



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

The Incidence and Economic Importance of the Entomofauna on the Growth and Production of Watermelon in Yagoua (Cameroon)

Azo'o Ela Michelson¹, Ngapete Litassou Monique², Djenatou Pédagie^{2,3}, Kengni Beaudelaine Stéphanie¹, Sakata ï Pierre Dérik^{2,3} & Tchuenguem Fohouo Fernand-Nestor⁴

¹ Department of Biological Sciences, Faculty of Science, University of Maroua, P.O. Box 814 Maroua, Cameroon

² Department of Agriculture, Livestock and By-Products, The National Polytechnic Higher School of Maroua, University of Maroua, P.O. Box 46 Maroua, Cameroon

³ Maroua Regional Agricultural Research Center for the Development (CRRRA-M), Institute of Agricultural Research for the Development, P.O. Box 33, Maroua, Cameroon

⁴ Department of Biological Sciences, Faculty of Science, University of Ngaoundere, P.O. Box 454 Ngaoundere, Cameroon

Correspondence: Azo'o Ela Michelson, Department of Biological Sciences, Faculty of Science, University of Maroua, Maroua, Cameroon. Tel: 237-655-772-022. E-mail: azooela@yahoo.fr

Received: January 10, 2021 Accepted: February 13, 2021 Online Published: February 21, 2021

doi:10.5539/sar.v10n2p33

URL: <https://doi.org/10.5539/sar.v10n2p33>

Abstract

In the Far-North region of Cameroon, watermelon cultivation still faces several constraints that represent a major threat to fruit production. This requires research for maintaining and improving the crop yields. The present study was aimed at investigating the insect fauna associated with watermelon for its optimal management. Observations allowed the identification of insect-visiting fauna to the crop, to assess the role played by each species on growing watermelon, to evaluate the means of protection used by farmers and to make useful projections towards the biological control of the natural enemies of insect pests. Twenty two insect species visited the vegetative organs of watermelon. Fruit flies were found to be the most common and most damaging group for watermelon production. The larval stage of Syrphidae and adults of Coccinellidae and Formicidae were identified as important biocontrol agents. Watermelon requires effective phytosanitary cover for its optimal production. A non-significant fruit set rate was obtained between experimental treatments (T). The rate of mature fruit was zero in T₀ which does not benefit from pollination and health care. Protective means used locally guaranteed the production of mature fruits by 24% in T₁ without any sanitary care, 36% in T₂ impregnated with neem *Azadirachta indica* (Meliaceae) leaf's extract, and 54% in T₃ treated with an insecticide named Optimal. Due to the strong involvement of chemicals in the protection of watermelon production at the study site, their use is often a problem for safeguarding the balance of the ecosystem and the health of farmers and consumers. It is therefore essential to promote the use of pollinators and to protect the natural enemies of insect pests to enhance sustainable production of watermelon in Yagoua.

Keywords: watermelon, production, pollinator, pest, natural enemy, biocontrol agent

1. Introduction

Watermelon (*Citrullus lanatus*) is one of the most widely cultivated crops in the world mainly in tropical and subtropical regions (Huh et al., 2003; Onyemauva, 2010). Watermelons are a member of the Cucurbitaceae family, which includes squash, pumpkins, cucumbers, muskmelons and gourds (Achu et al., 2005). It is a tender, warm season vegetable which is enjoyed by many people across the world as fresh fruit (Chogou et al., 2019). Watermelon flesh is highly nutritious, thirst-quenching and also contains vitamins C and A in the form of disease-fighting beta-carotene (Adeoye et al., 2011). Production of exotic fruits such as watermelon generate higher profit and provide more employment and income to the farmers than those of indigenous vegetables (Adeoye et al., 2011). Often referred to as the breadbasket of West Africa, Cameroon has considerable agricultural potential, both in terms of food and livestock and export crops (DSCE, 2009). The importance of the agricultural sector in the economy of Cameroon is considerable to the Gross Domestic Product (Mbondji, 1990).

Agriculture represents around 70% of activity in rural areas and is a key sector for the country's economic and social development (Bayiha et al., 2019). In this country, the rural sector is the main provider of agricultural production and therefore an important plinth of the national economy (DSCE, 2009). Farmers are generally engaged in income-generating activities of feed commodities as the main suppliers of market produce with various agricultural products such as watermelons.

As a cash crop, watermelon has gained a high level of economic importance in the generation of income and provision of nutritional value (Reetu & Tomar, 2017). This fruit is increasingly marketed in some urban and peri-rural areas of Cameroon. Yagoua is considered as one of the major production areas of watermelon in Cameroon where for some years within the strategy of diversifying agricultural production by peasants cultural pest prevention methods have been used. The high demand for watermelons compels farmers to specialize to meet the demands of consumers. Watermelon crop enables producers to significantly generate important income allowing them to fight against poverty more efficiently.

Insect pests impact negatively on the yields of watermelons and the quality of fruit set through their activity on the host plant (Kumar, 1991). Studying insect damage in agriculture includes both useful, as well as harmful insects (Kearns et al., 1998). In one case insect pollinators provide an essential ecosystem service that promotes the out-crossing and sexual reproduction of many plants. Without pollination, the flower dies and there is no development of the ovary in fruit or of the oocyte to seed (Southwick & Southwick, 1992). The exceptions are parthenocarpic plant species, that develop fruits and apomictic species that produce seeds without fertilization (Caron et al., 2005).

As insects influence both the yield and quality of the watermelon fruit harvested, an investigation into this was undertaken in the Yagoua production area of Cameroon. The aim of the study was therefore to examine entomological factors affecting production of watermelon among farmers of Yagoua, so as to improve their yield, income and living standards. This preoccupation has led us 1) to investigate whether the activity of insects visiting watermelon reaches a positive or negative economic threshold in Yagoua, 2) to evaluate the effectiveness of measures taken by farmers to protect watermelon culture against insect pests, and 3) to identify the beneficial organisms involved in biological control of major pests of watermelon in the stated locality.

2. Materials and Methods

2.1 Study Site

The study was carried out to examine factors affecting fruit production of watermelon among farmers of Yagoua (Far-North Region, Cameroon). The multipurpose station of the Institute of Agricultural Research for the Development of Yagoua served as a site for lab works. Investigations took place in peasant fields located in the floodplain agricultural area (15.13825 °E; 10.36128 °N) which is suitable for growing watermelon in the locality.

2.2 Materials

Plant materials consisted of a hybrid variety of watermelon (F1 Koloss) and neem *Azadirachta indica* (Meliaceae) leaves from which the active ingredients were extracted for the bio-efficacy test against watermelon insect pests as commonly carried out by farmers in the locality. The seeds of the cultivated watermelon variety were purchased from an approved store (SEMAGRI: Seeds for Agriculture) in Maroua. The animal material consisted of insects naturally present in the immediate environment of the study. The only chemical material used was a contact insecticide called Optimal, commonly used by watermelon growers in the locality for fighting against insect pests.

2.3 Methods

2.3.1 Establishment of Experimental Plots

Three plots of 1000 m² approximately 1 km apart from each other were used for experiments: a neutral plot (P₁) which was free from any phytosanitary product; a plot with watermelon plants under neem extract impregnation (P₂); and a third plot in which plants were impregnated with Optimal (P₃). Three stages including the preparation of the plots, sowing and plot maintenance were observed.

The preparation of the experimental plots followed clearing and cleaning of surfaces to be free of any plant fodder, and the creation of 2 m pockets spaced between the lines. Each pocket was impregnated with cow dung collected from a local farm for soil enrichment and was well watered for a week before sowing.

The watermelon field plot sowing consisted of three seeds per pocket, and was undertaken on April 8, 2017. Germination began six days after sowing. Weeding was carried out regularly to keep the field clean. Three weeks after sowing (April 29, 2017), plantlets were trimmed to one per hole; only the most vigorous *C. lanatus* plant

was preserved. NPK fertilizer (20-10-10) was spread using a beer capsule around each preserved plant. Water was supplied to the plants using a motor pump thrice a week during the evening. Fruit set took place about two weeks after flowering from the female flowers and mulching was done subsequently during the fruit set. The fruit harvesting took place three months after sowing.

2.3.2 Experimental Design

2.3.2.1 Comparative Design for the Management of Insects in Watermelon Plots

In P_1 , the pollination requirement of the watermelon was studied. Two treatments of 10 plants each were carried out on a randomized basis according to whether female flowers were bagged to prevent pollinator visits (T_0) or female flowers were freely exposed to pollinator visits (T_1).

A treatment consisting of 10 randomly chosen watermelon plants was carried out in P_2 (T_2). Fresh neem leaves were taken before sunrise, and were pounded with a mortar during the evening. Producers commonly used 1kg of leaves for 6 litres of water. The ground leaf material was soaked in drilling water at room temperature for 12 hours (6 p.m. to 6 a.m. the next day) filtered and immediately sprayed as a bio-pesticide. The various sprays began from the third week after sowing and were carried out thrice weekly until fruit harvesting.

Another treatment of 10 plants chosen at random was formed in P_3 (T_3). The plants labeled here were treated with Optimal[®] 20 SP (Acetamiprid 200 g/kg; SP) through a sprayer. Optimal[®] 20 SP is an insecticide formulated in soluble powder for cotton crop protection. This insecticide is commonly used by watermelon farmers in the study locality for fighting against harmful insects of watermelon. Three sachets of 25 g of Optimal each were used for a tank filled at 15 litres. The mixture was transferred to a sprayer for application on the P_3 plants. The interval period for impregnating Optimal was the same as above but the spraying frequency was once per two weeks to preserve the flower visiting activities of pollinators in this plot.

2.3.2.2 Study of the Entomofauna and Insect Activities on Watermelon

Observations were carried out on the T_1 plants from growth until fruit harvesting. These were made thrice a week on labeled plants, from April 23 to June 23 following three time intervals: 7 - 10 a.m., 11 a.m. - 2 p.m., 3 - 6 p.m. Specific richness studies of the entomofauna associated with watermelon was carried out on different vegetative organs of the crop (leaves, stems, flowers and fruits) using the instantaneous counting method. Since some insect species could have been observed more than once, counts were expressed as number of visits (Tchuenguem *et al.*, 2010). 2 to 5 insect morphospecies were captured using a hand net and were conserved in pill-boxes containing ethanol (70%) for subsequent identification.

The study on biological diversity of insects in watermelon fields was based on two important aspects, namely the compositional diversity and the functional diversity. The parameters for estimating the compositional diversity of the entomofauna associated with *C. lanatus* include: the specific richness (which is the number of insect species listed in activity on the watermelon organs in the field), the relative abundance, the frequency of appearance of each species, and distribution of insects according to the stages of plant growth. The functional diversity concerns the role played by different species of visiting insects on watermelon organs, as well as the interspecific interactions between them. This last aspect of the study made it possible to distinguish the different functional groups or trophic groups associated with watermelon in the field. In addition, the daily rate of activity of the listed insects made it possible to know the different peaks of activity of insect species recorded on *C. lanatus* organs.

2.3.3 Evaluation of Agronomic Parameters of Fruit Yield

The female flowers were individually monitored from bloom to potential maturity. The fruiting rate, the rate of mature fruits as well as the rate of aborted fruits were compared between treatments. For this last parameter, we noted the physical aspect of the fruits during development (wounds, punctures, rot or drying). The rotten fruits harvested were placed in rearing boxes for the potential studying of any adult insects that emerged.

2.4 Maggot Rearing Techniques

Any maggots collected within the infested watermelon fruits were reared in the laboratory in plastic parallelepiped shaped boxes, containing soil to a height of 2 cm in order to house cocoons. The larval development cycle was carefully observed until the emergence of adult insects or imago.

2.5 Estimates of Financial Income Expected Per Hectare of Watermelon Production

Under our spacing conditions, a density of 0.3 plants/m² or 3,000 plants/ha was achieved. The average number of edible fruit per plant was calculated to deduce the total number of fruit per hectare. Mature fruits from each treatment were weighted using a balance branded EKS and the mean was calculated for estimating fruit tonnage

per hectare. The estimates of the financial value of fruit yields per hectare in each experimental treatment was performed by extrapolation; the price set for analysis was from the wholesaler, 500 CFA Francs (\$ 0.92) per unit, to quickly sell the fruits and limit the damage in stock.

2.6 Data Analysis

The results obtained were submitted to descriptive statistics using SPSS 20.0 software. The cumulative results of insect counts were expressed by the number of visits. The relative abundance (F) was calculated using the following formula: $F (\%) = [(ni/N) \times 100]$ where $F (\%)$ represents the relative abundance of flower visits of species i ; ni the number of visits by individuals of the species and N the total number of visits by individuals of all species combined (Tchuenguem et al., 2002).

The frequency of occurrence (C) or frequency of appearance of insect species which refers to the frequency of a species is encountered in the samples, i.e. in percentage it is the ratio between the number of surveys containing the species considered (Pi) and the total number of surveys (P): $C (\%) = [(Pi/P) \times 100]$ (Dajoz, 2006). Bigot and Bodot (1973) classify frequencies of occurrence into four classes or categories of species as a function of the variation of the C -values: very accidental species or sporadic species ($C < 10 \%$), accidental species ($10 \% \leq C \leq 24 \%$); accessory species ($25 \% \leq C \leq 49 \%$), and constant species ($C \geq 50 \%$).

The following agronomic parameters were taken into account in the three experimental plots:

- 1- The fruit set rate (%) = [number of fruits formed/total number of female flowers studied] x 100]. In each treatment, only the first five female flowers formed were taken into account per plant labeled in this assessment.
- 2- The rate of mature fruits (%) = [total number of mature fruits/total number of female flowers studied] x 100].
- 3- The rate of abortion (%) = [100 - rate of mature fruits].

One-way analysis of variance (ANOVA) was performed to establish the difference in agronomic parameters between treatments. The method used to establish the difference between the means was the Honestly Significantly Difference (HSD) multiple comparison procedure of Tuckey-Kramer. The difference between the values was significant at $p < 0.05$.

3. Results and Discussion

3.1 Results

3.1.1 Entomofauna Associated with Watermelon in Yagoua

3.1.1.1 Compositional Diversity

Table 1 shows the insect occurrence and the relative abundance of the floral entomofauna associated with watermelon at Bidim (Yagoua, Cameroon). Five orders of insects namely Hemiptera, Hymenoptera, Diptera, Coleoptera and Lepidoptera were recorded. Among these different orders, the Hemiptera were prominent with a relative abundance of 43.72%. The other insect orders were in decreasing order: Hymenoptera (35.44%), Diptera (15.89%), Coleoptera (4.65%) and Lepidoptera (0.30%).

Twelve families were the major components of the five orders mentioned above. In decreasing order of their relative abundance, were Aphididae (43.72%), Formicidae (19.26%), Apidae (12.79%), Calliphoridae (8.66%), Coccinellidae (4.65%), Halictidae (3.40%), Tephritidae (3.83%), Syrphidae (2.23%), Muscidae (0.51%), Sarcophagidae (0.47%), Acraeidae (0.30%) and Rhiniidae (0.17%).

Twenty two insect species were recorded in activity on *C. lanatus* plants. Among these insects, *Aphis gossypii* was more abundant with 43.25% of visits. The other species of insects representing a relative high abundance of 56.75%; in decreasing order of their relative abundance were recorded: *Apis mellifera* (9.65%), *Chrysomia putoria* (8.66%), *Camponotus flavomarginatus* (7.88%), *Pheidole megacephala* (6.07%), *Myrmecaria opaciventris* (5.30%), *Coccinella septempunctata* (3.14%), *Bactrocera cucurbitae* (2.41%), *Lasioglossum* sp. 1 (2.24%), *Toxomerus floralis* (2.24%), *Eucara macrogatha* (1.42%), *Ceratitidis capitata* (1.42%), *Xylocopa olivacea* (1.16%), *Lasioglossum* sp. 2 (1.16%), *Cheilomenes lunata* (0.95%), *Dactylurina staudingeri* (0.56%), *Adalia bipunctata* (0.56%), *Musca domestica* (0.52%), *Riptortus dentipes* (0.42%), *Sarcophaga* sp. (0.42%), *Acraea acerata* (0.30%), *Rhyncomya pruinosa* (0.17%).

Table 1. Diversity of entomofauna associated with watermelon, *Citrullus lanatus* in Yagoua

| Orders | Families | Species | <i>nv</i> | <i>F</i> (%) | |
|---|--------------------------|-----------------------------------|----------------------------------|--------------|--------------|
| Hemiptera | Aphididae | <i>Aphis gossypii</i> | 1004 | 43.25 | |
| | | <i>Riptortus dentipes</i> | 11 | 0.47 | |
| Total Hemiptera | | | 1015 | 43.72 | |
| Hymenoptera | Formicidae | <i>Camponotus flavomarginatus</i> | 183 | 7.88 | |
| | | <i>Pheidole megacephala</i> | 141 | 6.07 | |
| | | <i>Myrmicaria opaciventris</i> | 123 | 5.30 | |
| | Total Formicidae | | | 447 | 19.26 |
| | Apidae | | <i>Apis mellifera</i> | 224 | 9.65 |
| | | | <i>Eucara macrogatha</i> | 33 | 1.42 |
| | | | <i>Xylocopa olivacea</i> | 27 | 1.16 |
| | | | <i>Dactylurina staudingeri</i> | 13 | 0.56 |
| | Total Apidae | | | 297 | 12.79 |
| | Halictidae | | <i>Lasioglossum</i> sp. 1 | 52 | 2.24 |
| <i>Lasioglossum</i> sp. 2 | | | 27 | 1.16 | |
| Total Halictidae | | | 79 | 3.40 | |
| Total Hymenoptera | | | 823 | 35.44 | |
| Diptera | Tephritidae | <i>Bactrocera cucurbitae</i> | 56 | 2.41 | |
| | | <i>Ceratitis capitata</i> | 33 | 1.42 | |
| | Total Tephritidae | | | 89 | 3.83 |
| | Calliphoridae | | <i>Chrysomia putoria</i> | 201 | 8.66 |
| | Muscidae | | <i>Musca domestica</i> | 12 | 0.52 |
| | Syrphidae | | <i>Toxomerus floralis</i> | 52 | 2.24 |
| | Sarcophagidae | | <i>Sarcophaga</i> sp. | 11 | 0.47 |
| | Rhiniidae | | <i>Rhyncomya pruinosa</i> | 4 | 0.17 |
| | Total Diptera | | | 369 | 15.89 |
| | Coleoptera | Coccinellidae | <i>Coccinella septempunctata</i> | 73 | 3.14 |
| <i>Cheilomenes lunata</i> | | | 22 | 0.95 | |
| <i>Adalia bipunctata</i> | | | 13 | 0.56 | |
| Total Coleoptera | | | 108 | 4.65 | |
| Lepidoptera | Acraeidae | <i>Acraea acerata</i> | 7 | 0.30 | |
| TOTAL: 5 orders 12 families 22 species | | | 2322 | 100 | |

Legend: *nv* = number of visits; *F* (%) = relative abundance

3.1.1.2 Distribution of Insect Visits According to the Daily Time Frames

The distribution of insect visits to the watermelon plants according to the observation time slots are reported in Table 2. The entomofauna associated with *C. lanatus* was more active in the morning (7-10 a.m.) with 57.32% of visits. These visits gradually decreased between 11 a.m. and 2 p.m. (28.51%) and tended to diminish with sunset (14.17%) or were for some insect species. However, a few species of insects deviated from this pace of activity; with *Lasioglossum* spp. active between 10 a.m. - 13 p.m., and *Bactrocera cucurbitae* which was abundant at the last time interval (2 - 5 p.m.).

Table 2. Distribution of insect visits according to observation time intervals

| Insect species | Time intervals | | | Total |
|---------------------------------|----------------|--------------|--------------|-------------|
| | 06-09 h | 10-13 h | 14-17 h | |
| <i>A. gossypii</i> | 614* | 216 | 174 | 1004 |
| <i>A. mellifera</i> | 155* | 69 | 0 | 224 |
| <i>C. flavomarginatus</i> | 112* | 52 | 19 | 183 |
| <i>P. megacephala</i> | 87* | 31 | 23 | 141 |
| <i>M. opaciventris</i> | 57* | 41 | 25 | 123 |
| <i>C. septempunctata</i> | 52* | 18 | 3 | 73 |
| <i>C. lunata</i> | 16* | 6 | 0 | 22 |
| <i>A. bipunctata</i> | 13* | 0 | 0 | 13 |
| <i>Lasioglossum</i> sp. 1 | 47* | 5 | 0 | 52 |
| <i>Lasioglossum</i> sp. 2 | 27* | 0 | 0 | 27 |
| <i>B. cucurbitae</i> | 17 | 8 | 31* | 56 |
| <i>T. floralis</i> | 18 | 8 | 26* | 52 |
| <i>C. capitata</i> | 3 | 9 | 3 | 33 |
| <i>E. macrognatha</i> | 26* | 7 | 0 | 33 |
| <i>X. olivacea</i> | 27* | 0 | 0 | 27 |
| <i>D. staudingeri</i> | 9* | 4 | 0 | 13 |
| <i>M. domestica</i> | 6* | 5 | 1 | 12 |
| <i>R. dentipes</i> | 2 | 5* | 4 | 11 |
| <i>Sarcophaga</i> sp. | 4 | 4 | 3 | 11 |
| <i>C. putoria</i> | 35 | 63 | 103* | 201 |
| <i>R. pruinosa</i> | 4 | 0 | 0 | 4 |
| <i>A. acerata</i> | 0 | 5* | 2 | 7 |
| Total | 1331 | 556 | 435 | 2322 |
| Percentage of visits (%) | 57.32* | 23.95 | 18.73 | 100 |

Legend: * = peak of activity

3.1.1.3 Distribution of Insects According to the Growth Stage of Watermelon

Table 3 shows the distribution of insect species as a function of the growth stage of watermelon. Seven insect species were recorded visiting watermelon plants before flowering: *A. gossypii*, *C. flavomarginatus*, *P. megacephala*, *M. opaciventris*, *C. septempunctata*, *C. lunata* and *A. bipunctata*. These insect species were active on the stem and leaves of the studied plants. At the beginning of the flowering stage, 14 insect species were counted. Apart from *A. bipunctata*, the other 6 insects listed above were identified foraging on *C. lanatus* flowers. Eight further insects were exclusively nectarophagous or pollinivorous: *A. mellifera*, *Lasioglossum* sp. 1, *Lasioglossum* sp. 2, *E. macrognatha*, *X. olivacea*, *D. staudingeri*, *A. acerata* and *T. floralis*. Bees are known to be flower-visiting insects. Once fruiting started two weeks after flowering, a further 6 new insect species were noted which showed affinity with fruits: *C. putoria*, *R. pruinosa*, *M. domestica*, *Sarcophaga* sp., *B. cucurbitae* and *C. capitata*.

Table 3. Distribution of insect visits according to growing stage of the plant

| Insect species | Growing stage of watermelon plants | | |
|--------------------------------|------------------------------------|------------|-----------------------|
| | Pre-blossoming | Blossoming | Blossoming & fruiting |
| <i>A. gossypii</i> | + | + | + |
| <i>A. mellifera</i> | - | + | + |
| <i>C. flavomarginatus</i> | + | + | + |
| <i>P. megacephala</i> | + | + | + |
| <i>M. opaciventris</i> | + | + | + |
| <i>C. septempunctata</i> | + | + | + |
| <i>C. lunata</i> | + | + | + |
| <i>A. bipunctata</i> | + | - | - |
| <i>Lasioglossum</i> sp. 1 | - | + | + |
| <i>Lasioglossum</i> sp. 2 | - | + | + |
| <i>B. cucurbitae</i> | - | - | + |
| <i>T. floralis</i> | - | + | + |
| <i>C. capitata</i> | - | - | + |
| <i>E. macrogantha</i> | - | + | + |
| <i>X. olivacea</i> | - | + | + |
| <i>D. staudingeri</i> | - | + | + |
| <i>M. domestica</i> | - | - | + |
| <i>R. dentipes</i> | - | - | + |
| <i>Sarcophaga</i> sp. | - | - | + |
| <i>C. putoria</i> | - | - | + |
| <i>R. pruinosa</i> | - | - | + |
| <i>A. acerata</i> | - | + | - |
| Total of insect species | 8 | 14 | 20 |

Legend: - = absent; + = present

3.1.1.4 Occurrence of Insect Species

Table 4 shows the different values of the frequency of appearance of insects during our observation period. Insect species recorded were classified into four categories according to the fact that they appeared during all the development cycle long or not:

1. Constant species are those encounter during the three development phases of watermelon; these were: *A. gossypii* and its main predators such as *M. opaciventris*, and *C. septempunctata*. *C. flavomarginatus* was observed feeding honeydew from *A. gossypii*;
2. Accessory species comprise insects which were exclusively found on certain organs of the host plant. These included flower-visiting insects such as bees.
3. Despite of their status as accidental species, the role of the corresponding insects was well defined in the general entomofauna of *C. lanatus*;
4. Sporadic species were scarcely seen visiting organs of watermelon, thus their function in the entomofauna of watermelon was sometimes unclear.

Table 4. Frequency of occurrence for each of insect species collected

| Insect species | P _i | C (%) | Category of insects | |
|---------------------------|----------------|-------|--|---------------------------------|
| <i>A. gossypii</i> | 23 | 76.66 | Constant species ($C \geq 50\%$) | |
| <i>M. opaciventris</i> | 17 | 56.66 | | |
| <i>C. flavomarginatus</i> | 16 | 53.33 | | |
| <i>C. septempunctata</i> | 15 | 50 | Accessory species ($25\% \leq C \leq 49\%$) | |
| <i>A. mellifera</i> | 12 | 40 | | |
| <i>P. megacephala</i> | 11 | 36.66 | | |
| <i>Lasioglossum</i> sp. 1 | 11 | 36.66 | | |
| <i>C. putoria</i> | 9 | 30 | | |
| <i>C. lunata</i> | 9 | 30 | | |
| <i>Lasioglossum</i> sp. 2 | 9 | 30 | | |
| <i>B. cucurbitae</i> | 9 | 30 | | |
| <i>T. floralis</i> | 9 | 30 | | |
| <i>D. staudingeri</i> | 8 | 26.66 | | |
| <i>Sarcophaga</i> sp. | 8 | 26.66 | Accidental species ($10\% \leq C \leq 24\%$) | |
| <i>X. olivacea</i> | 8 | 26.66 | | |
| <i>C. capitata</i> | 7 | 23.33 | | |
| <i>E. macrognatha</i> | 6 | 20 | | |
| <i>M. domestica</i> | 6 | 20 | | |
| <i>A. bipunctata</i> | 6 | 20 | | |
| <i>R. pruinosa</i> | 2 | 6.66 | | Sporadic species ($C < 10\%$) |
| <i>R. dentipes</i> | 2 | 6.66 | | |
| <i>A. acerata</i> | 1 | 3.33 | | |

Legend: $C = [(P_i/P) \times 100]$ = Frequency of occurrence P_i = Number of samples containing a given insect species; $P = 30$ = Total number of samples

3.1.1.5 Activity of the Insects Listed on the Organs of the Plant Studied

From germination to wilting of the plants, the different vegetative organs of *C. lanatus* were subjected to the activity of each insect. Table 5 highlights the distribution of visits by each species of insect listed according to its actual needs on each vegetative organ of the host plant studied.

1. Some insects electively visit a vegetative organ of watermelon plant; this is particularly the case with bee species on flowers (*A. mellifera*, *Lasioglossum* spp., *E. macrognatha*, *X. olivacea*, *D. staudingeri*, *A. acerata*) and certain species of fruit flies (*D. cucurbitae* and *C. capitata*).

2. Certain species of insects such as *A. gossypii*, *P. megacephala*, *M. opaciventris*, *C. septempunctata*, *C. lunata*, *A. bipunctata*, *Sarcophaga* sp., *C. putoria* visited more than one organ during their activity.

3. Certain insect species such as *C. flavomarginatus* have been recorded to be active on all four vegetative organs of *C. lanatus*.

Table 5. Distribution of insect visits according to vegetative organs

| Insect species | Number and percentage of visits per organ | | | | | | | |
|---------------------------|---|--------------|-------------|--------------|------------|--------------|------------|--------------|
| | Stems | | Leaves | | Flowers | | Fruits | |
| | nv | % | nv | % | nv | % | nv | % |
| <i>A. gossypii</i> | 128 | 12.75 | 876 | 87.25 | - | - | - | - |
| <i>A. mellifera</i> | - | - | - | - | 224 | 100 | - | - |
| <i>C. flavomarginatus</i> | 112 | 61.20 | 63 | 34.43 | 2 | 1.09 | 6 | 3.28 |
| <i>P. megacephala</i> | 86 | 60.99 | 44 | 31.20 | - | - | 11 | 7.80 |
| <i>M. opaciventris</i> | 77 | 62.60 | 39 | 31.71 | - | - | 7 | 5.69 |
| <i>Lasioglossum</i> spp. | - | - | - | - | 79 | 100 | - | - |
| <i>B. cucurbitae</i> | - | - | - | - | - | - | 56 | 100 |
| <i>T. floralis</i> | - | - | - | - | - | - | 52 | 100 |
| <i>C. capitata</i> | - | - | - | - | - | - | 33 | 100 |
| <i>E. macrognatha</i> | - | - | - | - | 33 | 100 | - | - |
| <i>X. olivacea</i> | - | - | - | - | 27 | 100 | - | - |
| <i>D. staudingeri</i> | - | - | - | - | 13 | 100 | - | - |
| <i>M. domestica</i> | - | - | - | - | - | - | 12 | 100 |
| <i>R. dentipes</i> | - | - | 11 | 100 | - | - | - | - |
| <i>C. septempunctata</i> | 36 | 49.31 | 23 | 31.51 | - | - | 14 | 19.18 |
| <i>C. lunata</i> | 4 | 18.18 | 10 | 45.46 | - | - | 8 | 36.36 |
| <i>A. bipunctata</i> | 6 | 46.15 | - | - | - | - | 7 | 53.85 |
| <i>Sarcophaga</i> sp. | - | - | 3 | 27.27 | - | - | 8 | 72.73 |
| <i>C. putoria</i> | - | - | 31 | 15.42 | 3 | 1.50 | 167 | 83.08 |
| <i>R. pruinosa</i> | - | - | 4 | 100 | - | - | - | - |
| <i>A. acerata</i> | - | - | - | - | 7 | 100 | - | - |
| Total | 449 | 19.34 | 1104 | 47.54 | 388 | 16.71 | 381 | 16.41 |

Legend: nv = number of visits; % = percentage

Overall, a visit to a given organ type is linked surely to the actual needs of each species of insect; hence the functional diversity associated with *C. lanatus* on which depends the number of trophic groups or guilds recorded in the activity on this culture.

3.1.2 Trophic Groups Associated with Watermelon Plants

Our observations show several guilds or functional groups or trophic groups defined through the precise activity of each insect or group of insects on one or more organs.

3.1.2.1 Stinging and Sucking Insects

These are the insects that feed on the leaves and stems of watermelon plants. Principle amongst them were the aphid *A. gossypii*. These were accumulated in large numbers on the leaf surface or on the stems and harvested the sap of *C. lanatus* plants.

3.1.2.2 Phytophagous Insects

These are insects that feed upon the leaves causing perforations of varying sizes and can reduce the photosynthetic capacity of *C. lanatus* plants. This is the case with the small beetle species *C. lunata*.

3.1.2.3 Pollinivorous Insects

This group includes mostly bees, which actively collect pollen from flowers and accumulate it on pollen baskets as a provision for their brood offspring. This group of watermelon flower-visitors played important influence on pollinating of this crop. *A. mellifera*, *E. macrognatha*, *D. staudingeri*, *X. olivacea* were well-represented.

3.1.2.4 Nectarophagous Insects

Of the nectar collecting insects, other than the ant *C. flavomarginatus* which is an opportunistic nectarophagous insect, the bees mentioned above are known to be specialist nectar-feeders, and enable the active pollination of female flowers visited. Lepidoptera *A. acerata* was also identified as exclusive nectar sucking insect of watermelon.

3.1.2.5 Saprophagous Insects

These are insects that feed on the rotting watermelon fruit. Among them are the species of flies belonging to the families of Sarcophagidae, Calliphoridae and Muscidae.

3.1.2.6 Fruit-feeding Insects

They are mainly flies of the Tephritidae family including *B. cucurbitae* and *C. capitata*. The females of these flies are equipped with a posterior-abdominal ovipositor through which they lay the eggs in the young fruits causing them either to drop prematurely or then to rot. Locally, producers of watermelon face huge fruit losses without efficient management scheme to control fruit fly populations.

3.1.2.7 Carnivorous Insects

They are aphid eaters. They are drawn to the leaves and stems of watermelon plants to feed on aphids, which operate in groups of several individuals. Among them are *A. bipunctata*, *C. septempunctata* on adult and larval stages, the larval stage of *T. floralis* and the adult stage of *M. opaciventris* and *C. flavomarginatus* (table 6).

Table 6. Predators and their prey recorded on watermelon

| Predators | Stage | Preys |
|---------------------------|-----------------|--|
| <i>C. lunata</i> | Adults & larvae | <i>A. gossypii</i> Fruit fly maggots and/or Adults |
| <i>C. septempunctata</i> | | |
| <i>A. bipunctata</i> | | |
| <i>M. opaciventris</i> | Adults | |
| <i>C. flavomarginatus</i> | | |
| <i>T. floralis</i> | Larvae | <i>A. gossypii</i> |

Maggot eaters were found to be active inside decaying fruits collecting and/or carrying maggots or larvae of flies of the Tephritidae family. Among these insects are two species of ants namely *M. opaciventris* and *C. flavomarginatus*; beetles at larval and adult stages such as *C. lunata*, *A. bipunctata* and *C. septempunctata*. We showed two larval stages of beetles feeding on adults of *B. cucurbitae* and ants species capturing them.

3.1.3 Population Dynamics of Fruit Flies

A bite of the watermelon fruit by Tephritidae causes eggs to deposit in the flesh of the developing fruit. The eggs hatch into maggots which feed on the substance of the fruit causing it to rot. Maggots or larvae develop by accumulating reserves. After 11 days, the last generations of larvae form nymphs or pupae (B). After 8 days, the pupae release a young adult or imago (C). From the larval stage to adult, the life cycle of *B. cucurbitae* (figure 1) was 19 days.

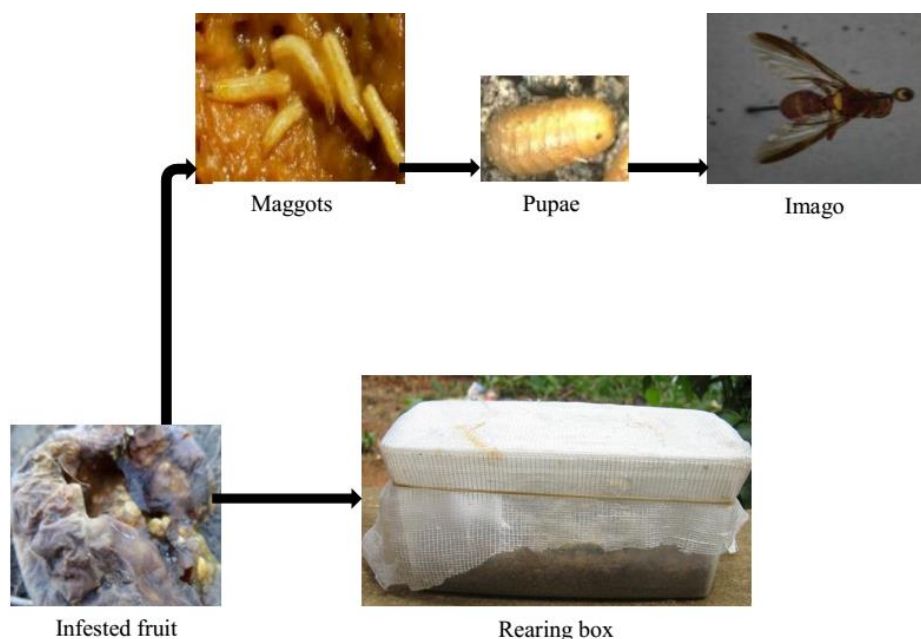


Figure 1. Life cycle of fruit-fly species responsible for watermelon fruit rotting

3.1.4 Fruit Yields Depending on the Different Treatments

Table 7 indicates the fruiting rate, the abortion rate and the rate of formation of mature fruits resulting from the various treatments. The fructification rate is 52% in treatment 1 whose plants have not benefited from any treatment, 56% in batch 2 whose plants have been treated with neem extract and 65% in batch 3 whose plants have benefited from a chemical phytosanitary treatment. The analysis of variance between these three treatments shows that the difference is not significant ($F = 2.94$; $df = (2, 147)$; $p = 0.38$).

The rate of mature fruits is 0% in T_0 , 24% in T_1 , 36% in T_2 and 54% in T_3 . The difference between these values is significant ($F = 44.84$; $df = (2, 147)$; $p < 0.05$). A pairwise comparison of these values using the HSD test shows that the difference is significant between treatments 1 and 2 ($p < 0.0001$), 2 and 3 ($p = 0.007$) and between 1 and 3 ($p < 0.0001$).

The rate of abortion was 100% in T_0 , 76% in T_1 , 64% in T_2 and 46% in T_3 . The difference between these values is also significant ($F = 11.56$; $df = (2, 147)$; $p < 0.05$). Overall, female flower without pollinator visits was free from mature fruit; treatments 1, 2 and 3 produced mature fruit although in different proportions. In these treatments two factors namely pollinators' activity and the phytosanitary products against insect pests were observed.

Table 7. Fruit yield of *Citrullus lanatus* according to the different treatments

| Yield parameters | Plot 1 | | Plot 2 | Plot 3 |
|----------------------------------|--------|-------|--------|--------|
| | T_0 | T_1 | T_2 | T_3 |
| Number of plants | 10 | 10 | 10 | 10 |
| Number of female flowers studied | 50 | 50 | 50 | 50 |
| Number of newly-formed fruits | 26 | 28 | 27 | 30 |
| Fruit set rate (%) | 52% | 56% | 54% | 60% |
| Number of ripe fruits | 0 | 12 | 18 | 27 |
| Rate of ripe fruits (%) | 0% | 24% | 36% | 54% |
| Number of fruits aborted | 50 | 38 | 32 | 23 |
| Abortion rate (%) | 100% | 76% | 64% | 46% |

3.1.5 Estimates of Financial Income Per Hectare of Watermelon Production

Table 8 shows parameters related to the estimates of financial income from watermelon treatments. The average number of fruits per plant was 0.3 in T_1 (i.e. 1,800 fruit/ha), 0.9 in T_2 (i.e. 2,700 fruit/ha) and 1.6 in T_3 (i.e. 4,050 fruit/ha). The average weight of an edible fruit is 4.14 in T_1 (i.e. 78.84 tonnes/ha), 4.53 in T_2 (i.e. 122.31 tonnes/ha) and 4.71 in T_3 (i.e. 184.68 tonnes/ha). The estimates of financial income per hectare was 900,000 cfa (\$ 1,661.73) in T_1 , 1,350,000 cfa (\$ 2,492.10) in T_2 and 2,025,000 cfa (\$ 3,738.90) in T_3 .

Table 8. Parameters for estimating expected income from each treatment

| Parameters | Treatments | | | |
|----------------------------------|------------|------------------------------|--------------------------------|--------------------------------|
| | T_0 | T_1 | T_2 | T_3 |
| Mean number of fruit/plant | 00 | 0,6 | 0,9 | 1,35 |
| Approximate number of plant/ha | 3000 | 3000 | 3000 | 3000 |
| Approximate number of fruit/ha | 00 | 1800 | 2700 | 4050 |
| Mean fruit weight (kg) | - | 4.38 ± 1.18 | 4.53 ± 1.36 | 4.59 ± 1.83 |
| Fruit tonnage per hectare | - | 78.84 t | 122.31 t | 184.68 t |
| Estimated wholesaler price/fruit | 00 | 500 cfa (\$ 0.92) | 500 cfa (\$ 0.92) | 500 cfa (\$ 0.92) |
| General income expected/ha | 00 | 900,000 cfa (\$ 1,661.73) | 1,350,000 cfa (\$ 2,492.10) | 2,025,000 cfa (\$ 3,738.90) |

3.2 Discussion

The study has provided information on the general entomofauna associated with *C. lanatus* being diverse at the watermelon production site established in Cameroon. Our results showed twenty two species grouped into five main orders of which the Hemiptera were predominant. Therefore, watermelon plants constitute an entire community which interacts with the local entomological fauna. Within this community, each insect shows a specific link which can be seen to be detrimental or beneficial to good growth and production of the host plant. Indeed, ecologists have deemed it necessary to group insects into functional groups to better appreciate the

interactions between them, their host plant, their natural enemies or the seasons (Speight, 2008).

Pollinivorous and nectarophagous insects in this study were essentially bees. Their floral visits were devoted to pollinating the studied plants. Previous work indicates *A. mellifera* as the main pollinating insect of *C. lanatus* in several regions of the world: USA (Stanghellini et al., 1998; Kremen et al., 2004), in Kenya (Njoroge et al., 2004) and in Cameroon (Azo'o et al., 2017). Pollinivorous and nectarophagous are classified in the entomofauna of *C. lanatus* as beneficial insects because they provide most of the fruit and grain yields of this crop through their pollination activity. The absence of pollinators in the present study is clearly a sufficient factor in the heavy loss of fruit production of watermelon in Yagoua. Indeed in T₀, fruit production is null. In consistently with our results, previous results showed that watermelon cannot produce fruits and seeds without bee pollination (Stanghellini et al., 1998). The lack of watermelon pollination reaches the negative economic threshold in Yagoua; thus, watermelon growers have to well-manage pollinators as the main production factor of the crop. Results indicate optimal abortion rates in T₁ although the corresponding female flowers were exposed-pollinated but received no phytosanitary treatment, despite similar fruiting rates than in T₂ and T₃. Thus, in addition to the pollinating activities which are essential for fruit and seed production, the cultivation of watermelon in Yagoua requires strict phytosanitary attention.

The phytophagous insects such as aphids which are exophagous stinging-sucking insects at a high population could become an important threat by reducing the photosynthetic capacity of the host plant. These insects suck the sap and sometimes to the extent to cause the leaves to turn yellow or wilt. In addition to direct damage from food intake, many of these insects can transmit pathogenic organisms, especially viruses (Mokam et al., 2014).

The preponderance of phytophagous insect activity on *C. lanatus* during the first interval of observation was favorable for depredation. In the morning, the leaves were more humid and the temperature probably more favorable for the activity of these insects (Kumar, 1991). Our work corroborates that of Mahomed (2002) who showed that infestation of cowpea (*Vigna unguiculata*) by *Megalurothrips sjostedti* is predominant in the morning. Moreover, the fruit feeders are more important in the evening, which would be linked to an optimal forage strategy (Dajoz, 1985).

Our work has also enabled us to identify other useful insects, potential agents of biological control, and formidable consumers of aphids. These insects include Ladybird beetle species, hoverflies and ant species. Our results are in agreement with those of Kenne (2006) who indicates *M. opaciventris* as a predatory insect and an auxiliary in the fight against phytophagous insects. The species of Coccinellidae listed in our experiment such as *C. lunata* have already been mentioned as important predators that can intervene in biological control in the larval and adult stages (Dji o & Al n  2006). The important role of some hoverflies as feeders on aphids at a larval stage make them beneficiary auxiliary organisms in crop protection (Speight et al., 2013; P remand et al., 2017).

The fact that larval stages of Tephritidae were captured and eaten by identified predators in our study site enabled a reduction in the number of fruit fly adults that emerged. The recrudescence of the natural enemies of fruit flies is a serious driver of the population dynamics of these fruit pests. Moreover, few fruit flies at their adult stage were seen to be fed on by the larval stage of beetles. Although we did not record the direct predation of fruit fly adults by ant species in our experiment, the study by Neuenschwander et al. (1983) showed two ant species, namely *Crematogaster sordidula* and *Tetramorium caespitum* were capable of destroying both larvae and adults of the olive fly *Bactrocera oleae*.

Beyond the physiological phenomena specific to the plant such as the sink effect which affects the fruiting of several plant species in general (Newman, 1995) and Cucurbitaceae in particular (Valantin-Morison et al., 2006), the rate of abortion is mainly caused by the depredation activity of fruit flies belonging to the Tephritidae family. These insects infest young fruits with their eggs; the eggs produce maggots which cause rotting and premature drop in infested fruit. Collingwood et al. (1984) as well as Vaissire & Froissart (1996) mention that in West Africa, *Dacus ciliatus* and *Dacus vertebratus* can cause fruit yield losses of *Cucumis melo* or melon of more than 60%. In pistachio *Cucumeropsis mannii*, young fruits with a diameter less than 10 cm were found to be the most vulnerable to *Dacus bivittatus* activity in Nkolbisson (Fomekong et al., 2008). Fruit yields were also affected by the emergence of a sudden fungal disease that caused the expected fruit to burst. This state of affairs also justifies the losses in the maximum yields recorded in the different treatments.

The treatment T₃ appears to provide farmers with a good yield and more profit in terms of financial income. However, consumers remain highly exposed to diseases following the ingestion of toxic products derived from Optimal. This should therefore encourage watermelon consumers of the region to adopt good pre-consumption hygiene. Farmers who use bio-insecticides as well as those who do not are not totally harmed. While the efforts

to obtain the neem extract seem quite considerable, the fruit yields allow great security in consumption as well as cover the expenses incurred especially at the family level. The neem extract therefore seems to provide added value from an economic and ecological purposes. Moreover, the proliferation of natural enemies in the environment can be considered for searching entomological solutions to pest problems in watermelon farms.

Overall, in Yagoua, watermelon growers do not seem able to distinguish, among the great diversity of insects, those likely to be beneficial in suppressing pests of their choice enterprises. Only that farmers do not act efficiently to benefit from such suppressors because they do not know them. It is this state of affairs that we tried to remedy by giving farmers, in simple and precise form, the practical notions essential to defend the fields against invaders and promote the use of useful insects for improving agricultural yields.

4. Conclusion

The objective of this study was to seek out entomological knowledge that can facilitate increased yields in current agricultural practices. The results obtained enabled us to justify the hypotheses formulated. In fact, the watermelon entomofauna is full of formidable pests that start fruit production and make use of crop protection methods. The phytosanitary cover used by the local producers made with pesticides makes it possible to preserve a certain quantity of the fruit yield. Nevertheless, the watermelon entomofauna is full of potential natural enemies of pests that can be considered in biological control. In addition, the recrudescence of female fruit flies may suggest an autocidal approach is possible. The presence of pollinating insects is also beneficial for increasing watermelon yields. For a further perspective, it would be important to carry out in-depth research on biopesticides based on local raw materials and encourage farmers for beekeeping in surrounding watermelon farms in a context of sustainable production of watermelon fruit in Yagoua.

Acknowledgement

Authors are thankful to Pete Boardman for proofreading the first draft of the manuscript and to anonymous reviewers who enabled improving this work.

References

- Achu, M. B., Fokou, E., Tchiengang, C., Fotso, M., & Mbiapo, F. T. (2005). Nutritive value of some Cucurbitaceous oilseeds from different regions of Cameroon. *African Journal of Biotechnology*, 4, 1329-1334.
- Adeoye, I. B., Olajide-Taiwo, F. B., Adebisi-Adelani, O., Usman, J. M., & Badmus, M. A. (2011). Economic analysis of watermelon based production system in Oyo State, Nigeria. *Journal of Agricultural and Biological Science*, 6(7), 53-59.
- Azo'o, E. M., Tchuengue, F. F. N., & Messi, J. (2017). Biological diversity of the entomofauna associated with *Citrullus lanatus* (Cucurbitaceae) flowers and assessment of its impact on yields. *Journal of Entomology and Zoology Studies*, 5(5), 810-815.
- Bayiha, G. P., Temple, L., Mathe, S., & Nesme, T. (2019). Typologie et perspective d'évolution de l'agriculture biologique au Cameroun. *Cahiers Agricultures*, 28(3), 1-8. <https://doi.org/10.1051/cagri/2019003>
- Bigot, L., & Bodot, P. (1973). Contribution à l'étude biocénétique de la garrigue à *Quecus coccifera* - Composition biotique du peuplement des invertébrés. *Vie et Milieu*, 23, 229-249.
- Caron, D., Burdick, E., Ostiguy, N., & Frazier, M. (2005). *Mid-Atlantic Apiculture Research and Extension Consortium Survey Preliminaries*. Department of Entomology, 501 Ag Sciences & Industries Bldg., Penn. State University, PA 16802 and Dept. of Entomology, 250 Townsend Hall, University of Delaware, Delaware.
- Chogou, S. K., Assogba, R., Degbey, H., Abokini, E., & Achigan-Dako, E. G. (2019). Market structure and performance of watermelon (*Citrullus lanatus*) in Benin. *Scientific African*, 3, 1-9. <https://doi.org/10.1016/j.sciaf.2019.e00048>
- Collingwood, E. F., Bourdhouxhe, L., & Defrancq, M. (1984). *Les principaux ennemis des cultures maraîchères au Sénégal*. ISRA-CDH (ed.), Dakar.
- Dajoz, R. (1985). *Précis d'écologie*. Dunod eds. Paris.
- Dajoz, R. (2006). *Précis d'Ecologie* (8 ed.). Dunod, Paris. p. 631.
- Djiéto, L. C., & Aláí D. C. (2006). Inventaire diagnostique des insectes de quelques cultures dans les exploitations maraîchères périurbaines dans la région de Yaoundé Cameroun. In Pôde de compétence en Partenariat (PCP) Grand Sud Cameroun. Actes atelier de présentation des résultats de recherche participative.

- IRAD/IRAD. Yaoundé Cameroun. p. 7-17.
- DSCE. (2009). *Document de Stratégie pour la croissance et l'emploi*. MINEPAT-Cameroun, Yaoundé
- Fomekong, A., Messi, J., Kekeunou, S., Tchuenguem, F. F. N., & Tamesse, J. L. (2008). Entomofauna of *Cucumeropsis manni* Naudin, its impact on plant yield and some aspects of the biology of *Dacus bivitatus* (Diptera: Tephritidae). *African Journal of Agricultural Research*, 3(5), 363-370.
- Huh, Y. C., Solmar, A., & Sari, N. (2003). *Morphological characterization of Korean and Turkish watermelon germplasm*. Proceedings of the 9th EUCAPIA Meeting on Geneica and Breeding of Cucurbitaceae. Pitrat M. Ed INRA, Avignon, France. p. 21-24.
- Kearns, C. A., Inouye, D. W., & Waser, N. (1998). Endangered mutualisms: the conservation of plant-pollinator interactions. *Annual Review of Ecology and Systematic*, 29, 83-112.
<https://doi.org/10.1146/annurev.ecolsys.29.1.83>
- Kenne, M. (2006). *Evaluation des possibilités d'utilisation d'une espèce de fourmi terricole dominante comme auxiliaire de lutte contre les insectes phytophages*. Thèse de Doctorat/Ph.D., Université Paul Sabatier, Toulouse III, Toulouse.
- Kremen, C., Williams, N. M., Bugg, R. L., Fay, J. P., & Thorp, R. W. (2004). The area requirements of ecosystem service: Crop pollination by native bee communities in California. *Ecology Letter*, 7, 1109-1119.
<https://doi.org/10.1111/j.1461-0248.2004.00662.x>
- Kumar, R. (1991). *La lutte contre les insectes ravageurs*. Eds. Edward Arnold Ltd, 41, Bedford Square London.
- Mahomed, B. (2002). *Evaluation de quelques plantes à potentiel insecticide et insectifuge contre Megalurothrips sjostedti* (Trybom, 1908), ravageur du ni ébé (*Vigna unguiculata* Walp.) à Nkolbisson (Yaoundé-Cameroun). Mémoire de Diplôme d'Etudes Approfondie (DEA). Laboratoire de Zoologie. Université de Yaoundé I, Yaoundé
- Mbondji, P. M. (1984). *Principaux insectes nuisibles au cacaoyer et aux caféiers du Cameroun-Biométrie et lutte*. Edition CEPER, Yaoundé
- Mokam, D. G., Djieto, L. C., & Bilong, B. C. F. (2014). Patterns of species richness and diversity of insects associated with cucurbit fruits in the southern Cameroon. *Journal of Insect Sciences*, 14(248), 1-9.
<https://doi.org/10.1093/jisesa/ieu110>
- Neuenschwander, P., Bigler, F., Delucchi, V., & Michelakis, S. (1983). Natural enemies of preimaginal stages of *Dacus oleae* in Western Crete. *Bollettino del Laboratorio di Entomologia Agraria*, 40, 3-32.
- Newman, B. (1995). Competitions for assimilates and fruit position affect fruit set in indeterminate greenhouse tomato. *Annal of Botany*, 75, 55-65. [https://doi.org/10.1016/S0305-7364\(05\)80009-5](https://doi.org/10.1016/S0305-7364(05)80009-5)
- Njoroge, G. N., Gemmill, B., Bussman, R., Newton, L. E., & Ngumi, V. W. (2004). Pollination ecology of *Citrullus lanatus* at Yatta, Kenya. *International Journal of Tropical Insect Sciences*, 24, 73-77.
<https://doi.org/10.1079/IJT20042>
- Onyemauva, C. (2010). Marketing margin and efficiency of watermelon marketing in Niger delta area of Nigeria. *Agriculture Tropicale et Subtropicale*, 43(3), 196-201.
- Páremand, G., Speight, M. C. D., Fleury, D., Castella, E., & Delabays, N. (2017). Hoverfly diversity supported by vineyards and the importance of ground cover management. *Bulletin of Insectology*, 70(1), 147-155.
- Reetu, V., & Tomar, M. (2017). Watermelon: A valuable horticultural crop with nutritional benefits. *Popular Kheti*, 5(2), 5-9.
- Southwick, E. E., & Southwick, L. (1992). Estimating the economic value of honey bee (Hymenoptera, Apidae) as agricultural pollinators in the United States. *Journal of Economic Entomology*, 85, 621-633.
<https://doi.org/10.1093/jee/85.3.621>
- Speight, M. C. D., Monteil, C., Castella, E., & Sarthou, J. P. (2013). *StN 2013*. Syrph, the NetPublications, Dublin.
- Speight, M. R., Hunter, M. D., & Watt, A. D. (2008). *Ecology of insects: concepts and applications* (2nd ed.). Wiley-Blackwell, Singapore.
- Stanghellini, M. S., Ambrose, J. T., & Schultheis, F. R. (1998). Seed production in watermelon: a comparison between two commercially available pollinators. *Horticultural Sciences*, 33, 28-30.
<https://doi.org/10.21273/HORTSCI.33.1.28>

- Tchuenguem, F. F. N., Fameni, T. S., Pharaon, M. A., Messi, J., & Brückner, D. (2010). Foraging behaviour of *Apis mellifera adansonii* (Hymenoptera: Apoidea) on *Combretum nigricans*, *Eryhrina sigmaidea*, *Lannea kerstingii* and *Vernonia amygdalina* flowers at Dang (Ngaoundéré Cameroon). *International Journal of Tropical Insect Science*, 30(1), 40-47. <https://doi.org/10.1017/S1742758410000019>
- Tchuenguem, F. F. N., Messi, J., & Pauly, A. (2002). L'activité de butinage des Apoïdes sauvages (Hymenoptera: Apoidea) sur les fleurs de maïs à Yaoundé (Cameroun) et réflexion sur la pollinisation des graminées tropicales. *Biotechnologie, Agronomie, Société et Environnement*, 6(2), 87-98.
- Vaissière, B. E., & Froissart, R. (1996). Pest management and pollination of Cantaloupes grown under spunbonded row covers in West Africa. *Journal of Horticultural Science*, 71(5), 755-766. <https://doi.org/10.1080/14620316.1996.11515456>
- Valantin-Morison, M., Vaissière, B. E., Gary, C., & Robin, P. (2006). Source sink balance affects reproductive development and fruit quality in cantaloup melon (*Cucumis melo* L.). *Journal of Horticultural Science and Biotechnology*, 81(1), 110-117. <https://doi.org/10.1080/14620316.2006.11512036>

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (<http://creativecommons.org/licenses/by/3.0/>).