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ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ISSN: 0976-3376

Asian Journal of Science and Technology
Vol. 14, Issue, 03, pp. 12423-12431, March, 2023

REVIEW ARTICLE

BIOLOGICAL DIVERSITY OF DIFFERENT FUNCTIONAL GROUPS AND IMPACT OF PARASITOIDS ON PEPPER FRUITS PESTS (*Capsicum annum*) IN THE LOCALITY OF YAOUNDÉ

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ARTICLE INFO

Article History:
Received 02nd January, 2023
Received in revised form
14th January, 2023
Accepted 20th February, 2023
Published online 27th March, 2023

Keywords:
Parasitoids, Pests, Pepper, Ceratitis capitata, Silbacapsicarum, Biological control.

ABSTRACT

Pepper is amongst the most consumed vegetable fruits in Cameroon. Its production remains seasonal. In order to increase plant yield. A study was lunched between March 2020 and December 2021 with the aim of contributing to the knowledge of insect fauna infesting pepper fruits and suggest biological control methods using parasitoids. A weekly inventory was made. Fruits stung by insects were collected and taken to the laboratory. Apest that emerged was conserved in alcohol at 70°Cand was exposed to parasitoids used here as biological control agents. 7 species were identified as pests associated to 7 species of parasitoids. *Ceratitis capitata*, *Silba capsicarum* and *Tuta absoluta* were the most abundant. These pests led to important losses in plant yield by 33 %, 27 % and 40 % respectively. four functional groups were identified which included: stinging/sucking, parasitoids, phyllophagous and licking/sucking. Amongst parasitoids, 4 species were more aggressive towards insect pests. This was the case of *Diachasmimorpha tryoni* whose parasitoidisme rate was 21.27%, *Diachasmimorpha longicaudata* 15.78%, *Fopiusarisanus* 19.43% and *Tetrastichus giffardianus*17.77%. Parasitoids led to a global improvement on plant yield of 14.48 % and thus, play an important role in the biological control of pests on pepper.

Citation: ***Voula Valteri Audrey, Aléné Désirée Chantal, Tadu Zephirin, Ngartoubam Laurence, Zang Affa'a Glwadys, Manga Essouma François, Zing Zing Bertrand and Djiéto-Lordon Champlain.* 2023.** "Biological diversity of different functional groups and impact of parasitoids on pepper fruits pests (*Capsicum Annum*) in the locality of yaoundé", *Asian Journal of Science and Technology*, 14, (03), xxxx-xxxx.

INTRODUCTION

The production of quality pepper, safe for human consumption with very low impact on the environment has become a major concern on the side of the farmers as well as the government whose role is to assure food security for the populations (Westphal *et al*., 1981; Kegne and De Jong, 2002). Just like tomato, this vegetable fruit is among the most important vegetables (Akesse et *al*., 2015) and the most consumed in the world as a whole and in Africa in particular by Cameroonians (Heumou *et al*., 2015). Statistics show that a Cameroonian no matter his age or sex consumes an average of 2kg of pepper per year (Odeyé and Bricas, 1985; Shankara, 2005). In Cameroon, pepper serves as a spice in different dishes like beef skewers, egusipuding, eru, fish ndomba, viper ndomba and many others (Tano *et al*., 2008; Kouassi, 2012, Voula et *al*., 2020). This high consumption of pepper has led to the intensification of its cultivation by increasing the cultivated areas both in urban and peri-urban areas so as to satisfy the demand that increases every day (Heumou *et al*., 2015). However, the intensification of this culture has led to its adaptation to different agro-ecological zones in the country and consequently to a diversification of insect pests which cause so much harm to pepper fruits on farm (Novotny and Basset, 2005, Heumou *et al*., 2015).

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These pests decrease the quality and quantity of pepper fruits. Stung pepper fruits decay in a few days and can neither be used by the farmers nor by the consumers. This leads to a decrease in their trade value, decreased plant yield and thus, loss in the farmer's revenue (Fondio *et al*., 2015). In effect, pepper is attacked by a number of pests which may be insects, birds, reptiles (snakes) and other small Mammals. The most detrimental are insects that sting the fruits (Ndoumbè-Nkeng *et al*., 2002). The later lead to high losses in plant yield that sometimes may reach a 100 % in the absence of appropriate phytosanitary treatments (Voula *et al*., 2018). Djiéto-Lordon and Aléné (2002, 2006) and Heumou *et al.* (2015) in their inventory works showed that tomato (*Lycopersicon esculentum* Mill. (1754)) and pepper (*Capsicum annuum* L. (1753)) are planting whose fruits and other organs are commonly attacked in natural milieu. These attacks are of two orders that is abiotic, induced either by global climatic change, or as a result of non-mastering of modern technics for the production of these crops by rural populations since most of them are sometimes uneducated (Akesse *et al*., 2015). On the other hand, they may also be biotic factors which seem more dangerous and cause important damages to the plant by reducing at the same time the yield and the efforts of the farmers (Ngando *et al*., 2022). However, despite the efforts made by the farmers, the production of pepper in terms of quality and quantity remains low, seasonal and very limited in time and space. Before such an alarming situation, farmers will resort to chemical control which is certainly efficient but whose active material cost a lot for the medium-sized farmer whose cultivated area rarely reaches a hectare (100 to 2000 m^2) Ngando *et* *al.* (2022). These chemical products pre sent dangers in terms of nature pollution, food poisoning for humans and animals due to accumulation of pesticide residues in water, soils and food stuffs. The massive, abusive and repeated use of these chemical products on cultivated plants bring about insect resistance to these insecticide molecules (E. Jones, 2008). The concept of « ONE HEALTH » which is our leitmotiv was brought forth with the will of suggesting solutions to this phenomenon of global pollution of the biosphere. For this purpose, many studies have been lunched since a few decades on the research of palliative methods or alternatives to chemical control. Among which; natural control by the use of aqueous, alcoholic and methanoic plant extracts (Ngando *et al.*, 2022). And by biological control using extracts and other suspensions of spores of entomo-pathogenic fungi (Mahot *et al.*, 2020, 2021, 2022). The use of these extracts presents some drawbacks since it is conditioned by the climate. The treatments are generally washed away by rain. Therefore, the use of living organisms such as predators and parasitoids are strongly encouraged in the biological control of crop pests (Nanga *et al.*, 2022). In effect, parasitoids and predators offer an excellent efficiency often close to 100% in controlled or uncontrolled milieu. Parasitoids also have the advantage of remaining in the area where they were introduced for several months. It is therefore not necessary to intervene regularly at precised dates. The later are non-polluting for the environment and present no danger for human health. In addition, inventory works on plant fauna were lunched by many researchers (Djiéto-Lordon and Aléné, 2002, 2006; Djiéto-Lordon *et al.*, 2014; Mokam *et al.*, 2014a) so as to study the behavior of insects vis-à-vis their food source which are fruits for some and leaves for others to better control them (Tindo and Tamo, 1999; Okolle and Tonifor, 2005). It is in this light that the present study was initiated with the aim of carrying out an inventory of fauna infesting red and yellow pepper fruits in the locality of Nkolmelen and evaluate the impact of parasitoids on pepper fruit pests consequently minimizing the use of chemical pesticides and their damages to human health and the environment.

MATERIALS AND METHODS

Study site: This study was carried out at Nkolmelen, suburb located towards the south-east entrance to Yaoundé. A farm was cultivated on an experimental plot (11º 08' East, 3º 22' north). This was a fallow that had undergone intense human activities. The plant cover was dominated by *Tithonia diversifolia* (Hemsl.) A. Gray, 1883 and *Imperata cylindrica* (L.) P. Beauv, 1812, two very invasive plants. This vegetation is characteristic of human disturbance derived from a forest landscape. The relief of Nkolmelen is orogenic and is composed of a junction of small hills of mean altitudes and valleys which confers it an aspect of a basin, characteristic of the town of Yaoundé. It consists of small streams that are tributaries of Mefou river and some shallows where market gardeners are practiced and other revenue-generating activities. The climate of Nkolmelen is of transitional subequatorial type, with characteristics specific to the town of Yaoundé (Suchel, 1988). Rainfall comprises between 1500 mm and 2500 mm and we note the existence of four seasons of unequal length: a short dry season (June to mid-August), a long rainy season (mid-August to mid-November), a long dry season (mid-November to mid-March) and a short rainy season (mid-March to mid-June). Wind speed varies averagely between 10 and 20 km/h. Mean annual hygrometry is 80% and varies between 35 % and 98 % during the day. Frequent winds are humid and blow in the South-West direction (Wéthé, 2001; Suchel (1987).

Biological material: This material was composed of red pepper plants and yellow pepper plants, collected pepper fruits and insects.

Experimental set-up: The experimental farm was made up of two plots each with one type of pepper. Each plot had four planks. Each plank was 12 m long and 0.8 m wide and had 12 pepper plants meaning 48 pepper plants for each type giving a total of 96 pepper plants for the whole farm. The distance between the planks was 1 m and the distance between the planks and the forest was 2 m to minimize the border effect. The two plots were separated by a distance of 4 m which gives a total area of 326.4 m^2.

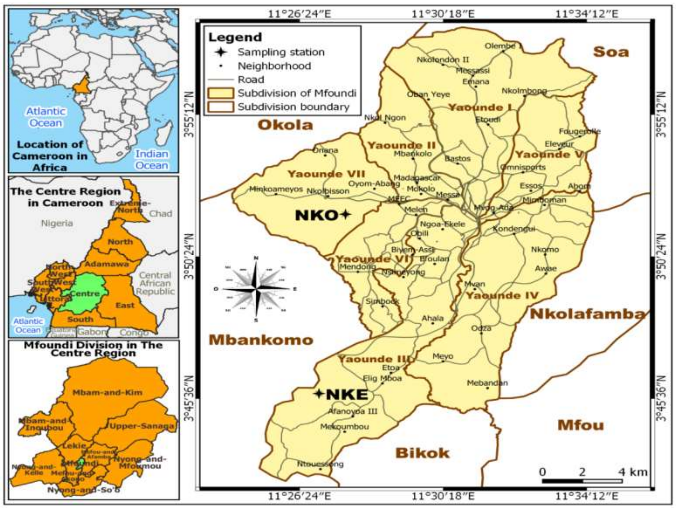

Fig. 1. Graphical representation of the study site of Nkolmelen (NKE)

METHODS

Inventory of fruit fauna: This inventory of pepper fruit fauna consisted of observing the plants very early in the morning and late in the afternoon when insects are less active. Stung pepper fruits or fruits with lesions were collected and placed in disinfected plastic bags and taken to the laboratory of entomology of the Institute of Agricultural Research for Development of Nkolbisson. Decaying and fallen fruits were also collected. Once in the laboratory, these fruits were washed with distilled water, weighed with a RADWAG balance, then placed in specific breeding boxes on which the date and place of sampling were mentioned. Insects that emerged were captured and conserved in pill boxes containing alcohol at 70 ^{o}C. To ease insect capture and prevent them from escaping, the boxes were introduced in cold china for 5 to 10 minutes for them to fall asleep. Thus, with the help of soft entomological forceps, insects were extracted from the boxes. These insects were therefore placed into functional or trophic groups following their activity while identifying the different orders and families to which they belong. Concerning parasitoid inventory, mummified insect larvae and sometimes decaying fruits were collected and introduced in petri dishes containing blotting paper to absorb any pouring liquid. These petri dishes were placed on the bench top at room temperature. At the end of 15 days maximum, the emergences were observed. Parasitoids so obtained were collected and conserved in tubes containing alcohol.

Figure 2. Insects conserved in pill boxes containing alcohol at 70^{o}C for later identification

Pest impact on yield loss: To estimate yield loss caused by insect pests on farm, an inventory of the number of fruits produced per plant was made. Then, denatured and healthy fruits were counted. The percentage of withered fruits was determined and lead to the evaluation of yield loss following this formula:

$$\text{Yield loss} = (\text{Fr S} - \frac{FrM}{NFrT})*100$$

Where: Fr S: Number of healthy fruits; Fr M: Number of withered fruits et NFrT: total number of fruits collected.

Yield improvement by parasitoids: Parasitoids obtained after isolation of mummies were in turn breed. They were introduced in rectangular cages of Plexiglas of 20 cm*15 cm with an opening covered very fine mesh canvas supported by a string. At the bottom, there were small plastic cups of 2 to 5 mm containing a juice composed of honey and water giving the taste of nectar and other plant juices. Beside these cups was a piece of cotton imbibed with water to cool down the temperature in the cage. The nectar served as food for parasitoids and insect pests. Each cage enclosed one precise species. After obtaining a good population density, five parasitoids were introduced in the cages containing ten insect pest larvae following the species in order to evaluate their capacity to interact with pest larvae and determine their efficiency in pest control and yield improvement.

Data analysis: Specimen identification was made in the laboratory of central Entomology of Nkolbisson with the help of available dichotomous keys. From absolute abundances, the relative abundances of different species, orders and families were calculated as well as parasitoidism rate and yield improvement. The test of Turkey allowed to determine the degree of significance of certain parameters at a threshold of 5 %.

RESULTS

Abundance of different Orders infesting fruits of *Capsicum annuum:* Insects which invade red pepper and yellow pepper fruits showed important variations from one taxonomic level to another. Thus, at the level of the order, three orders appeared: Order Diptera, Hymenoptera and Lepidoptera (Figure 3). Diptera were the most abundant in general (60861), followed by Hymenoptera (24962) and finally Lepidoptera (13217) (fig. 3). Yellow pepper fruits were mostly colonized by Diptera, followed by Hymenoptera while red pepper fruits were on the contrary mostly colonized by Lepidoptera. Perhaps, a significant difference was noted between red and yellow pepper concerning attacks by Diptera and Hymenoptera. However, no significant difference appeared between red and yellow pepper relative to Lepidoptera attacks. Yellow pepper attracted more insects than red pepper.

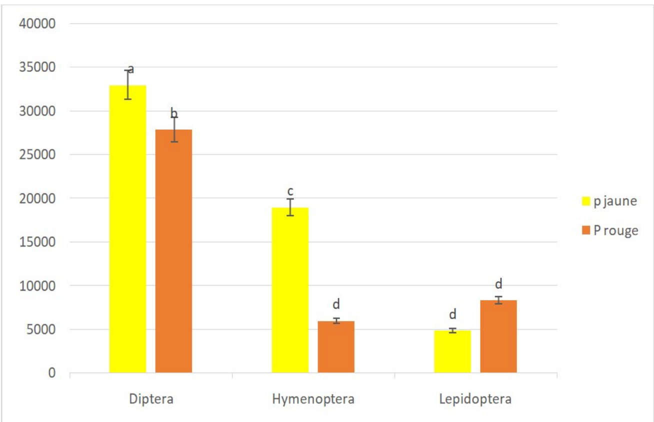

Figure 3. Abundance of different orders of insects that colonize yellow and red pepper fruits in the Nkolmelen zone

The comparison between yellow pepper and red pepper shows that yellow pepper assembled more insects than red pepper. Thus, the order Diptera was the most important with an absolute abundance of 32 976 for yellow pepper against 27 885 for red pepper. This order was more recurrent for yellow pepper 32976 (33.29) than for red pepper 27885 (28.15) (Table 1). This Order was numerically more important in the population in general followed by the Order Hymenoptera which was also more recurrent for yellow pepper 18 985 (19.16) than for red pepper 5 977(6.03). And finally, the Order Lepidoptera which was the least abundant (Table 1). The latter on the contrary showed a situation different from the first two since the insects identified in this order were more abundant on red pepper with a high recurrence of 8336(8.42) than on yellow pepper whose recurrence was strongly decreased to 4881(4.92) Tableau 1. The inferential test applied to these orders colonizing pepper fruits otherwise showed great significant differences between red pepper and yellow pepper ($P=0.000^{***}$) concerning the order Lepidoptera whose larval forms destroy both pepper leaves and fruit tegument (Table 1). Very significant differences were observed for the order Hymenoptera that is ($P=0.0004^{**}$), and finally, significant differences were observed between yellow pepper and red pepper for the order Diptera ($P=0.0011^{*}$). At family level, 12 families were listed. These included Anthomyiidae, Tephritidae Braconidae, Cicidomyiidae, Crambidae, Drosophilidae, Eulophidae, Figitidae, Gelechiidae, Lonchaeida, Mucidae and Pteromalidae (Table 2). The most abundant families were Tephritidae (19223) for yellow pepper as well as for red pepper (10327), followed by Braconidae whose values also varied between yellow pepper (11157) and red pepper (3240). The least represented families were Figitidae and Crambidae. Comparison between the two pepper varieties showed that Figitidae had more success (1412) for yellow pepper against 636 for red pepper. Crambidae however, presented a result contradictory to that of Figitidae that is less abundant for yellow pepper (182) and more abundant for red pepper (512). In addition, the inferential comparison between yellow pepper and red pepper showed greatly significant differences for the families of Braconidae (F=0.081; P=0.000***), Eulophidae (F=0.081; P=0.000***) and Lonchaeidae (F=6.342; P= 0.013 ***). Very significant differences for the families of Anthomyiidae (F=0.042; P=0.008**), Tephritidae (F=0.2454; P= 0.021**), Crambidae (F=7.456; P= 0.007 **) and Drosophilidae (F=7.61; 0P=.0069 **). Significant differences for the families of Gelechiidae (F=3.520; P= 0.064*). Others were non-significant and included the families Cicidomyiidae, Figitidae, Mucidae et des Pteromalidae (Tableau 2).

At species level, a strong parasitic pressure is observed giving a total of 14 species which colonize pepper fruits independently of the variety at Nkolmelen. (Table 3). The most abundantwas *Ceratitis capitata* whose abundances varied clearly between yellow pepper (19223) and red pepper (10327). This species is more present on yellow pepper than on red pepper. Followed by the species *Silba capsicarum* which is instead more present on red pepper than on yellow pepper. This abundance greatly varied between red pepper (11004) and yellow pepper (3353). However, the least abundant species was *Ostrini anubilalis* with 182 individuals for yellow pepper against 512 individuals for red pepper. It showed a higher abundance for red pepper than for yellow pepper. This species is directly followed by the species *Pachycrepoideus vindemmiae* which counted 1043 individuals on yellow pepper against 627 individuals on red pepper. This species was thus more abundant on yellow pepper than on red pepper. The comparison between yellow pepper and red pepper gave four groups of insects which were: species whose presence was very greatly significant such as *Adia cinerella* (F=0.0417; P= 0.000 ***), *Ceratitis capitata* (F=0.2454; P= 0.000 ***) and *Silba capsicarum* (F=6.3428; P=0.0005 ***). Species whose presence was very significant such as *Diachasmimorpha longicaudata* and *Diachasmimorpha tryoni* respectively (F=0.822; P=0.006** et F=0.0766; P=0.026**), *Drosophila melanogaster* (F=7.6107; F=0.006974 **), *Ostrinia nubilalis* (F=7.456; P=0.00755 **), *Tetrastichus giffardianus* (F=3.3057; F=0.00222 **) and lastly *Tuta absoluta* (F=3.5203; P=0.0037 **). A species whose presence was significant: this was *Spalangi acameroni* (F=1.3626; P=0.046*) and lastly, species whose presence was non-significant but not negligible. These included *Fopius arisanus, Musca domestica and Pachycrepoideus vindemmiae* (F=0.0036; P=0.9521 NS, F=0.6418; P=0.4251 NS et F=1.1559; P=0.0851 NS) respectively.

Table 1. Abundance of different orders found on yellow pepper and red pepper fruits in the locality of Nkolmelen

Ordres	Yellow Pepper		Red Pepper		Yellow Pepper	Red Pepper	F test
	AA	AR (%)	AA	AR (%)	Occurrences	Occurrences	
Diptera	32976	58.01	27885	66.08	32976 (33.29)	27885 (28.15)	F=6.592 ; P=0.011 *
Hymenoptera	18985	33.40	5977	14.16	18985 (19.16)	5977(6.03)	F=8.3456 ; P=0.004 **
Lepidoptera	4881	8.59	8336	19.75	4881 (4.92)	8336 (8.42)	F=11.898 ; P=0.000 ***
Total	56842	100	42198	100	99040		

Legend (AA: Absolute Abundance; RA: Relative Abundance in %; F-test: Tukey Test at 5% threshold)

Table 2. Determination of different families subservient to yellow and red pepper fruitsin the Nkolmelen locality

Family	Yellow	Fr(%)	Red	Fr(%)	F test
Anthomyiidae	1705	2.99	115	0.30	F=0.042 ; P=0.008**
Tephritidae	19223	33.81	10327	24.47	F=0.2454 ; P= 0.021**
Braconidae	11157	19.62	3240	7.68	F=0.081 ; P=0.000***
Cicidomyiidae	1549	2.72	965	2.29	F=0.185 ; P=0.667 NS
Crambidae	182	0.32	512	1.21	F=7.456 ;P= 0.007 **
Drosophilidae	4810	8.46	3276	7.76	F=7.61 ;0P=.0069 **
Eulophidae	4240	7.45	790	1.87	F=3.305 ; P=0.000 ***
Figitidae	1412	2.48	636	1.51	F=0.033 ; P=0.855 NS
Gelechiidae	4699	8.27	7824	18.54	F=3.520 ; P= 0.064*
Lonchaeida	1804	3.17	10039	23.79	F=6.342 ; P= 0.013 ***
Mucidae	3885	6.83	3163	7.49	F=0.6418 ; P= 0.4251 NS
Pteromalidae	2176	3.83	1311	3.11	F=0.6482 ; P= 0.4228 NS
Total	56842	100	42198	100	

Legend (Fr=Frequency; F-test = Tukey Test at 5% threshold)

Table 3. Distribution of different families of insects which colonizepepper fruits at Nkolmelen

Species	Yellow		Red		F test
	AA	AR	AA	AR	
Adia cinerella (Fallén, 1825)	1705	2,99	115	0,27	F=0.0417 ; P= 0.000 ***
Aganaspis daci (Weld, 1951)	1412	2,48	636	1,47	F=0.0334 ; P=0.8554
Ceratitis capitata (Wiedemann, 1824)	19223	33,81	10327	23,90	F=0.2454 ; P= 0.000 ***
Diachasmimorpha longicaudata (Ashmead, 1905)	3070	5,40	920	2,13	F=0.822 ; P=0.006**
Diachasmimorpha tryoni (Viereck, 1913)	4217	7,42	1215	2,81	F=0.0766 ; P=0.026**
Drosophila melanogaster (Meigen, 1830)	4810	8,46	3276	7,58	F=7.6107 ; F=0.006974 **
Fopius arisanus (Sona, 1932)	3870	6,80	2105	4,87	F=0.0036 ; P=0.9521 NS
Musca domestica (Linnaeus, 1758	3885	6,83	3163	7,32	F=0.6418 ; P=0.4251 NS
Ostrinia nubilalis (Hubner, 1796)	182	0,32	512	1,18	F=7.456 ; P=0.00755 **
Pachycrepoideus vindemmiae (Rondani, 1875)	1043	1,83	627	1,45	F=1.1559 ; P=0.0851 NS
Silba capsicarum (McAlpine,1956)	3353	5,89	11004	25,47	F=6.3428 ; P=0.0005 ***
Spalangia cameroni (Perkins, 1910)	1133	1,99	684	1,58	F=1.3626 ; P=0.046*
Tetrastichus giffardianus (Sivestri, 1915)	4240	7,45	790	1,82	F=3.3057 ; F=0.00222 **
Tuta absoluta (Meyrick, 1917)	4699	8,27	7824	18,11	F=3.5203 ; P=0.0037 **
Total	56842	100	43198	100	

Legend:(AA: absolute abundance, RA: Relative abundance)

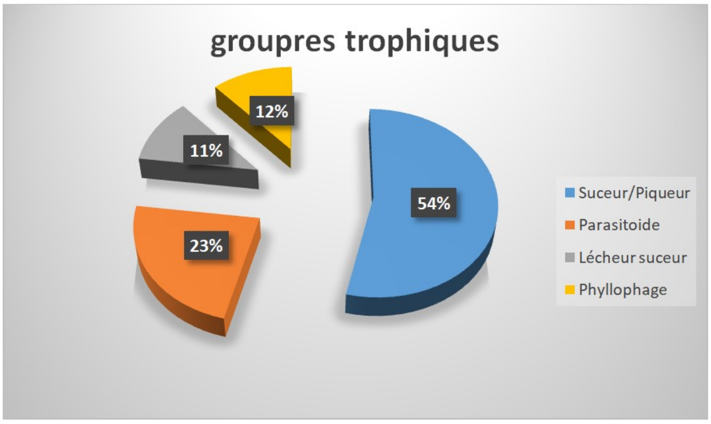

Figure 4. Graphical representation of different trophic groups of the population that colonize pepper fruits

The different functional groups that control the fauna on pepper at Nkolmelen: The fauna identified on pepper fruits at Nkolmelen was assembled into trophique groups which were: stinging sucking, phyllophagous, licking sucking and parasitoids. The stinging sucking were visibly more numerous. They represented more 50% of the total number of individuals. This group was followed by that of parasitoids with 23% that is almost half of the first group. Concerning phyllophagous, they represented 12% of the population and lastly, licking sucking which were only 11% of the population. Parasitoids are insects that depend on others for life notably stinging insects. While phyllophagous feed on the tegument of pepper fruits and the leaves. Licking sucking on the other hand are opportunistic, they feed on plant juice (liquid that flows when pepper fruits decay) produced during the decomposition of fruits caused by the others, principally stingers. The population of these pests greatly varied from one variety of pepper to another. Thus, stinging-sucking were numerically more abundant on yellow pepper than on red pepper. The later to ensure the survival of their species, sting the tegument of the pepper fruits to lay their eggs that will hatch into larvae and develop into adults during favourable conditions and the cycle will continue. These stinging-sucking were directly followed by parasitoids which were also more abundant for yellow pepper than for red pepper. Which is very normal since parasitoids live on the expense of stinging-sucking on which they achieve their biological cycle. An increase in the population of stinging-sucking at a given time forcibly leads to an exponential increase of parasitoids in that area. and all these species were more abundant for yellow pepper than for red pepper (Table 2). The most important species here were *Diachasmimorpha tryoni, Tetrastichus giffardianus* and *Fopius arisanus* for yellow pepper and *Diachasmimorpha tryoni, Fopius arisanus* and *Diachasmimorpha longicaudata* red pepper (Table 4). Concerning stinging sucking were represented by three species. The most important were *Ceratitis capitata* which had more affinity with yellow pepper (19223) than with red pepper (10327). *Silba capsicarum* which on the contrary showed more affinity with red pepper (11004) than with yellow pepper (3352). *Adia cinerella* also showed more affinity for yellow pepper (1705) than for red pepper (115).

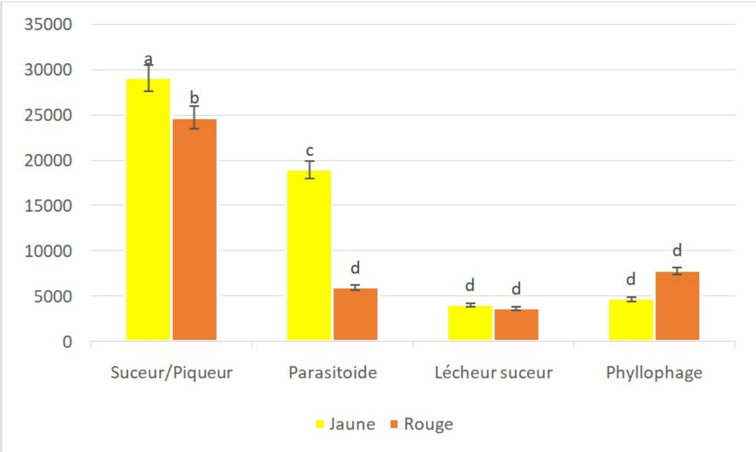

Figure 5. Comparison between functional groups depending on the variety of yellow pepper or red pepper of the entire population which parasitize pepper fruits

Tableau 4. Variation spécifique des différents groupes trophiques de la faune des fruits du piment

Functional groups	Species	Yellow		Red	
		AA	AR (%)	AA	AR (%)
Lick sucker	*Ostrinia nubilalis* (Hubner, 1796)	182	0,32	512	1,21
	Drosophila melanogaster (Meigen, 1830)	4810	8,46	3276	7,76
	Musca domestica (Linnaeus, 1758)	3885	6,83	3163	7,50
Parasitoïd	*Aganaspis daci* (Weld, 1951)	1412	2,48	636	1,51
	Diachasmimorpha longicaudata (Ashmead, 1905)	3070	5,40	920	2,18
	Diachasmimorpha tryoni (Viereck, 1913)	4217	7,42	1215	2,88
	Fopius arisanus (Sona, 1932)	3870	6,81	1105	2,62
	Pachycrepoideus vindemmiae (Rondani, 1875)	1043	1,83	627	1,49
	Spalangia cameroni (Perkins, 1910)	1133	1,99	684	1,62
	Tetrastichus giffardianus (Sivestri, 1915)	4240	7,46	790	1,87
Sucker/Picker	*Adia cinerella* (Fallén, 1825)	1705	3,00	115	0,27
	Ceratitis capitata (Wiedemann, 1824)	19223	33,82	10327	24,47
	Silba capsicarum (McAlpine,1956)	3352	5,90	11004	26,08
Phyllophagous	*Tuta absoluta* (Meyrick, 1917)	4699	8,27	7824	18,54
Total		56841	100	42198	100

Tableau 5. Factors impacting pepper production at Nkolmelen

Pests	Attack rate (%)			Emergence			production loss (%)			F test
	Yellow	Red	Total	Yellow	Red	Total	Yellow	Red	Total	
Ceratis capitata (Wiedemann, 1824)	52.36	35.42	43.89	8	6	7	35	30	33	F=7.45; P=0.001**
Silba capsicarum (McAlpine,1956)	25.44	37.74	31.29	18	17	18	28	25	27	F=7.89 ; P=0.003**
Tuta absoluta (Meyrick, 1917)	22.19	26.83	24.51	5	6	6	37	45	40	F=7.85 ; P=0.423 NS
Total	100	100	100	35	31	31	100	100	100	

Legend (NS: Non significant; **: Very significant)

The same event will occur for licking-sucking. Phyllophagous on the contrary, were more abundant for red pepper than for yellow pepper. These different trophic groups were represented by a certain number of species (Table 4). Among the licking-sucking, three species were distinguished namely: *Musca domestica* and *Drosophila melanogaster* more abundant for yellow pepper respectively (3885 et 4810) than for red pepper (3163 et 3276). While *Ostrini anubilalis* was more present for red pepper (512) than for yellow pepper (182). Amongst parasitoids, there were 7 species. This class is very dense These insects multiply rapidly in this environment causing important damages to the host plant (Table 4). Phyllophagous on the other hand, were represented by only one species *Tuta absoluta* which was more present for red pepper (7824) than for yellow pepper (4699). *Tuta absoluta* had a double action: It considerably destroys the tegument of pepper fruits and also feeds on pepper leaves (Table 4).

Estimationofyield losses caused by pests: Pepper fruits are very cherished by many insects. The later belong to divers' trophic groups.

Table 6. Evaluation du taux de parasitisme et d'amélioration de la production induites par les parasitoïdes

Parasitoïds	Parasitism rate (%)			Emergence			production (%)			F test
	Yellow	Red	Total	Yellow	Red	Total	Yellow	Red	Total	
Aganaspis daci (Weld, 1951)	7.44	10.64	9.04	2	2	2	11.42	12.90	12.16	F=7.871 : P=0.421 NS
Diachasmimorpha longicaudata (Ashmead, 1905)	16.17	15.39	15.78	3	3	3	17.14	16.12	16.63	F=7.881 : P=0.371 NS
Diachasmimorpha tryoni (Viereck, 1913)	22.22	20.33	21.27	4	3	4	20.03	19.38	19.70	F=7.870 : P=0.368 NS
Fopius arisanus (Sona, 1932)	20.38	18.49	19.43	3	3	3	14.28	16.12	15.20	F=7.901 : P=0.321 NS
Pachycrepoideus vindemmiae (Rondani, 1875)	5.49	10.49	15.98	1	2	1	8.57	12.90	10.73	F=7.84 : P=0.021 *
Spalangia cameroni (Perkins, 1910)	5.97	11.44	8.71	2	1	1	11.42	9.68	10.55	F=7.86 ; P=0.125 NS
Tetrastichus giffardianus (Sivestri, 1915)	22.33	13.22	17.77	3	2	3	17.14	12.90	15.02	F=7.96 ; P=0.012 *

Stinging/sucking and phyllophagous had a more or less considerable positive (negative) impact on the host plant (Table 5). Thus, *Ceratitis capitata* (Stinging-sucking) was the most abundant fruit fly in this milieu. It showed a global offensive rate of 43.89% that is 52.36% for yellow pepper against 35.36% for red pepper. An average of 7 individuals emerged from each fruit, that is 8 from yellow pepper and 6 from red pepper. This lead to a general yield loss estimated at 33%, that is 35% for yellow pepper and 30% for red pepper (Table 5). This species is followed by *Silba capsicarum* whose offensive rate on pepper fruits was 31.29%, that was 25.44% for yellow pepper and 37.74 for red pepper. It showed an average emergence rate of 18 individuals that was 18 for yellow pepper and 17 for red pepper. This rate remains constant between the two pepper varieties. However, the yield loss induced by this insect (27%) varied very weakly between yellow pepper 28% and red pepper 25%. Concerning *Tuta absoluta* (Phyllophage), which simultaneously destroys pepper leaves and fruits induced an offensive rate of 24.151% in general with a variation observed between yellow pepper 22.19% and red pepper 26.83%. The later showed a relatively constant emergence rate between yellow pepper (5 individuals) and red pepper (6 individuals). Plant yield loss induced by *T. absoluta* was the highest with a global rate of 40%. This yield loss rate turned out to be more important for red pepper (45%) than for yellow pepper (37%). Furthermore, *T. absoluta* showed the weakest offensive rate on pepper (fruits and leaves) but lead to the highest yield loss (table 5). Comparison in pairs between yellow pepper and red pepper showed significant differences for *C.capitata* and *S.capsicarum* (P=0.00).

Role of parasitoids subservient to pepper fruit pests in the improvement of plant yield: Parasitoids as far as they are concerned played an inverse role because they helped to improve the quality of plant yield (Table 6). Therefore, four species were noticed by their results. Amongst these, there were two species of the genus *Diachasmimorpha*. These were *Diachasmimorpha tryoni*, most common in this environment. The later contributed in a general way to 19.70 % in improving the yield of pepper fruits by neutralizing fruit stinging insect pests (Table 6). This rate did not vary much between yellow pepper (20.03 %) and red pepper (19.38). An average emergence rate of 4 individuals that was 3 for red pepper and 4 for yellow pepper. Which lead to a parasitoidism rate of 21.27 % that was 22.22 % for yellow pepper and 20.33 % for red pepper. Followed by *Diachasmimorpha longi caudata* which in its turn contributed in improving pepper plant yield at 16.63 % that was 16.12 % for red pepper against 17.14 % for yellow pepper. With a general emergence of 3 individuals per insect pest (Table 6). This rate remained constant between yellow pepper (3) and red pepper (3). Which lead to an aggressiveness rate of 15.78 % on the pests concerned, that was 16.17 % for yellow pepper and 15.39 % for red pepper. Then comes the species *Fopius arisanus* which showed an improvement rate on plant yield of 15.20 %. This rate varied between yellow pepper (14.28%) and red pepper (16.12%). With an emergence of 3 individuals which remained constant amongst yellow pepper and red pepper, leading to a parasitoidism rate of 19.43%. This rate between yellow pepper (20.38%) and red pepper (18.49%). And lastly, *Tetrastichus giffardianus* whose improvement rate on plant yield was 15.02%. This rate greatly varied between yellow pepper and red pepper. It was very important for yellow pepper 17.14% and relatively low for red pepper that was 12.90%. This species showed an emergence of 3 individuals per insect pest that was 3 for yellow pepper and 2 for red pepper, which lead to a parasitoidism rate of 17.77%. This rate was very high for yellow pepper (22.33%) and low for red pepper (13.22%). The rest of the species were less aggressive and included *Aganaspis daci*, *Pachycrepoideus vindemmiae* and *Spalangia cameroni* (Table 6).

DISCUSSION

Inventory of fauna subservient to yellow and red pepper fruits: The inventory of insect fauna which attacks pepper fruits in Cameroon is necessary in the elaboration of strategies for biological control and protection of these crops against insect pests and predators of the plant. This inventory permitted to identify at Nkolmelen suburb of Yaoundé three principal orders which were Diptera, Hemenoptera and Lepidoptera. The order Diptera was the most abundant and the most recurrent followed by Hymenoptera and lastly Lepidoptera. These results seem similar to those obtained by Heumou *et al.* (2015) at Koutaba in Cameroon and to those obtained by Akesse *et al.* (2015) in Ivory Coast. The later also registered three orders on pepper amongst which there were Diptera, Homoptera and Lepidoptera. These results are contrarily less diversified than those obtained by Djiéto-Lordon *et al.* (2014) who registered four orders which colonize red pepper and yellow pepper in Yaoundé. These orders included Hymenoptera, Hemiptera, Diptera, and Lepidoptera. However, they noted pointed out that Hymenoptera and Hemiptera were just traces meaning very weakly represented compared to Diptera and Lepidoptera which caused considerable damages on yellow and red pepper. Diptera and Lepidoptera were present in the three study sites of Cameroon and in Ivory Coast.

These two orders are the most recurrent and most abundant contrarily to Homoptera, Hemiptera and Hymenoptera which are intermittent and sporadic. They can lead to plant yield losses reaching 100 % in situations of rapid multiplication (Ndoumbè-Nkeng *et al.*, 2003). This is explained by their capacity to move easily, to reproduce and their great ability to adapt to new environmental conditions even when they seem harsh (Arredondo *et al.*, 2018). This confirms their status of major pests of pepper fruits and seriously deserves the concern of producers as well as the government. It is perhaps important to note here that although Lepidoptera are generally less numerous compared to Diptera, cause more important damages since they attack both pepper leaves and fruits. The larvae of these insects feed on the fruit tegument and pulp thus destroying the tissues of the fruit pericarp (Djiét-Lordon et *al.*, 2014), which leads to fruit decay in just a few days and development of many diseases on farm (Akesse *et al.*, 2015). These diseases are caused by cryptogamic, microscopic and sometimes endophytic fungi such as *Phytoptora sp*, *Aspergillus sp*., *Fusarium sp*., *Collectotricum sp.*, and sometimes *Lasiodiplodia sp.*, responsible of Dieback (Voula *et al.*, 2018; Mvondo-Ngandi et *al.*,2018 et Mbenoun *et al.*, 2016). These diseases lead to considerable losses. Lepidoptera therefore showed a higher affinity for yellow and red pepper varieties. Comparison between red and yellow pepper showed significant differences (P=0.00). The activities of Lepidoptera were marked on red pepper than on yellow pepper since butterflies are preferentially attracted by orange and red colors.

At family level, 12 families were registered. These included Anthomyiidae, Tephritidae Braconidae, Cicidomyiidae, Crambidae, Drosophilidae, Eulophidae, Figitidae, Gelechiidae, Lonchaeida, Mucidae and Pteromalidae. This result is very different and more diversified that of Heumou *et al.*, (2015) who obtained 5 insect pest families on pepper at Koutaba. This difference is certainly due to the difference in the two agro-ecological zones, the relief, the seasons and intense human activities in the locality. Our results are otherwise close to those of Kakam *et al.*, (2020) who listed 15 insect families in market gardener agro systems at Minko. Also, Vayssières *et al.*, (2001) on the Reunion Island, Fomekong *et al.*, (2008) as well as Chougourou *et al.*, (2012) in Benin also obtained similar results. Otherwise, red pepper was requested by insect families in terms of numerical abundance. The comparison in pairs between red pepper and yellow pepper showed significant differences (P=0.00) globally. Djiéto-Lordon*etal.*, (2014) also obtained differences at the level of families that colonize the pepper varieties. Concerning the different insects that colonize red pepper and yellow pepper at Nkolmelen, a suburb of Yaoundé, 14 species were listed. Yellow pepper was more sensitive than red pepper. These species were placed into four functional groups which were licking sucking for which the most abundant represented by *C.capitata*, *S. capsicarum*, followed by parasitoids, phyllophagous and lastly the licking sucking which were the least abundant. These results are different from those of Djiété-Lordon *et al.*, (2014) who listed 17 species of pests on three varieties of pepper which were yellow pepper, red pepper and soft pepper. Red pepper (85 098 individuals) was more infested than yellow pepper (83 464 individuals). Our results are contrarily more diversified than those of Akesse *et al.*, (2015) who obtained only two species in Ivory Coast. In effect, it is very difficult to estimate the exact species richness of pests that colonize a given plant (Heumou *et al.*, 2015), since many parameters have to be considered. These parameters which are biotic and abiotic are sometimes subjective and random (Akesse *et al*., 2015).

As to what concerns biotic parameters, the species variability is correlated to the intrinsic value of the plant through the nature of secondary metabolites secreted by the plant (Mahob *et al.*, 2021), the type of fruit produced, the quality and the colour of its flowers. Abiotic parameters on the other hand, are related to the different interactions between the plant and its environment, the nature of the soil, the surrounding flora and the climate of the ecosystem. A greatly diversified environment favours the specialization of pests to specific cultures (faithfulness to original habitat): this is monophagia, while a less diversified environment (absence of original habitat) leads to behavioural changes on the side of pests which thus become generalists (polyphagia) in order to ensure survival: this is the instinct of survival. It is an innate character specific to all living organisms. Thus, *C.capitata* has become a pest of many fruit crops present in all regions of mediterranean climate of the two hemispheres (Maazouz, 2016; Ronald, 2022) and was recently discovered on pepper in Cameroon (Djiéto-lordon., 2014). This phenomenon was also seen on the tick *Hilda patruelis* Stål, a Hemiptera having an ant behaviour tendency, observed on many unrelated plant species such as *Arachis hypogea* L., *Phaseolus vulgaris* L, *Hibiscus rosa-sinensis* L, Ficus on Forsskal in the afro-tropical region and in Cameroon on a new host plant, *Vernonia amygdalina* Delile (Aléné *et al.*, 2016; Voula *et al.*, 2020). This capacity for insect to adapt to new host plants and to new environment makes inventory studies more complex. This should appeal to different governments in the world to work together in putting in place integrated control methods globally to limit the expansion of these pests around the world, given that boundaries between states are not physical and homogenous.

Estimation plant yield losses induced by pests: Production or good yield is a very important value for the producer. Especially that in our country, this production is sustained by small farmers who work on less than a hectare of farmland. In this particular case, pests subservient to pepper plants have led to a global yield loss of 33,33% that is 40% for the species *T. absoluta* alone, 33% for *C. capitata* and 27% for the species *S.capsicarum*. These losses were more pronounced for yellow pepper than for red pepper. The species *C.capitata* therefore induced 35% yield loss for yellow pepper and 30% for red pepper with a global attack rate of 43.89% that is 52.36% for yellow pepper against 35.36% for red pepper. Likewise, *S.capsicarum* lead to a plant yield loss of 27%, that is 28% for yellow pepper and 25% for red pepper. With an attack rate on pepper fruits in the order of 31.29%, that is 25.44% for yellow pepper and 37.74 for red pepper. *T.absoluta* on the contrary, lead to important yield losses on red pepper in the order of 45% and 37% for yellow pepper. Yet with the weakest attack rates compared to the first two that is 24.15% in general with a variation observed between yellow pepper (22.19%) and red pepper (26.83%). The emergence rate of these insects obeys this tendency. These dense and alarming results are very different from those obtained by Djieto-Lordon *et al.* (2014) during their study on the evaluation of the impact of pepper fruit eating insects in Yaoundé. These authors obtained total yield losses of 13 à 16% for yellow and red pepper. According to these authors, *C.capitata* induced a yield loss of 7% for it alone. Likewise, Mbanye (2000) attributed the 21% yield loss observed on strong yellow and red pepper to the only species *C.capitata*. Although these yield losses are weak compared to ours, these observations are already very disturbing and worth appropriate counteracting measures adapted to the involved environmental conditions. For, the above values are from afar greater than the economic threshold estimated at 5% of yield loss or production. This equally confirms the status of *C.capitata* as being the most important pest of strong pepper in Yaoundé. This was already evoked earlier by Djiéto-Lordon and Aléné (2007). MacGowan and Rauf. (2019) on the other hand think that *Silba capsicarum* reported for the first time in Indonesia in 2019 on pepper is by far the pest that causes most damages to pepper compared to those already known and listed. Apart from that, these insects are considered by many authors as being very dangerous species for most fruit vegetables in the tropical zone (Kaspi *et al.*, 2002; Rigamonti, 2004).

Improvement of plant yield by parasitoids subservient to pepper fruit pests

Production or plant yield is something very important for the producer since it conditions his existence. Chemical products having shown their limits by causing important damages on both human health and the environment. The search of alternatives is considered through the use of living organisms and other natural molecules in the fight against these pests is recommended since a few decades in order to restore the equilibrium between nature and man and what he consumes. Divers' parasitoids are thus used to protect plants from their pests. Belhadi *et al.* (2011) in their work in glass houses used 5 species of parasitoids and predators against pests of pepper and this led to a yield gain of 12,34% against 20% in natural environment. This result enters the same reasoning as ours since in a general way, we obtained in a natural environment a parasitoidism rate of 15,42% that was 14,42% for yellow pepper against 14,58% for red pepper. With a global emergence rate of 3 parasitoids. This led to a general yield increase of 14,28%. This rate remained constant for both pepper varieties. This is the biological control against divers' pests. They played a major role in the protection of pepper. However, their actions remain insufficient for the global protection of the plant. They need a supplement by the combination of one or many other methods in order to maintain a convenient yield level and fight against hunger thereby ensuring food security. Thus, Ngando et *al*. (2022) used plant extracts to control tomato pests. Likewise, Mahot *et al*. (2019), Manga *et al*. (2021) used living organisms such as entomo-pathogenic fungi against pests of coffee berries and cocoa mirids. The protection with these methods although tedious will certainly lead to the healthy protection of the plant, the environment and man who is at the center of all activity.

CONCLUSION

At the end of this work on inventory and trial of biological control, it is seen that, 14 insect species are subservient to pepper fruits. These insects are distributed into 12 families and 3 orders. These insect pests cause considerable damages to the host plant. These damages had a negative impact on plant yield. Pepper is therefore threatened by many pests. The most detrimental being *C. capitata*, and *T. absoluta*. In addition to these two insects, there is *S. capsicarum* which was identified for the first time during this study as a pest of pepper in Cameroon and whose damages are quite important. To maintain an acceptable plant yield level, parasitoids were used as a means of biological control and they showed an acceptable efficiency. But this efficiency needs to be further improved to ensure a convenient yield at the state level in order for Cameroon to assure its role as the agricultural leader in the Central African sub-region. It is therefore clear that the biological control method alone cannot really grant an increase in plant yield. To this, other methods such as physical, mechanical and many others must be associated so as to favour good yield and better control pests and other enemies of pepper in natural environment. The use of parasitoids and other living organisms as biological control agents is therefore strongly recommended in order to save the planet and all its occupants from risks of all chemical.

Aknowledgements: We thank Ngono Eyenga Sophie Natacha Nina for her important contribution. We also wish to be very grateful towards all who from near or far took part in the achievement and maturation of this work.

Interest Conflicts: The author declares under honour that there exist no interest conflict concerning the production of this work.

Funding: The present work did not receive any funding either from the state or from any private organization.

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