International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 25, No. 1, p. 23-36, 2024

INNSPUB

RESEARCH PAPER OPEN ACCESS

Bacillus thuringiensis and pheromone traps effects on *Spodoptera frugiperda* (Lepidoptera: Noctuidae) population on maize (*Zea mays* L.) in the Menoua division of Cameroon

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Key words: Bio-insecticide, Maize, Pheromone Trap, *Spodopdera frugiperda,* Cameroon

http://dx.doi.org/10.12692/ijb/25.1.23-36 Article published on July 03, 2024

Abstract

A study on the comparative effects of bio-insecticide and pheromone traps on *Spodoptera frugiperda* population on maize in the West region of Cameroon was conducted during the first planting dates from October to January 2019/2020 and the second planting dates from April to July to help increase maize production. The experiment used a complete randomized block design with three repetitions. The bio-insecticide (T1) was Antario (*Bacillus thuringiensis* and Abamectin). The chemical insecticide (T2) was Caiman B (Emamectin benzoate), with the control (T3). Some plots received pheromone traps, and others did not. Data collection started at 35 days after sowing (DAS) on 10 randomly chosen plants in each experimental unit. Direct counting of larvae, attacked leaves, and growth variables was done from 35 DAS to 70 DAS. Yield was also assessed. The results showed that *Spodoptera frugiperda* were present. The leaf infestation peaks of larvae were at 35 DAS, and those of moths were at 42 DAS. The control had the highest leaf infestation for both planting dates and was least abundant in Antario. Regarding yield, maize variety Panner 53, due to its high productivity, showed higher yields with Antario, followed by Caiman B, and lastly the control for both planting dates, proving that these treatments are effective against pests and their damages. The best result was recorded in the second planting date on plots with pheromone traps treated with Antario (10.17 t/ha), followed by plots with pheromone traps treated with Caiman B (9.00 t/ha), and lastly the control (8.67 t/ha).

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Introduction

Maize (*Zea mays*) belongs to the family of Graminae and more especially to the family of Poaceae. Maize is the principal crop and major staple food in most African and South American countries (Denic *et al.*, 2008). The world maize production was estimated at 1,291 million tons in 2016 (FAO, 2018). It is estimated that about 70% of the maize produced in sub-Saharan Africa are for human consumption (Agora, 2007). Every part of the plant has economic value: the grain, leaves, stalk, tassel, and cob can all be used to produce a large variety of food and non-food products (IITA, 2009).

In Cameroon, maize is the most widely grown and consumed cereal crop. It is mainly produced by poor farmers in the entire 10 regions. Recently, it has become a cash crop and, therefore, an important source of income. In addition to its use as human food and animal feed, maize is the source of raw material for a large number of industries. According to FAOSTAT (2017) the yield for the cultivation of maize in Cameroon was 2 tons per hectare in 2014. The annual maize production was estimated at 1,647036 tons in 2013 (FAOSTAT, 2013). However, this production is not sufficient to meet the demand of the population.

In Cameroon, maize production is hampered by many biotic and abiotic factors including; poor soil, droughts, crop pest, diseases, weed and unsuitable temperatures. Among the biotic constraints we can cite the attacks of harmful insects in the fields, those causing damage of economic importance are known as stem borers (CTA, 2008). Several species of moths were identified to cause damage to maize but fall army worm (FAW) is a dangerous pest and polyphagous in nature (Knox, 2012). However, an alert was launched by FAO in May 2017 on the appearance of a new species of nocturnal moth on maize in the field in Africa which was reported for the first time in early 2016 in central and west Africa (Sao Tome and Principe, Nigeria, Benin and Togo), then at the end of 2016 and in 2017 in South Africa, in Angola, in Botswana, in Burundi, in Ivory Coast, in Ethiopia, in Ghana, in Kenya, Malawi, Mozambique, Namibia, Niger, Uganda, Sierra Leone, Tanzania, Zambia and Zimbabwe. Although the pathways of introduction have not yet been identified, its appearance in Africa in 2016 reveals the level of threat to other African regions and the tropical or subtropical regions of the world (Maiga, 2017).

In August 2016 in the North of Benin where the press puts forward a figure of 30,000 to 40,000 hectares of maize destroyed (Hama *et al.,* 2016) and according to information collected by the same authors, this caterpillar is effectively capable of migrating 2,000 km on the American continent. This assertion is supported by FAO (2017) which suggests that adults can travel up to 100 km per night. This species has been identified as *Spodoptera frugiperda* (Lepidoptera: Noctuidea) J.E. Smith or the American corn moth (Goergen *et al.*, 2016; FAO, 2017).

Goergen *et al.* (2016) published the first article in March 2016 which reports the presence of this species in West and Central Africa. Tindo *et al.* (2017) also published the first article confirming its presence in Cameroon between March and July 2015 in the West, Far North, Littoral, and South West regions, where the incidence of damage caused by this species varies from 25% to 75%.

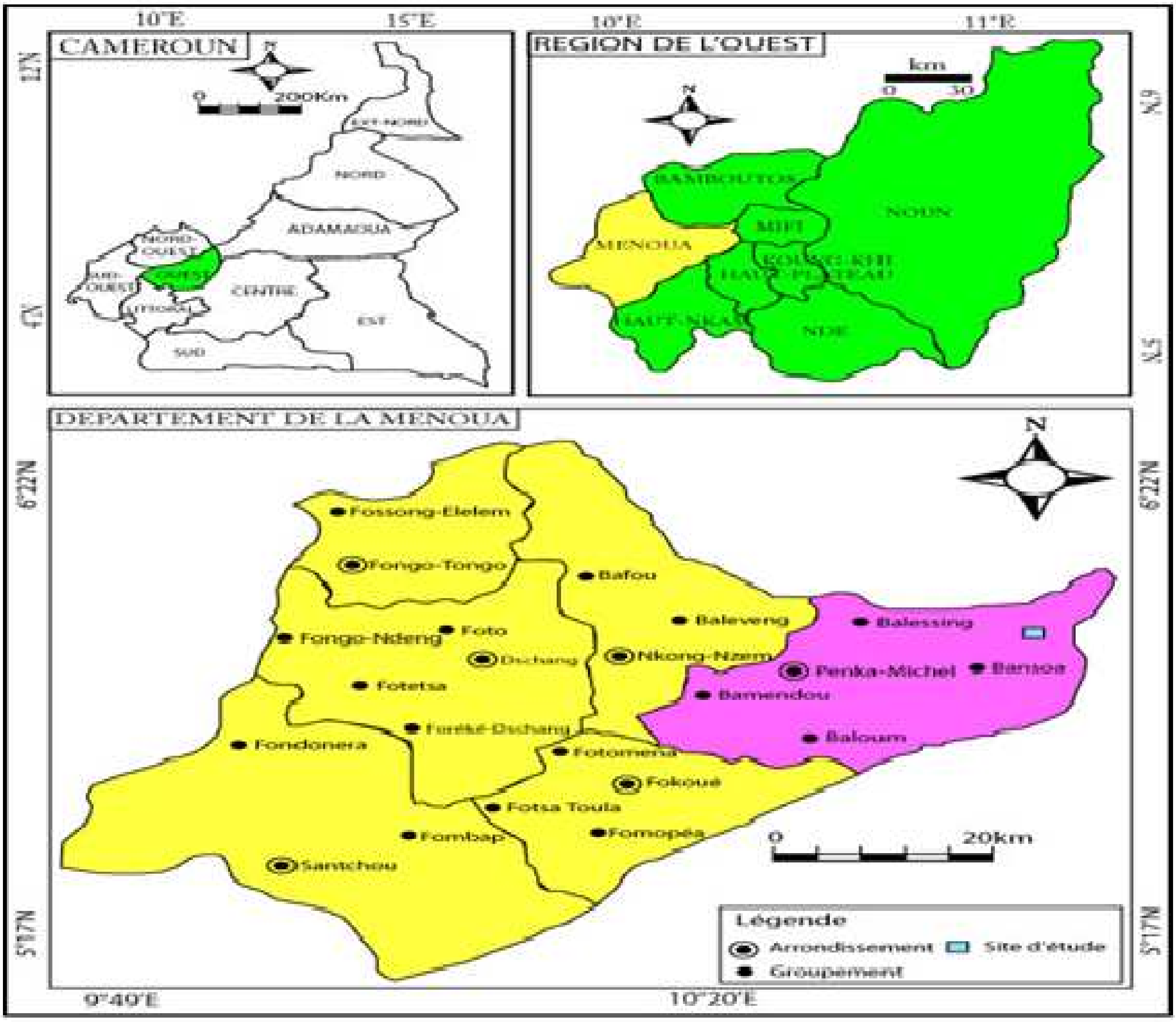
Fall armyworms larvae cause damages to the maize plant by consuming foliage parts under humid and warm climatic conditions. This pest affects the crop at different stages of growth, thereby disrupting the plant's grain filling ability. In maize, grain yield decreases of up to 58% have been reported (Chinwada *et al.*, 2019) and across Africa financial losses caused by this pest have been estimated to be between $2,481m and $6,187m (CABI, 2018). The fall armyworm is also known to quickly develop resistance to synthetic insecticides thus increasing the vulnerability of affected regions (Charleston, 2013). Adamczy *et al.* (1999); Abrahams *et al.* (2017) also state that in America this species is developing and continues to develop resistance to many synthetic insecticides and to transgenic corn. It is due to its ability to breed rapidly, migrate, and feed on a wide range of host plants, which make it very difficult to control.

Although the control of these insect pests with synthetic insecticides remains until today the most widespread practice, it is often ineffective and the frequent misuse of these insecticides has led to the emergence of insect resistance to several classes of pesticides (Goergen *et al.,* 2016). The use of bio-insecticide to manage fall army worm has the potential to be efficacious against the pest but safe to natural enemies and the environment. A recent review of Bateman *et al.* (2018) reported that certain bio-insecticides were effective against FAW or related pests but field trials in Africa were needed. In Tanzania bio-insecticide are registered and successfully used to manage other invasive Lepidoptera pests such as *Tuta absoluta* (Chidege *et al.,* 2016; Chidege *et al.,* 2018). The greatest strength of pheromone traps is their specificity, as most are essentially non-toxic and non-pathogenic to animals and humans (Stevenson *et al.,* 2017). The aim of this study is to contribute to the yield of maize production in the Menoua division by managing *Spodoptera frugiperda* population by using bio-insecticide and pheromone traps.

Materials and methods

Study area

This research was carried out on the Teaching, Research and Production Farm of the Faculty of Agronomy and Agricultural Sciences (FASA) of the University of Dschang at Bansoa (Fig.1).



Sources : Tchinda, (2020)

Fig. 1. Map of site localization

This work was conducted from October 2019 to July 2020. Locality situated in the Sub-division of Penka-Michel in the Menoua division of West Cameroon. It has a surface area of about 256km^3 with geographic coordinate between 5°26'54"north latitude and 10°18'49" east longitude with altitude of 1532m. Bansoa is situated at about 22km from Bafoussam, headquarter of the region and at 28km of Dschang. The research site has a gently slope resulting to a river flow at its base (Tchinda, 2020).

Climate

The climatic conditions of Bansoa reflect those of humid tropical, characterizes by a fresh and humid atmosphere condition. The average annual precipitations are between 1800 to 2000 mm and the annual temperature varies between 18.9°c and 21.5°c. The relative-humidity is above 60%. The raining frequency divide the year into two unequal seasons, namely a prolonged raining season beginning from Mid-March to Mid-November and a short dry season beginning from Mid-November to Mid-March (Tchinda, 2020).

Plant materials

The maize variety pannar (PAN 53) was used. This variety has been found to give 50% increase in grain yield over local varieties in the humid forest area of Cameroon (The *et al.,* 2001). Apart from its high yielding potential, it is highly demanded for consumption because of its sweet grain taste. Pannar is also rich for animal feed. It has a duration cycle of 90 to 110 days with productivity of about 6 to 10 tons/hectare. The certified seeds were bought from Balessing market distribution store.

Insecticides

The Bio-insecticide (Antario) contains *Bacillus thuringiensis* and *Abamectin*, this product works by producing an endotoxin inside insect larvae, quickly stopping insects from feeding and then killing them. Abamectin has a contact and stomach action with limited systemic activity, blocks electrical activity in nerves and muscles of pest. It is a wettable formulation. This treatment was applied at intervals of two weeks, starting from 35 days after sowing (DAS) at doses of 15g/snapsac sprayer. This product was provided by Africa IPM Ltd (Fig.2).

Chemical insecticide (Caiman B 50 WG) is a product derived from abamectin having as active ingredient emamectin benzoate which is an organic compound used as a systemic insecticide. It is a salt resulting from the reaction of benzoic acid with emamectin. It acts as an activator of the chloride channel by stimulating the release of g-aminobutyric acid, as a neurotransmitter inhibitor, thus causing paralysis. This product was bought from phytosanitary stores at Bansoa and was applied at two weeks' interval starting from 35 DAS at dose of 10g/snapsac sprayer for both planting dates.

Pheromone traps

Male pheromones trap associated with insecticidal strip (Dichlorovos) were used to capture adult fall armyworm insect, hence disrupting the insect population. The traps were set in the field 14days after seed sowing during the first and second planting date. The pheromone lure was replaced once on monthly bases. These materials were provided to us by Africa IPM Ltd during the first planting date, and were bought from Africa IPM distributor in Dschang during the second planting date.

Experimental design

A total area of 450m^2 was used for the experiment. This total area was divided into 2 experimental fields of equal sizes, one containing the pheromone trap and the other without pheromone trap. This experiment was set in place during two different planting dates. The portion without pheromone was not set in place during the first planting date because we received the pheromones traps at a time where all lands were already occupied and it was not possible to have a field with the same stage of development of the plants like the plot on which we set our experiment. Each of these fields was separated by a distance of at least 50m. Randomized Completed Block Design (RCBD) was used for the experiment on each field, with a total of three (3) treatments and three replications. These treatments are; Antario (T_1), CaïmanB (T_2) and Control (T_3).

The distance between the blocks and each experimental units were of 1.5m gap. The experimental units were 4 ^{x}4m each, with 5 sowing lines with 8 pockets per line and 2 seeds per pocket. The plant density was about 80 plants per plot. The maize was sown at the recommended spacing of 80 x 50 cm, which corresponds to 23 kg of seeds per ha and 50,000 plants per ha.

Cultural technics of maize production

Land preparation was done by clearing using machetes, then ploughing and staking using hoes, tapes and dabas. The seeds were sown at the rate of 2 seeds per pocket at a depth of 5 to 7cm deep with spacing of 80 x 50 cm.

An amendment based on poultry manure at the rate of 3 tons per ha was applied at sowing on each pocket. The first fertilizer application was carried out two weeks after sowing at a dose of 50 kg of urea plus 150 kg of NPK fertilizer (14-23-14-6S-1B2O3) per ha. Each plant receives approximately 5g of fertilizer. The second fertilizer application was done 6 weeks after sowing at a dose of 100kg of urea per ha.

Treatments were done in the early hours of the morning using a MATABI brand snapsac sprayer with a capacity of 15 liters. The porridge was prepared in a bucket before introducing in the sprayer. 15g of Antario and 10g of caiman B were used respectively per snapsac sprayer. Insecticide treatments were applied every 14 days from the 35th day after sowing. Pheromone lure was replaced after every 4 weeks.

The first weeding was carried out 3 weeks after sowing using hoes (manually). The second weeding took place 6 weeks after sowing using Extraxin 90%WD (Atrazine 900g/kg) which is a selective herbicide.

Data collection

Data collection started at 35 days after sowing for all parameters and continued once per week, making a total of six collections done, but data related to the number of moth capture by traps started at 35days after sowing and 14days before sowing for the first and second planting dates respectively. A total of ten and eighteen collections were done during the first and second planting dates respectively.

For sampling, 10 plants per experimental units were selected randomly (middle plants) and labeled using a marker. All data's collection was done throughout the growth stage of the plant up to cobs maturity. Visual observations were made on plants and remarks were noted in the data field sheet and photos were taken using a Samsung phone (16Mega pixel) depending on the objectives of the work. The specificity of these sampling as follows:

Pest identification

The presence of the pests on the leaves, stem and cobs were identified by observing galleries dug. Larvae were collected in the field on maize plants using forceps and put into plastic containers, then brought to the lab and placed in Petri dishes for identification. These larvae were rear by placing fresh maize leaves in petri dishes after every 2 days. Moths were trap by placing the pheromone set up. The key of morphological identification of Georgen *et al.* (2016) was used to identify the larvae, the adults and also the specimen in the laboratory.

Evaluation of the effects of planting date and pheromone trap on the leaf rate of infestation, abundance of larvae and growth variables of plant

The effects were determined on field with pheromone and those without pheromone for both planting dates. Parameters collected included: rate of infestation, abundance of larvae and growth variables of the plant.

Determination of infestation rate of plants

On each experimental unites, observations were made on 10 plants. The work consisted of counting the total number of leave per plant and the number of attacked leaves per plant. The number of attacked leave helped to determine the rate of infestation of plants by using the formula of Balajas *et al.* (2008):

$$Rate\ of\ infestation = \frac{Number\ of\ attacked\ leaves}{Total\ number\ of\ leaves} x100$$

Abundance of larvae

The first collection was done by carefully removing 10 plants in each experimental unite, these plants were carefully dissected with a sharp blade to collect all the larvae. Subsequent collection was done by opening and observing into the central leaves of the labeled plants. The number of larvae present per plants permitted to calculate the mean abundance of larvae on plants after each collection.

Growth variables of the plant

Plant height and stem circumference were recorded on the 10 labeled plants using a graduated tape (cm). This was done by measuring from the ground level up to the tip of the central leaf for plant height. The tape was rapped round the stem at about 10cm from ground level to get the stem circumference. The values obtain permitted to calculate the mean plant height and mean stem circumference.

Determination of interactions between planting date, pheromone traps and insecticides treatment on fall armyworm (FAW) population and the growth variables of maize

For both planting dates, pheromone traps were hung at the center of field on a stick, insecticides were applied every 14days.The 10 plants labeled were used to collected parameter of rate of infestation, abundance of larvae and pest severity. The procedure used to calculate rate of infestation and abundance of larvae was the same as described above.

Assessment of pest severity

The data related to pest severity was collected on weekly bases on 10 plants starting from 35 days after sowing (DAS) of the maize because it is at this stage that the plants are more attractive and vulnerable for colonization by stem related pests (ICIPE 2013). Severity was scored by visual observation using the scoring scale of 0–9 reported by Davis and Williams (2019) as shown below;

0: No visible leaf damage

1: Only pinhole damage on leaves

2: Pinhole and short hole damage to leaf

3: small elongated lesions (5-10 mm) on 1-3 leaves

4: Midsized lesions (10-30 mm) on 4-7 leaves

5: Large elongated lesions (>30 mm) or small portions eaten on 3-5 leaves

6: Elongated lesions (>30 mm) and large portions eaten on 3-5 leaves

7: Elongated lesions (> 30 cm) and 50% of leaf eaten

8: Elongated lesions (30 cm) and large portions eaten on 70% of leaves

9: Most leaves with long lesions and complete defoliation observed.

Estimation of the evolution of Spodopdera frugiperda moths with respect to planting date and pheromone.

After the installation of the traps, the moths captured were counted and recorded in the data field sheet weekly. The traps were then emptied and set back in place. The number of moths permitted to know their evolution during both planting dates.

Maize yield with respect to planting date, pheromones and insecticides.

This was done 120 days after sowing. On each experimental unit, harvest was done on the 10 sampling plants. On each mature plant, the ears and the husks were removed. The maize cobs were transported to the plant protection laboratory of university of Dschang where they were threshed, weighed to get the fresh weight and placed in an oven set at 70° C for 48 hours.

After drying, the seeds were weighed according to each experimental unit using a stainless steel electronic sensitive balance. The yield was calculated using the formula: (IRRI, 2017).

$$Yield = \frac{dry\ weight/plant}{unit\ surface\ area} x10000$$

Data analysis

Data (number of larvae, rate of infestation, pest severity, growth variables) were entered into the MS

Excel 2010 spreadsheet and analyzed using SAS JMP (Statistical Analysis System John's Macintosh Project) software version 8.0.2. Variance analyses by ANOVA. Means were compared using Turkey test at 5% probability level.

Results

Pest identification

After field captures and culturing the larvae in the laboratory, the main pests found in the different parts of maize plant was *Spodoptera frugiperda*. Only one species of pest was identified and collected during the experiment (Fig. 3).

The larvae raised took around 7-10 days before entering the pupation phase. The pupation phase lasted between 12 to 15 days before the adults emerged (Fig. 4).

Evaluation of the effects of planting date and pheromone trap on the leaf rate of infestation, abundance of larvae and growth variables of plant

During both planting dates, maize leaves were infested in the plot with and without pheromones. From Fig. 5A, the leaf rate of infestation was high in the first planting date and significantly (P<0.05) reduced during the second planting date.

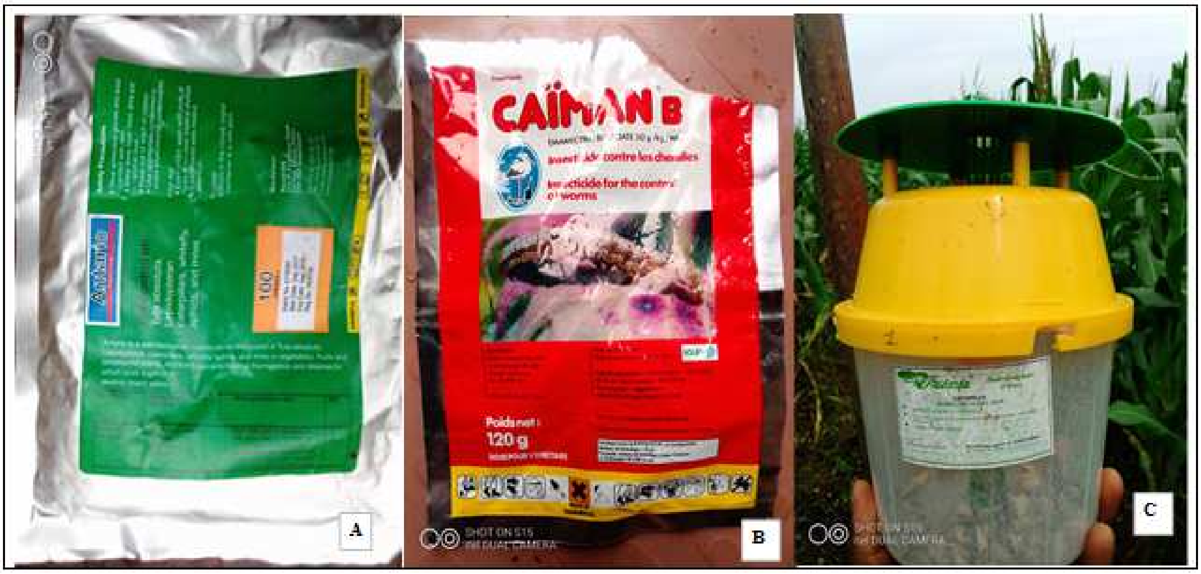
The difference between the plots with and without pheromone was not significant during this second planting date but slight increase was noted in plot with pheromones.

Table 1. Mean total yield of maize (t.ha-1) per planting date with and without pheromones traps.

Planting dates	Pheromone traps	Antario	Caiman B	Control
First planting	With pheromone	7.33±1.61a	8.00±1.32a	8.33±1.15a
	Without pheromone	0.00±0.00	0.00±0.00	0.00±0.00
Second planting	With pheromone	10.17±0.00a	9.00±0.00a	8.67±0.29a
	Without pheromone	8.83±0.76a	7.00±0.50b	7.33±0.29b

a, b: values affected with the same letters in the same line are not significantly (P>0.05) different.

The number of larvae (Fig. 5B) was more dominant during the first planting date, followed by the second planting date without pheromone trap. The portion with pheromone during the second planting date has very little number of larvae. Stem circumference (Fig. 5C) shows no significant difference during both planting dates on portion with and without pheromones. Plant height (figure 5 D) was slightly higher during the second planting date, but portions without pheromones traps has the greatest height.



(A) Antario, (B) Caiman B, (C) Pheromone trap

Fig. 2. Insecticides materials.

Determination of the interaction between planting dates, pheromone traps and insecticides treatment on Spodopdera frugiperda rate of infestation, abundance of larvae and severity

Mean number of larvae

Larvae were present in the two planting dates. The number of larvae was highly recorded during the first planting date (Fig. 6), Antario had the highest number of larvae at 35DAS.

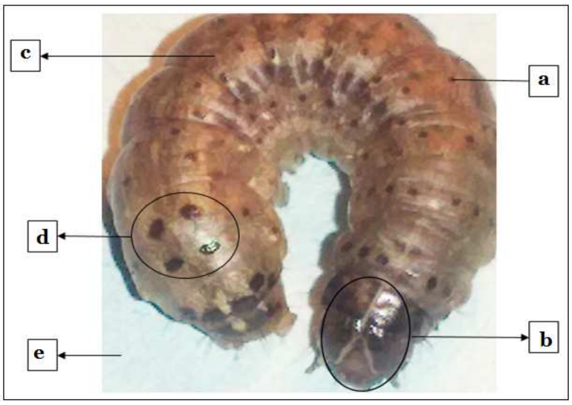


Fig. 3. photo attesting the presence of the characteristic Y and spots forming a square on *Spodoptera frugiperda* in the larval stage (a: pinnacle; b: inverted Y at the level of the head; c: abdominal segment; d: four black spots arranged in a square on the second to the last abdominal segment; e: cardboard support.

Antario experienced a normal reduction up to 56DAS where the number increased again before taking back it normal fall. This observation was also made with Caiman B. But for the control, the number of larvae reduced at 42DAS and rised at 49DAS before taking its normal reduction.

The presence of larvae was noted in plots with and without pheromones during the second planting date. Antario and Caimen B had their peak number of larvae at 35DAS and remained at zero throughout. The control had a great fall at 42DAS in plots with and without pheromones, before having an irregular frequency throughout.

Leaf rate of infestation

Leaves were damaged gradually throughout the 2 planting dates (Fig. 7), the first planting date presented significant difference (P<0.05) in leaf infestation rate and the curves were characterized by a zig zag form as compared to the second planting date were it is only the control that maintained the zig zag form up to 70 DAS. It can be seen that infestation rate reduced with respect to day after sowing (DAS) for all treatments during the first planting date and subsequently noted a gently increase at 70 DAS.

The control remained the most infested treatment at 70DAS for both planting date. The curves of caiman B and Antario remained confusing during the planting dates.

Fig. 4. different stages of development of *Spodoptera frugiperda:* Eggs stages (A) Larvae stages place on a maize leaf (B) Pupa stages place on a cardboard (C) Adult stages (D).

Mean severity

In Fig. 8, it can be seen that pest severity was high and varies from 0 to 6 score damage during the first planting date, all treatments experienced a gentle reduction in severity, up to 70DAS where an increase was recorded. The control had the highest result at 70DAS followed by Caïman B and lastly Antario.

In the second planting date the score damage did not exceeded one, the pest severity for Antario and Caimen B remained zero from 49 to 70 DAS for plot with and without pheromones. The control presented pest severity throughout the second planting date, having its highest values at 42DAS for plot with pheromone and 49 DAS for plot without pheromones.

Estimation of the evolution of Spodopdera frugiperda moths with respect to planting date and pheromone.

Fig. 9 shows that the curve for both planting dates had a zig zag form. The number of moth captured during the first planting date was more than that recorded during the second planting date.

The population of the moth was very small at -14 DAS right up to 35 days after sowing. The peak for both planting date was obtained at 42 days after sowing.

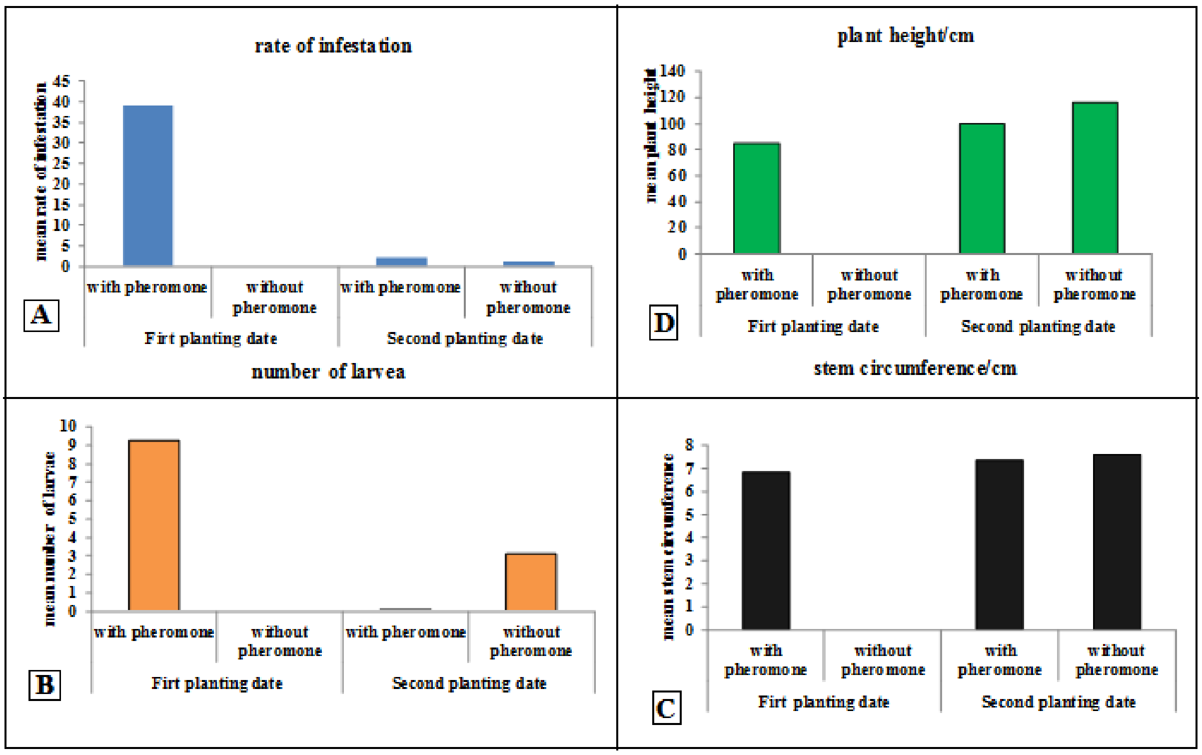


Fig. 5. Evolution of leaf rate of infestation (A), mean plant height (B), stem circumference (C) and number of larvae (D) with respect to planting date and pheromone.

Maize yield with respect to planting date, pheromones and insecticides.

The result obtained after analyses in Table 1 shows that, in general, high yield was obtained during the second planting date as compare to the first though there was no significant difference. The best yield was recorded on plots with pheromones during the second planting date with Antario topping first with a mean of 10.17 $t.ha^{-1}$, followed by caiman B and lastly the control although statistically values were similar. The control plot with pheromone during the first planting date recorded the least value of 6.33t/ha. It should be recalled here that the plot without pheromone was not set in place during the first planting date of the experiment.

Discussion

The presence of fall armyworm species alone in this experimental plot suggests that it might also prey on other caterpillar species, given its known cannibalistic behavior in the Americas, where it originated (Kammo *et al.*, 2019). Another hypothesis is that it has entered into competition with local species. This latter hypothesis seems more likely because, being new to this environment, it lacks specific natural predators, unlike the already present species, allowing it to multiply more rapidly. The morphological identification of the larvae matched descriptions provided by Goergen *et al.* (2016) and Maiga (2017), confirming it as *Spodoptera frugiperda*. *S. frugiperda* has the ability to migrate and reproduce rapidly (Murua and Virla, 2004; Belay, 2011; Capinera, 2014; Abrahams *et al.*, 2017). Its biology aligns with that described by CABI (2019), clearly outlining the different developmental stages of the fall armyworm.

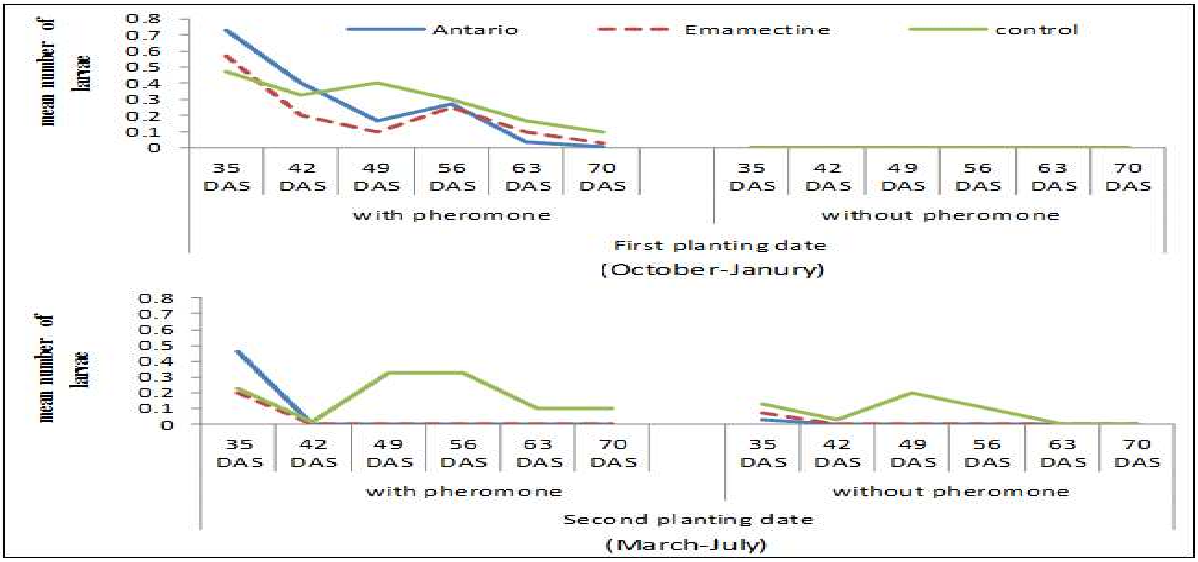


Fig. 6. Evolution of number of larvae on leaves with respect to planting date, pheromone and treatment.

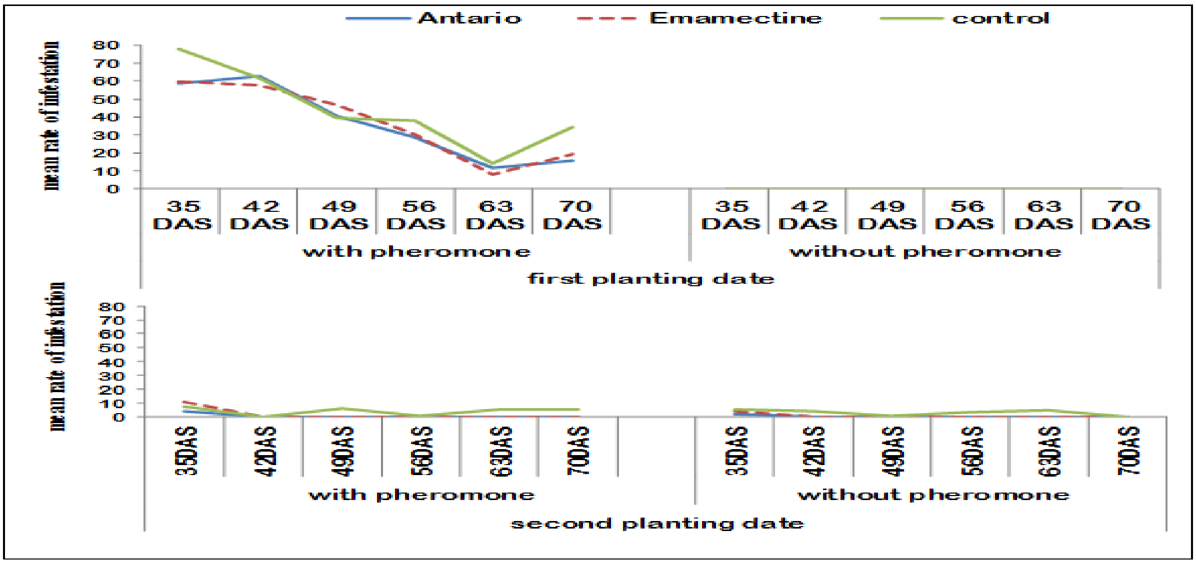


Fig. 7. Evolution of leaves rate of infestation with respect to planting date, pheromone and insecticide treatment.

Rainfall is a possible factor explaining the lower number of *S. frugiperda* larvae during the second planting date. Kammo *et al.* (2019) reported that heavy and light rain kill significant numbers of early instars of FAW. The relatively high rate of infestation during the first planting date, as shown in Figure 9, aligns with Tindo *et al.* (2017), who reported that the impact of infestation by *Spodoptera frugiperda* in different regions of Cameroon varied between 25% and 75%. The increase in plant height during the second planting date suggests that maize plants require a substantial amount of water for optimal growth and development.

The high number of larvae during the first planting date can be explained by the fact that, this period fulfilled favorable conditions (low rainfall and high temperatures) for larvae development. Generally, the results of this study show the effectiveness of all these different types of insecticides used in controlling fall armyworm. This is also in agreement with the results of Ogah *et al.* (2011) who reported that bio-insecticide significantly reduced the infestation of stem borers in rice. The gradual reduction of larvae population when treated with Antario shows the efficacy of the product to better control the pest in plot with and without pheromone. This also supports the results of Ande *et al.* (2010) who indicated the importance of the use of bio insecticides in the protection of maize against insect pests in the fields.

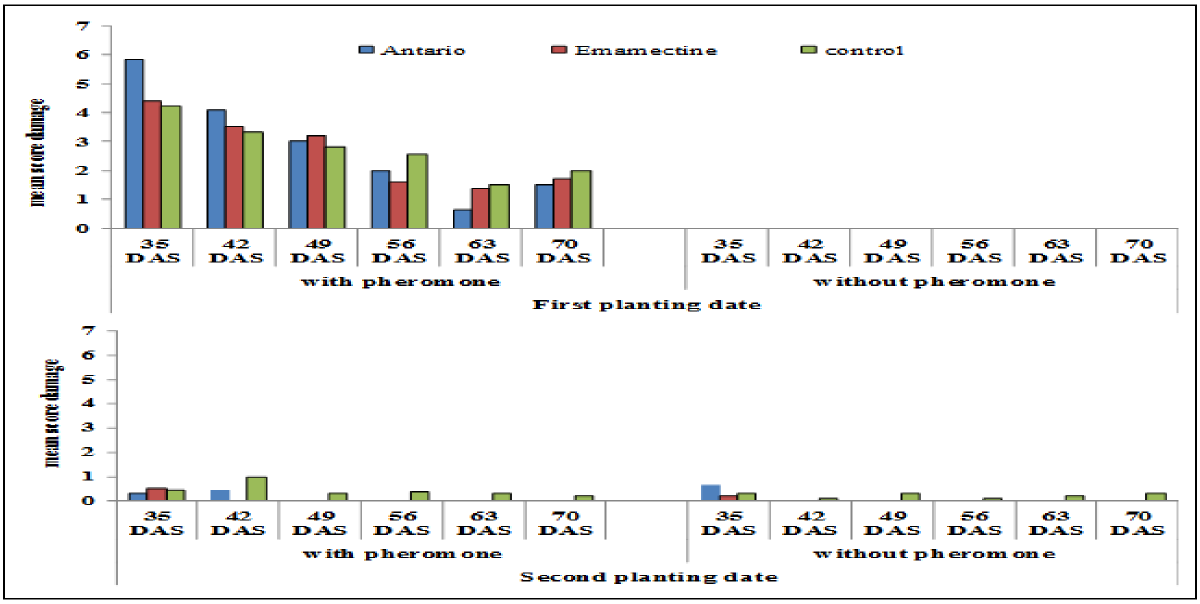


Fig. 8. Evolution of pest severity with respect to planting date, pheromone and treatment.

Our findings, which showed that attacks were more severe at 35 DAS, corroborate the fact that fall armyworm can attack maize at all stages of the plant's life cycle, with the most severe attacks usually on young plants (Tindo *et al.*, 2017). The reduction in infestation rate can also be explained by the gradual maturation of plant physiology; as the plant tissues become more turgid, they are less succulent and less attractive to the pest. The gentle increase in infestation at 63 DAS coincides with the period of tassel and ear formation, a stage when the plant is more succulent and susceptible to pest attacks.

The severity behavior greatly depends on the behavior of the number of larvae present on the leaves, which shows that the high severity score during the first planting date is as a result of the high number of larvae present in the field. The subsequent reduction of zero severity reported on plots treated with Antario and Caiman B during the second planting date tells us that there was no larvae present on the leaves.

This differentiation in the number of moths captured can be explain by the fact that during the first planting date, temperature was higher as compared to the second planting date which was dominated by cold weather. In general, our results from this site are in agreement with those reported by Kammo *et al.* (2019), who investigated the population trends of *S. frugiperda* along the Mexican Gulf Coast, the Isthmus of Tehuantepec, and the Yucatan Peninsula with pheromone traps. They found that low numbers of males were caught during cold weather, while peak captures occurred during warm weather. The zig zag form of the curve can be explained by the fact that the pheromone power reduces over time, hence reducing it capture ability and increases again after pheromone lure replacement.

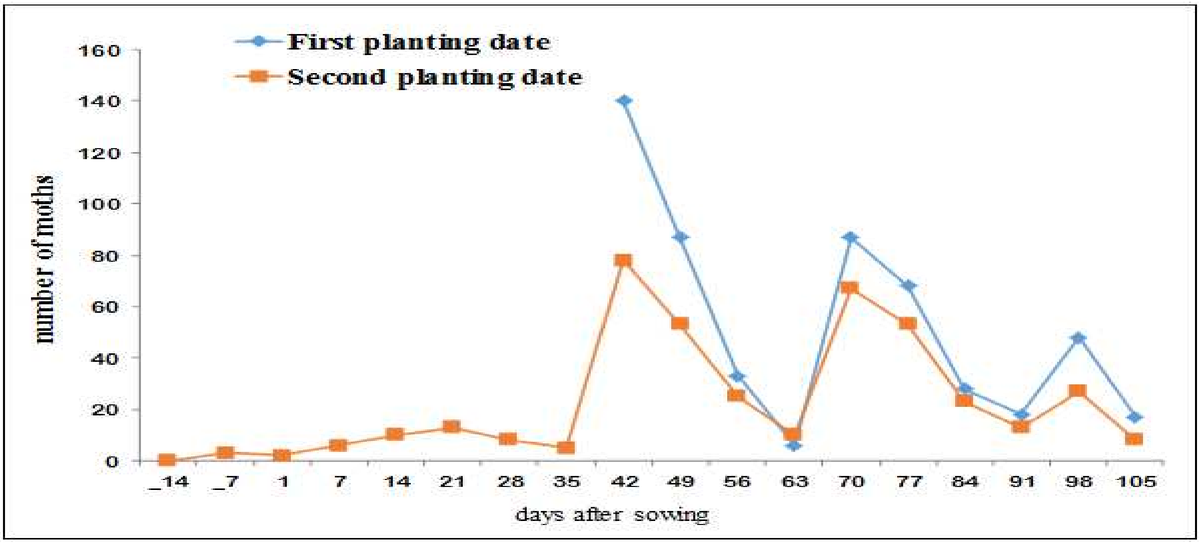


Fig. 9. Population of fall armyworm moths capture during the planting date.

Results clearly indicate that the yields obtained during the first and second planting dates were different. This difference could be attributed to the planting date, pheromone traps, and insecticide applications, which performed better during the second planting date. Wahedi *et al.* (2013) reported similar results on maize performance, demonstrating the effectiveness of different insecticides used for maize protection in the field. The plots with pheromone traps during the second planting date, treated with Antario and Caiman, recorded grain yields of 10.17 t/ha and 9.00 t/ha, respectively, compared to the control, which recorded 6.33 t/ha during the first planting date.

Conclusion

This study aimed to increase maize production in the Menoua division by managing the population of *Spodoptera frugiperda* using bio-insecticides and pheromone traps. Results relative to our objective indicate that the fall armyworm is the most significant pest, causing substantial yield losses. Larval abundance, leaf infestation rates, and pest severity were highest during the first planting date, peaking at 35 days after sowing (DAS). Growth variables were slightly greater during the second planting date. Among the methods tested, the second planting date combined with pheromone traps and Antario applied at 14-day intervals proved most effective in reducing pest incidence and severity, as well as larval numbers, while promoting optimal plant growth. The peak number of moths captured by pheromone traps for both planting seasons occurred at 42 DAS.

However, the bio-insecticide Antario, applied at two-week intervals during the second planting date on plots with pheromone traps, resulted in the highest yield performance, followed by Caiman B.

- Antario and pheromones can be recommended for the control of fall armyworm.
- It is recommended that farmers in Cameroon and other African countries affected by fall armyworm are made aware of this bio-insecticide and pheromone traps.
- Farmers are encouraged to adopt the second planting date combined with pheromone traps and treated with Antario to boost their production.
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Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Acknowledgements

We give thanks to Africa IPM you give us pheromones traps and Antario insecticide during the first planting of this research.

Author contributions

Djomaha ES was involved in planning, designing and supervising the work. Djomaha ES and Youmbi ND set up the trial, collected the data, drafted the manuscript, designed the figures, interpreting the facts and worked on the manuscript. All authors finalized the format and commented on the manuscript. All authors read and approved the final manuscript.

Funding

This article did not receive any speciic grant from funding agencies in the public, commercial, or not-for-proit sectors.

Availability of data and materials

Not applicable.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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