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Effect of Sivanto Energy 85 EC (Flupyradifurone 75 g/L, Deltamethrin 10 g/L) on *Coelaenomenodera lameensis* (Coleoptera, Chrysomelidae: Hispinae), main pest of oil palm tree in Côte d'Ivoire

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Abstract

Coelaenomenodera lameensis, the most dangerous pest of oil palm, causes damage that can provoke a production loss of up to more than 50%. Evisect-S (Thiocyclam-hydrogen-oxalate), the most effective chemical product against this insect, must be removed to the market because of its high ecotoxicity. This study aims to propose less toxic and effective alternative for better management of this pest's populations. Thus, Sivanto Energy 85 EC Insecticid (Flupyradifurone 75 g/L, Deltamethrin 10g/L) was evaluated from a cage test, a natural infestation test on small plots and then a confirmatory test performed on large area. Three doses of 0.6ml, 1.2ml and 2.5ml per palm of Sivanto Energy 85 EC and 1g per leaf of Evisect- S, were sprayed against *C. lameensis* adults. Mortality monitoring revealed the effectiveness of all treatments with a 100% of mortality. Three doses of Sivanto (450ml/ha, 600ml/ha, 750ml/ha) 500 g/ha of Evisect used in natural infestation also gave good results. The dose of Sivanto Energy 500ml/ha of was effective against *C. lameensis*. It could therefore serve as an alternative to Evisect-S.

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Introduction

In its policy to redynamize the agricultural sector, the State of Côte d'Ivoirehas emphasized the extension of many crops, including the oil palm tree *Elaeis guineensis* Jacq (Palmaceae), which quickly imposed itself in its economy (Osseni *et al.,* 2009; FAO, 2015).

In fact, the state launched a policy for the development of oil palm tree from 1959-1960 thanks to research carried out by the Oil and Oilseed Research Institute (IRHO). This policy resulted in the adoption of a vast programme of selected oil palm tree plantations (Anonymous, 2009). Oil palm tree then developed well on Ivorian soil. Its cultivation covers an area of about 300,000ha with an annual palm oil production of 415,000 t (FAO, 2015).

Currently, oil palm tree is a plant of capital interest for many countries in the intertropical zone. In Côte d'Ivoire for example, it employs more than one million people and generates a turnover of more than 400 billion CFA francs (D'Avignon, 2013).

The palm oil sector is in 4th place in the economy of Côte d'Ivoire. Côte d'Ivoire ranks 5th in the world after Malaysia, Indonesia, Nigeria and Colombia. It is also the 1st African exporter and the 2nd African producer behind Nigeria. Palm oil is used in the manufacture of many food products, cosmetics and biofuels (Ataga and Van der Vossen, 2007). Ivorian production should then continue to increase to meet the country's own needs, the West African demand for oilseeds (Anonymous, 2015) and the needs of the rest of the world. However, the expansion of oil palm cultivation is encountering enormous problems, particularly that of pests.

Indeed, the pests of oil palm are multiple and diversified. They belong to different classes, but the insect class is by far the most important since a large number of insects' attack oil palm from the seedling to the adult stage (Mariau *et al.,* 1981; Mariau, 2001; Koua, 2008). Thus, the organs of oil palm can be attacked by different insect species from the roots to the leaves. At the leaf level, damage is caused by caterpillars belonging to the families Limacodidae, Stenomidae, Hesperidae, Brassolidae and Chrysomelidae. And, the damage caused by Chrysomelidae is the most important.

These include *Coelaenomenodera lameensis* Berti & Mariau, 1999 (Coleoptera, Chrysomelidae: Hispinae) that is the most dammageable in West Africa and particularly in Côte d'Ivoire (Mariau *et al.*, 1981, Mariau, 2000, Koua, 2008). Damage is caused by both adults and larvae which are the most damageables. Adults make grooves of 12-15mm across the entire thickness of the leaflet from the underside and can, in large numbers, cause partial or even total drying of the leaves. The larval leafminers dig galleries for food, which enlarge with the development of the larval stages. In outbreak period, several thousand larvae per leaf can be counted, causing direct destruction or almost total drying of the palm (Mariau et Besombes, 1972). Therefore, palms may be more than 90% defoliated in two or three generations, leading to production drop average of 50% over a period of 2 years (Mariau *et al.,* 1981).

Population control of this pest is therefore necessary. Various control methods are available, including agronomic, chemical, biological and varietal control. But nowadays, chemical control of *C. lameensis* seems to be the most effective and widely used method, with chemicals such as Evisect-S (Thiocyclam-hydrogenoxalate), Cartap (Padan) and Propoxur (Uden) (Anonyme, 1989). However, frequent use of molecules of the same chemical family against an insect can, in the long term, lead to resistance of the insect. In addition, for eco-toxicological reasons, Evisect-S (Thiocyclam-hydrogen-oxalate), the main chemical control against *C. lameensis*, may be withdrawn from the market because of its high ecotoxicity. Thus, a wide range of effective products against *C. lameensis* could be a palliative to this situation.

In order to make the control efficient, it is therefore important to look for other molecules that are as effective as and less toxic than the existing ones. This could contribute in some way to the management of *C. lameensis* populations and also to the achievement of good production and also to the preservation of human health. It is with this in mind that this workhas been carried out with the aim of contributing to the fight against *C. lameensis* by proposing Sivanto Energy 85 EC chemical as an alternative to Evisect-S.

Material and methods

Study Sites

The experiment was carried out in the South-Eastern Côte d'Ivoire, precisely at the experimental station of the National Center for Agronomic Research (CNRA) of La Mé (5°26'LN, 3°50'LW) and on the site of the agro-industry DEKEL OIL (Aboisso) (5°24LN, 3°19LW). The climate is of the equatorial type of transition (Péné et Assa, 2003) characterized by 4 seasons of unequal duration including two distinct rainy seasons. A long rainfull season that lasts from April to July and a short rainfull season from October to November. These alternate with two dry seasons. A big one from December to March and a small one from August to September. This climate is generally consistent with that of the Côte d'Ivoire forest, conducive to the cultivation of oil palm.

Sampling method

Evaluation of the effectiveness of Sivanto Energy 85 EC against *C. lameensis* was done through 3 trials, a controlled environment (cage) trial, a trial on plots reduced in natural infestation and a trial in village plantation. Larvae and adults of *C. lameensis* were the main targets (Fig. 1).

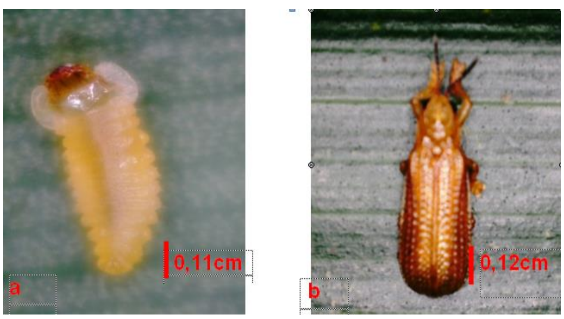

Fig. 1. Larva (a) and adult of *C. lameensis* (b).

The controlled infestation (cage) trial was carried out on one of the plots at the National Centre for Agronomic Research Center (CNRA) station in La Mé. The plot was 10 years old with an area of 5.45ha. The design for this trial was the Completely Randomized Device (DCA) with 3 repetitions comprising 5 objects (treatments). Fifteen (15) trees were randomly selected from the study plot. A large muslin cage was placed on a healthy row 17 palm of each tree. A total of 2250 adults of *C. lameensis* were collected from an infested plot of which 150 were introduced into each cage approximately 5 days before treatment. Three doses of Sivanto Energy 85 EC 0.6ml, 1.2ml and 2.5ml and a reference chemical Evisect-S at a rate of 1g per 500ml of water were applied per leaf to the adults of *C. lameensis* in each cage. The data were compared with the untreated cages.

After the cage trial, a natural infestation trial was carried out on another plot at the CNRA research station of La Mé. The plot was 12 years old with an area of 7.45ha. The experimental design used for this trial was a totally randomized Fisher block with 5 objects and 5 repetitions. Elementary plots were selected on the study plot. Each elementary plot consists of 8 trees arranged in 2 rows (4 trees/row), whether 560m². These plots are arranged in two directions. In North-Southern direction, 2 successive elementary plots are separated by 2 lines (1 tree/line); in East-Western direction, 2 elementary plots are separated by 4 lines. A total of 200 trees in 25 plots were selected for this trial. Three doses of Sivanto Energy 85 EC (450ml/ha, 500ml/ha, 750ml/ha) and one dose of Evisect-S (500 g/ha) were applied on the plots. The data were compared with the untreated plots. Then, the confirmatory test of Sivanto Energy 85 EC effectiveness was carried out on one of the plots of the agro-industry DEKEL OIL (Aboisso). This 7-year-old plot with a surface area of 14ha and a density of 140 trees/ha was naturally infested by *C. lameensis*. The plot was divided into two parts of 7ha each. One was treated with Sivanto Energy 85 EC at the rate of 500ml/ha and the other with Evisect-S (reference product) at the rate of 500g/ha. Two (2) litres of solution were applied per tree, or 280 litres/ha, using a sprayer. A total of 3500ml of Sivanto Energy 85 EC and 3500g of Evisect-S for 1960 litres of water respectively were used to prepare the spray mixture per block.

Monitoring the population level

In order to monitor the evolution of *C. lameensis* populations in controlled infestation (in cages), a control was carried out before treatment to replace dead adults. Afterwards, different checks were made to survey the mortality of *C. lameensis* after treatment. In fact, a first check was carried out 4 hours after treatment. It consisted of counting the dead insects which were then removed from the cages and the insects weakened by the product which were placed in cups placed inside the cages in order to survey their mortality during the following checks. Daily control was done for 7 days and then weekly for 3 weeks. *C. lameensis* larvae were counted at the last control (day 30) in the laboratory in the leaflet galleries on the palms enclosed in the cages.

For natural infestation, controls of the population level of *C. lameensis* were also carried out on each elementary plot before and after the different chemical applications. Before the chemical treatments, a control of the pest population level was carried out on two palms/tree (one low palm and one row 17 palm). Post-treatment controls were realized at 1 day, 7 days, 28 days and 63 days.

The 1-day control was done on two palms (one row 9 and one row 17). The other controls (7 days, 28 days and 63 days) were also carried out on two palms (one low fin and one row 17). These different controls consisted of counting the external adults on the underside of the leaflets. Larval control was only carried out from the 28^{th} day after treatments. This control was done by opening the galleries with pliers on the upper surface of the leaflets.

For the confirmatory test carried out in the village plantation, a control was made before treatment in order to know the mean index of *C. lameensis* on the plot. This control was done on one line out of 5 and two trees per line so that the northern, southern and central trees were checked at the same passage on each block. The control was done by alternating two leaves (one low palm and one row 17 palm). One (1) day after the application of each treatment, a special control was done randomly on selected palms on the treated area. This control was released on palms of rows 9 and 17. Then another three controls were done two weeks, one month and then at two months on low palms and row 17. All these controls allow to follow the evolution of the average *C. lameensis* index on the study plot.

Data analysis

The following parameters were studied:

- The adult mortality rate (AMR) which was determined using the formula :

  MR (%) = (Number of dead insects/Total number of insects) x 100

- The average *C. lameensis* index (I(x)) was determined by using the formula :

I(x) = Number of *C. lameensis* at stage "x" / Number of fins tested, with "x", the stage considered

- The effectiveness of different E(X) doses:

For the micro-test in cages and the test on plots reduced in natural infestation, the effectiveness E(X) of the different doses was determined according to the following formula:

$$E(X) = \frac{Im(TNT)\,pc - Im(X)pc}{Im(TNT)} \times 100$$

For the village plantation test, the effectiveness E(X) of the different doses was determined according to the following formula:

$$E(X) = \frac{Im(Avt)\,pc - Im(X)pc}{Im(Avt)} \times 100$$

NB : Im (TNT) = Mean index of external adults or larvae obtained with the untreated control (TNT); Im (Avt) = Mean index of external adults or larvae obtained before application of the treatments, pc = control period considered, Im(X) = Mean index of external adults or larvae of the object considered (X)

The data obtained during the micro-cage test and the test on plots reduced in natural infestation were subjected to an analysis of variance (ANOVA factor) using Statistica 7.1 software. The comparison of means was performed by the Newman-Keuls test at the threshold α of 5%. For the village plantation test, the Student's T-test allowed the means to be separated.

Results

Controlled infestation test (in cages)

Four hours (4h) after the various insecticide applications, the mortality rate of *C. lameensis* was very high with the high doses of Sivanto Energy 85 EC (1.2ml and 2.5ml) and the reference product Evisect-S compared to the untreated plot which gave 1.11% of mortality. Thus, significant differences (ANOVA, $P < 0.05$) were revealed between these treatments regarding to adult mortality rates of *C. lameensis*. During the first three days after of the treatment's application, the highest *C. lameensis* mortality rate (98.67%) was obtained with the 2.5ml dose of Sivanto Energy 85 EC. From 5th day, identical mortality rates were recorded (97.11 to 100%) for all insecticide treatments. After one week, a maximum mortality rate of 100% was recorded in the insecticide-treated cages. This mortality rate remained unchanged until day 30. However, a significant difference (ANOVA, $P < 0.05$) was observed between these treatments and the untreated control (Table 1).

Table 1. Mortality rate (%) of adults of *C. Lameensis*.

Doses	4hours	1st day	2nd day	3th day	4th day	5th day	6th day	7th day	14th day	21stday	30th day
TNT	1.11 ± 1.92 c	1.78 ± 2.04 d	2 ± 1.76 c	2.67 ± 1.76 c	3.56 ± 1.68 c	4.44 ± 3.15 b	5.56 ± 2.34 c	6.22 ± 2.52 b	10. 22 ± 2.77 b	13.11 ± 2.78 b	14.67± 1.76 b
EV-S	88 ± 0.67 a	92.67 ± 0.67 b	95.56 ± 1.02 b	96.89 ± 1.02 a	99.33± 0.67 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a
SE 0.6ml	78.67 ± 2 b	88.89 ± 1.02 c	94.22 ± 0.38 b	94.89 ± 0.38 b	95.78 ± 1.02 b	97.11 ± 0.38 a	97.78 ± 0.38 b	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a
SE 1.2ml	89.11 ± 1.02 a	94.67 ± 0.67 b	95.11 ± 0.38 b	98.67 ± 0.67 a	98.67 ± 0.67 a	99.11± 0.38 a	99.11 ± 0.38 b	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a
SE 2.5ml	90.67 ± 0.67 a	98 ± 1.33 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a

NB: Values in the same column with the same letter are not significantly different at the 0.05 threshold.

TNT = untreated plot ; EV-S = Evisect-S at the dose 1 g per palm ; SE 0.6ml = Sivanto Energy 85 EC at the dose 0.6ml per palm; SE 1.2ml = Sivanto Energy 85 EC at the dose 1.2ml per palm SE 2.5ml = Sivanto Energy 85 EC at the dose 2.5ml per palm.

In addition, Sivanto Energy 85 EChas significantly reduced the formation and development of *C. lameensis* larvae, as did the reference insecticide Evisect-S. Thus, average larvae indices per palm on Evisect-S and Sivanto Energy 85 EC treated palms ranged from 0.77 to 0.83 larvae per palm. These indices are statistically different from those obtained with the untreated control which was 17.23 larvae per palm (Fig. 2).

Test on plots reduced in natural infestation

Variation of the mean index of adults and larvae of C. lameensis

Before applications, an average adult *C. lameensis* index of 1.11 to 4.46/palm was recorded for the different treatments (Fig. 3). One day after treatments, a diminution of the mean adult *C. lameensis* index (0.07 to 0.19 adult/palm) was observed for the different doses of Evisect-S and Sivanto 85 EC compared to the untreated control (TNT) which recorded a higher mean index of 2.09 adults/palm. This index remained constant until day 28 before decreasing until day 63 (Fig. 3). In addition, by day 7, the different treatments significantly reduced the adult population level of *C. lameensis*, which is 0.11 to 0.34 adults/palm compared to the untreated control (2.09 adults per palm). And, a slight increase in the mean adult *C. lameensis* index (0.11 to 1.01 adults/palm) was observed between days 7 and 28 for all treatments. From day 28th, the mean adult *C. lameensis* indices of all treatments gradually increased until day 63 (0.21 to 1.01 adults per palm), except for the untreated control which decreased from 2.37 to 1.58 adults per palm (Fig. 3).

At the larval level, mean indices larvae of *C. lameensis* of 0.16 to 0.68 larvae per palm with the untreated control, the reference product Evisect-S and the different doses of Sivanto Energy 85 EC were recorded before the treatments. On day 28 after treatment, an overall decrease in the mean *C. lameensis* larval index was observed with a value between 0.07 and 0.35 larvae per palm. From day 28th, the mean index larvae of *C. lameensis* of the untreated plot (TNT) gradually increased until it reached a peak at day 42 with 2.37 larvae per palm, after which the larval numbers fall at 0.36 larvae per palm at day 63. Similarly, at the level of the reference product (Evisect-S) and the different doses of Sivanto Energy 85 EC, there is a decrease in the mean larval index of *C. lameensis* from day 1 to day 28. From this day until day 63 after treatment, the mean larval indices at the different treatments remained constant (Fig. 4).

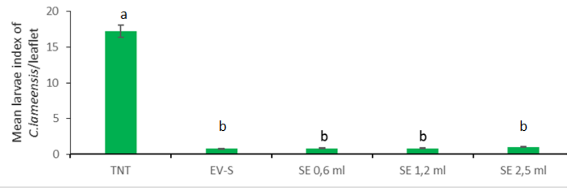

Fig. 2. Mean larval index of *C. lameensis* 30 days after application of the different rates.

NB: Bars topped with the same letter are not significantly different.

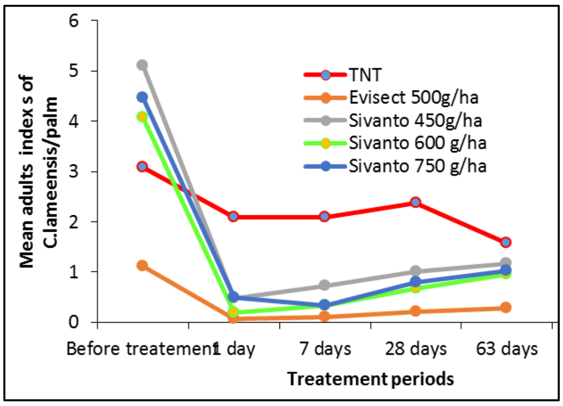

Fig. 3. Variation of indices average of *C. lameensis* adults according to the time.

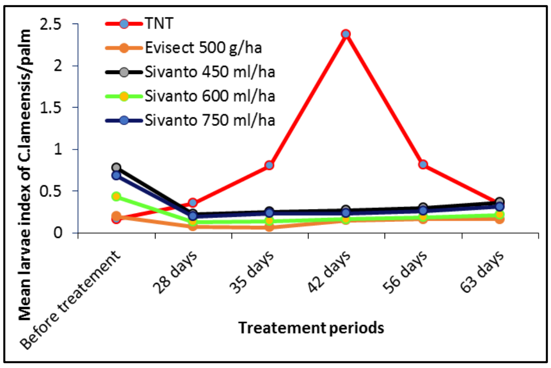

Fig. 4. Variation in the average larval index of *C. lameensis* according to the time.

Effectiveness of treatments on adults and larvae of C. lameensis

Four main time periods were considered for evaluating the effectiveness of different doses of the test product on adults of *C. lameensis*: 1 day, 7 days, 28 days and 63 days post-treatment. At 1 and 7 days after application, the high doses of Sivanto Energy 85 EC (600ml/ha and 750ml/ha) and the reference product Evisect-S (500 g/ha) gave higher effectiveness than Sivanto Energy 85 EC (450ml/ha). Thus, statistical analysis revealed a significant difference between the effectiveness with respect to the doses applied (ANOVA, $P < 0.05$). However, no significant variation (ANOVA, $P > 0.05$) was revealed for these 3 doses, Sivanto Energy 80 EC (600ml/ha and 750ml/ha) and Evisect-S (500 g/ha) during these two periods, with similar effectiveness, 95.27 to 98.77% for the 1st day and 90.44 to 92.71% for the 7th day (Table II). The efficacy of the different doses of the products used did not vary on day 28 (between 80% and 83.98%) and day 63 (between 75.10% and 78.38%). The analysis of variance did not show any significant difference between the effectiveness of the different doses during these two periods (ANOVA, $P > 0.05$) (Table 2).

At the larval level, the same observations were made regarding to the different doses of insecticide products from day 28 to day 63 after treatment. Indeed, the doses of Sivanto Energy 85 EC (450ml/ha, 600ml/ha and 750ml/ha) proved to be more effective than the dose of Evisect-S (500g/ha). Thus, the analysis of variance revealed a significant difference between the effectiveness regarding to these different doses applied (ANOVA, $P < 0.05$). However, the doses effectiveness of Sivanto Energy 85 EC remained identical throughout the treatment period (ANOVA, $P > 0.05$) (Table 3).

Confirmatory test of the effectiveness of Sivanto Energy 85 EC in a village plantation

Variation in the mean index of adults and larvae of C. lameensis

Before the treatment, adults of *C. lameensis* were present throughout the plot, with an index of 5.01 adults/palm in the Sivanto 85 EC block and 4.19 adults/palm in the Evisect-S 50 block. After applications, a decrease in the adult indices of *C. lameensis* was observed in each of the blocks for up to 60 days, from 4.19 to 0.22 adults per palm in the Evisect-S block and from 5.01 to 0.19 adults/palm in the Sivanto Energy 85 EC 500ml/ha block (Fig. 5). The larval indices of *C. lameensis* larvae were 1.27 and 1.73 larvae per palm in the blocks to be treated with Evisect-S 50 and Sivanto Energy 85 EC respectively. After treatments, no *C. lameensis* larvae were observed until day 14, with an index of 0 larvae per palm in both blocks. However, from day 14 to day 60, there was a sharp increase in the mean *C. lameensis* larval index (0 to 1.38 larvae per palm) in the block treated with Sivanto Energy 85 EC while in the block treated with Evisect-S, the mean *C. lameensis* larval index remained constant until day 60 (Fig. 6).

Table 2. Doses effectiveness on Adults of *C. Lameensis*.

Treatments	1 day	7 days	28 days	63 jours
Evisect-S 500 g/ha	95.27 ± 1.88 a	90.44 ± 1.84 a	81.22 ± 1.04 a	75.10 ± 3.45 a
Sivanto 450ml/ha	90.18 ± 1.84 b	85.19 ± 2.19 b	80 ± 1.02 a	75.32 ± 3.79 a
Sivanto 600ml/ha	97.12 ± 1.77 a	91.86 ± 2.62 a	83.36 ± 2.91 a	77.46 ± 3.63 a
Sivanto 750ml/ha	98.77 ± 0.36 a	92.71 ± 1.77 a	83.98 ± 2.60 a	78.38 ± 4.19 a

NB: Averages followed by the same letter in the same column are not statistically different.

Table 3. Doses effectiveness on larvae of *C. Lameensis*.

Treatments	28 days	35 days	42 days	49 days	56 days	63 days
Evisect-S 500 g/ha	64.39 ± 1.92 b	60.1 ± 1.82 b	25.30 ± 2.09 b	21.44 ± 2.01 b	18.36 ± 1.28 b	14.36 ± 4.15 b
Sivanto 450ml/ha	71.90 ± 1.76 a	66.88 ± 2.30 a	63.85 ± 2.49 a	61.08 ± 0.98 a	60.62 ± 0.98 a	53.28 ± 2.57 a
Sivanto 600ml/ha	71.82 ± 1.71 a	67.62 ± 4.43 a	64.94 ± 2.22 a	62.06 ± 1.09 a	60.82 ± 1.31 a	52.06 ± 1.72 a
Sivanto 750ml/ha	72.20 ± 1.74 a	67.60 ± 3.96 a	63.93 ± 3.52 a	63.00 ± 3.25 a	60.15 ± 0.94 a	52.98 ± 3.72 a

NB: Averages followed by the same letter in the same column are not statistically different.

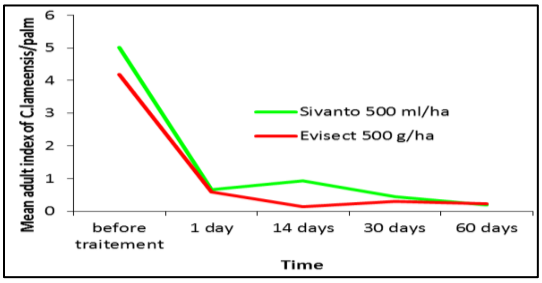

Fig. 5. Evolution of the mean adult index of *C. lameensis* according to the time.

Effectiveness of treatments on adults and larvae of C. lameensis

From day 1 to day 60 after treatment, Sivanto Energy 85 EC and the reference product Evisect-50 Shad the same effectiveness on adults of *C. lameensis*.

The efficacy ranged from 81.48% to 96.67%. Indeed, no significant difference was observed between the effectiveness of these 2 chemicals (Table 4).

Table 4. Effectiveness of products on adults and larvae of *C. Lameensis*.

	Treatments	1 day	14 days	30 days	60 days
Adults	Evisect-S 500 g/ha	86.36 ± 20.66 a	96.67 ± 8.29 a	93.86 ± 10.08 a	95.25 ± 9.96 a
	Sivanto 85 EC 500ml/ha	87.77 ± 14.4 a	81.48 ± 23.77 a	90.99 ± 14.63 a	95.94 ± 10.45 a
Larvae	Evisect-S 500ml/ha	100 ± 0.00 a	100 ± 0.00 a	100 ± 0.00 a	97.78 ± 6.68 a
	Sivanto 85 EC 500ml/ha	100 ± 0.00 a	100 ± 0.00 b	22.31 ± 44.05 b	3.,11 ± 47.14 b

NB: Averages followed by the same letter in the same column are not statistically different.

For larvae of *C. lameensis*, the same effectiveness was observed from day 1 to day 14 for Evisect-S and Sivanto Energy 85 EC. This effectiveness was 100%. At this level, no significant difference was observed. However, from day 30 to day 60, a low effectiveness was observed for Sivanto Energy 85 EC (22.31 to 36.11%) compared to Evisect-S (97.78 to 100%). Thus, a significant difference was observed between the effectiveness of Sivanto Energy 85 EC and Evisect-S regarding to *C. lameensis* larvae (Table 4).

Discussion

Micro-testing in cages

In the cage micro-test, it was found throughout the trial that the mortality rate of *C. lameensis*had remained very low in the untreated plot while it was greater than 78% in the cages where chemicals applied. The applied products were therefore responsible for the observed mortalities over time. Four hours (4h) after treatment, the rate of insects killed with the 0.6ml per palm dose of Sivanto Energy

85 EC was 78.67%. Philippe (1992) has defined two criteria that allow an insecticide to be retained as effective after a test. According to the first criterion, a product is said effective after a test if the mortality rate after 4 hours application is greater than 50% or 60%. In these conditions, the dose of 0.6ml/palm could be retained as effective. According to the second criterion, the product is confirmed effective if the mortality rate varies between 97% and 100% one day after application. With this second criterion, this rate is not effective because it eliminates only 88.89% of the pest (*C. lameensis*) population one day after treatment. So the dose of 1.2ml of Sivanto Energy 85 EC would be effective because ithas permitted to control more than 50% of the insects 4 hours after treatment. However, one day after treatment, the mortality rate increased to 94.67%. This percentage is below the 97% threshold established by Philippe (1992). However, this dosehas the same effectiveness than the reference chemical Evisect-S, 1 day after treatment, and could therefore be retained.

Concerning the dose of 2.5ml per palm of Sivanto Energy 85 EC, it caused a mortality of 90.67% 4h after treatment. This mortality rate is above the 50% threshold. Furthermore, 1 day after treatment, the mortality rate increased to 98%, which is above 97% threshold defined by Philippe (1992). Basing on the two selection criteria set by this author, this dose is effective. This mortality rate (98%) is also higher than that obtained with the reference product Evisect-S (92.67%), 1 day after treatment.

From day 5 to day 6, the dose of 0.6ml/palm of Sivanto 80 EC which wasn't seemed effective until day 4 after treatment, becomes effective with mortality rates of 97.11% on day 5 and 97.78% on day 6. The doses of 1.2ml per palm and 2.5ml per palm, which were already revealed effectives from day 1 and day 3 after treatment respectively, remained effectives with mortality rates still above the 97% threshold defined by Philippe (1992) at the same time (day 5 to day 6). After one week (7th day), a maximum mortality rate (100%) was recorded for all treatments applied. This rate remained stable until day 30. Overall, all applied doses were effective against adults of *C. lameensis*. In addition, the different doses applied resulted in a considerable reduction in larval formation and development compared to the untreated control. The mean larval index of Evisect-S and the 3 doses of Sivanto Energy 85 EC was lower than that of the untreated control. These mean larval indices recorded for all treatments reflect the effectiveness of these treatments. Thus, these treatmentshas acted as a brake on the formation and development of larvae. Then, most of the caged adults would be weakened by the chemicals and therefore could not be able to mate or would die after mating, hence the high mortality observed. This high mortality wouldhave resulted in low egg laying activity leading to low larval emergence which could also be explained by the mode of action of the different products applied (Sivanto Energy 85 EC and Evisect-S).

Evisect-S is a selective insecticide derived from Nereistoxin, a toxin acting by contact and ingestion (Philippe, 1990). It was isolated from a marine worm, *Lumbriconereis heteropoda* or *Lumbriconereis brevicirra*, which caused the death of carnivorous insects feeding on it. Ithas a paralysing effect and directly blocks the ganglia of the animal's central nervous system by masking neuron receptors (Nitta,1934 In Philippe 1990).

In addition, Sivanto Energy 85 EC contains two active ingredients, deltamethrin and flupyradifurone. On the onehand, deltamethrin acts both by contact and ingestion on a large number of insects. Ithas a very remarkable shock action (BAYER, 2011; Anonymous, 2013) and a repellent effect on flying insects (Nitta,1934 In Philippe 1990) which then enter a state of intense agitation followed by death (BAYER, 2011). On the otherhand, flupyradifurone acts on the central nervous system of insects by causing constant excitation of nicotinic acetylcholine receptors. This leads to paralysis and then death of the insect (BAYER, 2011; Anonymous, 2015). These 2 active ingredients thereforehave practically the same mode of action. Concerning deltamethrin, the works of Mehinto *et al.* (2014) had already revealed its efficacy on cowpea insect pests in central Benin.

Test on plots reduced in natural infestation

The results obtained with the reduced infested plots test indicate that the different treatments appliedhad different effects on the adult and larval populations of *Coelaenomenodera lameensis*. Overall, the mean adult *C. lameensis* indices for each dose of product used showed, on the onehand, a rather considerable decrease between day 1 and day 7 after the treatments and, on the otherhand, an increase beyond day 7. This drop in the index is thought to be due to a shock effect of the products applied (Evisect-S and Sivanto Energy 85 EC) on the insects. The shock effect of Evisect-S on external adults of *C. lameensis*had already been demonstrated by Philippe (1990). According to him, Evisect-S is a selective insecticide which would cause the death of many insects by contact and ingestion. Similarly, the type of active ingredient contained in Sivanto Energy 85 EC, as well as its mode of action, could explain the decrease in the average adult index during the study. Sivanto Energy 85 EC is an insecticide with the active ingredient deltamethrin, which acts on a wide range of insects by both contact and ingestion. It is also said tohave a remarkable shock and repellent effect on flying insects (Anonymous, 2013), thus explaining the rapid death of *C. lameensis*.

With the indices recorded on the first day after treatment, the effectiveness of each dose of the product was determined. The dose of 500 g/ha of Evisect-S and the doses of 600ml/ha and 750ml/ha of Sivanto Energy 85 EChad the same effectiveness between 95% and 98%, but higher than that recorded by the lowest dose of Sivanto Energy 85 EC (90.18%). The world health organization (2013)has indicated that any chemical with an effectiveness greater than or equal to 80% after treatment (entomological efficacy threshold) is considered to be effective. It can therefore be stated that the different doses studied were effective against external adult *C. lameensis* only from day 1 to day 28 after treatment since the effectiveness at these periods ranged from 80 to 98.77%. Beyond this period, the products used were less effective because the effectiveness obtained was below 80%. Indeed, an increase in the number of adults and a decrease in the effectiveness of the different doses of products used between the 7th and 63rd day would be linked to the low persistence of the products used. The insects would thereforehave recolonized the treated plots 7 days after the treatments. In addition, a decrease in the mean larval index at day 28 was observed at all rates except the untreated control. This decrease is thought to be related to the effect of the products as demonstrated at the adult level. Similarly, all three doses of Sivanto Energy 85 EChad the same effectiveness on larvae at the same time. This effectiveness ranged from 71.92 to 72.20% and was higher than that of Evisect-S (64.39%). Evisect-S and the 3 doses of Sivanto Energy 85 EC were therefore found to be ineffective against larvae according to entomological threshold of 80% defined by the world health organization (2013).

From day 35 to day 63, an increase in the mean larval index and a decrease in the effectiveness of all doses were observed. The 3 doses of Sivanto Energy 85 EC then recorded a similar effectiveness between 52.06 and 53.28% while Evisect-S recorded effectiveness of 14.36%. The different doses appear to be ineffective against larvae. This would be related to the type ofhabitat occupied by the larvae in oil palm, to the resistance of the larvae to the products and also to the mode of application (spraying) of the products used in this test. Indeed, *C. lameensis* larvae live in galleries that they dig in the leaflets. These galleries act as a protective envelope and thus constitute a barrier between them and the surrounding environment. These galleries, which are formed as a result of egg-laying activity, are a prerequisite for the development of these larvae. The location of the larvae inside the leaflet, in the galleries, would constitute a physical barrier protecting them against the spread of plant extracts (Tano, 2013). Consequently, stage 3 and 4 larvae wouldhave a low sensitivity to these plant extracts. This was also mentioned by Philippe (1990) during a study on the contact effect of Thiocyclam-hydrogenoxalate (Evisect-S) on *C. lameensis*. It is therefore difficult for any product used as a spray to penetrate into these galleries and act on these larvae. Conversely, it seems to be easier for sprayed products (Evisect-S and Sivanto Energy 85 EC) to come into contact with the adults because, unlike the larvae, they live on the underside of the leaflets and feed there by digging furrows parallel to the main vein. The ineffectiveness of the products against larvae could also be explained by the fact that permanent contact of the larvae with the products wouldhave resulted in their resistance to the products. The works of Séri-Kouassi (2004) reported that exposure of larvae to certain products could lead to the development of a Glutathion-S-Transferase (GST) type detoxification system capable of increasing resistance to treatment. Contrarly, an application by injection into the stipe of the palm tree mayhave been necessary to stop the activity of the larvae, as it would encourage penetration of the product into the sap, the tree's nourishing liquid. And since the larvae obtain their nutrients from the palm leaves that serve as theirhabitat, they will contaminate themselves by ingestion while feeding.

Confirmatory test in a village plantation

After application of the treatments, the average adult index of *C. lameensis* gradually decreased up to 60 days at the level of Evisect-S 500g/ha and Sivanto Energy 85 EC 500ml/ha. These 2 chemical insecticides with a dual action wouldhave acted systemically on a large number of nymphs and internal adults in the leaflet galleries explaining the progressive decrease in adult indices until day 60. According to Louat (2013) the sublethal effect of insecticides canhave a negative impact on insect survival. After application of the treatments, a sharp drop in the mean larval index was observed until day 14. The treatments would be applied at the last stage of development of the majority of larvae (stage 4), which then became pupae or died as a result of the effects of the various treatments.

This hypothesis was also raised by Mehinto *et al.* (2014) in their study on the comparative efficacy of different types of insecticides in the management of cowpea insect pests in central Benin.

Furthermore, the increase in the mean larval index from day 14 to day 60 after treatment is thought to be due to the emergence of new larvae stage 1. In fact, the insecticides usedhad not ovicidal action and *C. lameensis* eggs were able tohatch. This explains the increase in the larval population at this stage. According to Tano (2013), first instar larvae of *C. lameensis* emerge after an egg incubation period of 19-22 days. This incubation period defined by this author is within the period when the mean larval indexhas increased (14 to 60 days). According to the World Health Organization (2013), any chemical with an effectiveness greater than or equal to 80% is considered effective. Thus, Evisect-S and Sivanto Energy 85 EC were more than 81% effective on larvae and adults of *C. lameensis* during our study. However, Sivanto Energy 85 EChad an effectiveness of 22.31 to 36.11% from day 30 to day 60 on *C. lameensis* larvae. This is below the effectiveness threshold fixed by the World Health Organization (OMS). This ineffectiveness could be explained by the low remanence of flupyradifurone, the systemic active ingredient contained in Sivanto Energy 85 EC.

Conclusion

All doses of Sivanto Energy 85 EC tested in cage in this study were effective on adult *C. lameensis* and thosehave reduced significantly larval formation and development. In the reduced infested plots test, the 3 doses of Sivanto Energy 85 EC (450ml/ha, 600ml/ha and 750ml/ha) and the dose of the reference chemical Evisect-S were effective on external adults of *C. lameensis* until the day 28.

The confirmatory test in village plantations was realized with the doses of 500ml/ha of Sivanto Energy 85 EC and 500 g/ha of Evisect-S. The effectiveness of these different doseshas been also proven because they reduced considerably the population level of adults and larvae. However, the effectiveness of Sivanto Energy was limited from day 30 at the larval level. Consequently, in the current context of sustainable agriculture and environmental protection, Sivanto Energy 85 EC at 500ml/ha could be recommended as an alternative to Evisect-S for the control of *C. lameensis* populations.

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