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Biological diversity of arthropods associated with two varieties of pepper (*Capsicum annuum* L., 1753) at Nkolmelen (Yaoundé, Cameroon)

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ABSTRACT

Pepper is a vegetable which plays an important role in the human diet and health. Many insects attack this plant and decrease its production in the absence of appropriate phytosanitary treatment. Thus, the objective of the present study was to record the arthropods associated with the yellow and red pepper varieties. For this purpose, weekly observations were conducted during two cropping cycles on 192 plants, using a completely randomized device. As results, the fauna of the pepper was very diverse and stable (specific richness 47 and Equitability index 0.86). The yellow pepper was the most sensitive with an average of nine insect species per plant versus eight on the red pepper. These insects belonged to seven orders (Arachnida, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera and the Orthoptera), 28 families and 47 species. The densest orders were Diptera represented by *Ceratitis capitata*, *Silba capsicarum*, followed by Hymenoptera were represented by *Camponotus floridanus*, *Camponotus acvapimensis* and *Crematogaster* sp. and Hemiptera represented by *Aphis gossypii*, *Macrosiphum euphorbiae*, *Pseudococcus* sp. The present study provided a database on arthropodofauna of the pepper plant. This is of paramount importance for the development of healthy and sustainable protection strategies among pepper producers in order to improve national production.

Keywords: Arthropodofauna, *Ceratitis capitata*, inventory, pest, *Silba capsicarum*.

Diversité biologique des arthropodes associés à deux variétés de piment (*Capsicum annuum* L., 1753) à Nkolmelen (Yaoundé, Cameroun)

RESUME

Le piment est un légume important dans l'alimentation et la santé des populations humaines. De nombreux insectes attaquent cette plante et affectent sa production en absence de traitement phytosanitaire approprié. Ainsi, l'objectif de la présente étude est de faire l'inventaire des arthropodes associés aux piments jaunes et rouges. Pour ce faire, des observations hebdomadaires ont été réalisées pendant deux cycles de culture sur 192 plants en utilisant un dispositif complètement randomisé. Il en est ressorti que, la faune du piment était très diversifiée et stable (richesse spécifique 47 et Equitabilité 0.86). Le piment jaune a été plus sensible avec

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neuf espèces par plant contre huit pour le piment rouge. Ces insectes appartenaient à 7 ordres (Arachnida, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera et les orthoptera), 28 familles et 47 espèces. Les ordres les plus denses ont été les Diptera représentés par *Ceratitis capitata*, *Silba capsicarum*, suivi des Hymenoptera (*Camponotus floridanus*, *Camponotus acvapimensis* et de *Crematogaster* sp.) et des Hemiptera (*Aphis gossypii*, *Macrosiphum euphorbiae*, *Pseudococcus* sp.). La présente étude a fourni une base de données sur l'arthropodofaune du piment. Ceci est d'une importance capitale, pour l'élaboration des stratégies de protection saines et durables chez les producteurs de piment afin d'améliorer la production nationale.

Mots clés : Arthropodofaune, ravageur, inventaire, *Silba capsicarum Ceratistis capitata*.

INTRODUCTION

Pepper is a highly valued vegetable crop in the human diet (Kouassi Kouassi and Koffi-Nevry, 2012; Akesse et al., 2015). It is commonly consumed worldwide in several dishes such as meat, fish soup, etc. (Fabre et al., 2001; Kouassi Kouassi and Koffi-Nevry, 2012). Pepper is also used for exorcism in some traditional African societies (Ledi et al., 2020). It is among the vegetable crops highly valued economically and culturally. After tomato, pepper is the most requested spice for many dishes, especially in urban areas (Tossounon Yarou and Onzo, 2015). Its pungent flavour is highly sought for spicing all dishes; in this regard, pepper is one of the 40 most produced vegetable species worldwide (Lebeau, 2010; Kollmannsberger et al., 2011). It is rich in vitamin C and plays a very important role in natural therapy (Kollmannsberger et al., 2011). Africa is the third largest producer of pepper with a rate of 8.8% behind Asia and America (Akesse et al., 2015). In Africa, some countries such as Ghana and Nigeria have a regular production, which supplies the international market. In Cameroon, in 2019, 49500 metric tons of pepper fruits were produced on an area of 30378 ha. However, this production is seasonal and limited by biotic and abiotic factors (Akesse et al., 2015) such as insects, microorganisms, environmental factors. Its intensification in urban and suburban areas has led to an increase and diversification of pest insects (Aléné et al., 2019a). Among many factors, the quality of seeds and the knowledge of the producers' population have been pointed out as being the main sources of failure in cultivations worldwide (Djiéto-Lordon et al., 2007; Tendeng et al., 2017).

The revenues of the agricultural sector remain poorly known and the distribution channels even less so. Among the biotic factors, the pepper undergoes strong parasitic pressure due to insect pests that cause highly significant damage and yield losses (Weintraub, 2007). On one hand, these insects would directly attack the plant at all phenological stages; they feed on all organs, namely leaves, buds and fruits (Akesse et al, 2015); also, all the varieties (green, yellow and red) are susceptible to be attacked. On the other hand, insects would indirectly affect crops by transmitting diseases, causing considerable damage to the plant (Aléné et al., 2019a). About diseases, damages are not always obvious. Sap sucking insects such as hemipterans (aphids, white flies, etc.), in addition to sap robbing, are responsible of localized chlorosis close to the feeding site caused by disruption of chloroplasts, growth distortions on leaves, leaf curling (Aléné et al., 2019a; Guerrieri et al., 2008). Furthermore, caterpillars and Diptera attack the fruits (Mokam et al., 2014; Heumou, 2015; Elono-Azang et al., 2016). Stung fruits become unusable after a few days. Unfortunately, compared to other vegetable crops such as tomato, amaranth or onions, very little information is available on pepper pests and their impact on the crop in Cameroon. This lack of reliable data is a major constraint to the protection of the pepper crop, which is subject to several phytosanitary issues (James et al., 2010; Adango et al., 2012). Therefore, in order to provide support to producers and improve the productivity of pepper in quantity and quality, it is important to set up pest and potential pest insects adequate and efficient control strategies that are respectful to producers and consumers well-being. In this perspective, the present study aimed at characterizing the arthropodofauna of pepper in Cameroon, in order to conceive pest management strategies. For this purpose, (1) arthropodofauna associated with the pepper is monitored; (2) the relative sensitivity of pepper varieties (red and yellow) is determined, (3) the effect of insects of each taxon on pepper organs is described.

MATERIALS AND METHODS

Study site

The study was conducted in an experimental plot in Nkolmelen (11° 08' East, 3° 22' North), in the southwestern outskirt of the Yaoundé city (Figure1). Natural landscape is dominated by a disturbed forest patches and old fallows. Around the experimental garden, vegetation is mainly made up of *Tithonia diversifolia* (Hemsl.) A. Gray (Asteraceae), a common invasive herbaceous plant in fallows. This site was chosen for its easy access and its architectural and landscape features which are highly favourable for the cultivation of several crops in general and pepper in particular. The climate is of a transitional subequatorial type, with a specificity for Yaounde city (Suchel, 1988). Indeed, Yaoundé is located in a basin surrounded by several hills, which gives it a Yaoundé-type microclimate (Suchel, 1988). Compared to the Centre region where the average temperature is around 25ºC, that of the Yaoundé city, due to its altitude, is generally slightly lower (23ºC). The hottest months are January and February (28ºC on average) and the coldest are July and August (23.5ºC on average) (Suchel, 1988). The relative humidity is 82% and the wind speed varies between 6 km/h in the morning and 9 km/h in the evening, averaging at 7 km/h. The average rainfall is 1727 mm/year (Suchel, 1988). Rainfall is spread over two seasons. Thus, the climate of Yaoundé is divided into four seasons: a long dry season from late November to early March, a short rainy season from mid-March to June with a peak in late May or early June, a short dry season from July to mid-August, and a long rainy season from September to mid-November with a peak in October.

Nursery setting up

Hybrid seeds of pepper was bought from the approved importer JACO S.A. Then, on the site, an appropriate space was chosen near a water source to set up a nursery near the plot. Two square meters of surface were used to make the nursery for about four to five grams of seed for a total cultivable area of 100 m^2. We ploughed and loosened the soil and then made one-meter-wide beds and enriched the soil with mycorrhizae (biofertilizer) for about five centimetres below each seed. Sowing was done on rows of 10 cm, with two to three seeds in each pocket. Pockets, distant five centimetres from each another, were covered with a little amount of soil, and immediately watered; then, beds were covered with banana and palms leaves. All this was done under shade. The watering was done daily in the morning and evening. Plants lasted 40 to 45 days in the nursery after sowing. Then, they were transplanted in a garden once they reached a height of 10 to 15 cm with 6 to 8 true leaves.

Experimental design

In the experimental plot of 100 m^2, the soil was previously improved with chicken droppings and compost before the transplantation of the seedling. The plot was divided into two blocks both planted with yellow and red pepper. Each block was made of four boards of 12 m long, comprising 12 pepper plants one meter separated one another. This led to a total of 96 plants at the rate of 48 per variety. The two blocks were four meters separated each other while they were distant from the vegetation by two meters to avoid interference with the surrounding bushes.

Data collecting and Identification

The inventory of the arthropodofauna was carried out during two agricultural campaigns. The first one extended from August 2019 to February 2020 and the second one from August 2020 to February 2021. This inventory was done once a week, in the morning from 8 to 10. This included observations of each pepper plant by checking all its parts (roots, leaves and stems). Adult arthropods encountered were collected and stored in 70°C alcohol. Then they were sorted into morphotypes, functional groups and taxa. Immature arthropods, once at the laboratory, were reared up to adult stages. The ripe fruits bitten by insects were collected and incubated until insects' emerging. These insects were also preserved in 70°C alcohol and processed as previously.

The collected arthropods on the field and those reared at the laboratory were identified using dichotomic keys (Bohlen, 1978; Bolton, 1994; Couilloud, 1989; Villiers, 1952; Delabie, 2001; Delvare et al., 1989) at order, family, genera and species levels.

Data analysis

The diversity was characterized based on the evaluation of the species richness. The relative abundance of the fauna at order, family and genus level was computed and analysed. A taxon or a morphospecies was considered numerically dominant when its cumulative relative abundance on a pepper variety was more than 5%. Under this threshold, the taxon was considered occasional or accidental. The pepper variety effect on the abundance of the dominant arthropod species was assessed using ANOVA test (GLM proc). Over dispersion was corrected by Poisson error for the count data. These tests were performed using R software (version 3.2.2) and the results were appreciated at 5% confidence level.

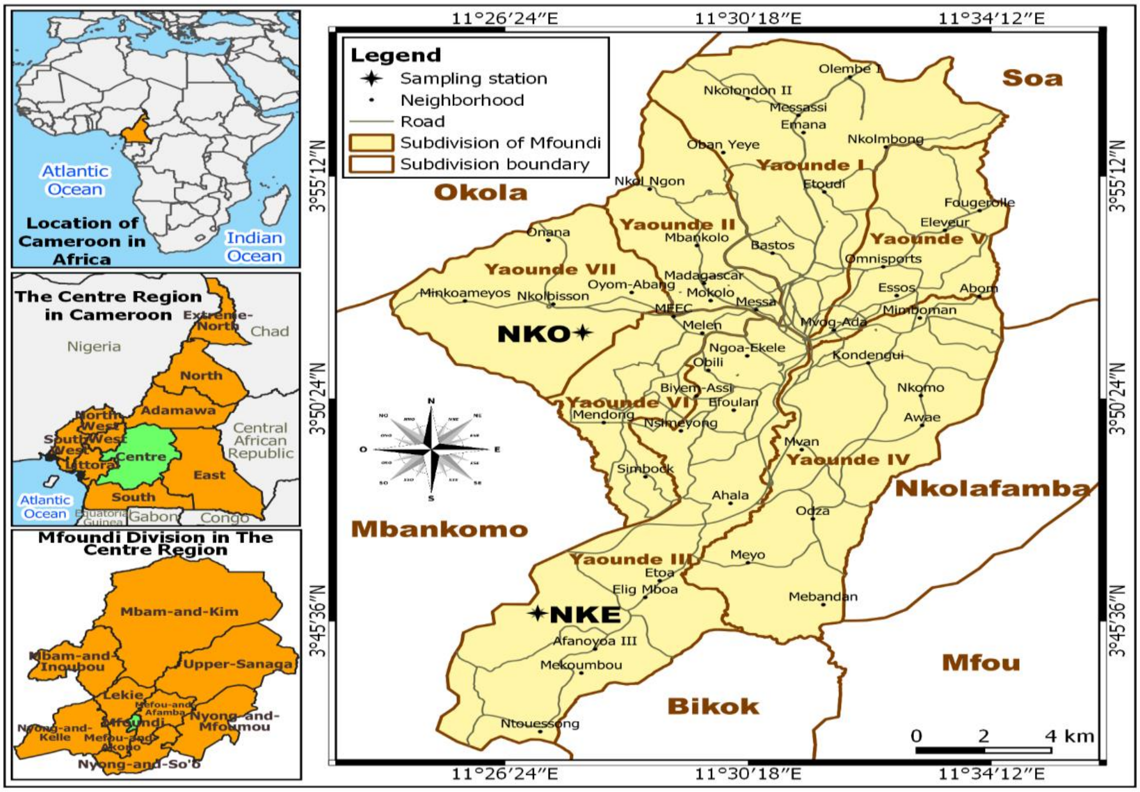

Figure 1: Map of the study site (Only the coordinates of Nkolmelen; *NKE* points are of interest).

RESULTS

Arthropod diversity on pepper

From the field sampling, 178.81 arthropod individuals, belonging to 7 orders, 28 families and 47 species were collected on the two pepper varieties. Among the 7 orders, six were insects: Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera and Orthoptera, and one was Arachnida. The main families encountered were Tephritidae, Aphididae, Braconidae, Formicidae, Gelechiidae, Lonchaeidae and Theridiidae. The absolute abundances at the specific level varied widely according to the varieties. Thus, the yellow pepper presented an absolute abundance of 99.45 individuals while that of red pepper was 72.88. The difference between the average species richness of the two varieties was significant (F = 12.47 ; P = 0.0001).

Variation of abundance at order level

Among the fauna collected from *C. annuum*, Diptera, represented 34.01% of the total individuals; Hymenoptera represented 28.83% while Hemiptera contributed for 15.21%. The three orders were the most abundant. Whatever the pepper variety, Diptera were more abundant than other orders. According to the variety effect, the abundance of Diptera on yellow pepper was higher than on red, with a significant difference (F = 6.59; df = 1; p = 0.01). It was the case for Hymenoptera, with a highly significant difference (F = 16.11; p < 0.0001***). In opposite, Hemiptera were less abundant on yellow pepper than on the red variety, with a highly significant difference (F= 12.49; df = 1; p < 0.0001). The same trend was observed for Lepidoptera, with a highly significant difference between the two varieties (Table 1).

Diversity and variation of abundance at family level

From the present inventory, 28 arthropod families were recorded on pepper. Based on their cumulative abundance, seven families were above 63.72% of the total number of individual while 21 families were occasional on the plant and represented 36.28% of the total fauna. Among these arthropods, Tephritidae and Formicidae were the most abundant families with a relative abundance of 16.53% and 14.87% respectively. According to varieties, the abundance of Tephritidae was higher on yellow than onred pepper. However, the difference between the two abundances was not significant (F = 0.24; df = 1; p = 0.62). It was the case for Formicidae with a significant difference. In opposite, the abundance of Aphididae and Lonchaeidae, lower on yellow pepper than on red, varied significantly with the plant variety (Table 2). For other arthropod families, their abundance varied according to the host plant variety (Table 6).

Variation of abundance at species' level

Among the 47 arthropod species recorded from pepper in the present study, only four insect species were numerically high with cumulative relative abundances of 33.11% while, for the remaining 43 species, the cumulative relative abundance was 66.89%, each contributing with a relative abundance less than 5% (Table 6). The dominant species were *Ceratitis capitata* (17.14%), *Tuta absoluta* (7.26%) and *Latrodectrus* sp (5.57%). According to the crop varieties, the relative abundance of *C. capitata* was higher on yellow pepper (19.32%) than on red pepper (14.17%), with a non-significant difference (F = 0.24; df = 1; p = 0.62). For *T. absoluta* whose relative abundance was lower on yellow pepper (4.73%) than on red pepper (10.73%), the difference was significant (F = 3.52; P = 0.004). For *Latrodectrus* sp., the relative abundance was 6.71% on the yellow pepper while it was 4.05% on the red one; this was significantly different (F = 6.52; df = 1; p = 0.003) (Table 3).

Distribution of the main species throughout the host plant organs

The 47 arthropod species collected on pepper were feeding on various organs of their host plant including leaves, fruits, stems and roots. The most numerous species were preferentially feeding on leaves and fruits. Three of them were only found on fruits (*C. capitata*, *T. absoluta* and *S. capsicarum*); another one *Latrodectus* sp. was exclusively found on leaves. The species *C. capitata* was collected on fruits with a highly relative abundance, 74.72% on yellow pepper and 36.63% on red pepper. However, *T. absoluta* and *S. capsicarum* were highly abundant on red pepper (27.75% and 35.61%, respectively) than on yellow pepper (18.26% and 7.02%, respectively). The species *Latrodectus* sp. was collected only on the leave with highly relative abundance on yellow pepper (69,31%) than on red pepper (30,68%) (Table 4). Significant differences between yellow and red pepper were recorded for the abundance of *C. capitata* (F = 8.16; df = 3; p < 0.0001) and *T. absoluta* (F = 3.51; df = 3; p = 0.02). No significant difference was found for *Latrodectus* sp. (F = 1.79; df = 3; p = 0.15) and *S. capsicarum* (F = 1; df = 3; p = 0.39).

Effect of variety and sensitivity of the pepper varieties to pest

The yellow pepper presented an average of 9 insects per plant, while the red pepper had 8 with respective relative abundances of 54.75% versus 45.25%. On Yellow pepper, the infestation levels were more important with an absolute abundance of 97901 than on the red pepper with an absolute abundance of 80910 (Table 6). Considering the three main insect species that emerged from the fruits, it appeared that *C. capitata* exhibited an absolute abundance of 19223 and a relative abundance of 70.48%. Those of *S. capsicarum* and *T. absoluta* were 3353 and 12.30% then 4699 and 17.22% respectively on the yellow pepper. On this yellow variety, the emergence rate (number of individuals emerging from a fruit) was 4 to 8 for *C. capitata*, 8 to 14 for *S. capsicarum* and 4 to 6 for *T. absultua*. For the red variety, C. *capitata* showed an absolute abundance of 10327 and a relative abundance of 51.23% while the emergence rate per fruit was 3 to 6. For *S. capsicarum,* the absolute abundance was 2004 and the relative abundance was 9.94% with an emergence rate of 6 to10. For *T. absoluta,* the absolute abundance was 7824 and the relative abundance was 38.9%, with an emergence rate of 2-5 (Table 5). Considering that the emergence rate reflects the sensitivity of the crop variety, the pepper sensitivity was different from one variety to another. In the present study, *S. capsicarum* presented a greater number of insects emerging from fruits (8-14) and (6-10) respectively for yellow and red varieties, followed by *C. capitata* (4-8) and (3-6) and finally *T. absoluta* (5-9) and (2-5) respectively. Thus, the yellow pepper was more attacked than the red pepper; therefore, it was more sensitive than the red pepper. The result also shows that *S. capcicarum* is more fertile than the other two insect species (Table 6).

Table 1: Diversity and variation of abundance of different arthropod orders collected on pepper at Nkolmelen.

Order	Variety		Total	F test (GLM proc)
	Yellow	Red		
Arachnida	6664 (6.81)	2950 (3.65)	9614 (5.38)	F = 0.03; p = 0.87 ns
Coleoptera	2755 (2.81)	2270 (2.81)	5025 (2.81)	F = 9.34, p = 0.002**
Diptera	32976 (33.68)	27885 (34.46)	60861 (34.01)	F = 6.59; p = 0.01*
Hemiptera	12448 (12.71)	14757 (18.24)	27205 (15.21)	F = 12.49; p < 0.0001***
Hymenoptera	32544 (33.24)	19001 (23.48)	51545 (28.83)	F = 16.11; p < 0.0001***
Lepidoptera	7388 (7.55)	9585 (11.85)	16973 (9.49)	F = 4.02; p = 0.04*
Othroptera	3126 (3.19)	4462 (5.51)	7588 (4.24)	F = 15.31; p < 0.0001***
Total	97901	80910	178811	

Legend: ns = non-significant; ** = very significant; *** = highly significant; p-value at level of 5%.

Table 2: Diversity and variation of abundance of the main arthropod families collected on pepper at Nkolmelen.

Famillies	Variety		Total	F test (GLM proc)
	Yellow	Red		
Tephritidae	19223 (19.63)	10327 (12.76)	29550 (16.53)	F = 0.24; p = 0.62 ns
Aphididae	3981 (4.06)	5456 (6.74)	9437 (5.28)	F = 11.06; p = 0.00**
Braconidae	11157 (11.39)	3240 (4.00)	14397 (8.05)	F = 0.08; p = 0.77 ns
Formicidae	13559 (13.84)	13024 (16.09)	26583 (14.87)	F = 9.96; p = 0.002**
Gelechiidae	4699 (4.79)	7824 (9.67)	12523 (7.0)	F = 3.52; p = 0.06 ns
Lonchaeidae	1804 (1.84)	10039 (12.40)	11843 (6.62)	F = 6.34; p = 0.01*
Theridiidae	6664 (6.80)	2950 (3.64)	9614 (5.38)	F = 0.02; p = 0.87 ns
Others	36814 (37.60)	28050 (34.67)	64864 (36.28)	
Total	97901	80910	178811	

Legend: ns = non-significant; * = Significant; ** = very Significant; p-value at level of 5%.

Table 3: Diversity and variation of abundance of the main arthropod species collected on pepper at Nkolmelen.

Species	Variety		Total	Ftest (GLMproc)
	Yellow	Red		
***Ceratitis capitata* (Wiedemann, 1924)**	19223 (19.63)	10327 (12.76)	29550 (16.52)	F = 0.24; P = 0.62 ns
***Latrodectrus* sp.**	6664 (6.80)	2950 (3.64)	9614 (5.37)	F = 0.02; P = 0.001 *
***Silba capsicarum* (McAlpine, 1956)**	3353 (3.44)	2004 (2.49)	5357 (2.99)	F = 6.52; P =0.003*
***Tuta absoluta* (Meyrick, 1917)**	4699 (4.80)	7824 (9.67)	12523 (7.03)	F = 3.52; P = 0.004*
Others	63962 (65.33)	57805 (71.44)	121767 (68.09)	
Total	97901 (54.75)	80910 (45.25)	178811	

Legend: ns = non-significant; * = Significant; p-value at level of 5%.

Table 4: Distribution of the main species on the pepper's organs at Nkolmelen.

Species	Varieties				Total	
	Leaves		Fruits			
	Yellow	Red	Yellow	Red	Leaves	Fruits
Ceratitis capitata (Wiedemann, 1824)	0 (0.00)	0 (0.00)	19223 (74.72)	10327 (36.63)	0 (0.00)	29550 (54.80)
Latrodectus sp.	6664 (69.31)	2950 (30,68)	0 (0.00)	0 (0.00)	9614 (100)	0 (0.00)
Silba capsicarum (McAlpine, 1956)	0(0.00)	0(0.00)	1804 (7.02)	10039 (35.61)	0 (0.00)	11843 (21.97)
Tuta absoluta (Meyrick, 1917)	0(0.00)	0 (0.00)	4699 (18.26)	7824 (27.75)	0 (0.00)	12523 (23.23)
Total	6664	2950	25726	28190	9614 (100)	53916 (100)

Table 5: Sensitivity of two pepper varieties (Yellow and Red) and emergence rate of insect pests on their fruits at Nkolmelen.

Species	Varieties				Total	
	Yellow			Red		
	AA	RA	ER	AA	RA	ER
Ceratitis capitata (Wiedemann, 1824)	19223	70.48%	(4-8)	10327	51.23%	(3-6)
Silba capsicarum (McAlpine, 1956)	3353	12.30%	(8-14)	2004	9.94%	(6-10)
Tuta absoluta (Meyrick, 1917)	4699	17.22 %	(4-6)	7824	38.9%	(2-5)
Total	27275	100 %	(5-9)	20155	99.97%	(4-7)

Legend: AA = Absolute abundance; RA = relative Abundance; ER = emergence rate.

Table 6: Diversity of athropodaufauna associated to the pepper at Nkolmelen in the center region of Cameroun.

Arthropodofauna	Variety				Total	
	Yellow		Red			
	AA	RA	AA	RA	AA	RA
Arachnida	**6664**	**6.81%**	**2950**	**3.65%**	**9614**	**5.38%**
Theridiidae	6664	6.81%	2950	3.65%	9614	5.38%
Latrodectus	6664	6.81%	2950	3.65%	9614	5.38%
Latrodectus sp.	6664	6.81%	2950	3.65%	9614	5.38%
Coleoptera	**2755**	**2.81%**	**2270**	**2.81%**	**5025**	**2.81%**
Chrysomelidae	1204	1.23%	1878	2.32%	3082	1.72%
Acalymma	635	0.65%	987	1.22%	1622	0.91%
Acalymma bivitlula (Fabricius, 1775)	635	0.65%	987	1.22%	1622	0.91%
Colaspis	347	0.35%	404	0.50%	751	0.42%
Colaspis sp	347	0.35%	404	0.50%	751	0.42%
Diabrotica	222	0.23%	487	0.60%	709	0.40%
Diabrotica speciosa (Germar, 1824)	222	0.23%	487	0.60%	709	0.40%
Curculionidae	1551	1.58%	392	0.48%	1943	1.09%
Isaniris	658	0.67%	202	0.25%	860	0.48%
Isaniris sp	658	0.67%	202	0.25%	860	0.48%

Otiorhynchus	893	0.91%	190	0.23%	1083	0.61%
Otiorhynchus cribricollis (Gyllenhal, 1834)	893	0.91%	190	0.23%	1083	0.61%
Diptera	**32976**	**33.68%**	**27885**	**34.46%**	**60861**	**34.04%**
Anthomyiidae	1705	1.74%	115	0.14%	1820	1.02%
Adia	1705	1.74%	115	0.14%	1820	1.02%
Adia cinerella (Fallén, 1825)	1705	1.74%	115	0.14%	1820	1.02%
Tephritidae	19223	19.64%	10327	12.76%	29550	16.53%
Ceratitis	19223	19.64%	10327	12.76%	29550	16.53%
Ceratitis capitata (Wiedemann, 1824)	19223	19.64%	10327	12.76%	29550	16.53%
Cicidomyiidae	1549	1.58%	965	1.19%	2514	1.41%
Clinodiplosis	1549	1.58%	965	1.19%	2514	1.41%
Clinodiplosis capsici (Gagne, 2000)	1549	1.58%	965	1.19%	2514	1.41%
Drosophilidae	4810	4.91%	3276	4.05%	8086	4.52%
Drosophila	4810	4.91%	3276	4.05%	8086	4.52%
Drosophila melanogaster (Meigen, 1830)	4810	4.91%	3276	4.05%	8086	4.52%
Lonchaeidae	1804	1.84%	10039	12.41%	11843	6.62%
Lonchaea	1804	1.84%	10039	12.41%	11843	6.62%
Silba capsicarum (McAlpine,1956)	1804	1.84%	10039	12.41%	11843	6.62%
Mucidae	3885	3.97%	3163	3.91%	7048	3.94%
Musca	3885	3.97%	3163	3.91%	7048	3.94%
Musca domestica (Linnaeus, 1758)	3885	3.97%	3163	3.91%	7048	3.94%
Hemiptera	**12448**	**12.71%**	**14757**	**18.24%**	**27205**	**15.21%**
Lygaeidae	1129	1.15%	1411	1.74%	2540	1.42%
Lygaeus	1129	1.15%	1411	1.74%	2540	1.42%
Lygaeus equestris (Linnaeus, 1758)	1129	1.15%	1411	1.74%	2540	1.42%
Aleyrodidae	846	0.86%	1291	1.60%	2137	1.20%
Aleurotrachelus	846	0.86%	1291	1.60%	2137	1.20%
Aleurotrachelus trachoides (Back, 1912)	846	0.86%	1291	1.60%	2137	1.20%
Aphididae	3981	4.07%	5456	6.74%	9437	5.28%
Aphis	550	0.56%	862	1.07%	1412	0.79%
Aphis gossypii (Glover, 1877)	550	0.56%	862	1.07%	1412	0.79%
Macrosiphum	1342	1.37%	1701	2.10%	3043	1.70%
Macrosiphum euphorbiae (Thomas, 1878)	1342	1.37%	1701	2.10%	3043	1.70%
Mysus	2089	2.13%	2893	3.58%	4982	2.79%
Mysus persicae (Sulzer, 1776)	2089	2.13%	2893	3.58%	4982	2.79%
Coreidae	1040	1.06%	1399	1.73%	2439	1.36%
Phthia	1040	1.06%	1399	1.73%	2439	1.36%
Phthia pictra (Drury, 1773)	1040	1.06%	1399	1.73%	2439	1.36%
Miridae	1149	1.17%	904	1.12%	2053	1.15%
Lygus	1149	1.17%	904	1.12%	2053	1.15%
Lygus pratensis (linnaeus, 1758)	192	0.20%	267	0.33%	459	0.26%
Lygus rugulipennis (Poppius, 1911)	957	0.98%	637	0.79%	1594	0.89%
Pentatomidae	2200	2.25%	1564	1.93%	3764	2.11%
Halyomorpha	213	0.22%	571	0.71%	784	0.44%
Halyomorpha halys (Stal, 1855)	213	0.22%	571	0.71%	784	0.44%
Palomena	1987	2.03%	993	1.23%	2980	1.67%
Palomena prasina (Linnaeus, 1761)	1987	2.03%	993	1.23%	2980	1.67%
Pseudococcidae	1035	1.06%	1994	2.46%	3029	1.69%

Pseudococcus	1035	1.06%	1994	2.46%	3029	1.69%
Pseudococcus sp	1035	1.06%	1994	2.46%	3029	1.69%
Pyrrhocoridae	1068	1.09%	738	0.91%	1806	1.01%
Dysdercus	1068	1.09%	738	0.91%	1806	1.01%
Dysdercus sp	1068	1.09%	738	0.91%	1806	1.01%
Hymenoptera	**32544**	**33.24%**	**19001**	**23.48%**	**51545**	**28.83%**
Braconidae	11157	11.40%	3240	4.00%	14397	8.05%
Diachasmimorpha	3070	3.14%	920	1.14%	3990	2.23%
Diachasmimorpha longicaudata (Ashmead, 1905)	3070	3.14%	920	1.14%	3990	2.23%
Diachasmimorpha	4217	4.31%	1215	1.50%	5432	3.04%
Diachasmimorpha tryoni (Viereck, 1913)	4217	4.31%	1215	1.50%	5432	3.04%
Fopius	3870	3.95%	1105	1.37%	4975	2.78%
Fopius arisanus (Sona, 1932)	3870	3.95%	1105	1.37%	4975	2.78%
Eulophidae	4240	4.33%	790	0.98%	5030	2.81%
Tetrastichus	4240	4.33%	790	0.98%	5030	2.81%
Tetrastichus giffardianus (Sivestri, 1915)	4240	4.33%	790	0.98%	5030	2.81%
Figitidae	1412	1.44%	636	0.79%	2048	1.15%
Aganaspis	1412	1.44%	636	0.79%	2048	1.15%
Aganaspis daci (Weld, 1951)	1412	1.44%	636	0.79%	2048	1.15%
Formicidae	13559	13.85%	13024	16.10%	26583	14.87%
Camponotus	4693	4.79%	3795	4.69%	8488	4.75%
Camponotus floridanus (Buckley, 1866)	2392	2.44%	2355	2.91%	4747	2.65%
Camponotus acvapimensis	2301	2.35%	1440	1.78%	3741	2.09%
Cphalotes	1019	1.04%	1142	1.41%	2161	1.21%
Cphalotes sp.	1019	1.04%	1142	1.41%	2161	1.21%
Crematogaster	2195	2.24%	1677	2.07%	3872	2.17%
Crematogaster sp.	2195	2.24%	1677	2.07%	3872	2.17%
Myrmicaria	3447	3.52%	2048	2.53%	5495	3.07%
Myrmicaria opaciventris (Emery, 1893)	3447	3.52%	2048	2.53%	5495	3.07%
Solenopsis	1760	1.80%	4012	4.96%	5772	3.23%
Solenopsis sp	1760	1.80%	4012	4.96%	5772	3.23%
Tetramorium	445	0.45%	350	0.43%	795	0.44%
Tetramorium sp	445	0.45%	350	0.43%	795	0.44%
Pteromalidae	2176	2.22%	1311	1.62%	3487	1.95%
Pachycrepoideus	1043	1.07%	627	0.77%	1670	0.93%
Pachycrepoideus vindemmiae (Rondani, 1875)	1043	1.07%	627	0.77%	1670	0.93%
Spalangia	1133	1.16%	684	0.85%	1817	1.02%
Spalangia cameroni (Perkins, 1910)	1133	1.16%	684	0.85%	1817	1.02%
Lepidoptera	**7388**	**7.55%**	**9585**	**11.85%**	**16973**	**9.49%**
Crambidae	182	0.19%	512	0.63%	694	0.39%
Ostrinia	182	0.19%	512	0.63%	694	0.39%
Ostrinia nubilalis (Hubner, 1796)	182	0.19%	512	0.63%	694	0.39%
Gelechiidae	4699	4.80%	7824	9.67%	12523	7.00%
Tuta	4699	4.80%	7824	9.67%	12523	7.00%
Tuta absoluta (Meyrick, 1917)	4699	4.80%	7824	9.67%	12523	7.00%
Pyralidae	2507	2.56%	1249	1.54%	3756	2.10%
Chilo	1723	1.76%	1095	1.35%	2818	1.58%

Chilo zacconius (Bleszynski, 1970)	1723	1.76%	1095	1.35%	2818	1.58%
Eldana	784	0.80%	154	0.19%	938	0.52%
Eldana saccharina (Walker, 1865)	784	0.80%	154	0.19%	938	0.52%
Orthoptera	**3126**	**3.19%**	**4462**	**5.51%**	**7588**	**4.24%**
Acrididae	2284	2.33%	3376	4.17%	5660	3.17%
Diabolocatantops	834	0.85%	1847	2.28%	2681	1.50%
Diabolocatantops axillaris (Thunberg, 1815)	834	0.85%	1847	2.28%	2681	1.50%
Acrotylus	303	0.31%	334	0.41%	637	0.36%
Acrotylus sp	303	0.31%	334	0.41%	637	0.36%
Aiolopus	167	0.17%	269	0.33%	436	0.24%
Aiolopus thalassinus (Fabricus, 1781)	167	0.17%	269	0.33%	436	0.24%
Locusta	980	1.00%	926	1.14%	1906	1.07%
Locusta migratoria (Linnaeus, 1758)	980	1.00%	926	1.14%	1906	1.07%
Gryllidae	624	0.64%	579	0.72%	1203	0.67%
Oecanthus	624	0.64%	579	0.72%	1203	0.67%
Oecanthus sp	624	0.64%	579	0.72%	1203	0.67%
Pyrgomorphidae	218	0.22%	507	0.63%	725	0.41%
Zonocerus	218	0.22%	507	0.63%	725	0.41%
Zonocerus variegatus (Linnaeus, 1758)	218	0.22%	507	0.63%	725	0.41%
Total	97901	100.00%	80910	100.00%	178811	100.00%

AA: Absolute abundance; RA: Relative abundance.

DISCUSSION

The present study was focused on the characterization of the arthropod fauna associated with pepper. Results showed that insect fauna and other arthropods in the Nkolmelen outskirt was rich and diverse. Arthropodofauna on pepper was composed of 7 orders, 28 families and 47 species.

The seven orders of arthropods recorded in this study were higher than those recorded by Heumou et al. (2015) who identified two orders, those recorded by Elono-Azang et al. (2016) who identified three orders, and those recorded by Mokam et al. (2014) who identified five orders, all working in the same agro-ecological zone. The present results also differ from that of Akesse et al. (2015) who recorded, on the same plant species in Ivory Coast, five orders. The disparities observed with the former studies could be due to the sampling conditions, the period and the duration. This could also be explained by the climate changes inducing some biological invasions which are now considered as a major component of global climate change. Then, insects, in order to face a new environment, could change their diet and move from specialist eater to generalist eater. Indeed, a stable environment allows an insect to remain in its original habitat and conserve its diet while any disturbance leading to some changes in flora composition would lead insects to try some other diet (Thompson, 1998).

At the family level, our results were very diverse and different from those of Elono-Azang et al. (2015) who recorded 12 families, Akesse et al. (2015) who recorded four families on pepper and Heumou et al. (2015) who recorded five families from incubations of pepper fruits in Cameroon. Unlikely, Aléné et al. (2019a), working on five species of vegetable plant including *Capsicum annuum,* recorded five families of Hemiptera which was interacting with three sub-families of ants. The higher fauna diversity of the present study, in comparison with those of the afore-mentioned studies, was probably due to the fact that arthropod inventory in our study was done on the whole plant whereas in the prior studies it was focused on fruits. Likewise, due to the development of agriculture and the exploitation of agricultural products on a large scale, the number of insect taxa colonizing plants is increasing (Guillemaud et al., 2011).

The species richness in the present study was higher than that obtained by Akesse et al. (2015) in Ivory Coast (4 species) and that of Djemel (2005) in Benin (5 species), Heumou et al. (2015) and Elono-Azang et al. (2015) in Cameroon (8 and 15 species respectively). The study conducted in Cameroon by Heumou et al. (2015) recorded a species richness and fauna composition on *C. annuum* very close to those recorded in the present study. This may be explained by the very similar environmental conditions between the study sites. Indeed, all these studies mentioned from Cameroon were carried out in the same agro-ecological zone. The high presence of these pests in a locality is maintained by the intensification of agricultural activities and by the subsisting wild vegetation which would serves as reservoir or refuge for insects. Indeed, as a given plant influences the presence of a pest in an environment, then some species or varieties of cultivated plant would attract given pest species (Voula et al., 2018). In this way, Chougourou et al. (2012) showed that the insect fauna was influenced by the nature of the plant variety cultivated in an area.

In the present study the species diversity was important when compared to the one observed by Akesse et al. (2015) who recorded two species (*Ceratitis capitata* and *Agrotis ipsilon*) and Yarou et al. (2015) who recorded 5 species of arthropods (*Aphis gossypii*, *Frankliniella schultzei*, *Bemisia tabac*, *Tetranychus* spp. and *Polyphagotarsonemus latus*) on green pepper. Many of them are known for their impact on many crops in the world's tropical areas (James et al., 2010). The three species, *Ceratitis capitata*, *Silba capsicarum* and *Tuta absoluta* which were the most abundant species in the studied plant are known to especially attack pepper fruits and cause significant damage (Mostefaoui et al., 2020). Furthermore, *C. capitata* is commonly recorded from a wide range of Solanaceae fruits pests (Elono-Azang et al., 2016; Heumou et al, 2015). Although *Macrosiphum euphorbiae*, and *Aphis gossypii* was among the least abundant species in our results, they could also cause significant damage to peppers as they are phloem eater and would deprive the plant with its sap and transmit pathogens by saliva, leading to the development of some plant pathologies. This has been observed by Voula et al. (2018) on cocoa.

The presence of ants like *Spalangia cameroni* and some hemipterans such as *Aphis gossypii* and *Pseudococcus* sp. suggested the existence of a mutualistic relationship between the two groups. The hemipterans provided the honeydew as food to the ants and in turn the ants supplied protection to the former (Aléné et al., 2019b). The presence of *Latrodectrus* sp. suggested the existence of predation relationships with hemipterans, thus protecting the plant from their attack. As the ants protected hemipterans, this predation was minimized so that hemipterans cold proliferate and reach high populations sizes on the studied pepper plants (Aléné et al., 2019b).

Moreover, looking at the effect of the varieties, it appeared that the yellow pepper was more attractive and could be more sensitive than the red pepper. In fact, the yellow color is known to be attractive for insects, explaining why some insect traps are yellow (Pinto-Zevallos and Vänninen, 2013). Leaves, fruits, twig or branches and roots were the main part of the host plant where many insect species were collected. *C. capitata*, *S. capsicarum* and *T. absoluta* were collected on the fruits while *Latrodectus* sp. was found on the leaves. Some groups such as Orthoptera appeared were found on the leaves and roots. Orthopterans were mainly found in the soil, at the root level, because they were resistant to the aridity in certain parts of their environment, but they remained very dependent of climatic and trophic factors (Chougourou, 2012; Voula et al., 2018). These Orthoptera caused considerable damage and deserve to be studied (Voula et al., 2018).

The present study revealed that the fauna identified comprised harmful pest species which would cause severe damage to peppers, thus affecting negatively the efforts of producers who, in the targeted region, are yet living in extreme poverty. This implies that integrated control measures should be taken into account in order to support the producers' endeavors and maintain a satisfactory level of production.

Conclusion

Definitely, the present study revealed that the studied varieties of peppers were under heavy pressure due to insects found on all parts of the plant (fruit, leaves and roots). It also showed that yellow pepper was slightly more attractive and sensitive than the red one, with a relative abundance of 57.71% of arthropods on yellow pepper *vs.* 42.29% on red pepper. The insects collected belonged to 7 orders of which the most occurring and damaging was Diptera, mainly the family Thephritidae which attack preferentially fruits. Some species of Hymenoptera, behaving as parasitoids and some arachnids behaving as predators are potentially beneficial for the host plant. They constitute a possible way to avoid chemicals currently systematically used by the producers. Nevertheless, the implementation of their use needs more other biological studies. This preliminary inventory is a basic document to support conception of integrated pest management strategies and decision-making for agricultural policies which take into account human health and environmental considerations.

COMPETING INTERESTS

The authors do not have any competing interests to declare.

AUTHORS' CONTRIBUTIONS

DCA and CDL conceived the project and the methodology, AVV collected data helped by EAM and FME; ZT perform statistical analyses. AVV wrote the manuscript and all the co-authors read and revised the manuscript.

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