Use of selected chemical and biological insecticides to control lepidopteran pests of maize fields in central Côte d'Ivoire

ABSTRACT

Control of lepidopteranlarvae, the main pests in maizefields, has becomenecessarysince the appearance and spread of *Spodopterafrugiperda*. The study was carried out at the Institut National PolytechniqueHouphouët-Boigny in Yamoussoukro (Central Côte d'Ivoire). The study aimedto determine the effectiveness of three chemical - Viper 46 EC (Acetamiprid 16 g/l and Indoxacarb 30 g/l), K-Optimal 35 EC (Lambdacyhalothrin 15 g/l and Acetamiprid 20 g/l) and Ampligo 150 ZC (Chlorantanlipol 100 g/l and Lambdacyhalothrin 50 g/l)- and one biological insecticide Bio-Elit (Azadirachtin, Salanin, Nimbin and Melandriol) on lepidopteran larvae in maize fields using a randomized complete block design with five treatments and three repetitions. Data on insect identification, plant infestation, damage, and yield were collected. Insects' identification was based on morphology using identification keys. Plant damage was assessed by visually estimating the plant health status (unattacked and attacked plants). Grain dry weight was used to estimate field yield. The encountered maize field insects belonged to 10 orders: Heteroptera, Hymenoptera, Homoptera, Coleoptera, Diptera, Dictyoptera, Odonata, Orthoptera, Dermaptera, and Lepidoptera. Five lepidopteran pest larvae have been recorded. Three of them were classified as minor pests (*Eldanasaccharina*, *Ostrinianubilalis*, and *Helicoverpazea*), one as important (*Sesamiacalamistis*),and one as a major pest (*Spodopterafrugiperda*). On untreated plots, more than 76% of plants were moderately to heavily attacked. However, on treated plots, plants showed isolated to moderate attacks. Insecticide sprayingscontrolled pest populations, reduced damage, and increased yield. The yields obtained on untreated plots (2.26±0.21 t/ha) were lower than those on treated plots (3.29±0.11 to 3.60±0.09 t/ha). The yield increase rate ranged from 45.74 to 59.63%. The best control was recorded with Ampligo (59.63%) and Bio-Elit (50.83%) compared to Viper (49.41%) and K-Optimal (45.74%). Therefore, the alternating use of synthetic or biological insecticides, which are not very toxic for humans and the environment but are effective on insect pests, increases the effectiveness of the control and provides a positive response to the problem of pest resistance while protecting the environment.

Keywords: Lepidoptera, larvae, damage,insecticides, Maize, Côte d'Ivoire

1. INTRODUCTION

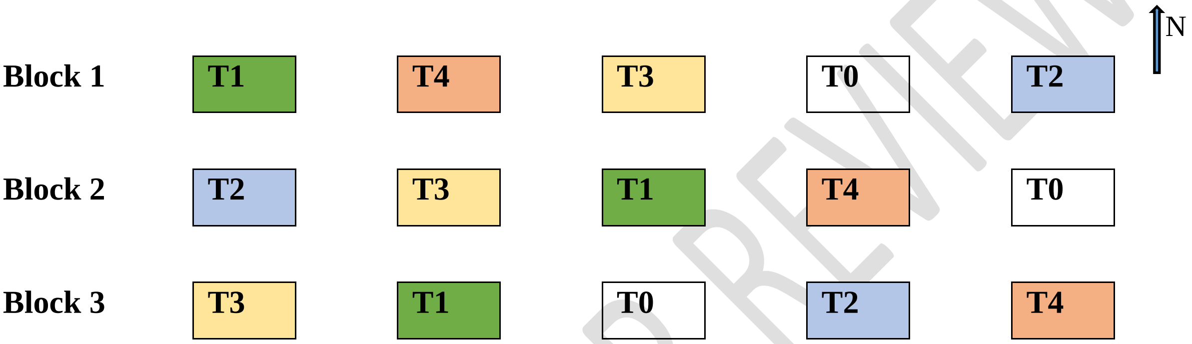
Maize (*Zea mays* L.) is one of the world's most important crops, with over 150 million hectares cultivated and an annual production of around 800 million tons of grain (1). The crop has become a staple food in many parts of the world, with total production surpassing wheat or rice performances. In addition to direct human consumption, maize is also used for animal feed and producing ethanol, syrup, and corn starch (2). Maize is vital for most smallholders and is usually grown alongside horticultural crops and other cereals, which collectively provide food and income (3). There are over 3,500 products where maize is used. The increasing demand from the poultry feed sector, the largest consumer of maize, and increasing demand for specialty corn (sweet corn, baby corn, popcorn, and quality protein maize), enhance the scope of its production and farmers' income (4). However, maize crops suffer abiotic and biotic stresses. Abiotic stresses dues to drought, salinity, and high and low temperatures (5; 6), together with biotic stresses caused by fungi, bacteria, and viruses (7; 8) and pests (9; 10) negatively affect maize growth, development, and eventually production (3). In addition, abiotic and biotic stresses are often present simultaneously and severely influence maize production (6).

Moreover, maize production is often subject to high losses caused by various insect pests (9; 3; 4; 11). More recently, an invasive insect, *Spodopterafrugiperda*(Smith) (Lepidoptera: Noctuidae), also known as the fall armyworm, became a major pest causing substantial yield losses on maize in the region (12; 13). This insect was detected in central and western Africa in early 2016 and quickly spread across all over within two years to more than forty African countries due to unscientific and uncontrolled trade. It is a highly polyphagous migratory lepidopteran pest species referring to the invasive behavior of larvae (12). Consequently, controlling pests is becoming a major concern for farmers. Multidisciplinary applied research and incentives for farmers to adopt innovative IPM strategies are essential to ensure the sustainability of pest management (14). Although insecticides have adverse consequences for the environment (15; 16), biodiversity and beneficial insects (17), human health (18; 19) leave food residues (20), and induce resistance phenomena in insects (21), chemical control has remained the most widely used due to the immediate effects observed after spraying. To overcome pest resistance, a wide range of insecticides is essential. The main objective of this study is to provide the best knowledge on lepidopteran pests of maize and to evaluate several insecticides to improve maize production.

2. MATERIAL AND METHODS

2.1. Experimental design

The trial was set up using a randomized complete block design containing 15 elementary plots with five treatments repeated thrice.The elementary plots covered 85.5 m² (19 m × 4.5 m) and were separated 2 m apart. Plots were spaced 0.75 m between rows and 0.5 m on the row, giving a density of 228 pots per elementary plot. The variety maize EV8728 SR was sowedin July 2021 at two seeds per pot. Subsequently, weeding was manually done when needed.



Block 1	T1	T4	T3	T0	T2
Block 2	T2	T3	T1	T4	T0
Block 3	T3	T1	T0	T2	T4

Figure 1. Experimental design

T0 :Untreated plots ; T1 : plots treatedwithViper 46 EC ; T2 : plots treatedwith K-Optimal 35 EC ; T3 : plots treatedwithAmpligo 150 ZC ; T4 : plots treatedwith Bio-Elit

Table 1. Insecticides used in this study

Treatments	Trade name	Active substances concentration	ChemicalFamilies
T0	Control	Untreated plots	
T1	Viper 46 EC	Acetamiprid 16 g/l Indoxacarb 30 g/l	Neonicotinoids Oxadiazins
T2	K-Optimal 35 EC	Lambdacyhalothrin 15 g/l Acetamiprid 20 g/l	Pyrethrinoids Neonicotinoids
T 3	Ampligo 150 ZC	Chlorantanlipol 100 g/l Lambdacyhalothrin 50 g/l	DiamidAnthranilics Pyrethrinoids
T4	Bio-Elit	Azadirachtin, Salanin, Nimbin, Melandriol	Bio-insecticide

2.2. Data collection

Thirty (30) plants were observed on the central rows per elementary plot to avoid border effects. Two observations were made three days before and after insecticide spraying at the following plant development stages: emergence, growth (vegetative), flowering, and fruiting. At the ripening stage, an observation was made without insecticide spraying. Plant infestation, damage, and yield were collected. Insect identification was based on morphological characteristics, using a binocular microscope (G × 50). Observed characteristics were compared with the laboratory’s collection and identification keys (22; 23; 24; 25; 26). In addition, the damage severity was assessed by visually evaluating the plant’s health status (non-attacked and attacked plants). Six indices ranging from 0 to 5 (Table 2) were adapted from the scoring scale proposed by Sally-Sy (27).

The yield was assessed by weighing the dry grains on 30 plants per plot, using a 15 kg capacity electronic scale. Similarly, the yield increase rate was calculated using the formula adopted by Adja (28).

$$Yield\ Increase\ Rate\ (\%) = \frac{(Yield\ of\ Treated\ Plot - Yield\ of\ Untreated\ plot) \times 100}{Yield\ of\ Untreated\ Plot}$$

Table 2. Damage severity index adapted from Sally-Sy (2013)

Indices	Severity damage	Observation
0	No visible damage	No visible attack
1	From 1 to 9% of damage	Isolatedattacks
2	From 10 to 24% of damage	Moderateattacks
3	From 25 to 49% of damage	Medium attacks
4	From 50 to 74% of damage	Heavy attacks
5	More than75% of damage	Plants destroyed

2.3. Data Analysis

Data were subjected to analysis of variance using STATISTICA 10.1. Where significant differences were found at a significance level of 0.05, Duncan’s test was performed for multiple pairwise mean comparisons. The percentage of plants attacked was determined based on damage indices for each treatment.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Insect inventory

A total of 3,416 individuals representing 43 species, 26 families, and ten orders were collected in the field (Table 3). The most diversified orders were Heteroptera (8 species and four families), Hymenoptera (6 species and two families), Diptera (5 species and five families), Orthoptera (5 species and four families), and Lepidoptera (5 species and three families). These orders are followed by Coleoptera (4 species and three families), Homoptera (3 species and two families), Odonatoptera (3 species and one family), Dictyoptera (3 species and one family), Dermatoptera (one species and one family) and Lepidoptera (2 species and one family). Dermaptera (one species and one family) (Table3) is the least diversified order in our test field.

Three trophic groups were identified: pests, predators, and pollinators. Pests were the most numerous and were found in Lepidoptera, Diptera, Coleoptera, Hymenoptera, Orthoptera, Homoptera, and Heteroptera. Predators belongedtoColeoptera, Hymenoptera, Heteroptera, Dermaptera, Dictyoptera, and Odonaptera. Pollinators were observed in Diptera, Hymenoptera, and Lepidoptera (Table 3).

Table 3. Status of insects collected in the tested maize field

Orders	**Families**	**Species**	**Status**	**Relative Abundance (%)**
Lepidoptera	Noctuidae	*Spodopterafrugiperda*	Pests	13.14
		Sesamiacalamistis	Pests	1.64
		Helicoverpazea	Pests	1.00
	Crambidae	*Ostrinianubilalis*	Pests	0.94
	Pyralidae	*Eldanasaccharina*	Pests	0.97
Diptera	Tachinidae	*Dexia rustica*	Pests	0.20
	Antomyiidae	*Deliaplatura*	Pests	0.18
	Diopsidae	*Diopsisthoracica*	Pests	0.23
	Muscidae	*Muscadomestica*	Pollinators	3.22
	Tephritidae	*Dacusciliatus*	Pests	0.35
Coleoptera	Cocccinelidae	*Cheilomenessulphurae*	Predators	2.08
		Henosepilachna argus	Pests	1.38
	Curculionidae	*Sphenophoruscallosus*	Pests	0.20
	Tenebrionidae	*Lagriavillosa*	Pests	1.64
Hymenoptera	Formicidae	*Camponotussp.*	Predators	30.94

		Polyrhachissp.	Pests/Predators	1.93
		Pachycondylasylvestri	Pests/Predators	1.70
		Crematogasterquadriformis	Pests/Predators	3.89
		Oecophyllalonginoda	Pests/Predators	2.14
	Apidae	*Apis mellifera*	Pollinators	2.20
Orthoptera	Pyrgomorphidae	*Zonocerusvariegatus*	Pests	0.41
		Atractomorphaacutipennis	Pests	0.85
	Gryllidae	*Gyllusbimaculatus*	Pests	0.32
	Tetrigidae	*Tetrixundulata*	Pests	0.85
	Acrididae	*Chorthippusalbomarginatus*	Pests	0.44
Homoptera	Aphididae	*Rhopalosiphummaidis*	Pests	1.17
		Aphisgossipii	Pests	2.05
	Cercopidae	*Deoisflavopicta*	Pests	1.17
Heteroptera	Pentatomidae	*Aspaviaarmigera*	Pests	8.34
		Acrosternumheegeri	Pests	0.50
		Hediocorisfasciatus	Pests	1.08
		Eysarcorisinconspicuus	Pests	0.29
	Reduviidae	*Rhynocorishutsebauti*	Pests	0.50
	Pyrrhocoridae	*Dysdercuswoelkerii*	Pests	3.81
		Dysdecussupertitiosus	Pests	1.17
	Miridae	*Helopeltisantonii*	Pests	0.67
Dermaptera	Forficulidae	*Forficulasp.*	Predators	2.75
Dictyoptera	Mantidae	*Sphodromantis*sp.	Predators	0.35
		Tarachodesafzelii	Predators	0.15
		Mantisreligiosa	Predators	0.76
Odonaptera	Libellulidae	*Sympetrumflaveolum*	Predators	0.97
		Plathemislydia	Predators	0.94
		Libellulasp.	Predators	0.50
Total: 10	**26**	**43**	**03**	**100**

3.1.2. Impact of insecticides on populations of Lepidopteran pests

Impact of insecticides on populations of *Spodopterafrugiperda*

*Spodopterafrugiperda*larvae were present on all plots at the time of emergence (4.33±0.57 to 5.33±0.57 individuals on 30 plants per elementary plot). This population fluctuated in the untreated plots during all stages of plant development (Figure 2a). At emergence, after insecticide spraying, the larval population was significantly higher (F $_{(4;14)}$ = 53.93; p = 0.00001) on control plots (8±1 individuals) than on treated plots Viper (2±0 individuals) and K-Optimal (3±1 individuals), which were higher than those on other treated plots Ampligo (0.33±0.57 individuals) and Bio-Elit (0.67±0.57 individuals). From the growing to the ripening stage, *S. frugiperda* larvae on Control plots (8.33±0.57 to 14±1 individuals) were significantly higher than those on treated plots Viper, K-Optimal T2, T3Ampligo, and T4 Bio-Elit(less than 3±1 individuals). Analysis of variance showed significant differences (F $(_{4;14})$ =43.25 to 257; $p = 0.00001$) between treatments at each plant development stage (Appendix 1).

Impact of insecticides on populations of *Sesamiacalamistis*

During emergence, *Sesamiacalamistis* was present in the plots (0.33±0.57 to 1±1 individual per plot). In control plots, *S. calamistis* populations increased from the growing (vegetative) to the flowering stage (Figure 2b). At emergence, after insecticide spraying, the *S. calamistis* population on control plots T0 (2±0 individuals) was significantly higher (F $(_{4;14})$ = 34; $p = 0.000009$)than those on treated plots Viper, K-Optimal, Ampligo, and Bio-Elit (less than 0.33±0.57 individuals). From the growing to the flowering stage, *S. calamistis* populations on control plots T0 (2.33±0.57 to 3.33±0.57 individuals) were significantly higher (F $(_{4;14})$ =14.5 to 121; $p < 0.00036$)than those on treated plots T1, T2, T3, and T4 (less than 0.33±0.57 individuals). From fruiting to ripening, *S. calamistis* was absent.

Impact of insecticides on the population of *Helocoverpazea*

Helicoverpazea was absent on all plots fromthe emergence to the growing stages. From flowering to ripening, the population of *H. zea* increased (Figure 2c). After insecticide spray, the population of *H. zea* on the control plot (0.66±0.57 to 3.33±1.15 individuals per elementary plot) was significantly higher (F $(_{4;14})$ = 4 to 49; $p < 0.0343$)than those on the treated plots Viper, K-Optimal, Ampligo, and Bio-Elit (less than 0.33±0.57 individual).

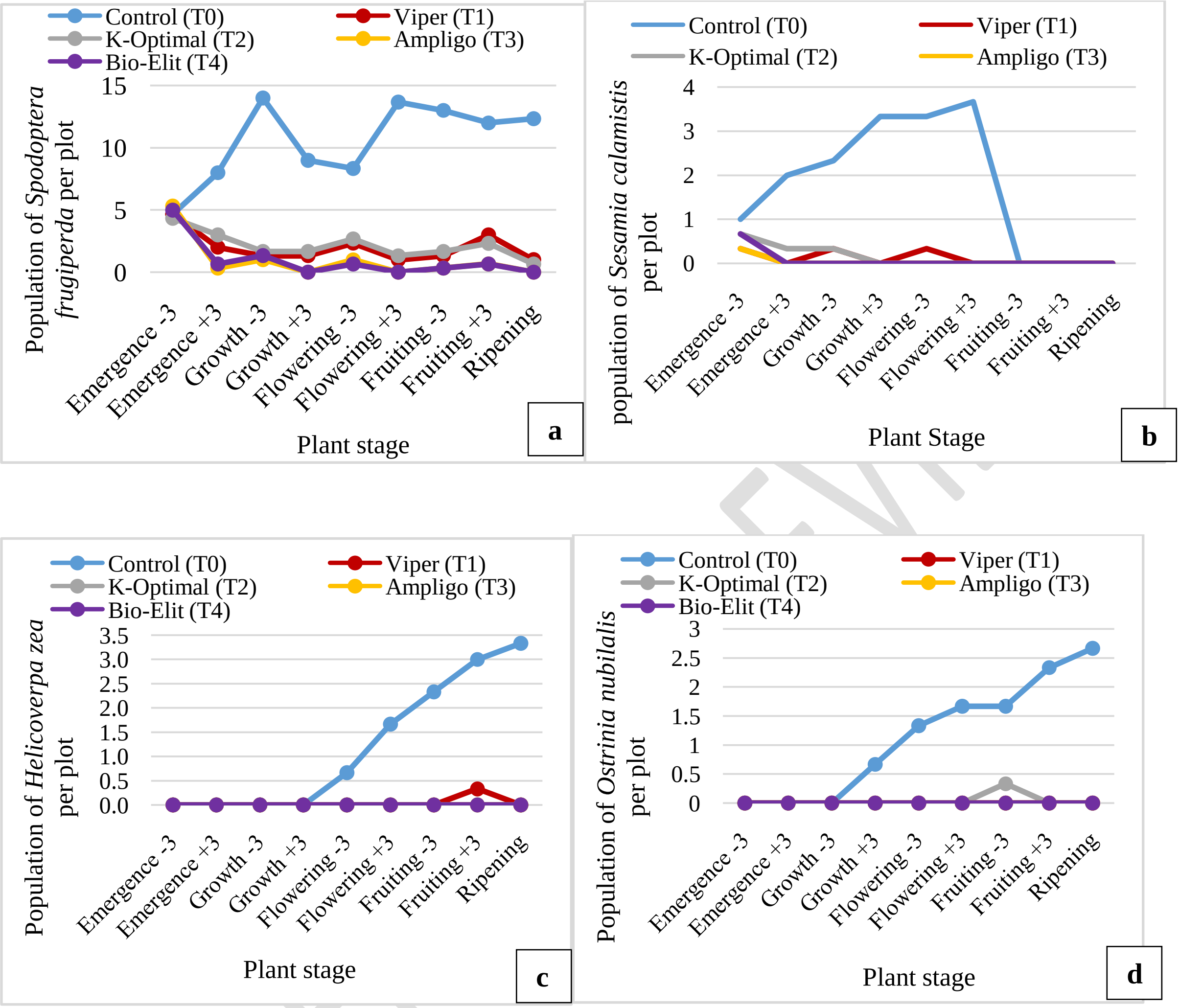
Impact of insecticides on the population of *Ostrinianubilalis*

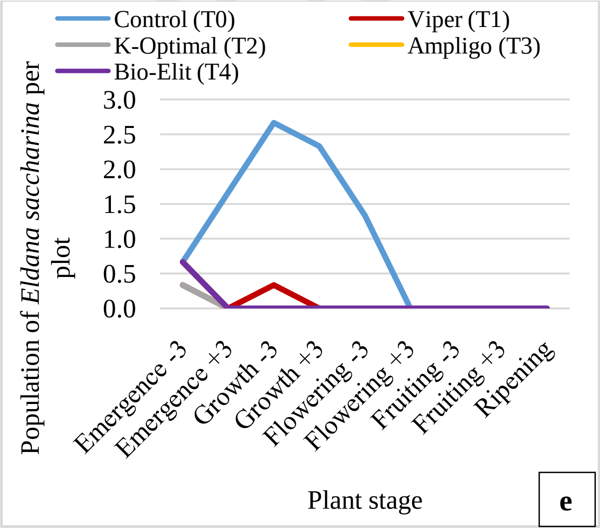
*Ostrinianubilalis*was absent from all plots from the emergence to the growing or vegetative stage. From flowering to ripening, the *O. nubilalis* population increased (Figure 2d). After insecticide spraying, the *O. nubilalis* population on the control plot (0.66±0.57 to 2.66±0.57 individuals per elementary plot) was significantly higher (F $(_{4;14})$ = 4 to 64; $p < 0.0343$)than on the treated plots Viper, K-Optimal, Ampligo, and Bio-Elit(less than 0.33±0.57 individuals)

Impact of insecticides on the population of *Eldana saccharina*

During the emergence, *Eldana saccharina* was present on the plots (0.33±0.57 to 0.66±1.15 individual per elementary plot). On control plots, the populations of *E. saccharina* increased from emergence to the growing stages and decreased at the flowering stage (Figure 2e). At emergence, after the insecticide spraying, the population of *E. saccharina* on control plots T0 (1.66±0.57 to 2.66±1.15 individuals) was significantly higher (F $(_{4;14})$ = 12.2 to 49; p <

0.00073) than those on the treated plots Viper, K-Optimal, Ampligo, and Bio-Elit(less than 0.33±0.57 individual). *E. saccharina* was absent on all the plots, from the flowering to the ripening.





Legend

a)*Spodopterafrugiperda*,

b) *Sesamiacalamistis*,

c) *Helicoverpazea*,

d) *Ostrinianubilalis*,

e) *Eldana saccharina*

Plant stage -3: three days before srasying;

Plant stage+3: three days after sraying

Ex: Emergence -3: three days before spraying during emergence, Emergence +3: three days after spraying during emergence.

Figure 2. Dynamic of lepidopteran larvae following insecticide treatments

3.1.3. Impact of insecticides on insect plant damage

At emergence, before insecticide spraying, 70 to 76.66% of all plots plants were healthy (index 0), while 13.33 to 16.66% of plants showed isolated attacks, 10 to 13.33% were moderatelyattacked, and 1.11% displayed medium attacks. After insecticide spraying, 66.66% of the plants were healthy on untreated plots, compared to 70 - 73.33%on treated plots. Moreover, the plants attacked on untreated plots showed isolated attacks (13.33%), moderate attacks (10%), and medium attacks (10%). On treated plots, 16.66 to 20% of plants showed isolated attacks and 10 to 13.33% moderate attacks.

During the growing phase,60 to 63.33% of the plants on untreated plots were healthy, compared to those of treated plots (70 to 80%). On average, 13.33 to 20% of attacked plants on untreated plots presented isolated attacks, 13.33% moderate attacks, 3.33 to 6.66% showed medium attacks, and 3.33% were heavily attacked. On treated plots, attacked plants showed isolated attacks (13.33 to 16.66%) and moderated attacks (6.66 to 13.33%).

During flowering on untreated plots, 50 to 56.66% of plants were healthy, compared to those on treated plots (73.33 to 83.33%). Attacked plants on untreated plots presented isolated attacks (20%), moderate attacks (13.33 to 16.66%), medium attacks (6 to 10%), and heavy attacks (3.33%). On treated plots, 10 to 16.66% of attacked plants had isolated attacks, 6.66 to 13.33% were moderately attacked, and3.33 to 16.66% displayed medium attacks.

During fruiting on untreated plots, 50% of plants were healthy compared to those on treated plots (76.66 to 86.66%). Attacked plants on untreated plots showed isolated attacks (16.66%), moderate attacks (16.66%), medium attacks (13.33%), and heavy attacks (3.33%). On treated plots, attacked plants had isolated attacks (6.66 to 13.33%) and moderate attacks (3.33 to 10%).

During ripening,46.66% of plants were healthy on untreated plots compared to those on treated plots (80 to 90%). Attacked plants on untreated plots presented isolated attacks (20%), moderated attacks (16.66%), medium attacks (13.33%), and heavy attacks (3.33%). On treated plots, attacked plants showed isolated attacks (6.66 to 10%) and moderate attacks (3.33 to 10%).

3.1.4. Impact of the treatments on the maize yield

There were significant differences ($p<0.05$) between the treatments. The yield on untreated plot T0 (2.26±0.21 t/ha) was significantly lower than on treated plot T2 (3.29±0.11 t/ha), which remained lower than treated plot T3 (3.61±0.22 t/ha). However,the yield on treated plots T1 (3.37±0.06) and T4 (3.41±0.09) was close and did not differ from those on T2 and T3 (Figure 3). The difference in yield between treated plots and untreated plots ranged from 1,034 to 1,348 t/ha. Then, the yield increase rate between the treated and untreated plots ranged from 45.74 to 59.63%. This rate is more important on T3 (Ampligo) than those on the other treated plots T1 (49.41%), T2 (45,74%), and T4 (50.83%) (Figure 3).

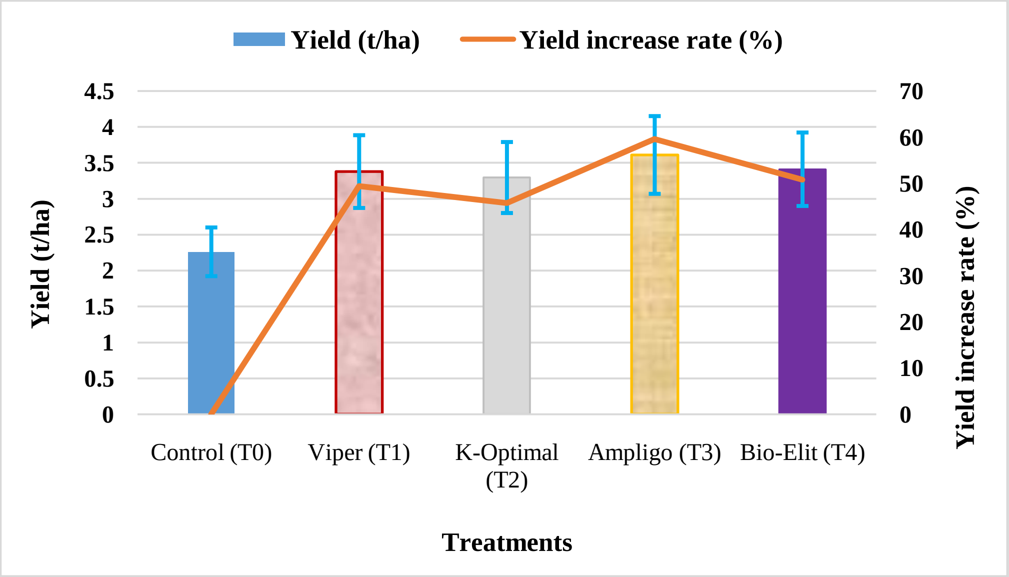


Figure 3. Effect of insecticide treatments on the maize field yield

Discussion

The insects encountered on the studied maize field belong to 10 orders (Heteroptera, Hymenoptera, Homoptera, Coleoptera, Diptera, Dictyoptera, Odonata, Orthoptera, Dermaptera, and Lepidoptera). Five species of Lepidopteran larvae were attacking the maize field. Those Lepidopteranlarvea were reported by several authors in Côte d'Ivoire (29; 30) and in Africa (7; 10). Three of the encountered Lepidoptera larvae were classified as minor pests (*Eldanasaccharina*, *Ostrinianubilalis*, and *Helicoverpazea*), while the two others, *Sesamiacalamistis*, and *Spodopterafrugiperda* were respectively important and major pests (11). *S. frugiperda* was the most abundant among the Lepidopteran larvae, which caused critical damage. This insect is a recently encountered pest in Africa (31; 12). The populations of Lepidopteran larvae fluctuated during the plant development stages on untreated plots. There is a synchronization between the plant's development stage and its pest, meaning that the pest outbreak occurs when the plant's stage is favorable to the pest's development (22).

This study revealed reductions in Lepidoptera larvae populations due to the tested insecticides. Lepidopteran larvae populations were significantly lower on treated plots than on untreated ones. The efficiency of the insecticides appears to be linked to their mode of action and doses. The most efficient insecticide is Ampligo. Its efficiency is due to its two active ingredients, chlorantraniliprole (anthranilicdiamides) and lambda-cyhalothrin (pyrethrinoids). Chlorantraniliprole is a new insecticide belonging to the anthranilic diamide chemical class for use against Lepidoptera, Coleoptera, and certain dipteran pests in cash-crop agriculture on perennial and annual crops (32). Ingestion is the most effective route of entry and generally requires a lower dose to elicit a response. Chlorantraniliprole offers excellent plant protection, as affected insects cease feeding almost immediately after contact with the insecticide. Insects exposed to chlorantraniliprole show general lethargy and muscular paralysis, followed ultimately by death (33). Based on feeding cessation and reduction in feeding damage, chlorantraniliprole is among the fastest-acting insecticides available for lepidopteran pest control, comparable in speed of action with methomyl, lambdacyhalothrin and esfenvalerate, and faster than emamectin benzoate, indoxacarb, methoxyfenozide and metaflumizone (32). Lambdacyhalotrin (pyrethrinoids) is a systemic insecticide that also acts by contact with various larval pests (34). Chlorantraniliprole and lambdacyhalothrin double-loaded nano-microcapsules for synergistic pest control have been reported by Feng et al. (35).
K-Optimal 35 EC and Viper 46 EC had a similar effect on lepidopteran larvae and were moderately effective on lepidopteran larvae. K-Optimal contains lambda-cyhalothrin (pyrethrinoids) and acetamiprid (neonicotinoids). Acetamiprid is a systemic chemical that acts on caterpillars via ingestion and contact (36). Neonicotinoids had an additive effect when mixed with the tested pyrethrinoids (37). Viper contains acetamiprid (neonicotinoids) and indoxacarb (oxadiazines). Indoxacarb is highly active on Lepidoptera larvae. Affected insects stop feeding, become paralyzed, and die (36). This combined mixture consisting of indoxacarb with outstanding translocation properties, and acetamiprid with excellent systemic properties, has a superb, long-lasting efficacy (36).

Bio-Elit is a bio-insecticide containing azadirachtin, salanine, nimbin, and melandriol. This insecticide has shown high control of larval Lepidoptera, close to that of Ampligo. Azadirachtin is used to control insects (Lepidoptera, Diptera, Coleoptera, Hymenoptera, Heteroptera, Homoptera, and Hemiptera), mites, and other arthropods (38; 39). In target species, azadirachtin has anti-feeding, sterilizing, and development-regulating effects (40; 41), induces cytotoxicity, tissue apoptosis, antimitotic effects, and growth abnormalities (inhibited, abnormal, or delayed molting) (38). Azadirachtin also alters various reproductive processes, such as fecundity, fertility, and oviposition. *Azadirachtaindica* (Neem) is a source of several bioactive triterpenoids. However, only azadirachtins have been commercially exploited (42). Salanin and nimbin are the other major active potential bioactive compounds that can be used for insecticide development (43). Salanin and nimbin have been reported from neem seeds, kernels, and neem oil (44). Meliantiol and salanin are bioinsecticidal compounds that have been extracted from *Azadirachtaindica*. The efficacy of neem on insect pests of crops has been reported by several authors (45; 46; 38). Due to their relative selectivity, neem products can be recommended for many integrated pest management programs (41).

Bio-Elit, with natural neem substances (Azadirachtin, Salanin, Nimbin, Melandriol), was very effective against *S. frugiperda* larvae and the other lepidopteran larvae but showed a phytotoxic effect on young plants (at emergence).Before insecticide sprayings, infestations were medium on all the plots. Lepidopteran larvae populations were higher on untreated plots than on treated plots. The damage was caused by the larvae, which fed on leaves, stems, flowers, and fruits and reduced fruit quality and, subsequently, the yields (11). The damage was null to low on the plots treated with Ampligo and Bio-Elit, whereas the damage was low on the plots treated with Viper and K-Optimal. However, untreated plots showed very high damage. Feeding and stem tunneling by borer larvae on plants results in crop losses as a consequence of the destruction of the apical meristem, early leaf senescence, interference with translocation of metabolites and nutrients that result in malformation of the grain, stem breakage, plant stunting, lodging, and direct damage to ears (10). Infestations by stem borers increase the incidence and severity of stalk rots (47). Insecticide sprayings reduced insect pest populations and, consequently, the severity of their damage. In this study, grain yields obtained on untreated plot (2.26±0.21 t/ha) was lower than those on treated plots. The yield on the Ampligo-treated plot (3.6±0.22 t/ha) was higher than on the K-Optimal-treated plot (3.29±0.11 t/ha). However, the yield on the Viper-treated plot (3.37±0.06 t/ha) and Bio-Elit plot (3.41±0.09 t/ha) did not significantly differ from those of Ampligo and K-Optimal. In Côte d'Ivoire, the yield of dry grains on untreated field varied between 2.4±0.42 t/ha to 2.61±0.71 t/ha (11) or between 1.64 to 2.34 t/ha (29). Maize yields were 2.46 t/ha in Nepal (8) and 1.84 to 1.88 t/ha in India (48). In addition, the computed yield increase rate was high on the plot treated with Ampligo (59.63%) and average on the plots treated with Bio-Elit (50.85%), Viper (49.41%), and K-Optimal (45.74%). In Kenya, stalk borer-induced crop yield losses vary from 10% to 88%, depending on the infestation intensity (49). On an economic scale, 14% of Kenya’s annual maize yields are estimated to be lost due to stalk borer damage, representing 0.4 million tonnes or $25-60 million, enough to feed 3.5 million people yearly, with a 125 kg per capita maize consumption. (49). As with pests, predators and pollinators have also been observed in the field. The effectiveness of native predators on several species of borers has been the subject of several studies over the past decade (49; 50). In addition, agricultural practices such as organic and mineral fertilization, improved fallow cover crops, the use of repellent or insecticidal plants, intercropping, training farmers in pest recognition and damage estimation, and alert threshold treatments could improve pest control (14).

4. CONCLUSION

This study was conducted to determine the effectiveness of three chemical and one biological insecticide on lepidopteran larvae in maize field. The insects recorded on maize field in this study belong to 10 orders: Heteroptera, Hymenoptera, Homoptera, Coleoptera, Diptera, Dictyoptera, Odonata, Orthoptera, Dermaptera, and Lepidoptera. Five lepidopteran larvae were pests. Threeof them were minor pests (*Eldanasaccharina*, *Ostrinianubilalis*, and *Helicoverpazea*), one was classified as an important pest (*Sesamiacalamistis*),and the other one as a major pest (*Spodopterafrugiperda*). These insects caused considerable damage to the plants and crops. On untreated plots, more than 76% of plants were attacked with moderate to heavy attacks. However, on treated plots, attacked plants presented isolated to moderate attacks. Consequently,the sprayingof insecticides controlled pest populations, reduced damage, and increased yield. Treated plots with insecticide presented higher yields than untreated plots. The yields obtained on untreated plots (2.26±0.21 t/ha) were lower than those on treated plots (3.29±0.11 to 3.60±0.09 t/ha). The yield increase rate ranged from 45.74 to 59.63%. All of these insecticides effectively controlled pests.Nevertheless, the best control of insect pests of maize in Yamoussoukro was obtained on plots treated with Ampligo and Bio-Elit compared with Viper and K-Optimal. So, the alternating use of synthetic or biological insecticides, which are not very toxic for humans and the environment but are effective on insect pests, increases the effectiveness of the control and provides a positive response to the problem of pest resistance while protecting the environment.

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Appendix1

List 1: Data statistics

	Emergence-3	**Emergence +3**	**Growth -3**	**Growth +3**	**Flowring-3**	**Flowering+3**	**Fructification-3**	**Fructification+3**	**Maturation**
Spodopterafrugiperda									
F	0.5	53.93	160.72	79.81	43.25	194.56	190	112.05	257
p	0.736	0.000001	0.000001	0.00001	0.00003	0.000001	0.000001	0.000001	0.000001
Sesamiaclamistis									
F	0.2692	34	14.5	100	48	121			
p	0.8911	0.000009	0.00036	0.00001	0.000002	0.000001			
Helicoverpaarmigera									
F					4	25	49	19.37	25
P					0.0343	0.00003	0.000002	0.0001	0.00003
Ostrinianubilalis									
F				4	16	25	11.75	49	64
P				0.0343	0.00024	0.00003	0.00085	0.000001	0.000001
Eldanasaccharina									
F	0.1875	25	12.2	49	16				
P	0.939	0.000034	0.00073	0.000001	0.00024				