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

Azo'o Ela Michelson[1], Ngapete Litassou Monique[2], Djenatou Pélagie[2, 3], Kengni Beaudelaine Stéphanie[1], Sakataï Pierre Dérik[2, 3] & Tchuenguem Fohouo Fernand-Nestor[4]

[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 (CRRA-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

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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 T_0 which does not benefit from pollination and health care. Protective means used locally guaranteed the production of mature fruits by 24% in T_1 without any sanitary care, 36% in T_2 impregnated with neem *Azadirachta indica* (Meliaceae) leaf's extract, and 54% in T_3 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 m^2 approximately 1 km apart from each other were used for experiments: a neutral plot (P_1) which was free from any phytosanitary product; a plot with watermelon plants under neem extract impregnation (P_2); and a third plot in which plants were impregnated with Optimal (P_3). 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/m^2 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) x 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) x 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%), *Myrmicaria opaciventris* (5.30%), *Coccinella septempunctata* (3.14%), *Bactrocera cucurbitae* (2.41%), *Lasioglossum* sp. 1 (2.24%), *Toxomerus floralis* (2.24%), *Eucara macrognatha* (1.42%), *Ceratitis 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	*nv*	*F* (%)
Hemiptera	Aphididae	*Aphis gossypii*	1004	43.25
		Riptortus dentipes	11	0.47
Total Hemiptera			**1015**	**43.72**
Hymenoptera	Formicidae	*Camponotus flavomarginatus*	183	7.88
		Pheidole megacephala	141	6.07
		Myrmicaria opaciventris	123	5.30
	Total Formicidae		**447**	**19.26**
	Apidae	*Apis mellifera*	224	9.65
		Eucara macrognatha	33	1.42
		Xylocopa olivacea	27	1.16
		Dactylurina staudingeri	13	0.56
	Total Apidae		**297**	**12.79**
	Halictidae	*Lasioglossum* sp. 1	52	2.24
		Lasioglossum sp. 2	27	1.16
	Total Halictidae		**79**	**3.40**
Total Hymenoptera			**823**	**35.44**
Diptera	Tephritidae	*Bactrocera cucurbitae*	56	2.41
		Ceratitis capitata	33	1.42
	Total Tephritidae		**89**	**3.83**
	Calliphoridae	*Chrysomia putoria*	201	8.66
	Muscidae	*Musca domestica*	12	0.52
	Syrphidae	*Toxomerus floralis*	52	2.24
	Sarcophagidae	*Sarcophaga* sp.	11	0.47
	Rhiniidae	*Rhyncomya pruinosa*	4	0.17
Total Diptera			**369**	**15.89**
Coleoptera	Coccinellidae	*Coccinella septempunctata*	73	3.14
		Cheilomenes lunata	22	0.95
		Adalia bipunctata	13	0.56
Total Coleoptera			**108**	**4.65**
Lepidoptera	Acraeidae	*Acraea acerata*	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

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

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

Legend: $C = [(P_i/P) \text{ x } 100]$ = 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. Certains 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

	Number and percentage of visits per organ							
	Stems		**Leaves**		**Flowers**		**Fruits**	
Insect species	**nv**	**%**	**nv**	**%**	**nv**	**%**	**nv**	**%**
A. gossypii	128	12.75	876	87.25	-	-	-	-
A. mellifera	-	-	-	-	224	100	-	-
C. flavomarginatus	112	61.20	63	34.43	2	1.09	6	3.28
P. megacephala	86	60.99	44	31.20	-	-	11	7.80
M. opaciventris	77	62.60	39	31.71	-	-	7	5.69
Lasioglossum spp.	-	-	-	-	79	100	-	-
B. cucurbitae	-	-	-	-	-	-	56	100
T. floralis	-	-	-	-	-	-	52	100
C. capitata	-	-	-	-	-	-	33	100
E. macrognatha	-	-	-	-	33	100	-	-
X. olivacea	-	-	-	-	27	100	-	-
D. staudingeri	-	-	-	-	13	100	-	-
M. domestica	-	-	-	-	-	-	12	100
R. dentipes	-	-	11	100	-	-	-	-
C. septempunctata	36	49.31	23	31.51	-	-	14	19.18
C. lunata	4	18.18	10	45.46	-	-	8	36.36
A. bipunctata	6	46.15	-	-	-	-	7	53,85
Sarcophaga sp.	-	-	3	27.27	-	-	8	72.73
C. putoria	-	-	31	15.42	3	1.50	167	83.08
R. pruinosa	-	-	4	100	-	-	-	-
A. acerata	-	-	-	-	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
C. lunata	Adults & larvae	*A. gossypii* Fruit fly maggots and/or Adults
C. septempunctata		
A. bipunctata		
M. opaciventris	Adults	
C. flavomarginatus		
T. floralis	Larvae	*A. gossypii*

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.

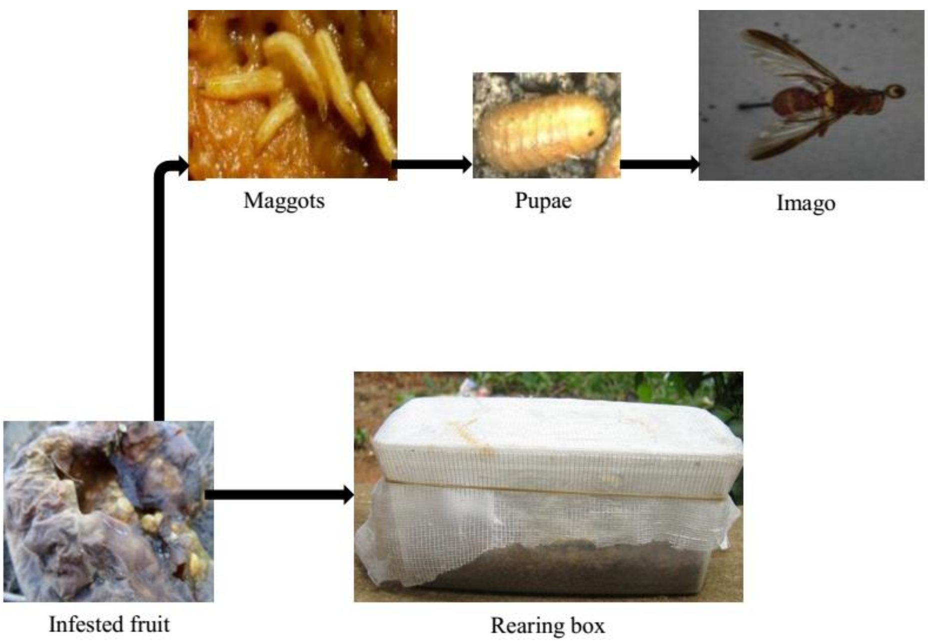

Figure 1. Life cycle of fruit-fly species responsible for watermelon fruit rotting

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

	Plot 1		Plot 2	Plot 3
Yield parameters	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

	Treatments			
Parameters	T0	T1	T2	T3
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 T_0, fruit production is null. In consistently with our results, previews 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 T_1 although the corresponding female flowers were exposed-pollinated but received no phytosanitary treatment, despite similar fruiting rates than in T_2 and T_3. 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 (Djiéto & Aléné, 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; Pétremand 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 Vaissière & 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 T_3 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.

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