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Diversity and agronomic status of tomato and pepper fruit pests in two agro-ecological zones of Southern Cameroon: Western Highland and the Southern Plateau of Cameroon

Heumou Cyril Roméo[1]*, Djiéto-Lordon Champlain[2], Aléné Désirée Chantal[2] and Elono Azang Pierre Stephan[3]

[1]University of Bamenda, P. O. Box 39 Bamenda, Cameroon.
[2]Laboratory of Zoology, Department of Animal Biology and Physiology, Faculty of Science, University of Yaounde I, P. O. Box. 812 Yaoundé Cameroon.
[3]Laboratory of Zoology, Department of Biology, University of Yaoundé I, Higher Teaching Training College, P. O. Box 47 Yaoundé Cameroon.

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Tomato and pepper are two major market gardening crops in Cameroon. In order improve pest insects control strategies, we assessed their diversity and evaluated their impact on yield losses in two agro-ecological areas of southern Cameroon. To achieve this, estimations of damages by visual observations were done twice per month from March 2010 to February 2011, in trap gardens set up respectively at Koutaba (Western Highlands) and at Okola (Southern Plateau). During each sampling, all fruits present in the garden were counted, those attacked or fallen on the ground collected and incubated in the laboratory for pest identification needs. Seven insect pests species belonging to two orders were identified. Among them, *Dacus punctatifrons* (Diptera-Tephritidae) *and, Chrysodeixis chalcites* (Lepidoptera-Noctuidae) were recorded on tomato, *Ceratitis capitata* (Diptera-Tephritidae), *Chryptophlebia leucotreta and Leucinoides orbonalis* (Lepidoptera-Pyralidea) on pepper while *Spodoptera littoralis,* and *Helicoverpa armigera* (Lepidoptera-Noctuidae) were recorded on both plants species. Fruit loses related to insects' activities were greater in Koutaba (43-47%) than they were at Okola (28-33%). These rates varied with seasons. For instance, frequencies of fruits affected by *D. punctatifrons, C. capitata, C. leucotreta* were positively correlated to the abiotic factors, especially temperature and rainfall.

Key words: Gardening, pest insect, damages, abiotic factors.

INTRODUCTION

With the global economic crisis, subsequent structural adjustment and the crash of cash crops prices in developing countries in the late 1980s, rural populations and low-income workers of public and private sectors,

*Corresponding author. E-mail: hcyrilromeo@yahoo.fr, Tel: (237) 77 28 61 81.

who lost their jobs, converted to food crop production in various areas of Cameroon. This was especially the case in the Western Highlands of Cameroon and in the urban and peri-urban areas of the Center and Littoral Region, where large areas previously occupied by cocoa and coffee farms, are currently occupied by food crop plantations and market crop gardens. For a great part of the population; especially in these zones, market gardening is presently the main activity (Westphal et al., 1981; Kegne and De Jong, 2002).

The intensiveness of this activity has led to the development of a diversified fauna of pests whose damages are very harmful to crops and their yield (Novotny and Basset, 2005). Up to date, the only arms disposed by the Cameroonian producers for pest control are large spectrum of synthetic chemicals. Moreover, farmer's knowledge about these constraints is usually very poor; leading to the misuse of these chemicals. This can cause environmental pollution, accumulation of chemical residues in crops, selection of resistant insects, etc (Edwards-Jones, 2008). To solve this problem, researchers have undertaken several studies, including inventories of entomofauna in market gardening (Djiéto-Lordon and Aléné, 2002, 2006; Djiéto-Lordon et al., 2014; Mokam et al., 2014a), biological and behavioral studies of some insect pests (Tindo and Tamo, 1999; Okolle and Tonifor, 2005), laboratories and field tests of alternative methods to chemicals (Berry and Mansfield, 2006), cultural practice tests (Wood and Reilly, 2000), etc. All these studies were intended to find ways to reduce the chemicals used in pest control. In their inventory, Djiéto-Lordon and Aléné (2002, 2006) showed that in *Lycopersicon esculentum* Mill. (1754) and *Capsicum annuum L.* (1753), fruits were the most affected organs. Recently, several studies provided some important data on the biology and ecology of some pests (Djiéto-Lordon et al., 2014; Mokam et al., 2014b). Despite their predominant agronomic and economic importance in market gardening in Cameroon, few data are available on pest of both tomato and pepper in the Western Highlands and Southern Plateau Regions of the country.

Considering that climatic conditions (altitude, rainfall, temperature, hygrometry, and vegetation) often influence insect species richness, the following hypothesis was stated: The diversity and dynamism of pest's communities of the two Solanaceous plants may vary according to agro-ecological zones, and that the rate of fruit losses would be affected by variations of weather conditions.

The study aims to provide basic data on diversity and ecology of the main fruit pests of tomato and pepper plants in two major gardening basins of the country: The southern plateau and the Western Highlands of Cameroon. For this purpose, (i) an inventory of the fruit entomofauna of these plants was done in order to supply an annotated list of the carpophagous insects associated with tomato and pepper in the two Regions, (ii) damages due to the main fruit insect pests were assessed in the two sites and (iii) dynamics of fruit losses were surveyed.

MATERIALS AND METHODS

Study sites

Data collection was conducted from March 2010 to February 2011, in trap gardens settled in two sites located in two main gardening basin of Cameroon: (i) Okola (04°01'39, 0'' N; 011°23' 00, 1'' E, altitude: 604 m) on the southern plateau, with bimodal rainfall regime (monthly rainfall varying between 415.6 and 7.2 mm, the mean value being 162.82 mm in 2010 and temperatures extending between 23 and 25.9°C, the mean value being 24.46°C; (ii) Koutaba (05°38'47, 9'' N; 010°48' 22, 2'' E, altitude: 1186 m) in the Western Highlands, with unimodal rainfall regime (monthly rainfalls varying between 315.4 and 0 mm, the mean rainfall being 130.04 mm in 2010 and temperature varying between 17.2 and 20.4°C, the mean value being 18.66°C). These two Regions are known to be pioneer in the market gardening practices in Cameroon (Westphal et al., 1981), and remain the main market crop gardening areas of the country. The two sites, characterized by the different altitudes and weather conditions presented different vegetation structures. The Okola's vegetation is a mosaic of more or less disturbed semi-decidious forest, cocoa based agroforestry systems and food crop farmlands. Here, cocoa plants were associated to various fruit trees including mango trees (*Mangifera indica)*, plum trees (*Dacryodes edulis*) etc. The main cropping system in this farmland is slashed and burned farming. Food crops include cassava (*Manihot esculenta*), corn (*Zea mays*), groundnut (*Arachis hypogaea*), bananas and plantain (*Musa* spp.) and market gardening lands of (pepper, tomato, green spices, and vegetables). The Koutaba's vegetation is composed of bushy savannah with remains of deciduous and gallery forests (Olivry and Chastanet, 1986). It is characterized by a mosaic of *Pennisetum purpureum* and *Imperata cylindrica* savannahs (Letouzey, 1963). According to the farmers, areas colonized by *Pennisetum purpureum* supported high fertile soils contrarily to those colonized by *Imperata cylindrica*. This site also holds coffee based plantations, fruit trees such as mango trees (*Mangifera indica*), avocado trees (*Persea americana*) and guava trees (*Psidium guajava*) and food crop farmlands.

For the assessment of the diversity of insects associated to the studied species, additional data were collected all around these two main sites.

Experimental design

Each trap garden was composed of a total of 16 ridges (11 m long × 1 m wide) separated by 50 cm furrow set up following local technics. Poultry manure was used to enrich the soil, 8 ridges were used for tomatoes and 8 used to plant pepper. On each ridge, 20 seedlings were planted on two lines and spacing of 0.7 m between the plants of the same line and 0.6 m between the plants of two different lines. A total of 80 seedlings of each studied species were planted, and all of them were systematically examined during each sampling.

Data collection

Fruit loss and pest biodiversity

Data collection started when the first fruits appeared. All the fruits present in the garden were counted and examined visually. Those fallen on the ground or with oviposition or larvae penetration holes were collected for further incubation in the laboratory, following protocols of Djiéto-Lordon and Aléné (2006), Diamantidis et al. (2009) and Vayssières et al. (2002). For this need, we used plastic boxes (7 × 10 × 17 cm) previously containing a small quantity of sand for insect's pupation and covered with close mesh net to prevent the insects escape at emergence. Once emerged, insects were collected, counted and preserved in 70% ethanol. This was done twice per month alternatively on the two study sites. Advantages of these methods were the possibility to provide a quasi-exhaustive list of insects associated with different fruit species, to observe their activities, to establish their specificities and to assess their yield loss due to each pest species.

Determinations were done by using several identification keys: Delvare and Aberlenc (1989), Daly et al. (1998), Borror et al. (1976) for families and some genus of insects; Bezzi (1915) for syrphids species, Villiers (1952) for hemipterans; Goureau (1974) for coccinelids, White and Elson-Harris (2004) for fruit flies. These determinations were confirmed by the taxonomists of the faunistic laboratory of the CIRAD (Montpellier).

Climatic data

About weather conditions, data used in this study are from the National center of Meteorology of Yaoundé for Okola site and from the airport station of Koutaba for Koutaba site.

Data analysis

Yield losses

The yield loss due to a given pest (T_{xi}) was calculated by the following formula:

$$Txi = \frac{ni}{N} \times 100$$

Where (*ni)* is the number of fruits attacked by this pest, (*N)* the total number of fruits obtained with the whole harvest.

Evaluation of the sampling success

In order to evaluate the strength (S) of the sampling effort, the theoretical species richness (TSR) was calculated on the base of eight different non-parametric estimators: ACE (Abundance-based Coverage), Jack1 and Jack2 (first and second order Jack-knife), Chao1 and Chao2, ICE (Incidence based Cover Estimator), MMM (Michaelis Menten Mean) and Bootstrap Estimator, using EstimateS 8.2 software (Colwell, 2006; Magurran, 2004). The strength of sampling effort was expressed as the ratio:

$$S = \frac{OSR}{TSR} \times 100$$

where OSR is the Observed Species Richness and TSR the Theoretical Species Richness.

The mean of the theoretical species richness obtained was compared to the observed species richness for each site. Also, rarefaction curve based on the evolution of species richness with increasing plot number was plotted.

Evaluation of species richness and diversity

To determine and compare species diversity within habitats (alpha diversity), the Shannon Wiener's index H' was used Barbault, (1997), in the formula: $H' = -\sum Pi \, Log_2 Pi$ ($0 \leq H \leq Log_2 S$); where *Pi* is the relative proportion of species *i* in a sample; S the number of species present in a sample. An equitability index was used to assess the number of individuals in the species $E = H'/Log_2 S$; ($0 \leq E \leq 1$).

Evaluation of fruit losses in relation to abiotic factors

Each month, amongst all mature fruits harvested on the two study sites, the attacked ones, recognized by the type of wounds seen on their surface, were grouped and counted. Then all the fruits with the same wounds or the fruits where the same insect species emerged were counted monthly. After that, the dynamics of monthly fruit loss were analyzed with respect to the environmental data.

Statistical analysis

Species richness was estimated using Estimates 8.2 software (Colwell, 2006). Communities comparison between the habitats were done using Shannon-Weiner index, equitability index of Pielou was used to appreciate equitability using Past Software and then the non-parametric correlation of Spearman was used, to analyze the relationship between the abiotic factors and fruit loss using the SPSS 17.5 software.

RESULTS

Fauna diversity and abundance

Sampling success

Species accumulation curves were calculated for each plant species for each site (Figure 1). In the two sites, the curves showed a similar pattern, with a species saturation plateau. This suggests a high sampling effort. The slope of the tomato's diversity curve at Okola (T. Okola curve) was similar to that of pepper at Okola (P. Okola), and the slope of pepper at Koutaba (P. Koutaba curve) is similar to that of tomato at Koutaba (T. Koutaba), indicating that, the increase of the new species number in the last five sampling were about 2 to 3 species in the Okola forest areas and only one species in the Koutaba savannah zone.

Virtually all the species were recorded after 5 to 6 sampling periods. So the data collected on each site were representatives of the community and may be used in community studies.

Taxonomic composition of pest diversity

A total of eight insect species belonging to seven genus, five families and two orders were identified from a sample of 1669 specimen obtained from the incubations of fruits collected on tomato and pepper fruits at both Okola and Koutaba sites (Table 1). Among them, *Dacus* (*Dacus*) *punctatifrons* (Krasch, 1887), *D.* (*Dacus*) *bivittatus* (Bigot, 1858) were reared form tomato fruits whereas *Ceratitis capitata* (Wiedermann, 1824)*, Leucinoides orbonalis* (Guenée, 1854) and *Cryptopheibia leucotrata* (Meyrick, 1913) were reared from the pepper fruits. *Helicoverpa armigera* (Hübner, 1808)*, Spodoptera littoralis* (Boiduval,

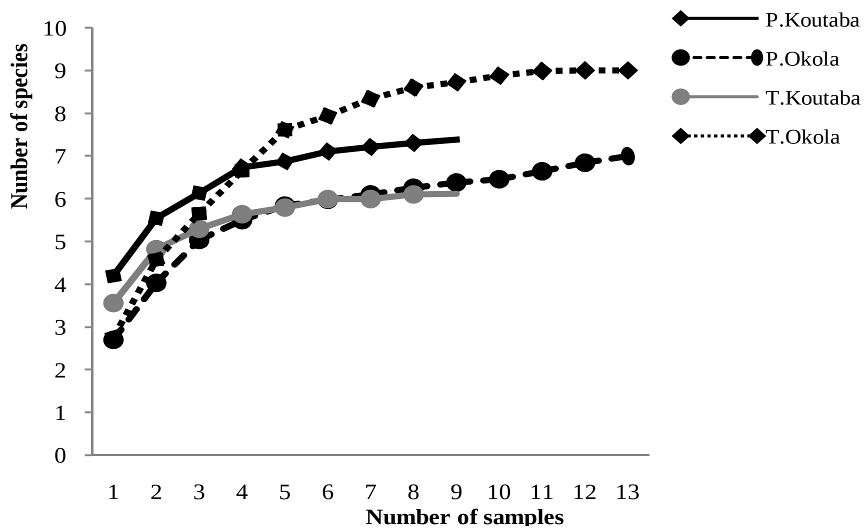

Figure 1. Species accumulation curves of occurrence of tomato (T) and pepper (P) pest at Okola and Koutaba.

Table 1. Absolute and relative abundances of pest species found in incubated boxes.

Plant species	Pest family	Pest species	Okolani (%)	Koutabani (%)
Lycopersicon esculentum	Noctuidea	*Helicoverpa armigera (Hübner, 1808)*	12(2.1)	53(8)
		Spodoptera littoralis (Boiduval, 1833)	1(0.1)	7(1)
		Chrysodeisis chalcites (Esper, 1789)	1(0.1)	0(0)
	Thephritidae	*Dacus puctatifrons* (Karsch, 1858)	557(97)	587(89)
		Dacus bivittatus (Bigot, 1858)	0(0)	11(1.6)
Capsicum annuum	Noctuidae	*Spodoptera littoralis*(Boiduval, 1833)	0(0)	4(2.19)
		Chrysodeixis chalcites(Esper, 1789)	1(0.01)	0(0)
	Pyralidae	*Cryptophlebia leucotreta (*Meyrick, 1913)	28(28)	43(23.62)
		*Leucinoide sorbonalis (*Guinée, 1854)	9(9)	0(0)
	Thephritidae	*Ceratitis capittata*(Weidemann, 1824)	62(62)	135(74.17)

1833) and *Chrysodeixis chalcites* (Esper, 1789) were common to fruits of the two species.

Species richness estimators

Based on eight different species richness estimators nine species were expected both on pepper at Okola and Koutaba and on tomato at Okola, while seven species were expected on Tomatoes at Koutaba (Table 2). Compared to the observed species richness, the sampling effort varied between 83.35 and 96.87%) (Table 2).

Considering estimators individually, the rates varied between 63 and 100%. Almost seven of the eight estimators showed highest estimated success of 100% on pepper in the two sites and on tomato at Koutaba. The lowest mean sampling success was (Jack2) 63% on pepper at Okala (Table 2).

Pest abundance

Independent of the study site, fruit pests of tomato were dominant, by *D. punctatifrons*, with respectively 97% of the total community at Okola and 89 at Koutaba. It was followed by *H. armigera* with (2%) and (8%) respectively. On pepper community, the populations of *C. capitata* were the most important in the two study sites, 62% and 74.17% respectively, followed by *C. leucotreta* (Table 1). The pest community of Koutaba was more diversified than the one of Okola, the Shannon index was H_1'=0.992 and H_2'=0.666 respectively. The abundance distribution among species were more equitable in Koutaba than in

Table 2. Recorded and expected number of species as calculated with different species richness estimators.

Variables	Samples	S.obs.	ACE	ICE	Chao 1	Chao 2	Jack 1	Jack 2	Bootstrap	MMMean	Mean
P.Koutaba	8	7	7(100)	8(87.5)	7(100)	7(100)	9(77.77)	9(77.77)	8(87.5)	10(70)	9(87.56)
T.Okola	13	9	9(100)	9(100)	9(100)	9(100)	9(100)	9(100)	9(100)	12(75)	9(96.87)
T.Koutaba	8	6	6(100)	6(100)	6(100)	6(100)	7(85.71)	8(75)	6(100)	7(85.71)	7(93.30)
P.Okola	13	7	8(87.5)	8(87.5)	8(87.5)	8(87.5)	9(77.77)	11(**63.63**)	8(87.5)	8(87.5)	9(83.35)

The sampling success given as proportion of sampled species (Sobs) to the estimated species numbers are given in brackets. Maximum and minimum successes are indicated by bold numbers. P=pepper, T=tomato, S. obs = Species observed.

Table 3. Distribution of fruit loss relative abundance in relation to the pest species at Okala and Koutaba.

Host plant	Pest species	Okola (%)	Koutaba (%)
L. esculentum	Healthy fruits	66.6	50.24
	FA *D. punctatifrons*	19.34	24.8
	FA *H. armigera*	11.17	23.51
	FA *C. chalcites*	1.3	0.24
	FA *S. litoralis*	0.53	0.65
	FA Other pest	1.0	0.57
C. annuum	Healthy fruits	52.97	71.69
	FA *C. capitata*	21.0	16.95
	FA *C. leucotreta*	22.32	9.44
	FA *L. orbonalis*	1.06	0.07
	FA *H. armigera*	0.0	0.51
	FA *S. litoralis*	0.0	0.04
	FA Other pest	2.64	1.3

FA=fruit attacked by the pest species.

Okola; Equitability index of Pielou (J) was J_1=0.51 at Koutaba and J_2=0.32 at Okola.

Yield loss

The two paired comparison of Wilcoxon shows that the yield loss for pepper and tomato were greater in Koutaba than in Okola (P<0.05). A total of 757 fruits of pepper were harvested at Koutaba, 356 fruits were damage which represents the yield loss of 47.03%. On the other hand at Okola, 2755 fruits were harvested and 780 showed traces of attacks which represented the yield loss of 28.31%. For tomatoes, 3264 fruits were harvested at Koutaba, 1624 were attacked, that is 49.76% of yield loss. At Okola, on 7693 fruits harvested 2565 were attacked, equal to 33.4% of yields loss (Table 3).

Fruit losses dynamics in relation to abiotic factors

Considering the low rate of fruits affected by S. *littoralis C., chalcites, D. bivittatus, L. orbonalis* respectively, they were not taken into account in the following analysis as, they were considered as secondary pest of these crops. Pest species that had economic important damages were selected to analyze their potential correlation with weather factors (rainfall, Temperature and sunshine):

1. *C. leucotreta* damage has shown a positive and non-significant relationship with precipitation both at Koutaba and at Okola (Tables 4 and 5). Meaning that, the population of this pest was not significantly affected by rainfall. A similar result was obtained with temperature at Okola (r=0.142; P=0.662). Contrarily, a positive and significant correlation was obtained with temperature at Koutaba (r=0.681; P=0.03).
2. *Ceratitis capitata* damage showed a negative and non-significant correlation with precipitation on the two sites(r=-0.366; P=0.298 and r=-0.210; P=0.513). A similar result was obtained for temperature at Koutaba (r=-0.065; P=0.854); but not in Okola where a non-significant positive correlation was found (r=0.067; P=0.837). Globally, population fluctuations were not affected by temperature.
3. *D. punctatifrons* damage had a strong positive and significant correlation with precipitation (r=0.835;

Table 4. Result of correlation test between of climatic factors on pest insect damages at Koutaba Cameroon.

Factor		*Cryptophlebia leucotreta*	*Ceratitis capitata*	*Dacus punctatifrons*	*Helicoverpa armigera*
Rainfall	r-Value	0.474	-0.366	0.835**	-0.553
	P-value Sig (2-tailed)	0.166	0.298	0.003	0.097
	N	10	10	10	10
Temperature	r-Value	-0.681*	-0.067	-0.219	-0.139
	P-value, Sig (2-tailed)	0.030	0.854	0.544	0.701
	N	10	10	10	10

*Correlation is significant at the 0.05 level, **correlation significant at the 0.01 level.

Table 5. Result of correlation test between climatic factors on insect pest damages at Okola Cameroon.

Factor		*C. leucotreta*	*C. capitata*	*D. punctatifrons*	*H. armigera*
Rainfall	r-value	0.125	-0.210	0.853**	-0.245
	P-value, Sig (2-tailed)	0.699	0.513	0.000	0.442
	N	12	12	12	12
Temperature	r-value	0.141	0.067	0.130	-0.067
	P-value, Sig (2-tailed)	0.662	0.837	0.687	0.836
	N	12	12	12	12

*Correlation is significant at the 0.05 level, **Correlation significant at the 0.01 level.

p=0.003 and r=0.853; p=0.0001) in the two areas. This means, when the precipitation increases, the population of these pest increases. Temperature had a negative but non-significant correlation with the damage at Koutaba (r=-0.219; P=0.544); and a positive but also non-significant correlation at Okola (r=0.130; P=0.688).

4. *H. armigera* damage had a negative and non-significant correlation with precipitation on the two sites (r=-0.553; P=0.097 and r=-0.245; P=0.442). Temperature was negative and non-significantly correlated to the damage caused by *H. armigera* both at Koutaba (r=-0.139; P=0.710); and at Okola (r=-0.067; P=0.836).

DISCUSSION

Pest diversity

It is commonly accepted that species richness in a whole-community is very difficult to measure and usually requires the use of various sampling technics as well as theoretical estimators (Longino et al., 2002). In the present study, two main estimation tools were used: The species accumulation curves and non-parametric estimators (Longino et al., 2002; Gotelli and Colwell, 2013). The species accumulation curves showed that after 6 samplings, the rate of new species occurring in each community was very low. The pest insect communities found on almost all the localities within the study areas were very close, but significant differences occurred in the abundant distribution amongst species. For instance, numerical domination of *H. armigera* and *D. punctatifrons* populations were more obvious in the humid savannah of Western Highlands than in the forest zone of the southern plateau. Geographical variations of abundant distributions amongst communities with close species composition may be explained by a certain number of factors, including availability of food resources, constraints of natural enemies, weather condition or interspecific competitions (Futuyma, 2005; Molles, 2008). The lower abundance of pests observed in the forest zone may be related to higher diversity of potential host plants. Altieri, (1999) established that the level of internal functioning regulations in agro-ecosystems is largely dependent on the level of plant and animal diversity. The high abundance of *H. armigera* and *D. punctatifrons* in Highland can also be explained by weather conditions, the mean temperature is 18°C different from the temperature of forest area where the mean is about 24°C and moisture was about 80%, different to 75% in Okola. Altitude also influence either directly by the changing of weather conditions or indirectly through insect communities interactions (Hodkinson, 2005).Generally, biodiversity decreases with altitude (Nabors, 2004; Atalay, 2006). Also insect populations are affected by habitat disturbance Atalay (2006). For example in the savannah area where bush fires are frequent, phytophagous insects tend to move in cultivated areas where moisture is constant and nesting sites available. Mac Arthur cited by Molles (2008) was one of the first ecologists to demonstrate and quantify the relationship between species diversity and environmental heterogeneity using the Shannon-Wienner index H'. The presence of encountered pest species in all examined habitats from 600 to 1200 m suggested that these pests can tolerate a high range of altitudes and other environmental conditions if their host plants are present.

Yield loss

The yield loss at Koutaba (47.03 and 49.76% on pepper and tomato respectively) were higher than those observed at Okola (28.31 and 33.4% on pepper and tomato respectively). This difference may be due to altitudes of the sites (600 m altitude and 1200 m respectively). Air temperature can influence the specific richness particularly the predators like ants that normally reduces the pest populations by feeding on their larvae. Cagnolo et al. (2002) demonstrated a decrease of certain species of insects on the altitudinal gradient. The difference in yield loss can be also due to surrounding vegetation; the first site is in a forest area with wild trees and the second is in a savannah dominated by mono-specific vegetation made of Graminaceae which are not usually used as food by the studied pest larvae (caterpillars or maggots). The forest vegetation which is more diversified than the savannah offers a larger spectrum of food resources to the phyllophages insects. Moreover, the physical environment of Okola offers more favorable micro -habitats for the development of many other organisms that could prevent outbreaks of pests on cultivated crops. In this forest vegetation, trophic network are more complex and it is well known in ecology that, the more trophic network is complex the better the agro-system is balanced (Russell et al., 2008). Mate-finding failure can also explain the different impacts of pest on the yield. Russell et al. (2008) demonstrate the negative effect of landscape fragmentation on animal mating. At Koutaba food resources are not diversified this may explain why the phyllophagous insects concentrate their reproduction on the agro system. Moreover the landscape was less fragmented and sexual mate easily met. Yield loss was important during our study period but some pests such as *D. punctatifrons* were particularly harmful to fruits 19.34 and 24.8% at Koutaba and Okola respectively. In the early 1990s Tindo and Tamo (1999) signaled *D. punctatifrons* as the major pest of tomato at Nkometou and Obala, two sites located in the same landscape as Okola. These authors mentioned that the rate of infested fruit increased from 9.8% in 1996 to 42.6-33% in 1997. The difference in the infestation rate can be due to the sampling periods. In fact, rainy seasons are favorable to the development of *D. punctatifrons*. The infestation rate was higher during the rainy season than in the dry season. However in the present study, infestation rate was evaluated throughout the year so the effect of the season was accumulated. As for *H. armigera* 11.17 and 23.51% fruit loss were obtained respectively in Okola and Koutaba. This pest was recorded as the main pest of tomato in northern India with a fruit yield loss of about 70% (Metha et al., 2010).

The season appeared to have an influence on infestation rate of our main pest. So, *H. armigera* appeared more active during the dry season than during the humid one. For *C. capitata* the fruit loss of 21 and 16.95%; were recorded respectively in Okola and Koutaba and for *C. leucotreta,* 22.32 and 9.44% respectively in Okola and Koutaba. Infestation rates of 14.86% for *C. leucotreta* and 6.71% for *C. capitata* were reported on the pepper in Yaoundé central Region (Djieto Lordon et al., 2014).

Fruit loss dynamic in relation to abiotic factors

Bateman (1972) demonstrated that the principal components of the life cycle of fruit pests are temperature, photoperiod, food, natural enemies and symbiosis. But none of these can stand out as a great important determinant of fruit loss. The contribution of each environmental factor varies with environmental and biotic conditions of the area. The main factor determining fruit loss in our study appeared to be the rainfall. It can be direct or indirect. The increase in damage due to *D. punctatifrons* by rainfall can be direct as rainfall induces a high level of moisture in the soil, enabling pupae to hatch easily. During dry period, the soil is compact; thus pupae become quiescent during a long period. In this form many pupae undergo dryness and die. Rainfall can also be indirectly involved in the increasing damage due to *D. punctatifrons* since the rainy season is the period when almost all plant species bloom, increasing the availability of food resources for adult flies (secretions, nectar, sap exuding from trunk, stem, leaf, rotting fruits) (Christenson and Foote, 1960). Adult flies can also feed on fruit injuries such as those caused by mechanical damage or biting holes due to some herbivorous insects. Adults *D. punctatifrons* were also observed flying around Aphids honeydew (*Macrosiphom euphorbiae and Aphis gossipy*) (pers. observ.). These different sources of insect food may help in egg maturation of the fruit flies. Christenson and Foote (1960) realized that honeydew secreted by homopterous insects provides hydrolyzed proteins, minerals, and vitamins that can be required by *D. dorsalis* for normal fertility and fecundity. The increase of fruits which are the breeding sites and food for insects' larvae were also proposed to explain increasing damage of *D. punctatifrons* during the rainy season, but this idea cannot be the best because in Cameroon gardening practices are permanent and do not depend on climate.

Rainfall is negatively correlated with damages due to *H. armigera*. This may be due to the fact that females of this butter fly lay it is eggs on the external surface of fruits, and flowers. Thus, most of these eggs are destroyed by the rainfall before hatching. Amongst the larvae which successfully penetrated the fruit, many are drowned by water licking through the entrance hole.

Conflict of Interest

The authors have not declared any conflict of interest.

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