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Evaluation of the seasonal fluctuation of populations of the armyworm, *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae) and its natural enemies in maize crops in Togo

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ABSTRACT
Objective: to evaluate the seasonal fluctuations of S. *frugiperda* and its natural enemies in maize farming in Togo.
Methodology and Results: It consisted in surveying fields in twenty-seven (27) prefectures during the period from October 2019 to November 2021. It consisted in surveying fields and collecting data such as egg, larva and pupa clusters, infestation rates and the main natural enemies encountered according to the FAO "W" method. Then, the collected data were reared in the laboratory for the emergence of potential natural enemies over two seasons.
Conclusions and application of findings: It was found that infestation rates; number of egg clusters and larvae; emergence rate and natural enemies of *S. frugiperda* varied not only according to the survey area, but also and especially according to the season. The infestation rates over the two seasons ranged from 62.55 to 32.55%. On average, the number of larvae was higher in the great season (0.87) compared to the short season (0.41). Meanwhile, the adults emergence ranged from 38.22 to 100.00%; therefore, there are many natural enemies obtained such as *Cotesia icipe*; *Campotelis* sp., *Trichogramma pretiosum*, *Winthemia trinitatis*, *Doru luteipes*, *Geocoris punctipes* and *Hexamermis* sp. candidate to control *S. frugiperda*. Additional experiments are however necessary to evaluate climatological aspects on the life table parameters of the main candidate natural enemies.
Keywords: maize, *S. frugiperda*, natural enemies, sustainable management, Togo.

INTRODUCTION

Maize (*Zea mays* L.) is the staple food in sub-Saharan Africa with an average annual area of 34 million hectares devoted to its production (Kostandini *et al.*, 2015). Average annual production is estimated at over 70 million tonnes and is a source of food and income for about 300 million people (Kostandini *et al.*, 2015). Maize plays a central role in the staple diet in sub-Saharan Africa and in particular Togo as is the case of rice or wheat in Asia (Macauley and Ramadjita, 2015). It is consumed by almost the entire population with varying preferences and socio-economic contexts. Despite its importance and the assets Togo has, maize grain yields are still low; 1.39t/ha against a potential of between 5-6t/ha (DSID, 2016). The maize farming system, combined with population growth and the FAW (Fall Army Worm) invasion of recent years, have resulted in an increasingly marked decline in production. The armyworm is the most devastating insect pest present in maize fields in sub-Saharan Africa (Sisay *et al.*, 2018). Faced with these various problems, much research has been conducted in Togo and has shown the effectiveness of certain chemicals including Emacot and neem oil in reducing the population dynamics of the pest. However, these chemicals have a financial impact that the subsistence farmer cannot afford (Kasongo *et al.,* 2013). It is therefore becoming imperative to determine *S. frugiperda* management techniques such as identification and enhancement of its natural enemies that will enable farmers to sustainably increase not only crop yields; but also and above all to increase their income in order to improve their standard of living. Successful management of pests by means of their natural enemies in general, and those of maize in particular, is based on mastery of their behaviour in their various ecosystems. This knowledge enables the production and release of natural enemies (parasites, parasitoids and predators) to be carried out later. It is to address this issue that this study was initiated. This study aims to develop a new control strategy for *S. frugiperda* by controlling its seasonal population fluctuations and its natural enemies on maize production in Togo. This study will broaden the range of biological control methods in a sustainable maize pest management option using its natural enemies.

MATERIALS AND METHODS

Experimental site: The study was carried out in 27 prefectures throughout Togo (Figure 1). Togo is a West African country located between 6°06N and 11°08N latitude and 0°09W and 1°49W longitude, with a population of 6,191,155; of which more than 60% (62.3%) live in rural areas (RGPH, 2010).

Figure 1: Map of the prefectures covered by the survey on the seasonal fluctuation of *S. frugiperda* and its natural enemies in maize crops in Togo.

Material: The material used in this study includes plant; animal; technical; laboratory and other. Maize fields were inspected throughout the country, mainly in 27 prefectures. The animal material consisted of eggs, larvae, pupae and adults of *S. frugiperda* and its natural enemies. The technical equipment consisted of, among other things, GPS devices for recording the geographical coordinates of the surveyed fields. Gloves and bags labelled with 'staedtler' marker were used for the collection of adults. Breeding boxes covered with mesh netting were used to collect egg masses, larvae and pupae of *S. frugiperda*.

Other equipment: The laboratory equipment used consisted of tweezers for handling larvae, pupae and adult insects. Circular transparent plastic boxes of 16 cm diameter and 8 cm height were used for incubation of egg masses (Figure 2A). Circular transparent plastic boxes with a diameter of 8.4 cm and a height of 4.2 cm were used for individual rearing of larvae (Figure 2B). The lids of the boxes were provided with an opening made of 3 µm mesh for ventilation of the boxes.

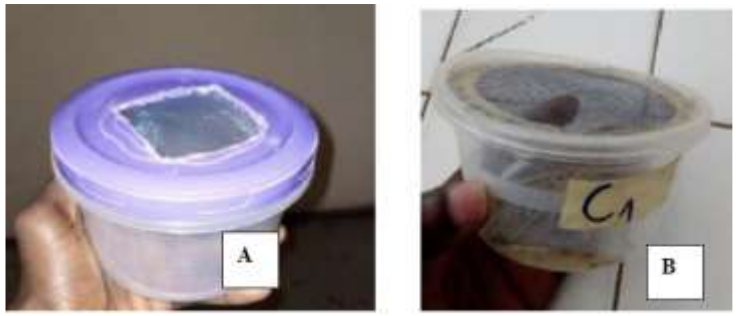


Figure 2: Egg mass incubation box (A); Individual larval rearing box (B).

Monocular magnifying glasses were used for close observation of some of the adults, but also of the larvae that showed some characteristic symptoms. Pruning shears were used to cut the maize leaves to feed the larvae in the laboratory. Tweezers were used to handle the larvae and pupae.

Methods: The methodology of data collection for this study was done in two phases: a first phase dedicated to the survey and data collection in the field and a second phase conducted in the laboratory for the rearing of egg masses, larvae and pupae collected in the field to detect potential natural enemies of the pest. The eggs of *S. frugiperda* collected in the field were placed in boxes and monitored until the larvae hatched. Then, placed one per box, to avoid cannibalistic effect and fed on fresh maize leaves until pupation (pupae). The pupae, placed in boxes, were kept in a humid place to facilitate the emergence of the adults. Pupae collected in the field were placed directly in a humid area to facilitate emergence. At emergence, monocular magnifiers were used to observe the different adults that emerged for identification. This study was conducted in four seasons to assess the seasonal fluctuation of *S. frugiperda* and its natural enemies in selected prefectures.

Field data collection: Field surveys were carried out in two phases in a coordinated manner according to the production season for each survey area.

Collection of egg masses, larvae and pupae: The egg and larva masses per plant were carefully observed on the different organs of the plant (leaves, stems, spikes). The surveys carried out in mainly 27 prefectures made it possible to collect information on the seasonal fluctuation of *S. frugiperda* and its natural enemies. For each of the prefectures concerned and for each collection phase, the FAO "W" sampling method was used (Figure 3). Pupae were looked for at the bottom of the plants in the first centimetres of soil or in the debris at the foot of the plant. In the collection of larvae, special attention was given to any larvae showing signs of infection for laboratory detection of possible attack by a potential natural enemy (pathogen, parasitoid). Information such as the infestation rate of the plants, the estimated level of damage to the plant, the average number of larvae per plant and the main natural enemies encountered were collected.

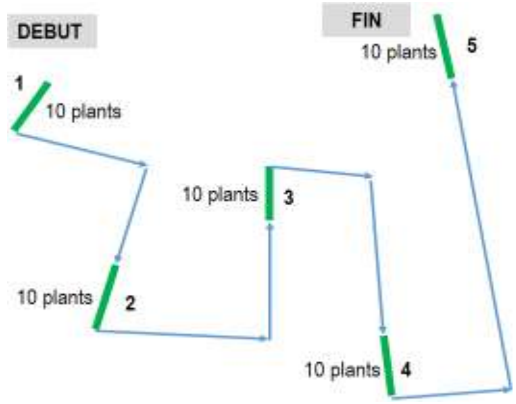


Figure 3: Survey using the FAO "W" approach

Assessment of the fructuation of the *S. frugiperda* population in Togo: Data were collected by selecting ten plants at each of the five points of the letter "W" on which observations were made. Data collected through direct observations of maize plots according to the method were used to assess prevalence, incidence or infestation rate, larval density and damage levels.

- Prevalence is the ratio of the number of infested fields to the total number of fields visited during the survey. It is calculated by the following formula (Eq 1):

$$Prevalence\ (P) = \frac{Number\ of\ infested\ fields}{Total\ number\ of\ fields\ surveyed} x\ 100 \quad (Eq\ 1)$$

The larval density is the average number of larvae of the insect on a maize plant. The number of larvae per plant was determined according to the Urbaneja García (2000) method; Diez (2001). It is calculated by the following formula (Eq 2):

These observations were made in time and space to highlight the dispersion of the armyworm. No. of larvae/plant =

(Number of larvae collected) / (Total number of plants examined) (Eq 2)

Assessment of infestation rates and damage levels

Infestation rates: The infestation rate of plants in a given plot is the ratio of the number of infested plants to the total number of plants sampled (usually 50 plants). A plant was considered to be caterpillar-infested if it had one of three caterpillar characteristics: presence of egg mass; presence of live larvae; and presence of fresh dregs (escrements). The infestation rate was calculated according to Urbaneja García (2000); Diez (2001) by the following formula (Eq 3):

$$Infestation\ rate = \frac{Number\ of\ infestade\ plants}{Total\ number\ of\ plants\ examined} x\ 100$$

Assessment of the level of damage of *S. frugiperda* on the plants: Particular attention was paid to the appearance of the plants in the field with the presence of glazed holes and translucent patches on the young leaves. Damage was assessed as no damage, low damage, moderate damage or high damage. To assess the level of damage to the plants, the method of Davis *et al.* (1989) was used to estimate the damage to the plants. A total of 50 plants were selected per surveyed field according to the FAO "W" method. The selected plants were cut and stripped to collect eggs, larvae and to assess the damage on the leaves. A visual maize damage rating scale (1 = no leaf damage; 9 = severe leaf damage) established by Davis (Davis *et al.*, 1989; Davis *et al.*, 1992) was used to assess leaf damage. For this purpose, each leaf is assigned a percentage corresponding to the leaf screening rates in relation to the total leaf area. Thus, the damage level of an infested plant was assessed according to the formula (Eq 4):

$$N_d = \sum_{i=1}^{n} \left(\frac{x_i n_i}{n} \right)$$

Nd=i=1nxinin
(Eq 4)

where Nd is the level of damage or infestation, xi is the score assigned to the attacked leaf, ni is the number of leaves with the score xi, n is the total number of leaves in the plant.

Collection and identification of natural enemies associated with *S. frugiperda*: Samples of egg masses, larvae and pupae were collected in the field and brought back to the laboratory. Each natural enemy species was tested specifically for the type of natural enemy. Thus for the:

Parasitoids: egg masses were incubated in wooden mesh cages covered with fine mesh netting until they hatched to obtain *S. frugiperda* larvae and/or parasitoids. The larvae obtained after hatching of the eggs in the laboratory as well as the larvae and pupae of *S. frugiperda* collected in the field during the surveys (Figure 4), were reared in the laboratory until the emergence of the adults (Figure 5).

Figure 4: Egg clusters (A), larvae (B) and chrysalids of *S. frugiperda* **(C)**

Figure 5: Rearing of *S. frugiperda* larvae in the laboratory

After a rearing period of 6 to 18 days, the emergence rate was calculated as the ratio of the number of emerged larvae and pupae to the total number of incubated larvae and pupae. The emergence rate was calculated according to the following formula (Eq 5):

$$\text{Emergence rate} = \frac{Number\ of\ larvae+pupae\ emerged}{Total\ number\ of\ larvae+pupae\ incubated} x\ 100$$ (Eq 5)

At emergence, parasitoids as well as the number of non-emerged pupae were counted and isolated for later identification. Identifications were made to genus and/or species level in situ. Identification of parasites and parasitoids was done through reference documents such as Molina-Ochoa et al. (2004); FAO (2018b); Tendeng *et al.* (2019) and Firake and Behere (2020).

Entomopathogens: The incidence of pathogens was determined in the field and laboratory through collections and visual observations of symptoms observed on larvae in the field and laboratory according to FAO (2018b); Baker and Capinera (1997). Larvae found dead were collected from the field and brought to the laboratory for detection of the pathogen responsible for their death by the characteristic signs of each pathogen, which will be presented as follows:

Bacteria: flaccid larvae, they become brownish-black after death; Fungus: dried out corpse after death, body covered with mycelium. Entomopathogenic nematodes: direct observations in the field and/or in the laboratory of adult nematode larvae emerging from incubated larvae or pupae. Apart from dead larvae collected in the field, live larvae were also collected and brought back to the laboratory and placed in rearing cages.

Predators: Predators were observed in action or not in the field during the surveys. Predators were stored in boxes containing 95% alcohol. Predator identification was carried out through Waller et al. (1999); Girod and Lassalle (2017); FAO (2018b); Tendeng *et al.* (2019) and the website https://www.gbif.org /.

Statistical analysis: QGIS software was used to make the geographical distribution of the caterpillar and its natural enemies over the whole territory and according to ecological zones. The data collected concerning egg clusters, larvae and/or chrysalises, adult emergence or identification of potential natural enemies were entered and processed with the Excel spreadsheet and then analysed with XLSTAT version 2020. The discrimination of means was done using the Student-Newman-Keuls (SNK) test at the 5% threshold. The percentage data were first transformed with Arcsin ($\sqrt{(x/100)}$) where x represents the observations, while the arithmetic data were transformed into Log (x+1), x being the observations (Quinn and Keough, 2002). Linear correlations were established with the Excel spreadsheet between climatic parameters and numbers of larvae per plant, infestation rates and damage levels of *S. frugiperda*.

RESULTS

Fluctuation of *S. frugiperda* during the 2020 period: Results on the number of larvae per plant, infestation rates and damage levels during the year 2020 are summarised in Table 1.

Tableau 1: Evolution of the number of larvae, the infestation rate and the damage levels per season

PRÉFECTURE	Number of larvae/plant (Mean*)			Damage levels (Mean*)		
	Great season	Short season	Great season	Short season	Great season	Short season
AGOU	0.26 b	0.58 ab	38.20 ab	28.00 bc	4.00 a	0.70 c
ANIE	0.32 b	0.18 ab	37.40 b	15.00 d	2.84 b	0.70 c
AVE	1.46 a	1.13 a	45.70 a	35.00 b	1.48 b	0.70 c
HAHO	0.87 ab	0.38 ab	53.86 a	21.30 cd	3.34 ab	0.53 c
EST MONO	0.45 b	0.38 ab	35.00 b	27.00 bc	2.70 b	0.50 c
KLOTO	0.54 b	0.20 ab	37.90 b	45.00 a	4.48 a	0.48 dc
KPELE	0.76 ab	0.80 ab	43.60 a	44.14 a	2.06 b	0.34 cd
OGOU	0.60 b	0.00 b	37.00 b	0.00 e	3.04 ab	0.26 e

**Data are reported as means and standard errors for four (4) replicates per treatment. Significant differences between treatments are indicated by different letters (Student-Newman-Keuls test at the 5% threshold).*

The relative results show that the collection area significantly affects the fluctuation of insects. The number of larvae was highest in both collection seasons in the prefecture of Avé. The lowest values were obtained in Ogou and Kloto. Concerning the infestation rate, Ave and Haho prefectures were the most affected. In the short season, Avé was the third most affected prefecture out of the 8 concerned by this study. The highest level of damage, in the great season was observed in the Agou and Haho prefectures.

Evaluation of the incidence, prevalence and number of larvae per plant of *S. frugiperda* by season in 2021: During the entire collection period, all fields and plants surveyed were attacked by *S. frugiperda*, resulting in an incidence and prevalence of 100%. On the other hand, egg clusters were rare and were only obtained in the prefectures of Bassar and Tone. The results on the average number of larvae per plant in Table 2.

Table 2: Evolution of the number of larvae per plant surveyed according to the zones and the collection season

PREFECTURE	Number of larvae per plant (Mean ± ES*)		
	Great season	**Short season**	***Moy***
AVE	0.49 ± 0.01 cd	0.85 ± 0.05 c	***0.67***
LACS	0.66 ± 0.03 bcd	0.32 ± 0.06 de	***0.49***
VO	0.70 ± 0.10 bcd	0.11 ± 0.01 de	***0.41***
YOTO	0.88 ± 0.09 bcd	0.34 ± 0.04 de	***0.61***
ZIO	0.94 ± 0.05 bcd	0.36 ± 0.03 de	***0.65***
AGOU	0.43 ± 0.02 cd	0.87 ± 0.07 c	***0.65***
ANIE	0.12 ± 0.01 d	1.99 ± 0.13 b	***1.06***
HAHO	3.11 ± 0.07 a	0.37 ± 0.04 de	***1.74***
EST MONO	0.35 ± 0.03 cd	0.79 ± 0.07 c	***0.57***
KLOTO	0.22 ± 0.02 d	2.40 ± 0.18 a	***1.31***
KPELE	1.12 ± 0.11 bcd	0.20 ± 0.03 de	***0.66***
MOYEN MONO	1.32 ± 0.02 bcd	0.61 ± 0.05 cde	***0.97***
OGOU	0.81 ± 0.06 bcd	0.66 ± 0.02 cd	***0.74***
BLITTA	0.38 ± 0.02 cd	0.23 ± 0.01 de	***0.31***
SOTOUBOUA	0.42 ± 0.04 cd	0.14 ± 0.01 de	***0.29***
TCHAMBA	0.39 ± 0.01 cd	0.10 ± 0.01 de	***0.24***
TCHAOUDJO	0.40 ± 0.03 cd	0.17 ± 0.01 de	***0.28***
ASSOLI	0.96 ± 0.07 bcd	0.06 ± 0.01 de	***0.51***
BASSAR	0.39 ± 0.03 cd	0.09 ± 0.00 de	***0.24***
BINAH	1.12 ± 0.07 bcd	0.02 ± 0.01 e	***0.57***
DOUFELGOU	0.36 ± 0.02 cd	0.08 ± 0.01 de	***0.22***
KOZAH	0.97 ± 0.02 bcd	0.09 ± 0.00 de	***0.53***
CINKASSE	1.62 ± 0.07 cb	0.11 ± 0.01 de	***0.87***
KPENDJAL	0.6 ± 0.06 bcd	0.09 ± 0.00 de	***0.34***
OTI	2.24 ± 0.18 b	0.35 ± 0.03 de	***1.30***
TANDJOARE	0.91 ± 0.06 bcd	0.09 ± 0.01 de	***0.50***
TONE	0.91 ± 0.07 bcd	0.10 ± 0.01 de	***0.50***
Mean	***0.85***	***0.43***	

**Data are reported as means and standard errors for four (4) replicates per treatment. Significant differences between treatments are indicated by different letters (Student-Newman-Keuls test at the 5% threshold).*

The study shows that the average number of larvae varies from one prefecture to another and according to the season. It was higher in the great season than in the short season. The highest average value over the two seasons was obtained in Haho and the lowest in Doufelgou. The highest average number of larvae in the great season was obtained in Haho prefecture and the lowest in Doufelgou. On the other hand, in the low season, the highest and lowest values were recorded in Kloto and Binah Prefectures respectively. In addition to the average number of larvae per plant, observations were made to evaluate the infestation rate of the insect.

Assessment of *S. frugiperda* plant infestation rates and levels of damage caused by *S. frugiperda* according to zones and season in 2021: The rate of infestation of plants and the damage assessed was evaluated according to seasons and data collection areas and the main results are presented in Table 3.

Table 3: Evolution of plant infestation rates and Levels of damage caused by *S. frugiperda* according to zones and season en 2021

	Infestation rate of plants (Mean ± ES*)			Estimation of damage levels (Mean ± ES*)		
PREFECTURE	**Great season**	**Short season**	***Mean***	**Great season**	**Short season**	***Mean***
AVE	33.80 ± 0.42 bc	51.20 ± 1.50 b	***42.50***	0.64 ± 0.01 b	3.19 ± 0.10 a	***1.92***
LACS	67.50 ± 2.18 abc	46.90 ± 0.98 b	***57.20***	0.60 ± 0.06 b	2.82 ± 0.16 a	***1.71***
VO	73.00 ± 1.53 ab	41.40 ± 0.46 b	***57.20***	0.52 ± 0.01 b	1.49 ± 0.06 a	***1.01***
YOTO	81.70 ± 2.37 a	42.00 ± 2.40 b	***61.85***	0.55 ± 0.01 b	1.80 ± 0.07 a	***1.17***
ZIO	79.60 ± 2.31 a	45.50 ± 2.35 b	***62.55***	0.66 ± 0.01 b	2.01 ± 0.25 a	***1.34***
AGOU	35.80 ± 1.37 bc	50.80 ± 0.79 b	***43.30***	0.92 ± 0.07 b	1.41 ± 0.07 a	***1.16***
ANIE	31.80 ± 1.87 bc	76.10 ± 1.07 a	***53.95***	0.62 ± 0.11 b	1.67 ± 0.04 a	***1.14***
HAHO	80.30 ± 4.86 a	34.50 ± 3.61 bc	***57.40***	0.53 ± 0.06 b	3.73 ± 0.09 a	***2.13***
EST MONO	36.80 ± 1.51 bc	43.60 ± 0.56 b	***40.20***	0.50 ± 0.02 b	2.94 ± 0.13 a	***1.72***
KLOTO	25.05 ± 0.98 c	91.20 ± 2.24 a	***58.13***	3.98 ± 0.29 a	0.44 ± 0.04 a	***2.21***
KPELE	68.32 ± 1.34 abc	38.00 ± 3.18 bc	***53.16***	0.55 ± 0.05 b	3.61 ± 0.20 a	***2.08***
MOYEN MONO	82.70 ± 1.59 a	42.15 ± 1.10 b	***62.43***	0.55 ± 0.01 b	2.31 ± 0.10 a	***1.43***
OGOU	62.90 ± 1.96 abc	50.30 ± 2.55 b	***56.60***	2.49 ± 0.11 a	0.35 ± 0.03 a	***1.42***
BLITTA	57.08 ± 3.56 abc	18.20 ± 0.64 c	***37.64***	0.56 ± 0.06 b	1.84 ± 0.08 a	***1.20***
SOTOUBOUA	52.90 ± 1.80 abc	12.20 ± 0.55 bc	***32.55***	0.51 ± 0.03 b	2.51 ± 0.12 a	***1.51***
TCHAMBA	55.68 ± 4.97 abc	16.25 ± 0.66 bc	***35.97***	0.45 ± 0.09 b	2.88 ± 0.31 a	***1.66***
TCHAOUDJO	54.94 ± 0.63 abc	17.00 ± 1.53 bc	***35.97***	0.49 ± 0.09 b	2.53 ± 0.02 a	***1.51***
ASSOLI	64.70 ± 1.44 abc	16.00 ± 1.00bc	***40.35***	0.70 ± 0.04 b	2.67 ± 0.13 a	***1.68***
BASSAR	52.40 ± 1.70 abc	33.67 ± 1.24 bc	***43.03***	0.49 ± 0.03 b	2.61 ± 0.17 a	***1.55***
BINAH	53.70 ± 0.35 abc	16.00 ± 1.15 bc	***34.85***	0.69 ± 0.02 b	3.14 ± 0.06 a	***1.92***
DOUFELGOU	51.00 ± 1.53 abc	24.00 ± 0.58 bc	***37.50***	0.58 ± 0.09 b	1.92 ± 0.08 a	***1.25***
KOZAH	54.10 ± 2.15 abc	27.50 ± 1.04 bc	***40.80***	0.95 ± 0.12 b	2.16 ± 0.08 a	***1.56***
CINKASSE	63.90 ± 2.18 abc	38.33 ± 1.43 b	***51.12***	0.36 ± 0.02 b	2.59 ± 0.10 a	***1.47***
KPENDJAL	67.33 ± 3.26 abc	30.40 ± 0.87 bc	***48.87***	0.49 ± 0.05 b	3.60 ± 0.21 a	***2.04***
OTI	45.20 ± 1.60 abc	50.00 ± 2.52 bc	***47.60***	0.58 ± 0.06 b	4.56 ± 0.07 a	***2.47***
TANDJOARE	43.90 ± 2.01 abc	30.80 ± 2.22 bc	***37.35***	0.53 ± 0.06 b	2.65 ± 0.06 a	***1.59***
TONE	69.80 ± 3.80 ab	27.25 ± 0.19 bc	***48.53***	0.47 ± 0.00 b	4.07 ± 0.33 a	***2.27***
Mean	***57.25***	***37.45***		***0.78***	***2.46***	

**Data are reported as means and standard errors for four (4) replicates per treatment. Significant differences between treatments are indicated by different letters (Student-Newman-Keuls test at the 5% threshold).*

Infestations were generally higher in the great season than in the short season. The average infestation rate in the main collection season was higher than in the short season. The prefectures of Moyen Mono, Yoto, Haho, Zio and Tchamba had high infestation rates compared to Kloto. In some prefectures such as Anié and Kloto, infestations in the short season were very high. Over the two seasons as a whole, average infestations therefore varied considerably. Particular analysis was also made of the levels of damage caused by *S. frugiperda*. The extent of damage assessed for these two seasons is summarised in Table 4. The extent of the damage during the short season was statistically identical. However, in the high season they varied according to the prefectures surveyed. The prefectures of Oti, Kloto and Ogou recorded more damage from *S. frugiperda* than the other prefectures surveyed. In general, *S. frugiperda* attacks were higher in the off-season.

Inventories of natural enemies of *S. frugiperda* in the field: Direct observations in the fields allowed the identification of many natural enemies of *S. frugiperda* such as predators, parasites and parasitoids. The main predators were: *Doru luteipes* (Scudder, 1876) (Dermaptera: Forficulidae); *Mantis religiosa* (Linnaeus, 1758) (Dictyoptera: Mantidae); Spiders; Ants; Ladybirds; *Podisus* sp. (Hemiptera: Pentatomidae) and *Forficula auricularia* Linnaeus (Dermaptera: Forficulidae) (Figure 6).

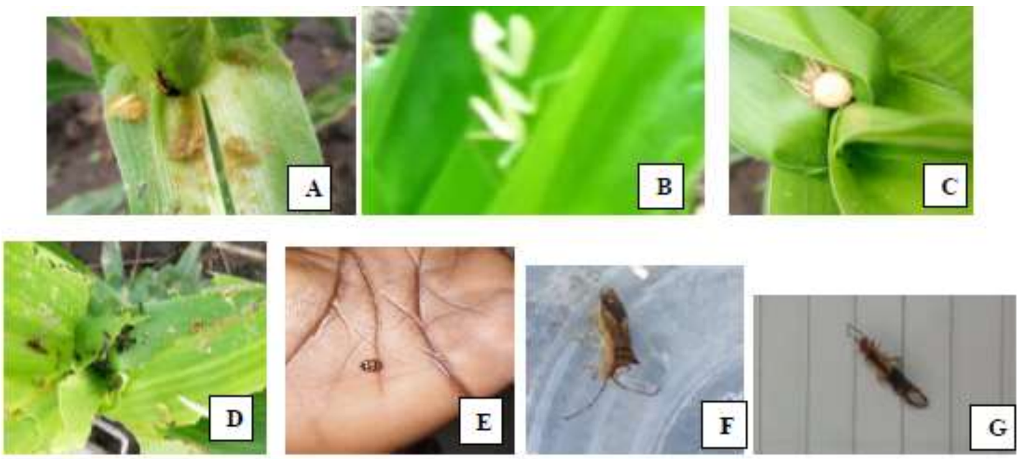


Figure 6: Main predators of *S. frugiperda* collected (A-*D. luteipes*; B-*M. religiosa*; C- Spiders; D-Ants; E-Coccinellae and F- *Podisus* sp. and G-*F. auricularia*).

In addition to these predators, parasitoids belonging mainly to the orders Hymenoptera and Diptera were inventoried. The main ones encountered were: *Chelonus insularis* Cresson (Hymenoptera: Braconidae); *Winthemia trinitatis* Thompson (Diptera: Tachinidae); Rhynocoris sp. (Fiigure 7).

Figure 7: Parasitoids found during the field survey (A- *C. insularis*; B- *W. trinitatis* and C- *Rhynocoris* sp.).

Assessment of the total number of incubated larvae and emerged adults in the laboratory: The average data obtained by zone is given in Table 5**.** A national average of

11.65 larvae per site were reared in the laboratory in the great season compared to only 7.88 in the short season. The average number of larvae incubated over the two seasons ranged from 19.00 (Vo) to 4.25 (East Mono). The highest average numbers of larvae were recorded in Vo (31) and Bassar (12.5) respectively, and the lowest were 2.00 (Est Mono) and 3.50 (Sotouboua) in the great and short maize seasons respectively (Table 5).

Table 5: Total number of incubated larvae and emerged adults of *S. frugiperda* per prefecture and survey season

PREFECTURE	Total number of incubated larvae (Mean ± ES*)			Adult emergence rate (Mean ± ES*)		
	Great season	Short season	***Mean***	Great season	Short season	***Mean***
AVE	8.00 ± 0.00 defg	6.00 ± 1.00 bcde	***7.00***	100.00 ± 0.00a	90.0± 10.00 a	***95.00***
LACS	21.00 ± 2.00 bc	6.50 ± 0.50 bcde	***13.75***	76.19 ± 9.52 b	53.57 ± 3.57 c	***64.88***
VO	31.00 ± 7.00 a	7.00 ± 1.00 bcde	***19.00***	70.18 ± 3.51 b	50.00 ± 0.00 c	***60.09***
YOTO	14.50 ± 1.50 cdef	7.50 ± 1.50 bcde	***11.00***	83.65 ± 8.65ab	88.89 ± 11.11 ab	***86.87***
ZIO	25.50 ± 0.50 ab	8.50 ± 1.50 abcd	***17.00***	50.92 ± 2.92 c	70.71 ± 0.71 b	***60.82***
AGOU	5.50 ± 0.50 efg	6.00 ± 0.00 bcde	***5.75***	100.00 ± 0.00a	91.67 ± 8.33 a	***95.83***
EST MONO	2.00 ± 0.00 g	6.50 ± 0. 50 bcde	***4.25***	50.00 ± 5.00 c	78.57 ± 21.4 b	***64.29***
HAHO	9.00 ± 1.00 defg	7.50 ± 1.50 bcde	***8.25***	27.50 ± 2.50 d	50.00 ± 6.67 c	***.38.75***
KLOTO	3.50 ± 1.50 g	5.00 ± 1.00 cde	***4.25***	83.33±16.67ab	75.00 ± 15.0 b	***79.17***
MOYEN MONO	11.00 ± 2.00 defg	8.50 ± 0.50 abcd	***9.75***	49.15± 4.70 c	70.83 ± 4.17 b	***59.99***
OGOU	7.00 ± 0.00 efg	8.00 ± 0.00 bcd	***7.50***	100.00± 0.00 a	100.00 ± 0.0 a	***100.00***
BLITTA	8.50 ± 1.50 defg	8.50 ± 1.50 abcd	***8.50***	80.71± 9.29 ab	80.71 ± 9.29 b	***80.71***
SOTOUBOUA	8.50 ± 0.50 defg	3.50 ± 0.50 e	***6.00***	65.28 ± 9.72 b	100.00 ± 0.0 a	***82.64***
TCHAMBA	3.50 ± 0.50 g	8.50 ± 0.50 abcd	***6.00***	100.00 ± 0.00a	65.28 ± 9.72 b	***82.64***
TCHAOUDJO	4.50 ± 0.50 fg	4.50 ± 0.50 de	***4.50***	87.50 ± 4.00ab	87.50 ± 12.5 ab	***87.50***
ASSOLI	6.00 ± 0. 00 efg	10.00 ± 0 .00 ab	***8.00***	85.00 ± 4.30ab	85.00 ± 5.00 ab	***85.00***
BASSAR	15.00 ± 0.00bcde	12.5 ± 2.50 a	***13.75***	100.00 ± 0.00a	100.00 ± 0.0 a	***100.00***
KOZAH	18.375 ± 1.45bcd	9.33 ± 0.49 abc	***13.85***	97.21 ± 1.48 a	98.33 ± 1.67 a	***97.77***
KPENDJAL	16.43 ± 0.92 bcd	9.57 ± 0.43 ab	***13.00***	91.43 ± 5.58 a	95.71 ± 4.29 a	***93.57***
OTI	10.75 ± 0.48 defg	9.75 ± 0.25 ab	***10.25***	87.50 ±12.5ab	100.00 ± 0.0 a	***93.57***
TANDJOARE	15.60 ± 1.69 cde	9.6 ± 0.40 ab	***12.60***	96.00 ± 9.72 a	92.00 ± 8.00 a	***94.00***
TONE	12.80 ± 1.39 cdef	10.00 ± 0.00 ab	***11.40***	91.96 ± 5.04 a	100.00 ± 0.0 a	***95.98***
Mean	***11.65***	***7.88***		***80.15***	***83.64***	

**Data are reported as means and standard errors for four (4) replicates per treatment. Significant differences between treatments are indicated by different letters (Student-Newman-Keuls test at the 5% threshold).*

Adult emergence rates were high and estimated at over 80% nationally for all seasons. The lowest adult emergence rate was observed in Haho over the two collection seasons.

Laboratory inventories of natural enemies of *S. frugiperda:* The parasitoids that emerged were: *Cotesia icipe* Fernandez (Hymenoptera: Braconidae), *Campotelis* sp. (Hymenoptera: Ichneumonidae) and *Trichogramma* sp. (Hymenoptera: Trichogrammatidae) (Figure 8).

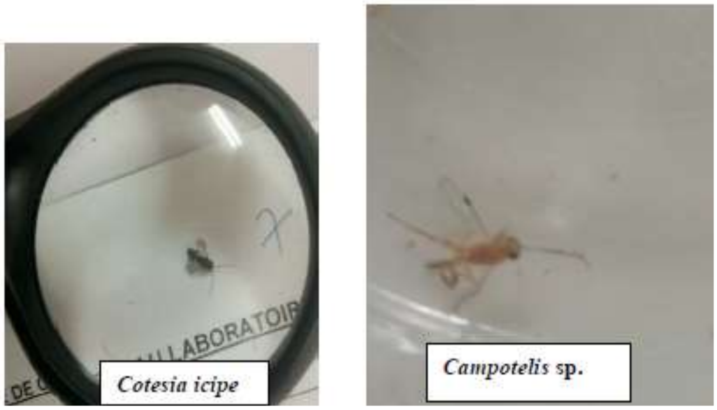


Figure 8: Adults of *Cotesia icipe* and *Campotelis* sp. emerging in the laboratory

The entomopathogens identified at the end of rearing were mainly the nematodes Hexamermis sp. (Nematoda: Mermithidae) and bacteria from the prefectures of Moyen Mono and Kloto (Figure 9A and B).

Figure 9: A-Nematode *Hexamermis* sp. emerging from a *S. frugiperda* larva after 4 days of incubation, B-Chrysalid showing symptoms of bacterial attack

Effect of climatic parameters on the fluctuation of *S. frugiperda:* Regression matrices between the fluctuation of the S. frugiperda population and that of temperature and rainfall were established. Significant positive linear regressions between temperature and rainfall variations over the two years were found (Figure 10 A and B). The coefficients of determination of these regressions were respectively r2 = 0.616; r2 = 0.994 for both regressions.

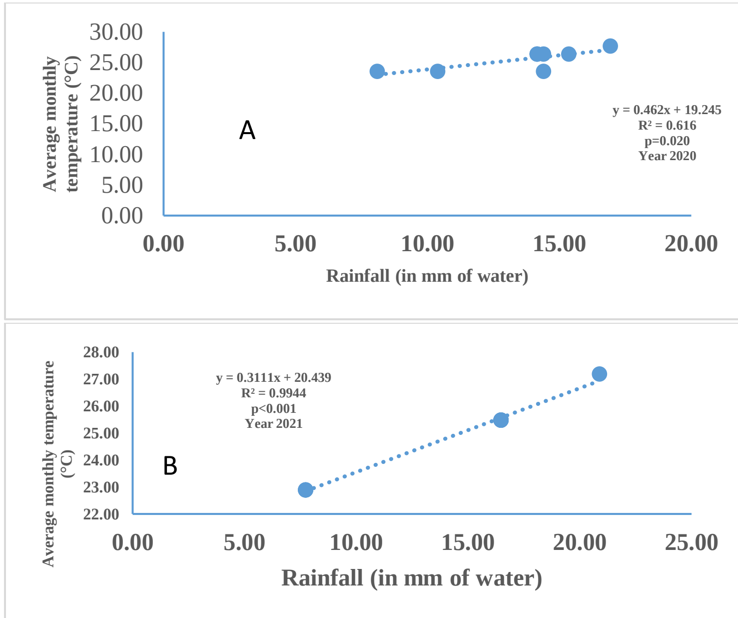
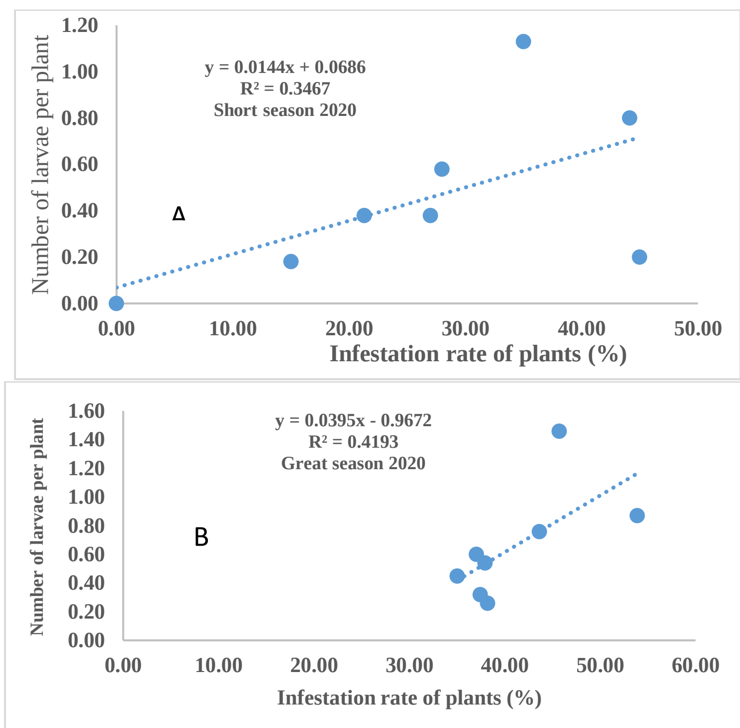


Figure 10: Linear relationship between rainfall and average temperatures in 2020 and 2021 (A and B)

Significant positive linear regressions were established between infestation rates and the number of S. frugiperda larvae per plant over all four seasons (Figure 11). The coefficients of determination of these regressions were r2 = 0.3467; r2 = 0.4193; r2 = 0.9652 and r2 = 0.7347 for infestation rates and numbers of larvae per plant for all four seasons.



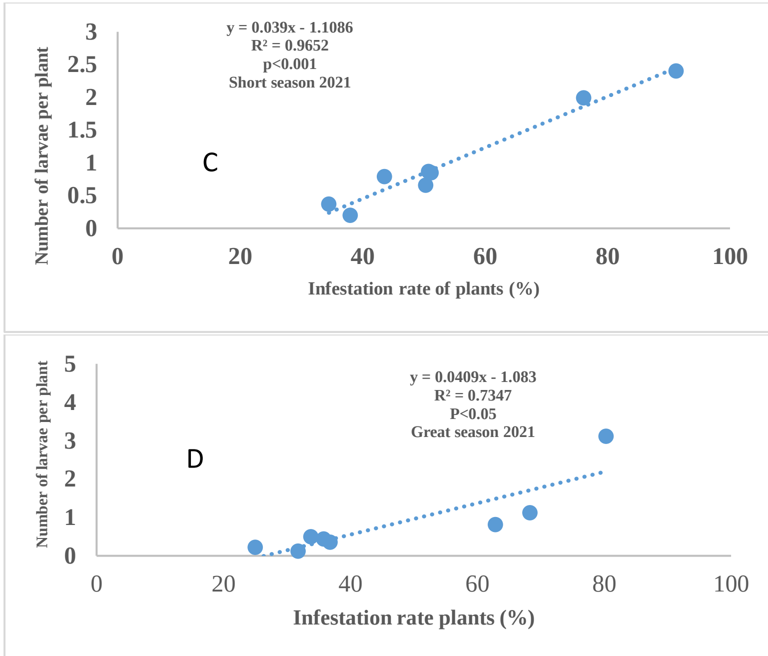


Figure 11: Linear relationship between infestation rate and number of larvae per plant for all seasons 2020 and 2021 (A, B, C and D).

A significant negative linear regression was observed between rainfall and the level of damage during the main rainy season in 2020 (Figure 12).

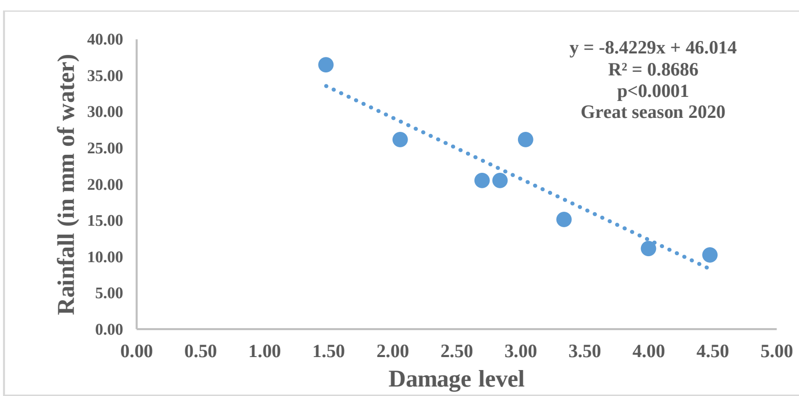


Figure 12: Linear relationship between damage levels and rainfall in the main season 2020

The coefficient of determination of its regression was r2 = 0.8686 for the parameters damage levels and rainfall in the 2020 (Figure 12).

DISCUSSION

This study on *S. frugiperda* population fluctuation revealed a considerable variation in the number of larvae and in the areas of collection with a scarcity of egg clusters. This scarcity is justified by the fact that the eggs being deposited on the surface of the leaves are often exposed to different natural enemies and are sometimes washed away by rainfall phenomena. The number of larvae was higher in some areas, especially towards the south.

This tendency can be explained by the drought phenomena, which are more accentuated towards the north, thus leading to a reduction in the larvae population. Towards the south, the rains are frequent and this has been a real means of proliferation of the pest population. In addition, the high insect population often results in a high biodiversity of associated natural enemies, which in turn regulates the pest population. Our results confirm those of Silvain and Ti-A-Hing (1985) who showed that the population fluctuation of *S. frugiperda* is generally high in the rainy season and low in the dry season. They also confirm those of Koffi *et al.* (2020) who showed that the population of *S. frugiperda* would vary according to regions and years and would be more important towards the south than the north during the rainy season. Although the fields surveyed were all infested by *S. frugiperda*, the assessment of damage levels and infestation rates was dependent on the study area, but also on environmental parameters. Rainfall and temperature conditions seriously affected the fluctuation and impact of *S. frugiperda* on the crop. This trend confirms the results of several researchers. Indeed, Ashley (1986) showed that the fluctuation of *S. frugiperda* was strongly dependent on environmental conditions. Furthermore, Murúa et al (2006) demonstrated over a period of four years that temperature and rainfall were the two main climatic parameters that significantly influenced the population fluctuation of *S. frugiperda* and its natural enemies in Argentina. In the same sense, Day *et al.* (2017) pointed out that regular rainfall and temperatures between 25 and 28°C ensured the insect's proliferation. Du Plessis *et al.* (2018) noted that the optimal temperature for the development of the insect was around 25°C. In the same sense, Valdez-Torres *et al.* (2012); Jeger *et al.* (2017) and López *et al.* (2019) showed that the good development of the insect was strongly dependent on temperature. The rearing of egg masses and larvae of *S. frugiperda* allowed the identification of mainly five natural enemies. Larval parasitoids such as *Cotesia icipe* Fernandez; *Campotelis sonorensis* (Cameron, 1886) (Hymenoptera: Ichneumonidae) and *Trichogramma pretosium* (Riley, 1879) (Hymenoptera: Trichogrammatidae) were identified in addition to a nematode *Hexamermis* sp. and a bacterium. Parasitoids were the most abundant of the emerging natural enemies. These results are justified by the biology of these parasitoids which, in order to ensure their progeny, pass through a larval life within the host. Our results confirm those of Murúa *et al.* (2006) who showed in Brazil that among the natural enemies of *S. frugiperda*, parasitoids such as Campoletis grioti (Blanchard, 1946) (Hymenoptera: Ichneumonidae); Chelonus Insularis Cresson (Hymenoptera: Braconidae) presented the highest rates of parasitism with respectively 39.4 and 5.7%. Wyckhuys and O'Neil (2006) also showed that *C. sonorensis* was the most abundant parasitoid of *S. frugiperda* in Yegu, Australia. In this case, the analysis of climatic factors during the study period showed a strong influence of rainfall and temperature fluctuation on the insect population. The average number of larvae was strongly dependent on the infestation rate of the plants. The high infestation rates could be justified by the existence of rainfall conditions and pockets of temporal drought that favoured the proliferation of the insect. Our results corroborate those of Looli Boyombe *et al.* (2021), who in the Democratic Republic of Congo demonstrated that climatic conditions in Africa favoured infestations of the insect. They also recorded plant infestation rates of between 64.5 and 75.5%. Despite the sometimes high infestation rates, damage levels were low. The presence of natural enemies is believed to influence the severity of the insect. Our results contradict those of Looli Boyombe *et al.* (2021) who found a high severity of pest attacks in Kisangani. During the main seasons of these collection periods, rainfall was regular, which was not the case in the short seasons. This resulted in a reduction in both the infestation rate and the number of larvae per plant. These trends are justified by the fact that the data were collected between May-July for the main seasons and september-november for the short seasons, a period during which rainfall was high in the great season and low in the second. Our results corroborate those of Silvain and Ti-A-Hing (1985), Murúa et al. (2006) and Koffi *et al.* (2020) who showed the influence of temperature and rainfall on the fluctuation of *S. frugiperda*. Rahmathulla et al. (2015) also showed that the fluctuation of *S. frugiperda* was dependent on rainfall conditions. Many natural enemies were surveyed in the field, mainly predators followed by parasitoids. Among the predators, *Doru luteipes* (Scudder, 1876) (Dermaptera: Forficulidae); *Forficula auricularia* (Linnaeus, 1758) (Dermaptera: Forficulidae); *Podisus* sp. Parasitoids such as *Chelonus insularis* Cresson (Hymenoptera: Braconidae); *Winthemia trinitatis* Thompson (Diptera: Tachinidae) and *Rhynocoris* sp. were the main ones surveyed. Our results confirm those of Sisay et al. (2018) who reported that predators were the most abundant natural enemies of *S. frugiperda* in the field. In contrast, in the laboratory, rearing of larval eggs and egg clusters identified 3 parasitoids: *C. icipe*; *Campoletis* sp., *Trichogramma* sp.; a bacterium and *Hexamermis* sp. Predators feeding directly on larvae and adults were seen more than parasitoids. In addition, parasitoids are nocturnal and cannot be abundant during the full days when the surveys took place.

CONCLUSION AND APPLICATION OF RESULTS

The study on the seasonal fluctuation of the armyworm and its natural enemies over four seasons identified many natural enemies. The natural enemies encountered were parasitoids; predators and entomopathogens. Predators were more abundant in the fields than other natural enemies. The main ones were: *Doru luteipes* Scudder (Dermaptera: Forficulidae); *Forficula auricularia* Linnaeus (Dermaptera: Forficulidae), ladybirds and ants. The main parasitoids were *Cotesia icipe* Fernandez (Hymenoptera: Braconidae); *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae), *Campotelis* sp. (Hymenoptera: Ichneumonidae). This study identified *Hexamermis* sp. (Nematoda: Mermithidae), an entomopathogenic nematode. In the current context of sustainable pest management, this study has provided a solid basis on natural enemies candidate in maize cultivation in Togo and on the African continent.

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