSS 16.0. Tukey’s (Honest Significant Difference) multiple range test (p = 0.05) was applied for mean separation.

### 3. Results

From the investigations of that study, 413 individuals of insect pollinators belonging to 18 species, 10 families and five orders (Table 1) were recorded. Insect population seize was higher during the dry season (290 individuals belonging to 18 species) than the rainy season (123 individuals belonging to 17 species). More than half of individuals recorded belonged to the order of Hymenoptera. *Amegilla* sp. (56.10%) and *Apis mellifera* (25.86%) were the most frequent floral visitors of *G. hirsutum* during the rainy season and dry season, respectively. Floral products, nectar and pollen were harvested by the species belonging to the order Hymenoptera; nectar was harvested by those belonging to Diptera and Lepidoptera orders, while pollen was harvested by Coleopteran and Orthopteran.

The impact of aqueous extracts of *C. occidentalis, E. camaldulensis* and *H. suaveolens* on the foraging behaviour of *A. mellifera* and *Amegilla* sp. 1 was significant (F = 12.43, 16.93; p < 0.001) (Table 2). All the tested extracts were attractive to the both insect species compare to control, and standard synthetic insecticide which was very repellent. *E. camaldulensis* and *C. occidentalis* extracts were the most attractive.

*Apis mellifera* and *Amegilla* sp. 1 were found to visit *G. hirsutum* flowers from 6 a.m. to 5 p.m (Figure 1). Foraging activities fluctuated from the morning to the evening. Frequency of appearance was noted more between 10 a.m. to 1 p.m. for *A. mellifera* (dry season) and between 12 to 3 p.m. for *Amegilla* sp. 1 (rainy season). The peaks of activities were 12–1 p.m. and 2–3 p.m., respectively for *A. mellifera* and *Amegilla* sp. 1. Insecticidal products were either repulsive or attractive to pollinators.

### Table 1. Distribution of insects depending on the species and number of visits on *Gossypium hirsutum* flowers during the rainy and dry seasons.

| Order          | Family       | Genus, species, floral products | Rainy season | Dry season | Total |
|----------------|--------------|--------------------------------|--------------|------------|-------|
|                |              |                                | n1 P1 (%)    | n2 P2 (%)  | nT PT |
| Hymenoptera    | Apidae       | *Amegilla* sp. 1 (Ne, Po)      | 69           | 56.10      | 109   |
|                |              | *Amegilla* sp. 2 (Ne, Po)      | 4            | 3.25       | 12    |
|                |              | *Apis mellifera* (Ne, Po)      | 5            | 4.07       | 80    |
|                |              | *Xylocopa olivacea* (Ne, Po)   | 1            | 0.81       | 11    |
|                |              | *Xylocopa* sp. 1 (Ne, Po)      | 2            | 1.63       | 13    |
|                |              | *Xylocopa* sp. 2 (Ne, Po)      | 0            | 0.00       | 21    |
| Megachilidae   |              | *Megalchile* sp. 1 (Ne, Po)    | 5            | 4.07       | 20    |
| Vespidae       |              | (1 sp.) (Ne, Po)               | 2            | 1.63       | 9     |
|                |              | 8 species                      | 88           | 71.54      | 275   |
| Diptera        | Syrphidae    | (1 sp.) (Ne)                   | 1            | 0.81       | 11    |
|                |              | (1 sp. 2) (Ne)                 | 3            | 2.44       | 10    |
|                |              | (1 sp. 3) (Ne)                 | 5            | 4.07       | 16    |
| Lepidoptera    |              | 3 species                      | 9            | 7.31       | 37    |
| Coleoptera     |              | 3 species                      | 7            | 5.69       | 36    |
| Orthoptera     | Acrididae    | (1 sp. 1) (Po)                 | 1            | 0.81       | 12    |
|                |              | (1 sp. 2) (Po)                 | 1            | 0.81       | 12    |
|                | Pyrgomorphidae| *Tettigonia viridissima* (Po)  | 1            | 0.81       | 8     |
|                |              | 2 species                      | 19           | 15.45      | 65    |
| Total          |              | 10 families 18 species         | 123 100%     | 290 100%   | 413 100 |

n1 and n2: number of visits on 120 flowers; percentage of visits: p1 = (n1/123) * 100; p2 = (n1/290) * 100; Ne: collection of nectar; Po: collection of pollen; sp.: unidentified species.
depending on the periods of foraging activities. Overall, extracts were more moderately attractive to *Amegilla* sp. 1 than the control treatment, early in the morning (6–7 a.m.) and in the evening (4–5 p.m.). At 8–9 a.m. and 10–11 a.m., *H. suaveolens* and *E. camaldulensis* were also respectively more attractive to *Amegilla* sp. 1 compare to the control treatment. Furthermore, all the extracts were more attractive to *Amegilla* sp. 1 than the standard synthetic insecticide TEMA, before noon and in the evening at 4–5 p.m. However, TEMA was very attractive to *Amegilla* sp. 1 compared to the extracts at 12–3 p.m. At 8–9 a.m., extracts were most attractive to *A. mellifera* than control and synthetic insecticide. In fact, the standard synthetic insecticide was repellent to *A. mellifera* compare to extracts, except at 12–1 p.m.

### Table 2. Abundance of *Amegilla* sp. and *Apis mellifera* foragers per 1000 flowers of *Gossypium hirsutum* treated with insecticidal products.

| Insect/season | Insecticide | Control | *C. occidentalis* | *E. camaldulensis* | *H. suaveolens* | TEMA | F |
|---------------|-------------|---------|------------------|-------------------|----------------|------|---|
| Amegilla sp. 1/Rainy season |              | 100.24 ± 0.67** | 122.52 ± 3.54^b | 128.59 ± 4.21^b | 113.79 ± 2.20^b | 93.27 ± 2.87^c | 11.47*** |
| A. mellifera/dry season |              | 105.26 ± 1.21** | 115.11 ± 1.52^b | 133.86 ± 3.35^a | 111.99 ± 1.21^b | 101.26 ± 2.29^c | 25.04*** |

**:** p < 0.01.  
*:** p < 0.001.  
Means within the same line followed by the same letter do not differ significantly (p < 0.05; Tukey’s test).

![Figure 1. Frequency of *Amegilla* sp. 1 and *Apis mellifera* visits on *Gossypium hirsutum* flowers according to daily periods and insecticide treatments during the rainy (A) and dry (B) seasons.](image-url)
The number of insect pest species (Figure 2) recorded on *G. hirsutum* plants varied between treatments. Six, seven and eight species were recorded from *C. occidentalis*, *H. suaveolens* and *E. Camaldulensis* treatments, respectively. The same species were recorded on plants treated with *E. Camaldulensis* and on those without treatment. Treatment with the standard synthetic insecticide TEMA recorded the highest number of species (nine). Overall, insect abundance between treatments including the control was not significant (Table 3).

The comparison of fruiting rate (Fr), average number of seeds per capsule (ANSPC) and normal seeds percent (NSP) under diverse reproduction system (Tables 4 and 5) showed that observed differences were significant between some treatments. *Eucalyptus camaldulensis* extract significantly (\(F_{4,115} = 3.13–10.83, p = 0.05–0.001\)) improved Fr, ANSPC and NSP when the flowers were exclusively allowed for self-pollination during the rainy and dry seasons. During the dry season (Table 5), *E. camaldulensis* and *H. suaveolens* treatments as well as the standard insecticide improved ANSPC and NSP harvested from the flowers visited exclusively by *Amegilla* sp.1. The contributions of *Amegilla* sp. 1 to increase ANSPC and NSP during the rainy and dry seasons was significant for control (\(F_{4,8} = 6.96, 7.78, p = 0.01, 0.05\)) and treatment with aqueous extract of *H. suaveolens* (\(F_{4,8} = 10.21, 18.42, p = 0.01, 0.001\)). During the dry season, *C. occidentalis* improved the Fr and ANS of *G. hirsutum* pollinated by *Amegilla* sp.1.

The mean fruiting indexes were 0.99 and 0.87 in treatments 1 and 2, respectively. During rainy season, the allogamy rate was 12.12% and the autogamy rate was 87.88%. During the dry season, the rates of 28.72% and 71.28% were recorded in the same order. It appears that autogamy rate was 87.88%. During the dry season, the allogamy rate was 12.12% and the control was not significant (Table 3).

Seed yields were not significantly different (\(F_{4,15} = 0.64, p > 0.05\)) between the treatments during the rainy season and significantly different (\(F_{4,15} = 3.37, p < 0.05\)) during the dry season (Table 6). Seed yields were higher during the dry season. The impact of insecticidal products on seed yield during the rainy season was not significant. During the dry season, aqueous extracts and the standard synthetic insecticide recorded significant higher seed yields compare to the control; *C. occidentalis* being recording the highest value.

4. Discussion

According to this study, insects pollinate *G. hirsutum* in exchange of nectar and/or pollen, thus both are mutually benefitted. Insects are important pollinators for *G. hirsutum*. However, the specific type of insect varies across the globe (Bozbek et al., 2008; Parys et al., 2020). From that investigation, *Amegilla* sp. 1 was found as constant species visiting *G. hirsutum* during the rainy season. *A. mellifera* was accessory during the dry season and all other species were sporadic either during the rainy or dry seasons according to the classification of Bigot and Bodot (1973). Relative abundance of *A. mellifera* found in the present study as the major insect pollinators of *G. hirsutum* during the dry season might be partially explained by the presence of five colonies of that Apidae identified around the study area, and optimum environmental conditions for their foraging activities. The absence during the dry season or the presence during the rainy season of others flowering plants around the site of study might be another plausible reason of that seasonal abundance of *A. mellifera*. *Amegilla* sp. 1 was found to be the major insect pollinator of *G. hirsutum* during the rainy season in contrast to the finding reported by Mazi et al. (2020), where *A. mellifera* was found to be more abundant. The contrast between the results of these studies might be due to the impact of environmental conditions on the population size of each species. According to Ghosh et al. (2020), the temperature around 20–28 °C is optimum for *A. mellifera* to forage and foragers rarely work below 13 °C and above 38 °C (Abou-Shaara, 2018). Since the temperature of

Figure 2. Insect pest species recorded on *Gossypium hirsutum* plants treated with botanical insecticides. A: *Aphis gossypii*, B: *Dysdercus delaeunyi*, C: *Chellomenes propinquus*, D: *Pachnoda cordata*, E: *Anthonomus sp.*, F: *Halairodes derogata*, G: *Diparopsis wateri*, H: *Lacusta migratoria*, I: *Zonocerus variegatus*. 
conditions which might be not the same for the both insect species. Ghosh et al. (2020) demonstrated that the honey bees were more active in the afternoon than in the morning and found the highest foraging activity at 1 p.m. because the highest amount of pollen foraged during this period of the day. These finding including ours did not corroborate with that of Adamou et al. (2020) who reported the peak of activity of A. mellifera at 12 p.m. and that of Amegilla sp. 1 before noon.

Table 3. Abundance of insect pest species on Gossypium hirsutum plants treated with insecticidal products.

| Insect pest species | Insecticide | Control | Cassia occidentalis | Eucalyptus camaldulensis | Hyptis suaveolens | TEMA |
|---------------------|-------------|---------|---------------------|--------------------------|------------------|------|
| Aphis gossypii       | Control     | 4.75 ± 1.70 | 2.50 ± 0.50         | 5.75 ± 0.85             | 4.25 ± 0.75      | 1.60* |
| Dysdercus delaeanyi  | Control     | 2.00 ± 2.00 | 0.75 ± 0.47         | 0.25 ± 0.25             | 0.00 ± 0.00      | 0.74* |
| Chelonomus propinquus| Control     | 2.25 ± 1.03 | 0.75 ± 0.47         | 2.00 ± 0.81             | 2.25 ± 1.60      | 1.15* |
| Pachnoda cordata     | Control     | 6.00 ± 4.06 | 3.50 ± 1.50         | 3.50 ± 1.04             | 4.25 ± 1.43      | 0.31* |
| Anthonomus sp.       | Control     | 0.50 ± 0.28 | 2.25 ± 1.03         | 2.75 ± 0.95             | 2.00 ± 1.08      | 1.19* |
| Haliorhodes derugata | Control     | 0.00 ± 0.00 | 0.50 ± 0.29         | 0.50 ± 0.29             | 0.25 ± 0.25      | 1.36* |
| Diparopsis wateri    | Control     | 0.25 ± 0.25 | 0.00 ± 0.00         | 1.25 ± 1.25             | 2.25 ± 2.25      | 0.57* |
| Lacista migratoria   | Control     | 4.25 ± 1.60 | 3.25 ± 1.10         | 0.75 ± 0.25             | 1.60 ± 0.71      | 2.25* |
| Zonocerus variegatus  | Control     | 2.50 ± 1.44 | 0.50 ± 0.50         | 0.00 ± 0.00             | 0.25 ± 0.25      | 0.60* |
| Total                | Control     | 22.50 ± 8.00 | 14.50 ± 2.40       | 25.25 ± 2.87             | 15.75 ± 3.77      | 0.76* |

Table 4. Fruiting rate, average number of seeds per capsule and normal seeds percent of Gossypium hirsutum treated with insecticidal products under diverse reproduction system during the rainy season.

| Parameter          | TREATMENTS | Cassia occidentalis | Eucalyptus camaldulensis | Hyptis suaveolens | TEMA | F4,175 |
|--------------------|------------|---------------------|--------------------------|------------------|------|--------|
| Fruiting rate (%)  | FF         | 100 ± 0.00          | 95.83 ± 4.11*            | 100 ± 0.00       | 100 ± 0.00 | 1.00*   |
|                    | BF         | 83.33 ± 8.33        | 100.00 ± 0.00*           | 91.66 ± 8.33     | 100 ± 0.00 | 2.00*   |
|                    | FvA        | 88.09 ± 8.58        | 84.92 ± 4.76*            | 100 ± 0.00       | 100 ± 0.00 | 1.41*   |
|                    | FOWV       | 74.60 ± 9.11*       | 84.92 ± 0.79*            | 100 ± 0.00*      | 95.24 ± 4.76* | 10.83***|
| FvB                | 2.55*      | 4.04*               | 1.00*                    | 1.00*            |       |        |
| Average number of seeds | FF     | 16.92 ± 2.18*   | 18.25 ± 6.18             | 22.09 ± 1.17     | 26.71 ± 0.25* | 29.17 ± 0.93 | 3.07*\
|                    | BF         | 18.33 ± 0.73*      | 25.42 ± 1.16*            | 21.88 ± 1.96*    | 16.67 ± 2.96* | 28.79 ± 1.00* | 8.03**\
|                    | FvA        | 27.53 ± 2.56*      | 24.66 ± 0.88             | 28.03 ± 0.76     | 29.33 ± 0.35* | 28.61 ± 1.32 | 1.63**\
|                    | FOWV       | 19.92 ± 0.94*      | 10.42 ± 2.09*            | 27.34 ± 1.81*    | 24.96 ± 2.66* | 22.63 ± 3.88* | 6.99**\
| FvB                | 6.96*      | 4.35*               | 4.81*                    | 7.47*            | 2.09*     |        |
| Normal seeds (%)   | FF         | 59.03 ± 4.87        | 62.83 ± 19.36            | 81.54 ± 1.93     | 84.13 ± 2.47* | 95.85 ± 0.24 | 2.90*\
|                    | BF         | 49.01 ± 5.62*      | 72.85 ± 1.75*            | 68.61 ± 9.73*    | 46.06 ± 9.17* | 82.90 ± 5.29* | 5.19*\
|                    | FvA        | 68.14 ± 10.48*     | 68.63 ± 6.09*            | 84.14 ± 3.93*    | 94.40 ± 0.45* | 86.33 ± 8.16* | 2.99*\
|                    | FOWV       | 48.77 ± 8.49*      | 56.38 ± 4.94*            | 84.67 ± 3.13*    | 64.32 ± 3.10* | 75.79 ± 6.10* | 7.17**\
| FvB                | 1.44*      | 0.46*               | 1.84*                    | 18.42***         | 1.76*     |        |

Means within the same column and line followed respectively by the same small and capital letter do not differ significantly (p < 0.05; Tukey’s test).

Environmental area of the study was above 30 °C during the dry season and lower during the rainy season, temperature is less important factor to explain that seasonal variation of the abundance of A. mellifera visiting G. hirsutum. The plausible reason should be the availability of diverse resources more attractive than G. hirsutum to honey bees during the rainy season. However, further study is required to assess the attractiveness of floristic plants surrounding cotton plantation to honey bees. The relative humidity, rainfall and wind speed might be also other factors which had significant negative effect on the foraging activity of A. mellifera during the rainy season. In a simple legitimate way, each bee pollinator has specific ecological threshold for foraging activity which might differ inter specifically depending upon the level of adaptation of a given species in an environment as reported by previous researchers (Burill and Dietz, 1981; Abrol and Kapil, 1986).

The peak of activity of A. mellifera at 12–1 p.m. and that of Amegilla sp. 1 at 2–3 p.m. was probably linked to the daily periods of greater availability of the floral products of G. hirsutum, at optimum environmental conditions which might be not the same for the both insect species. Ghosh et al. (2020) demonstrated that the honey bees were more active in the afternoon than in the morning and found the highest foraging activity at 1 p.m. because the highest amount of pollen foraged during this period of the day. These finding including ours did not corroborate with that of Adamou et al. (2020) who reported the peak of activity of Amegilla sp. 1 before noon at 10–11 a.m. The peak of the pollinator activity would depend on the daily flower blooming rate which may also depend on several abiotic factors. More details concerning the assessment of available resources, flower blooming rate and abiotic factors should be considered in the further study to more elucidate these contrasts.

Eucalyptus camaldulensis extract improved Fr, ANSPC and NSP of G. hirsutum allowed for self-pollination and this suggest that the use of botanicals to control the pests at vegetative stage of a plant might improve some plant yield parameters. This may be attributed to insecticidal activities of that plant. Abdelkhalek et al. (2020) reported the bark extract of that plant to be effective against Tribolium castaneum and Sitophilus oryzae. According to Dwibedi et al. (2017), the grain yield is highly correlated with the vegetative parameters and this relationship
may be influenced by pests (Chastain and Young, 1998). In fact, insect pests have a direct impact on agricultural food production by chewing the leaves and stamens of crop plants, sucking out plant juices, boring within the roots, stems or leaves, and spreading plant pathogens. *Eucalyptus camaldulensis* and *H. suaveolens* aqueous extracts might be toxic to non-target insects such as *Amegilla* sp, but toxic to insect pests, hence the improvement of ANSPC and NSP harvested from non-protected flowers by gauze bags and may be therefore recommended as good candidates for incorporation in the management of insect pollinators at flowering period of *G. hirsutum*. Aqueous extract of *C. occidentalis* improved FR, ANS and seed yield, especially during the dry season. Hence, *C. occidentalis* extract may be also recommended to control field insect pests at different stages of the development of *G. hirsutum*.

### Declarations

**Author contribution statement**

Moïse Adamou, Ph.D; Elias N. Nukenine, Ph.D; Daniel Kosini, Ph.D; A. Tchoubou-Salé, Ms; M. Mohammadou, Ms; T. F.C. Tchocgnia, Ms; M. Mohammadou, Ms; O. Youssoufa, Ms: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Odette D. Massah, Ms: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

T. F. C. Tchocgnia, Ms; M. Mohammadou, Ms; O. Youssoufa, Ms: Performed the experiments.

**Funding statement**

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Abdelkhalak, A., Salem, M.Z.M., Kordy, A.M., Salem, A.Z.M., Behiry, S.I., 2020. Antiviral, antifungal, and insecticidal activities of Eucalyptus bark extract: HPLC analysis of polyphenolic compounds. Microb. Pathog. 147, 1–11.
Abou-Shaara, H., 2018. The foraging behaviour of honey bees, Apis mellifera: a review. Vet. Med. 59, 1–10.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Adamou et al. Heliyon 8 (2022) e10937

Additional information

No additional information is available for this paper.

References

Abdelkhalak, A., Salem, M.Z.M., Kordy, A.M., Salem, A.Z.M., Behiry, S.I., 2020. Antiviral, antifungal, and insecticidal activities of Eucalyptus bark extract: HPLC analysis of polyphenolic compounds. Microb. Pathog. 147, 1–11.
Abou-Shaara, H., 2018. The foraging behaviour of honey bees, Apis mellifera: a review. Vet. Med. 59, 1–10.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Adamou et al. Heliyon 8 (2022) e10937

Additional information

No additional information is available for this paper.

References

Abdelkhalak, A., Salem, M.Z.M., Kordy, A.M., Salem, A.Z.M., Behiry, S.I., 2020. Antiviral, antifungal, and insecticidal activities of Eucalyptus bark extract: HPLC analysis of polyphenolic compounds. Microb. Pathog. 147, 1–11.
Abou-Shaara, H., 2018. The foraging behaviour of honey bees, Apis mellifera: a review. Vet. Med. 59, 1–10.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Adamou et al. Heliyon 8 (2022) e10937

Additional information

No additional information is available for this paper.

References

Abdelkhalak, A., Salem, M.Z.M., Kordy, A.M., Salem, A.Z.M., Behiry, S.I., 2020. Antiviral, antifungal, and insecticidal activities of Eucalyptus bark extract: HPLC analysis of polyphenolic compounds. Microb. Pathog. 147, 1–11.
Abou-Shaara, H., 2018. The foraging behaviour of honey bees, Apis mellifera: a review. Vet. Med. 59, 1–10.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Adamou et al. Heliyon 8 (2022) e10937

Additional information

No additional information is available for this paper.

References

Abdelkhalak, A., Salem, M.Z.M., Kordy, A.M., Salem, A.Z.M., Behiry, S.I., 2020. Antiviral, antifungal, and insecticidal activities of Eucalyptus bark extract: HPLC analysis of polyphenolic compounds. Microb. Pathog. 147, 1–11.
Abou-Shaara, H., 2018. The foraging behaviour of honey bees, Apis mellifera: a review. Vet. Med. 59, 1–10.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Adamou et al. Heliyon 8 (2022) e10937

Additional information

No additional information is available for this paper.

References

Abdelkhalak, A., Salem, M.Z.M., Kordy, A.M., Salem, A.Z.M., Behiry, S.I., 2020. Antiviral, antifungal, and insecticidal activities of Eucalyptus bark extract: HPLC analysis of polyphenolic compounds. Microb. Pathog. 147, 1–11.
Abou-Shaara, H., 2018. The foraging behaviour of honey bees, Apis mellifera: a review. Vet. Med. 59, 1–10.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Adamou et al. Heliyon 8 (2022) e10937

Additional information

No additional information is available for this paper.

References

Abdelkhalak, A., Salem, M.Z.M., Kordy, A.M., Salem, A.Z.M., Behiry, S.I., 2020. Antiviral, antifungal, and insecticidal activities of Eucalyptus bark extract: HPLC analysis of polyphenolic compounds. Microb. Pathog. 147, 1–11.
Abou-Shaara, H., 2018. The foraging behaviour of honey bees, Apis mellifera: a review. Vet. Med. 59, 1–10.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.
Abrol, D.P., Kapil, R.P., 1986. Factors affecting pollination activity of Amaranthus hybridus L. (Coleoptera, Bruchidae), insecte ravageur des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale : synthèse bibliographique. Biotechnol. Agron. Soc. Environ. 15, 183–194.