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RESEARCH ARTICLE

EFFICACY OF TWO BIOPESTICIDES NECO 50 EC AND LIMOCIDE 60 ME ON *COELAENOMENODERA LAMEENSIS* (COLEOPTERA, CHRYSOMELIDAE: HISPINAE), THE MAIN PEST OF OIL PALM (DALOA, CÔTE D'IVOIRE)

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Abstract

Coelaenomenodera lameensis (Coleoptera: Chrysomelidae, Hispinae), the leafminer of oil palm, is the most feared insect for this crop in Côte d'Ivoire. The aim of this study was to evaluate the efficacy of two biopesticides (NECO 50 EC and LIMOCIDE 60 ME) on *C. lameensis* adults. Trials were carried out under controlled infestation on an oil palm plot at the University Jean Lorougnon Guédé in Daloa. To assess the insecticidal effect of the products, male and female adults of C. lameensis were introduced into cages placed on palms containing palm leaflets. These adults were sprayed 48 hours later, at concentrations ranging from: 1.92×10^{-3} to 8.33×10^{-3} g/ml (NECO); from 3.58×10^{-4} to 1.75×10^{-3} g/ml (LIMOCIDE) and from 3.02×10^{-4} to 2.07×10^{-3} g/ml (Sivanto Energy, chemical reference insecticide). Controls were carried out from the 1st to the 15th day after treatment. NECO 50 EC induced maximum mortality rates of 100% (females and males) from day 4 after treatment. For LIMOCIDE, concentrations of 8.9×10^{-4} g/ml and 1.75×10^{-3} g/ml respectively induced mortality rates reaching 100% (females) on days 13 and 10 post-treatment. In males, only the 1.75×10^{-3} g/ml concentration produced mortality rates of 100% on day 12. In the case of Sivanto Energy, mortality rates of 100% (females and males) were recorded as early as day 2 at a concentration of 8.42×10^{-4} g/ml. Lethal Concentrations (LC_{50}) were 4.96×10^{-3} g/ml (females) and 5.37×10^{-3}g/ml (males) for NECO, 1.15×10^{-3}g/ml (females) and 1.38×10^{-3} g/ml (males) for LIMOCIDE. These two biopesticides could be used as an alternative to the abusive use of synthetic insecticides to reduce *C. lameensis* damage and increase palm oil production in Côte d'Ivoire.

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Introduction:-

Oil palm is of major importance worldwide. It is a vital crop for many tropical countries, due to the high oil content of its fruit. This crop represents the leading source of vegetable oil, with production of 65 million tonnes worldwide, 85% of which is supplied by Malaysia and Indonesia (Rival, 2020). Since 2018, Côte d'Ivoire has passed the 500,000 tonne mark for crude palm oil, derived from the processing of at least 2,236,000 tonnes of palm bunches from 290,000 ha of plantations, 70% of which are owned by village planters (Bessou and Dubos, 2020). Côte d'Ivoire is

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Africa's 2nd largest producer and 1st largest exporter. It also ranks 5th worldwide (Cucumel, 2020). The palm oil industry employs over a million people south of the forest zone and generates over 400 billion CFA francs in sales (D'Avignon, 2013).

Unfortunately, this crop is subject to several aggressions throughout its development. These include attacks by insect pests, the most important of which is *Coelaenomenodera lameensis* Berti et Mariau, 1999 (Anougba, 2022). Adult *C. lameensis* insects make grooves measuring 12 to 15 mm across the entire leaflet, starting from the underside, which can lead to palm desiccation (Kouassi et al., 2020). Control of this pest is therefore essential. Various control methods are available, including chemical and biological control. The massive use of synthetic insecticides creates numerous problems, environmental pollution and human poisoning (Hénault-Ethier, 2015). It would therefore be interesting to turn to other control methods that are effective and non-polluting. The aim of this study is to evaluate the efficacy of two biopesticides compared with a reference chemical insecticide on *C. lameensis*.

Materials and Methods:-

Study site

The experiments were carried out at the University Jean Lorougnon Guédé, located in the department of Daloa, in the Haut-Sassandra region. This University, located to the north-east of the town of Daloa, stretches from latitude 6°54' north to longitude 6°26' west. It is influenced by a humid tropical climate, with rainfall ranging from 1,200 to 1,600 millimeters per year (Coulibaly et al., 2021). Temperature ranged from 25 to 28°C, with an average of 26.62 ± 1.02°C. Relative humidity ranged from 73 to 84%, with an average of 79.83 ± 4.12% (Coulibaly et al., 2021).

Materials:-

The plant material used was oil palm. The animal material consisted of adult males and females of Coelaenomenodera lameensis. The treatment equipment consisted of a hand-held sprayer and cylindrical white muslin sleeves (0.50 mm mesh) of large size (300 cm x 80 cm) for rearing and small size (100 cm x 80 cm) for treatment. The products used were two biopesticides, NECO 50 EC and LIMOCIDE 60 ME, and a chemical insecticide, Sivanto Energy 85 EC.

Methods:-

Breeding of *C. lameensis*

For *C. lameensis* rearing, large sleeves (300 cm x 80 cm) were used. These sleeves were fitted with an opening lined with adhesive strips to prevent the insects placed on the leaflets from escaping.

Using cylindrical boxes 8 cm in diameter and 10 cm high, fitted with lids, adult pairs of *C. lameensis*, including egg-laying females, were placed on leaflets covered with muslin sleeves. The pairs were monitored for 120 days, during which time new individuals were obtained for testing.

Evaluating the efficacy of biopesticides

Determination of concentrations

NECO 50 EC is a biopesticide based on the essential oil of *Ocimum gratissimum*. The recommended dose is 1 l of the product diluted in 25 l of water, corresponding to a concentration of 1.92 g/l (1.92×10^{-3} g/ml). Dilution of NECO (1 ml) in distilled water (25 ml; 20 ml; 15 ml; 10 ml and 5 ml) gave five respective concentrations: 1.92×10^{-3} g/ml; 2.38×10^{-3} g/ml; 3.12×10^{-3} g/ml; 4.54×10^{-3} g/ml and 8.33×10^{-3} g/ml. LIMOCIDE 60 ME is a biopesticide based on sweet orange essential oil, extracted from pressed orange peel. The recommended dose is 150 ml of the product diluted in 15 l of water, i.e. 1.5 ml of the product in 150 ml of water (5.9×10^{-4} g/ml). Dilution of LIMOCIDE (1.5 ml) in distilled water (250 ml; 200 ml; 150 ml; 100 ml and 50 ml) gave five respective concentrations: 3.58×10^{-4}g/ml; 4.5×10^{-4}g/ml, 5.9×10^{-4}g/ml; 8.9×10^{-4} g/ml; and 1.75×10^{-3} g/ml.

The chemical reference insecticide used is Sivanto Energy 85 EC, with the following active ingredients: Flupyradifurone 75 g/l, Deltamethrin 10 g/l. The recommended dose for treating one hectare is 250 ml of the product diluted in 40 l of water, which corresponds to 62.5 ml of the product diluted in 10 l of water to treat ¼ of a hectare (5.28×10^{-4} g/ml). Dilution (1 ml of the product) in distilled water (280 ml; 220 ml; 160 ml; 100 ml and 40 ml) gave 3.02×10^{-4}; 3.85×10^{-4} g/ml, 5.28×10^{-4} g/ml; 8.42×10^{-4} g/ml and 2.07×10^{-3} g/ml respectively.

Spraying of products on *C. lameensis* adults

A 2430 m² (54 m x 45 m) plot containing 30 oil palms was used for this trial. Forty (40) adult males and females of *C. lameensis* were introduced into cages (100 cm x 80 cm) covered with white muslin and placed on the palm trees. Two days later, they were treated with the above-mentioned insecticides at different concentrations. Dead insects were counted for 15 days after application.

Three replicates were made per concentration and per insecticide. For each concentration, average mortality rates were calculated and corrected using the Abott (1925) formula.

$$\mathrm{M} = \frac{\text{Number of dead insects}}{\text{Total number of insects}} \times 100$$

$$\mathrm{Mc} = \frac{\mathrm{Mo}-\mathrm{Mt}}{100-\mathrm{Mt}} \times 100$$

With MC: corrected mortality; Mo: observed treatment mortality and Mt: control mortality.
The lethal concentration 50 or LC_{50} is that which causes the death of 50% of a population of treated insects after 24 hours. It was determined by a regression model using log probit.

Statistical analysis

Data processing was carried out using Statistica version 7.1 software. An analysis of variance (ANOVA) was used to identify significant differences between the data. The Student-Newman-Keuls test at the 5% threshold was used to classify means into homogeneous groups.

LC_{50} and LC_{90} were determined using Rstudio software version 4.3.2. The regression model used to determine lethal doses is log probit, which allows values to be predicted.

Results:-

Effect of products on adult males and females of *Coelaenomenadera lameensis*
Effect of NECO 50 EC on adult males and females of *C. lameensis*
Adult males:

Twenty-four hours (24h) after spraying, the five concentrations 1.92×10^{-3} g/ml; 2.38×10^{-3} g/ml; 3.12×10^{-3} g/ml; 4.54×10^{-3} g/ml and 8.33×10^{-3} g/ml recorded mortality rates of 0 ± 0; 0.83 ± 1.44; 25.83 ± 3.81; 56.66 ± 3.81 and 65.83 ± 2.88% respectively. Four days after application, the highest concentration 8.33×10^{-3} g/ml caused a maximum mortality rate of 100 ± 0%. The other concentrations 3.12×10^{-3} g/ml and 4.54×10^{-3} g/ml induced mortality rates of 100 ± 0% on days 7 and 5 respectively (Table 1). Statistical analysis revealed significant differences between mortality rates for the different concentrations (F= 28.7; ddl= 89; p =0.000).

Adult females:

Mortality rates ranged from 0 ± 0% to 70 ± 5% twenty-four hours (24h) after application of the product at different concentrations (1.92×10^{-3} g/ml; 2.38×10^{-3} g/ml; 3.12×10^{-3} g/ml; 4.54×10^{-3} g/ml and 8.33×10^{-3} g/ml). Of the five concentrations, the lowest, 1.92×10^{-3} g/ml; 2.38×10^{-3} g/ml and 3.12×10^{-3} g/ml, failed to cause 50% insect mortality twenty-four hours after spraying. Four days after treatment, the highest concentration 8.33×10^{-3} g/ml induced a mortality rate of 100 ± 0%. Mortality rates increased to a maximum of 100 ± 0% on days 10, 6 and 5 respectively with concentrations 2.38×10^{-3} g/ml; 3.12×10^{-3} g/ml and 4.54×10^{-3} g/ml (Table 2). Statistical analysis revealed significant differences between mortality rates for the different concentrations (F= 12.18; ddl= 89; p =0.000).

Table 1:- Mortality rate of *C. lameensis* males after treatment with NECO 50 EC.

			Concentrations			
Number of days after treatment	**1.92×10^{-3} g/ml**	**2.38×10^{-3} g/ml**	**3.12×10^{-3} g/ml**	**4.54×10^{-3} g/ml**	**8.33×10^{-3} g/ml**	witness
1	0 ± 0 q	0.83 ± 1.44 q	25.83 ± 3.81 mn	56.66 ± 3.81 ij	65.83 ± 2.88 hi	0 ± 0 q
2	6.67 ± 6.29 p	22.50 ± 2.50 mn	55.83 ± 8.77 ij	68.33 ± 5.77 gh	80 ± 5 fg	0 ± 0 q

3	16.64 ± 5.10 o	44.47 ± 3.88 jk	73.87 ± 8.94 fg	80.60 ± 5.46 fg	89.88 ± 2.56 def	1.00 ± 1.00 q
4	26.89 ± 8.63 mn	63.46 ± 3.52 hi	82.16 ± 7.52 def	95.73 ± 3.92 ab	100 ± 0 a	2.00 ± 1.00 q
5	34.51 ± 8.35 lm	72.84 ± 9.39 fg	91.52 ± 3.80 cde	100 ± 0 a	100 ± 0 a	2.00 ± 1.00 q
6	36.98 ± 8.82 kl	85.37 ± 5.30 def	96.57 ± 3.93 ab	100 ± 0 a	100 ± 0 a	3.33 ± 1.52 pq
7	38.32 ± 7.19 kl	87.86 ± 4.41 def	100 ± 0 a	100 ± 0 a	100 ± 0 a	4.00 ± 1.00 p
8	39.20 ± 7.70 kl	91.08 ± 6.75 cde	100 ± 0 a	100 ± 0 a	100 ± 0 a	6.66 ± 1.52 p
9	42.54 ± 8.77 kl	92.87 ± 8.23 bcd	100 ± 0 a	100 ± 0 a	100 ± 0 a	7.00 ± 2.00 p
10	42.54 ± 8.77 kl	92.87 ± 8.23 bcd	100 ± 0 a	100 ± 0 a	100 ± 0 a	7.00 ± 2.00 p
11	45.64 ± 11.95 kl	93.72 ± 8.64 abc	100 ± 0 a	100 ± 0 a	100 ± 0 a	8.00 ± 1.00 p
12	45.64 ± 11.95 kl	93.72 ± 8.64 abc	100 ± 0 a	100 ± 0 a	100 ± 0 a	8.00 ± 1.00 p
13	45.64 ± 11.95 kl	93.72 ± 8.64 abc	100 ± 0 a	100 ± 0 a	100 ± 0 a	8.00 ± 1.00 p
14	45.64 ± 11.95 kl	93.72 ± 8.64 abc	100 ± 0 a	100 ± 0 a	100 ± 0 a	8.00 ± 1.00 p
15	45.64 ± 11.95 kl	93.72 ± 8.64 abc	100 ± 0 a	100 ± 0	100 ± 0	8.00 ± 1.00 p

Newman-Keuls test at the threshold of 5% (F= 28.7; ddl= 89 ; p =0.000)
Mortality rates followed by the same letters are not significantly different

Table 2:- Mortality rate of *C. lameensis* females after treatment with NECO 50 EC.

			Concentrations			
Number of days after treatment	**1.92×10^{-3} g/ml**	**2.38×10^{-3} g/ml**	**3.12×10^{-3} g/ml**	**4.54×10^{-3} g/ml**	**8.33×10^{-3} g/ml**	witness
1	0 ± 0 q	1.67 ± 2.87 q	32.50 ± 4.33 lm	61.66 ± 2.88 hi	70 ± 5 gh	0 ± 0 q
2	12.5 ± 5 o	30 ± 2.50 lm	65 ± 6.61 hi	75 ± 5 fg	80.83 ± 6.29 fg	0 ± 0 q
3	27.86 ± 4.52 mn	49.71 ± 6.12 jk	78.21 ± 3.62 fg	85.76 ± 5.12 def	92.46 ± 2.44 abc	0,66 ± 1.54 q
4	38.56 ± 5.14 kl	69.69 ± 2.68 gh	89.06 ± 1.35 def	96.62 ± 1.49 ab	100 ± 0 a	1 ± 1 q
5	41.72 ± 5.15 kl	88.18 ± 8.95 def	98.31 ± 1.45 a	100 ± 0 a	100 ± 0 a	1.33 ± 1.15 q
6	46.53 ± 6.78 jk	92.21 ± 6.91 bcd	100 ± 0 a	100 ± 0 a	100 ± 0 a	3.33 ± 0.57 pq
7	48.93 ± 4.46 jk	96.51 ± 4.03 ab	100 ± 0 a	100 ± 0 a	100 ± 0 a	3.66 ± 1.15 pq
8	53.74 ± 6.04 ij	98.23 ± 3.07 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	6.33 ± 1.52 p
9	57.16 ± 6.89 ij	99.11 ± 1.54 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	6.66 ± 1.15 p
10	57.16 ± 6.89 ij	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	6.66 ± 1.15 p

11	57.79 ± 7.71 ij	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7.33 ± 1.15 p
12	58.58 ± 8.80 ij	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7.66 ± 1.52 p
13	58.58 ± 8.80 ij	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7.66 ± 1.52 p
14	58.58 ± 8.80 ij	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7.66 ± 1.52 p
15	58.58 ± 8.80 ij	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7.66 ± 1.52 p

Newman-Keuls test at the threshold of 5% (F= 12.18; ddl= 89 ; p =0.000)
Mortality rates followed by the same letters are not significantly different.

Effect of LIMOCIDE 60 ME on adult males and females of *C. lameensis*

Adult males:

Following application of the product at different concentrations (3.58×10^{-4}g/ml; 4.5×10^{-4}g/ml, 5.9×10^{-4}g/ml; 8.9×10^{-4} g/ml; and 1.75×10^{-3} g/ml), mortality rates varied from 0 ± 0% to 100 ± 0% over the 15-day control period. Only the 1.75×10^{-3} g/ml concentration was able to induce a mortality rate greater than 50% twenty-four hours (24h) after spraying. Fifteen days after treatment, the highest mortality rate (100 ± 0%) was obtained with the highest concentration 1.75×10^{-3} g/ml. The other concentrations 3.58×10^{-4}g/ml; 4.5×10^{-4}g/ml, 5.9×10^{-4}g/ml and 8.9×10^{-4} g/ml produced mortality rates of 39.98 ± 3.37%; 52.88 ± 2.03%; 79.17 ± 4.06% and 92.10 ± 2.68% respectively (Table 3). Statistical analysis revealed significant differences between mortality rates for the different concentrations (F= 6.74; ddl= 89; p =0.000).

Adult females:

Of the five concentrations 3.58×10^{-4} g/ml; 4.5×10^{-4} g/ml, 5.9×10^{-4}g/ml; 8.9×10^{-4} g/ml; and 1.75×10^{-3} g/ml, those which achieved 50% insect mortality twenty-four hours (24h) after spraying were 8.9×10^{-4} g/ml and 1.75×10^{-3} g/ml. Twelve days after product application, the 4.5×10^{-4} g/ml and 5.9×10^{-4} g/ml concentrations produced mortality rates of 67.60 ± 9.30% and 81.05 ± 2.64% respectively. These mortality rates remained stable until day 15 post-treatment. Concentrations of 8.9×10^{-4} g/ml and 1.75×10^{-3} g/ml resulted in mortality rates of 100 ± 0% on days 13 and 10 post-treatment (Table 4). Statistical analysis revealed significant differences between mortality rates for the different concentrations (F= 5.3; ddl= 89; p =0.000).

Table 3:- Mortality rate of *C. lameensis* males after treatment with LIMOCIDE 60 ME.

			Concentrations			
Number of days after treatment	**3.58×10^{-4} g/ml**	**4.5×10^{-4} g/ml**	**5.9×10^{-4} g/ml**	**8.9×10^{-4} g/ml**	**1.75×10^{-3} g/ml**	witness
1	0 ± 0 q	10.83 ± 2.87 o	21.66 ± 3.81 mn	41.66 ± 3.81 kl	52.50 ± 2.89 ij	0 ± 0 q
2	3.33 ± 3.82 pq	17.50 ± 2.50 o	30.83 ± 6.29 lm	51.66 ± 6.29 jk	65.83 ± 6.61 hi	0 ± 0 q
3	5.73 ± 2.16 p	26.72 ± 7.21 mn	37.61 ± 15.33 kl	62.13 ± 4.89 hi	68 ± 4.22 gh	1.00 ± 1.00 q
4	20.06 ± 4.21 mn	31.95 ± 4.19 lm	48.98 ± 11.06 jk	63.47 ± 6.04 hi	69.41 ± 7.53 gh	2.00 ± 1.00 q
5	25.19 ± 4.82 mn	36.20 ± 3.20kl	56.64 ± 13.39 ij	67.70 ± 2.65 gh	70.26± 5.17 gh	2.00 ± 1.00 q
6	34.94 ± 5.27 lm	37.05 ± 3.33 kl	62.00 ± 8.64 hi	69.82 ± 2.92 gh	74.17 ± 5.30 fg	3.33 ± 1.52 pq
7	36.86 ± 5.07 kl	41.79 ± 5.22 kl	63.49 ± 7.22 hi	74.80 ± 4.12 fg	78.33 ± 5.42 fg	4.00 ± 1.00 p
8	37.33 ± 5.40 kl	44.56 ± 8.49 jk	66.90 ± 5.98 hi	82.14 ± 1.52 def	84.86 ± 3.04 def	6.66 ± 1.52 q

9	37.51 ± 5.23 kl	47.95 ± 5.22 jk	67.69 ± 5.68 hi	84.74 ± 1.82 def	89.34 ± 3.04 def	7.00 ± 2.00 q
10	39.07 ± 3.88 kl	51.57 ± 3.37 jk	71.27 ± 4.47 gh	86.49 ± 4.85 def	94.64 ± 0 ab	7.00 ± 2.00 q
11	39.07 ± 3.88 kl	51.96 ± 3.61 jk	74.62 ± 5.74 fg	88.23 ± 5.61 def	97.27 ± 0 ab	8.00 ± 1.00 q
12	39.98 ± 3.37 kl	52.88 ± 2.03 ij	75.54 ± 4.71 fg	90.96 ± 4.06 cde	100 ± 0 a	8.00 ± 1.00 q
13	39.98 ± 3.37 kl	52.88 ± 2.03 ij	77.35 ± 3.15 fg	91.85 ± 2.66 cde	100 ± 0 a	8.00 ± 1.00 q
14	39.98 ± 3.37 kl	52.88 ± 2.03 ij	79.17 ± 4.06 fg	91.85 ± 2.66 cde	100 ± 0 a	8.00 ± 1.00 q
15	39.98 ± 3.37 kl	52.88 ± 2.03 ij	79.17 ± 4.06 fg	92.10 ± 2.68 bcd	100 ± 0 a	8.00 ± 1.00 q

Newman-Keuls test at the threshold of 5% (F= 6.74; ddl= 89 ; p =0.000)
Mortality rates followed by the same letters are not significantly different

Table 4:- Taux de mortalité des femelles de *C. lameensis* après traitement au LIMOCIDE 60 ME.

			Concentrations			
Number of days after treatment	**3.58×10^{-4} g/ml**	**4.5×10^{-4} g/ml**	**5.9×10^{-4} g/ml**	**8.9×10^{-4} g/ml**	**1.75×10^{-3} g/ml**	witness
1	0 ± 0 q	10.83 ± 3.81 o	29.16 ± 3.81 lm	51.66 ± 3.81 jk	59.17 ± 2.89 ij	0 ± 0 q
2	1.67 ± 1.44 q	21.66 ± 9.46 mn	43.33 ± 6.29 kl	64.16 ± 6.29 hi	70 ± 6.61 gh	0 ± 0 q
3	10.24 ± 2.53 o	34.50 ± 9.64 lm	52.14 ± 5.54 ij	73.91 ± 3.79 fg	77.36 ± 4.22 fg	0.66 ± 1.54 q
4	21.72 ± 2.23 mn	40.16 ± 11.06 kl	57.72 ± 4.48ij	81.36 ± 2.88 def	82.34 ± 7.53 def	1 ± 1 q
5	29.88 ± 3.41 lm	46.68 ± 13,93 jk	58.73 ± 3.26ij	82.14 ± 2.55 def	86.51± 5.17 def	1.33 ± 1.15 q
6	34.48 ± 1.38 lm	48.23 ± 13.88 jk	62.05 ± 4.12 hi	87.93 ± 1.42 def	88.82 ± 5.30 def	3.33 ± 0.57 pq
7	37.06 ± 3.19 kl	51.51 ± 12.99 jk	65.36 ± 4.38 hi	93.07 ± 3.95 abc	93.92 ± 5.42 abc	3.66 ± 1.15 pq
8	40.40 ± 3.70 kl	57.21 ± 9.72 ij	70.62 ± 2.83 gh	97.33 ± 2.63 ab	98.24 ± 3.04 a	6.33 ± 1.52 p
9	42.86 ± 1.33 kl	58.89 ± 10.29 ij	74.07 ± 4.34 fg	97.33 ± 2.63 ab	98.24 ± 3.04 a	6.66 ± 1.15 p
10	43.76 ± 2.11 kl	61.59 ± 10.83 hi	74.07 ± 4.34 fh	97.33 ± 2.63 ab	100 ± 0 a	6.66 ± 1.15 p
11	44.26 ± 2.40 jk	64.09 ± 10.54 hi	78.41 ± 2.73 fg	99.09 ± 1.56 a	100 ± 0 a	7.33 ± 1.15 p
12	44.98 ± 3.21 jk	67.60 ± 9.30 hi	81.05 ± 2.64 fg	99.09 ± 1.56 a	100 ± 0 a	7.66 ± 1.52 p
13	46.75 ± 1.08 jk	67.60 ± 9.30 hi	81.05 ± 2.64 fg	100 ± 0 a	100 ± 0 a	7.66 ± 1.52 p
14	46.75 ± 1.08 jk	67.60 ± 9.30 hi	81.96 ± 4.03 def	100 ± 0 a	100 ± 0 a	7.66 ± 1.52 p
15	46.75 ± 1.08 jl	67.60 ± 9.30 hi	81.96 ± 4.03 def	100 ± 0 a	100 ± 0 a	7.66 ± 1.52 p

Newman-Keuls test at the threshold of 5% (F= 5.3 ; ddl= 89 ; p =0.000)

Mortality rates followed by the same letters are not significantly different

Effect of Sivanto Energy 85 EC on adult males and females of *C. lameensis*

Adult males:

Twenty-four hours (24h) after spraying, the five concentrations 3.02×10^{-4} g/ml; 3.85×10^{-4} g/ml, 5.28×10^{-4} g/ml; 8.42×10^{-4} g/ml and 2.07×10^{-3} g/ml produced mortality rates of 56.67 ± 2.87; 75 ± 5; 83.33 ± 7.63; 95 ± 6.61 and 100 ± 0% respectively. Mortality rates caused by concentrations of 3.02×10^{-4} g/ml; 3.85×10^{-4} g/ml, 5.28×10^{-4} g/ml and 8.42×10^{-4} g/ml increased to 100 ± 0% on days 5, 3 and 2 after product application (Table 5). Statistical analysis revealed significant differences between the mortality rates of the different concentrations (F= 46; ddl= 89; p =0.000).

Female adults:

Sivanto Energy 85 EC caused high mortality (64.17 ± 5.20; 80 ± 8.66; 89.16 ± 6.29; 98.33 ± 2.88 and 100 ± 0%) of female *C. lameensis* adules at different concentrations (3.02×10^{-4} g/ml; 3.85×10^{-4} g/ml, 5.28×10^{-4} g/ml; 8.42×10^{-4} g/ml and 2.07×10^{-3} g/ml) twenty-four hours (24h) after spraying. These mortality rates reached a maximum of 100 ± 0% on the 2nd post-treatment day with the 8.42×10^{-4} g/ml concentration, on the 3rd post-treatment day with the 3.85×10^{-4} g/ml and 5.28×10^{-4}g/ml concentrations, and on the 5th day with the 3.02×10^{-4} g/ml concentration (Table 6). Statistical analysis revealed significant differences between mortality rates for the different concentrations (F= 19.5; ddl= 89; p =0.000).

Table 5:- Mortality rate of *C. lameensis* males after treatment with Sivanto Energy 85 EC.

			Concentrations			
Number of days after treatment	**3.02×10^{-4} g/ml**	**3.85×10^{-4} g/ml**	**5.28×10^{-4} g/ml**	**8.42×10^{-4} g/ml**	**2.07×10^{-3} g/ml**	**witness**
1	56.67 ± 2.87 ij	75 ± 5 fg	83.33 ± 7.63 def	95 ± 6.61 ab	100 ± 0 a	0 ± 0 q
2	65.83 ± 2.87 hi	93.33 ± 2.88 abc	97.50 ± 4.33 ab	100 ± 0 a	100 ± 0 a	0 ± 0 q
3	75.57 ± 3 fg	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	1.00 ± 1.00 q
4	88.94 ± 2.95 def	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	2.00 ± 1.00 q
5	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	2.00 ± 1.00 q
6	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	3.33 ± 1.52 pq
7	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	4.00 ± 1.00 pq
8	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	6.66 ± 1.52 p
9	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7.00 ± 2.00 p
10	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7.00 ± 2.00 p
11	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	8.00 ± 1.00 p
12	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	8.00 ± 1.00 p
13	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	8.00 ± 1.00 p
14	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	8.00 ± 1.00 p
15	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	8.00 ± 1.00 p

Newman-Keuls test at the threshold of 5% (F= 46; ddl= 89 ; p =0.000)
Mortality rates followed by the same letters are not significantly different

Table 6:- Mortality rate of *C. lameensis* females after treatment with Sivanto Energy 85 EC.

			Concentrations			
Number of days after treatment	**3.02×10^{-4} g/ml**	**3.85×10^{-4} g/ml**	**5.28×10^{-4} g/ml**	**8.42×10^{-4} g/ml**	**2.07×10^{-3} g/ml**	**witness**
1	64.17 ± 5.20 hi	80 ± 8.66 fg	89.16 ± 6.29 def	98.33 ± 2,88 a	100 ± 0 a	0 ± 0 q
2	75.83 ± 3.82 fg	95.83 ± 1.44 ab	99.16 ± 1.44 a	100 ± 0 a	100 ± 0 a	0 ± 0 q
3	91.56 ± 8.97 cde	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	0,66 ± 1,54 q
4	98.30 ± 2.95 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	1 ± 1 q
5	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	1,33 ± 1,15 q
6	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	3,33 ± 0,57 pq
7	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	3,66 ± 1,15 pq
8	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	6,33 ± 1,52 p
9	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	6,66 ± 1,15 p
10	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	6,66 ± 1,15 p
11	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7,33 ± 1,15 p
12	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7,66 ± 1,52 p
13	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7,66 ± 1,52 p
14	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	7,66 ± 1,52 p
15	100 ± 0 a	100 ± 0	100 ± 0 a	100 ± 0 a	100 ± 0 a	7,66 ± 1,52 p

Newman-Keuls test at the threshold of 5% (F= 19.5; ddl= 89; p =0.000)
Mortality rates followed by the same letters are not significantly different

Overall mortality rate of adult females and males of *C. lameensis* following spraying with products

Overall mortality rates for adult *C. lameensis* females and males ranged for NECO 50 EC from 45.08 ± 18.76 to 96.21 ± 8.88% (females) and from 34.16 ± 16.47 to 95.71 ± 9.84 (males). LIMOCIDE 60 ME rates ranged from 32.77 ± 16.31 to 90.31 ± 13.02% (females) and 29.27 ± 14.82 to 82.98 ± 15.77% (males). For Sivanto Energy, rates ranged from 95.32 ± 10.77 to 100 ± 0% for females and 92.47 ± 14.16 to 100 ± 0% for males (Table 7).

Table 7:- Overall mortality rate of *C. lameensis* females and males.

		Sex	
Products	**Concentrations**	**females**	**Males**
NECO 50 EC	1.92×10^{-3}g/ml	45.08 ± 18.76 hi	34.16 ± 16.47 j
	2.38×10^{-3} g/ml	81.69 ± 30.17 cd	74.85 ± 29.47d
	3.12×10^{-3}g/ml	90.87 ± 18.79 bc	88.39 ±21.35 bc

	4.54×10^{-3}g/ml	94.60 ± 11.42 ab	93.42 ± 13.54 ab
	8.33×10^{-3}g/ml	96.22 ± 8.88 ab	95.71 ± 9.84 ab
LIMOCIDE 60 ME	3.58×10^{-4} g/ml	32.77 ± 16.31 j	29.27 ± 14.82 k
	4.5×10^{-4}g/ml	51.05 ± 19.33 g	40.65 ± 13.92 h
	5.9×10^{-4}g/ml	66.12 ± 15.75 e	60.87 ± 18.99 f
	8.9×10^{-4}g/ml	88.30 ± 14.80 bc	75.98 ± 15.99d
	1.75×10^{-3}g/ml	90.31 ± 13.02 bc	82.98 ± 15.77 cd
SIVANTO ENERGY 85 EC	3.02×10^{-4} g/ml	95.32 ± 10.77 ab	92.47 ± 14.16bc
	3.85×10^{-4}g/ml	98.39 ±5.41 a	97.89 ± 6.53 a
	5.28×10^{-4}g/ml	99.22 ± 3.05 a	98.72 ± 4.60 a
	8.42×10^{-4}g/ml	99.89 ± 0.75 a	99.67 ± 1.89 a
	2.07×10^{-3} g/ml	100 ± 0 a	100 ± 0 a

Newman-Keuls test at the threshold of 5% (F= 1.95; ddl= 29; p =0.000)
Mortality rates followed by the same letters are not significantly different

Lethal concentrations (LC_{50} and LC_{90}) of products tested on *C. lameensis*

Lethal concentrations resulting in the death of 50% (LC_{50}) and 90% (LC_{90}) of *C. lameensis* adults twenty-four hours (24h) after spraying were determined for each product. Comparison of the three products used shows that the two biopesticides have higher LC values than the reference insecticide (Table 8).

Table 8:- Lethal concentrations (LC_{50} and LC_{90}) of products tested during the study.

Products	**Sex**	**Lethal concentrations (LC)**	
		LC_{50}	**LC_{90}**
NECO 50 EC (g/ml)	Females	4.96×10^{-3}	1.03×10^{-2}
	Males	5.37×10^{-3}	1.14×10^{-2}
LIMOCIDE 60 ME (g/ml)	Females	1.15×10^{-3}	3.33×10^{-3}
	Males	1.38×10^{-3}	4.35×10^{-3}
SIVANTO ENERGY 85 EC (g/ml)	Females	2.46×10^{-4}	5.30×10^{-4}
	Males	2.60×10^{-4}	6.33×10^{-4}

Discussion:-

In view of the extensive damage caused by *C. lameensis*, control methods have been tested to reduce the level of attack to a reasonable economic level. Among these methods, the use of biopesticides (NECO 50 EC and LIMOCIDE 60 ME) was evaluated in the present study. Results showed that the products tested effectively eliminated adult female and male *C. lameensis*. The synthetic chemical (Sivanto Energy 85 EC) proved most effective in managing *C. lameensis* adults, followed by NECO 50 EC and LIMOCIDE 60 ME according to observation time. The effectiveness of Sivanto Energy was revealed by Kouassi et al., (2020) in their work on the same insect. These authors reported that Sivanto Energy at a dose of 2.5 ml eliminated 100% of *C. lameensis* adults at a shorter observation time (2 days).This effectiveness would be due to the difference in insecticidal power and mode of action of the different products. This explanation is in line with that of Tounou et al., (2018), who reported in their work on *Podagrica* spp that synthetic chemicals have a higher insecticidal power. Sivanto Energy 85 EC is composed of two active ingredients, deltamethrin and flupyradifurone. Both active ingredients act both by contact and by ingestion on a large number of insects, but the effect of flupyradifurone is more powerful by ingestion (Bayer, 2011). The efficacy of deltamethrin had already been demonstrated on insect pests of cowpea in Central Benin (Mehinto et al., 2014), on the cockroach *Periplaneta americana* (Blattodea: Blattidae) in the laboratory (Caballero, 2019) and on *Prosoestus sculptilis* and *Prosoestus minor* (Coleoptera: Curculionidae), insect pests of female oil palm inflorescences (Hala, 2020).The results also showed that the biopesticides used induced mortality rates that evolved as a function of time and concentration. At a concentration of 8.33×10^{-3} g/ml, NECO 50 EC recorded a mortality rate of 70% twenty-four hours (24h) after spraying in females. This formulation could be considered effective. This observation is in line with those of Begnon et al., (1990), Tano et al., (2019) and Yéboué et al., (2022), who reported that a product with an insecticidal effect is effective when it generates a mortality rate of at least 70% on an insect pest twenty-four hours (24h) after treatment. Four concentrations (2.38×10^{-3} g/ml, 3.12×10^{-3} g/ml, 4.54×10^{-3} g/ml and 8.33×10^{-3} g/ml) of NECO 50 EC applied to adult males and females of *C. lameensis*, induced 100% mortality. These results confirm those of Nguemtchouin (2012), who recorded mortality rates of 100% on *Sitophilus zeamais* adults with a powder formulation by adsorption of essential oils of *Ocimum gratissimum*, the main component of NECO 50 EC. These results also concur with those of Ouedraogo et al., (2016), Johnson et al., (2018) and Akéssé et al., (2020), who in their studies showed its effectiveness in controlling adults of *S. zeamais* and *Diastocera trifasciata*. The insecticidal properties of essential oils from species of the *Ocimum genus* in the control of various orders of insect pests have already been reported by several authors (Kobenan et al., 2018, Tia et al., 2019, Tano et al., 2019, Kassi et al., 2021, Yoboué et al., 2022). This effectiveness of NECO 50 EC on insects could be due to the insecticidal action of Thymol and γ-Terpinene, which are the active molecules in the essential oil of *Ocimum gratissimum* (Koffi et al., 2013; Kassi et al., 2014; Kobenan et al., 2018).

Under the effect of LIMOCIDE 60 ME, only the 1.75×10^{-3} g/ml concentration caused the death of 50% of adult males twenty-four hours (24h) after treatment, while in females, it was the 8.9×10^{-4} g/ml and 1.75×10^{-3} g/ml concentrations that were able to induce a mortality rate in excess of 50%. At 13 and 15 days post-treatment, LIMOCIDE 60 ME induced high mortality rates of 100 ± 0% in females and 92.10 ± 2.68% in males at 8.9×10^{-4} g/ml, respectively. These results show that this biopesticide is equally effective against adult males and females of *C. lameensis*. Previous studies have shown that powders and essential oils from the fresh branches and leaves of aromatic plants are used to protect stored cowpea (*V. unguiculata* (L.) Walp.), maize (*Zea mays* L.) and bean (*P. vulgaris* L.) grains from attack by various stock insects (Kalomal et al., 2008). Similar work has reported that essential oils of *Citrus sinensis*, *Citrus aurantium* and neem (*Azadirachta indica* Juss.) have larvicidal and insecticidal activity on *Culex pipens* larvae and adules (EL Akhal et al., 2014) and *Maruca vitrata* (Traore et al., 2019). According to Gandeho et al., (2022), orange peel powder and essential oil have shown efficacy on *Callosobruchus maculatus* Fab, a cowpea predator in stock.These insecticidal activities of sweet orange essential oil could be due to their chemical composition. EL Akhal et al., (2014) revealed that the essential oils of *Citrus sinensis* and *Citrus aurantium* are predominantly composed of limonene, with percentages of 95.36% in *Citrus sinensis* and 90.0% in *Citrus aurantium*. On the other hand, work carried out by Rossi et al., (2013) and Dongmo et al., (2002) on *C. sinensis* proved this result with respective percentages of 95.1% and 82.36% limonene in orange peel.

Conclusion:-

Evaluation of the efficacy of the two biopesticides used on *C. lameensis* showed high mortality rates with NECO 50 EC. These rates were 100% on the 10th, 6th, 5th and 4th days of treatment at the different concentrations 2.38×10^{-3} g/ml; 3.12×10^{-3} g/ml; 4.54×10^{-3} g/ml and 8.33×10^{-3} g/ml in females and 100% on the 7th, 5th and 4th days of treatment at the concentrations 3.12×10^{-3} g/ml; 4.54×10^{-3} g/ml and 8.33×10^{-3} g/ml in males. LIMOCIDE 60 ME produced mortality rates of 100% on day 12 after spraying at 1.75×10^{-3} g/ml (males) and 100% on days 12 and 10 after treatment at 8.9×10^{-4} g/ml and 1.75×10^{-3} g/ml. The results obtained from the mortality rates show that NECO 50 EC and LIMOCIDE 60 ME could be used against adult *C. lameensis* at 8.33×10^{-3} g/ml and 1.75×10^{-3} g/ml respectively.

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