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Biological control of fall armyworm *Sopdoptera frugiperda* (Lepidoptera: Noctuidae) by using the pheromone Z7-dodecenyl acetate, Z11-hexadecenyl acetate, Z9-tetradecenyl acetate

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Abstract— *With an energy value of 86 kcal/100 g to 386 kcal/100 g, maize is a staple food for many people. In Côte d'Ivoire, maize is grown mainly in the north of the country, where it is an enormous source of income for the local population. However, maize cultivation is severely limited by parasitic constraints that affect the organoleptic quality and production of maize. These include the fall armyworm Spodoptera frugiperda, whose damage can cause up to 73% of yield losses. Today, in a sustainable agriculture and food security context, biological control constitutes an essential element. The aim of this study was to carry out biological control of the fall armyworm using the pheromones Z7-dodecenyl acetate, Z11-hexadecenyl acetate, Z9-tetradecenyl acetate. The study was carried out at the maize, millet and sorghum research station of the Centre National de Recherche Agronomique in Ferkessédougou in the north of the country. The experimental design was a total randomization, with four (4) plots containing the pheromone and one control plot. Three (3) vegetative stages of the EV 8728 maize variety sown, were monitored. The results showed a high average number of S. frugiperda adults caught (129 adults), with a low infestation rate (19.42%) and a high average number of other insects caught (162 insects caught) at phenological stage 2 of the maize. Maize yields in plots containing the pheromone ranged from 6.13 tons/ha to 6.27 tons/ha, around twice that of the control plot, which was 3.03 tons/ha. This pheromone can therefore be used to combat the fall armyworm.*

Keywords— ***Biological control, fall armyworm, Spodoptera frugiperda, pheromone, maize***

I. INTRODUCTION

Maize is a very important cereal crop in sub-Saharan Africa. With an energy value of 86 kcal/100 g to 386 kcal/100 g (Yapi and Kouassi, 2017), maize is a staple food for many people. It is grown mainly for its grains, which are an important source of nutrition for humans. In fact, these grains contain around 72 to 73% carbohydrates, 8 to 11% protein, 3 to 18% lipids, dietary fiber and many other minerals (P, K, Ca, Mg, Na, Fe, etc.) as well as vitamins A and E (Yapi and De Kouassi, 2017; Ranum et *al*., 2014). In Côte d'Ivoire, maize is grown mainly in the northern part of the country, with the Savannas region alone accounting for 60% of production (N'Da et *al*., 2022). Maize is an enormous source of revenue for the people of Côte d'Ivoire and Africa. Maize production from 2016 to 2018 grew exponentially from 967,196 to 1,054,960 tons per year (Ceresco, 2020). Despite this major nutritional and economic contribution to the population, maize growing is severely limited by a large number of parasitic constraints that affect the organoleptic quality and production of maize in Côte d'Ivoire. These include rodents, birds, diseases and insect pests. The latter include the fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae), which was first recorded in West Africa in 2016 (Goergen et *al*., 2016). It is a polyphagous insect, attacking crops such as cotton, rice, sugarcane, sorghum, millet, maize etc. (FAO, 2017; Prasanna et *al*., 2018). Damage caused by the fall armyworm can result in yield losses of between 15% and 73% (Bhusal and Chapagain, 2020). Several control methods have been used to reduce pest populations to acceptable levels. Chemical control using certain chemical insecticides such as cypermethrin and profenos, for example, has shown resistance phenomena (Koffi et *al*., 2021). Today, in order to protect plants and human health and for sustainable agriculture, new integrated pest management approaches exist. These include the use of biopesticides, biological agents and pheromones to control the fall armyworm (Duval *et* al., 2018; FAO, 2020; N'Guessan et *al*., 2022).

The aim of this work was to control *Spodoptera frugiperda* populations using pheromone. Specifically, it was to:

- assess the number of insects captured by pheromone traps;
- evaluate these insects in relation to the phenological stage of the maize;
- assess plot yields as a function of treatments.

II. MATERIALS AND METHODS

2.1. Study site

This study was carried out at the maize, millet and sorghum research station (MMS) of the National Center of Agronomic Research (CNRA) in Ferkessédougou (9°36′00″ Nord, 5°12′00″ Ouest). The town is the capital of the Tchologo region, which borders Mali and Burkina Faso. Ferkessédougou is located to 650 km from Abidjan, the country's economic capital and largest city, and to 360 km from Yamoussoukro, the political capital. The vegetation of the region is that of the treed savannah. The climate is very hot and very dry (similar to the Sudanese climate), with the harmattan, a powerful wind from the Sahara, considerably lowering the temperature in December and January. The long dry season (October-May) precedes the rainy season, marked by two rainfall maxima, one in June and the other in September (Figure 1).

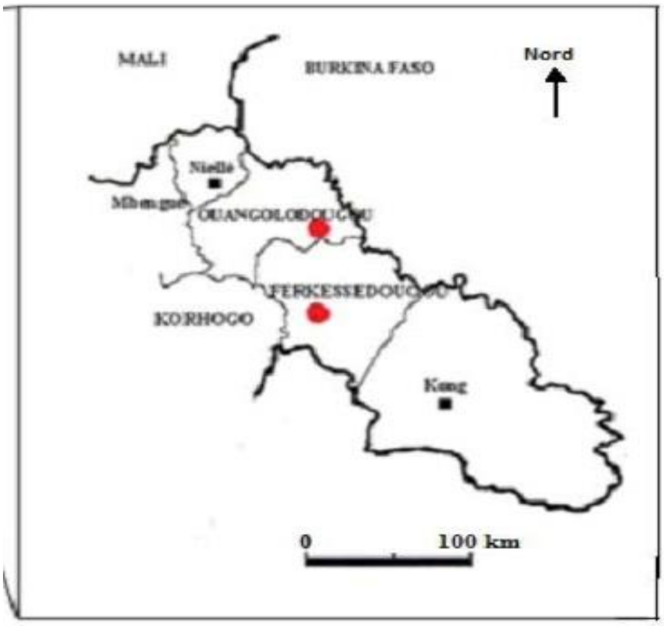


Fig. 1: Map of Ferkessédougou (Saraka, 2017)

2.2. Study device

The study design was based on total randomization. Five 0.5-hectare maize plots were replicated three times. The maize variety EV8728 was used for sowing. This is the most widely cultivated variety in Côte d'Ivoire. The pheromone Z7-dodecenyl acetate, Z11-hexadecenyl acetate, Z9-tetradecenyl acetate was placed in the middle of 4 plots and 1 plot without the pheromone was used as an untreated control. A total of 5 plots were set up for this study.

2.3. Monitoring of trial plots

The EV8728 variety is used for sowing. For the monitoring, 3 phenological stages of maize were chosen as followed:

- Stage 1: 2-3 leaves (approximately 15 cm in height).

- Stage 2: 6-8 leaves (70-90 cm high).
- Stage 3: flowering-heading.

A suitable location was chosen to place the trap. Indeed, the trap was placed in the middle of each plot using a piece of wood approximately 1.5 m long at the end of which it was suspended (Figure 2), at the rate of one trap per plot. The trap was equipped with a pheromone Z7-dodecenyl acetate, Z11-hexadecenyl acetate, Z9-tetradecenyl acetate (4.35 g/kg), and the water, when it is set up. The pheromone was replaced every 10 days, corresponding to it persistence duration.

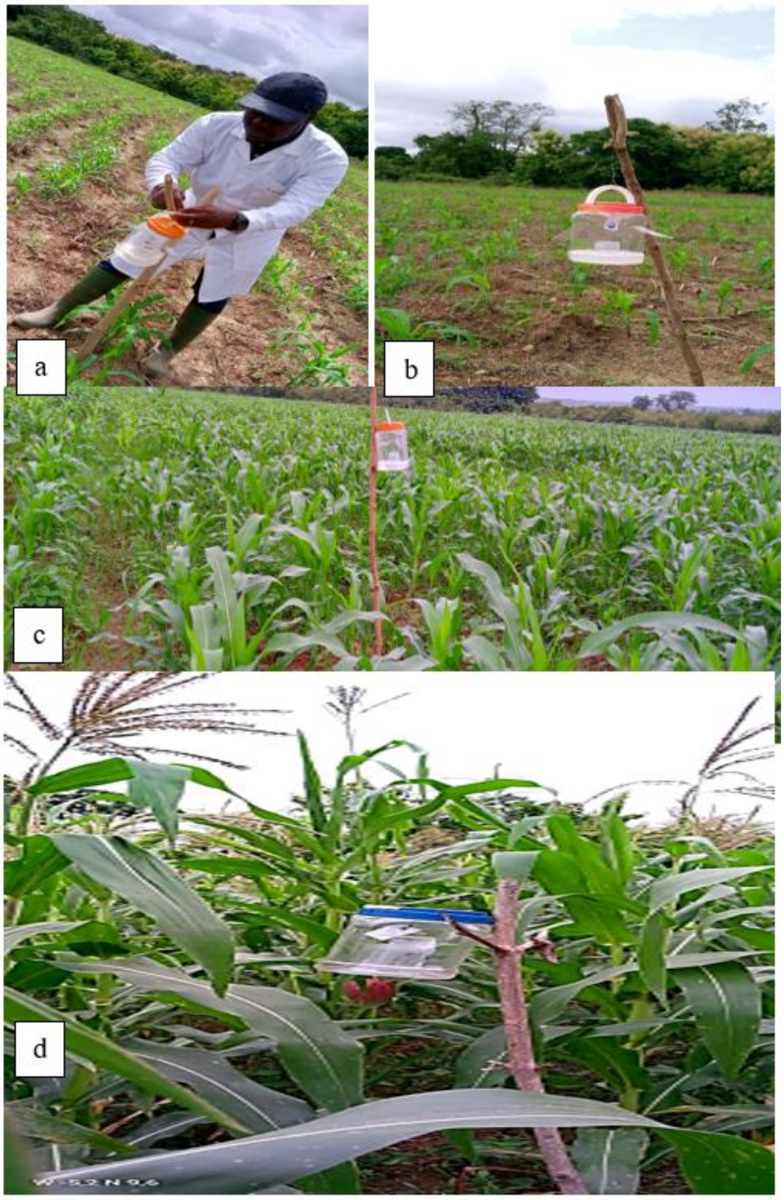


Fig. 2: Pheromone traps placed at different phenological stages of maize

A, b : Stage 1, c : Stage 2, d: Stage 3

2.4. Observations

Daily visits of the pheromone traps made it possible to collect the captured insects. To do this, the trap was opened by turning the transparent box located at the bottom of the trap counterclockwise, while firmly holding the closure above. The captured insects were collected and sorted every day. Adults of fall armyworm were counted separately from other captured species. It should be noted that perfect knowledge of fall armyworm adults is the basis for monitoring this pest.

2.5. Data analysis

Collected data during this study were submitted to Analysis of variance by SAS 9.4. software. Means comparison was realized with the LSD test at 0.05 threshold.

III. RESULT AND DISCUSSION

3.1. Number of insects trapped in the trial plots

Pheromone traps were used to capture several adults of *S. frugiperda* and many other insects. Other parameters such as the infestation rate and the number of live larvae were assessed to see how the pest was behaving in the plots. Table I shows the number of *S. frugiperda* adults caught at each phenological stage of maize.

At stage 1, corresponding to the 2 to 3 leaf stage, i.e. 10 to 24 days after germination, the pheromone traps captured 116 *S. frugiperda* adults. The infestation rate in the plots was lower (9.83% of plants infested) than in the control plot without pheromone, where an average of 27.33% of plants were infested. The number of live larvae collected in plots containing pheromone traps was 22 larvae compared with 53 larvae in the control plot. As for the other insects caught, there were 184 insects (Table I, Figure 3).

At stage 2, corresponding to the 6 to 8 leaf stage (25th to 39th day), the number of captured *S. frugiperda* adults was 129 with an average infestation rate of 19.42% of plants compared with 60.33% of infested plants in the control plot. The number of live *S. frugiperda* larvae was 26, which was lower than the control (48 larvae). One hundred and sixty-two (162) other insects were caught in the pheromone trap (Table I, Figure 3).

At stage 3, corresponding to heading (40 to 50 days after germination), the number of adults of *S. frugiperda* tended to fall, with 53 adults caught, an infestation rate of 23.25% compared with 73.67% in the control plot. Very few larvae were collected in both the plots containing pheromones and the control plot, with 3 and 4 larvae respectively. In addition, 143 other insects were caught in the pheromone trap (Table I, Figure 3).

The use of the pheromone Z7-dodecenyl acetate, Z11-hexadecenyl acetate, Z9-tetradecenyl acetate revealed the effectiveness of this semiochemical in controlling the armyworm. The results showed that at phenological stage 2 of maize, 129 adults of *S. frugiperda* were caught by pheromone traps, compared with 116 at stage 1 and 53 adults at stage 3. The high number of adults of *S. frugiperda* caught at the first two phenological stages of maize is thought to be due to the strong presence of the armyworm in the maize plots. At this stage, the maize plants, being younger, would have many succulent serves, thus attracting a large number of pests, including the armyworm. Kouamé *et al* (2014) and N'Guessan *et al* (2014) indicated that succulent plant parts are an important food source for certain pests. This could explain the high presence of *S. frugiperda* on maize plants during these first two phenological stages compared with phenological stage 3. Also, during these first two phenological stages of maize, the plants are thought to host numerous pests in the corncob. This was not the case at phenological stage 3, when the corncob disappeared and flowers appeared. Adeye *et al.* (2018) indicated that the drop in population levels of *S. frugiperda* larvae in untreated plots can be explained on one hand by their entry into chrysalidation and on the other hand by the disappearance of the cones where the larvae were lodged, which gave way to maize flowers, thus explaining the low number of individuals caught at phenological stage 3.

Table I: Some parameters observed as a function of the phenological stage of maize

Some parameters studied	Stade 1	Untreated control	Stade 2	Untreated control	Stade 3	Untreated control
S. frugiperda Adults	116	0	129	0	53	0
Infestation rate (%)	9.83	27.33	19.42	60.33	23.25	73.67
Live larvae	22	53	26	48	3	4
Other insects	184	0	162	0	143	0

Fig. 3: Spodoptera frugiperda larvae in the whorl of a maize plant

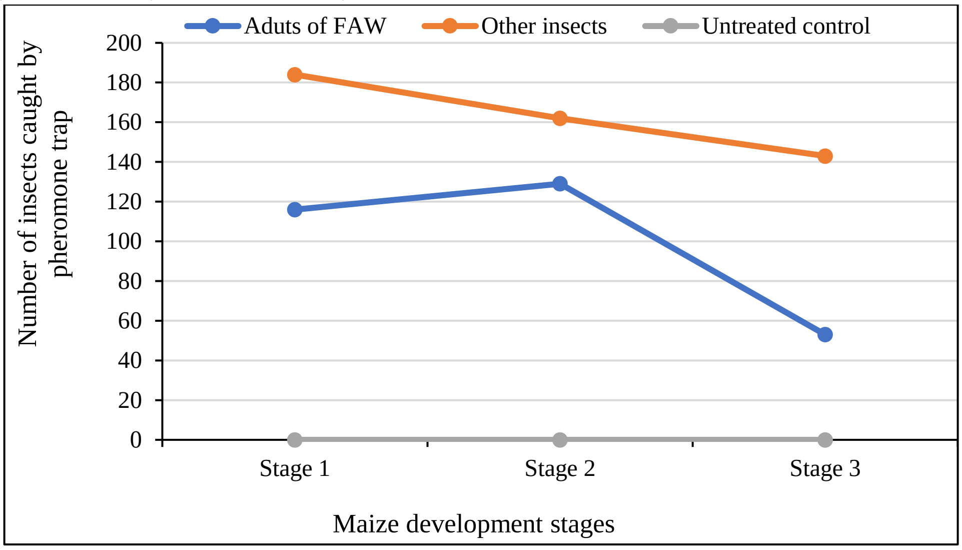
3.2. Evolution of insect population trapped as relation of phenological stages of maize

From the first phenological stage of maize (2-3 leaves), the number of *S. frugiperda* adults captured increased strongly at the second phenological stage corresponding to 6-8 leaves. Then this number fell drastically at phenological stage 3, i.e. flowering or ear-heading of the maize (Figure 3). The results obtained during this study showed that the number of *S. frugiperda* individuals trapped by the pheromone Z7-dodecenyl acetate, Z11-hexadecenyl acetate, Z9-tetradecenyl acetate increases from phenological stage 1, with a peak at phenological stage 2 and then decreases until phenological stage 3 of maize. The peak observed at phenological stage 2 of the maize could be due to the many leaves (6 to 8 leaves per plant) acquired by the maize plants, which could serve as a food source, breeding ground and oviposition site for *S. frugiperda*. According to Malausa and Marival (1981), maize is most susceptible to *S. frugiperda* at the 6-8 leaf stage. They state that it is at this stage that the largest number of larvae are collected. As a consequence, he indicates that the eggs are deposited on the very young plants (stage 1) and the most significant damage is caused at the following stage (2) by the older larvae that emerge from these eggs; these larvae then hang around in the maize corncob where they devour the young leaves.

As for the other insects caught, at phenological stage 1, a high number were captured by the pheromone trap. The number of other insects caught continued to fall until the 3rd phenological stage of the maize, i.e. flowering or heading (Figure 3). In the untreated control plot, no insects were caught throughout the maize cycle. This number remained static because no trap had been installed to capture insects (Figure 3). With regard to the other insects captured by the pheromone, a higher number of individuals were captured at phenological stage 1 of the maize. Beyond that, a decrease in the number of individuals trapped was observed up to phenological stage 3. This could be due to the fact that at phenological stage 1, the smaller maize plants (2 to 3 leaves) are very sensitive to several groups of insects. At the early season, a large number of pests can be found in maize crops (armyworms, black cutworms and other noctuidae, potato stemworms, white grubs (chafer sp.), wireworms, codling moths, corn flea beetles, seed maggots, prairie tent caterpillars, slugs, brown plant bugs, etc.) (Labrie *et al.*, 2020). In the control plot, no insects were caught because there was no treatment.

3.3. Yield assessment depending on the treatments

Control of the armyworm using the pheromone Z7-dodecenyl acetate, Z11-hexadecenyl acetate, Z9-tetradecenyl acetate (4.35 g/kg) placed in 4 different plots made it possible to give results on the yield of the experimental plots. These results are given in the table below (Table 2). Plots 1, 2, 3 and 4, in which the pheromone traps were placed, gave yields ranging from 6.13 tons per hectare to 6.27 tons per hectare. This is much higher than the yield from the untreated plot, which gave only 3.03 tons per hectare. These results are significantly different ($p = 0.0001$) at the 0.05 threshold (Table II). The use of the pheromone Z7-dodecenyl acetate, Z11-hexadecenyl acetate, Z9-tetradecenyl acetate revealed the efficacy of this biological control through the yield of the different plots of maize. Plots 1, 2, 3 and 4, in which pheromone traps were placed, gave a yield of between 6.13 ± 0.38 tons per hectare and 6.27 ± 0.58 tons per hectare of maize grain, compared with the control plot, which gave a lower yield of 3.03 ± 0.30 tons per hectare of maize grain. This difference in yield between these treated plots and the untreated control plot could be explained by the fact that the control plot without the pheromone would be virtually ravaged by insect pests, in particular the fall armyworm. N'Guessan et al (2023) indicated that this caterpillar attacks all phenological stages of maize. The only maize variety used in this study was EV 8728. However, CABI (2017) advised using a mixture of varieties in order to avoid numerous attacks by the armyworm. This led to an increase in numbers of caterpillars and attack rates in the control plot, resulting in a halving of the yield in this plot.



FAW: Fall Armyworm

Fig.3 : Evolution of the number of adults of S. frugiperda and other insects caught in the pheromone trap according to the phenological stages of the maize

Table II: Yield assessment of the applied treatments.

Parcels	**Yield (t/ha)**
Parcel 1	6.13 ± 0.38^{a}
Parcel 2	6.20 ± 0.34^{a}
Parcel 3	6.27 ± 0.50^{a}
Parcel 4	6.27 ± 0.58^{a}
Untreated parcel	3.03 ± 0.30^{b}
p	**0.0001**

Averages with the same letter in the same column are not statistically different (LSD test; 5%)

IV. CONCLUSION

The pheromone Z7-dodecenyl acetate, Z11-hexadecenyl acetate, Z9-tetradecenyl acetate allowed to trap a high number of *Sopodoptera frugiperda* larvae and other pests. It made it possible to reduce the number of live larvae of this pest as well as the rate of attack in the plots, and helped to increase maize grain yields by more than 50%. This pheromone is therefore an important element in the biological fight against the armyworm, and should be proposed to professionals in the maize sector.

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