Original Research Article

Insecticidal effect of *Jatropha curcas* L. (Euphorbiaceae) oil on *Spodoptera frugiperda* J.E.SMITH, 1797 (Lepidoptera: Noctuidae) larvae.

ABSTRACT

The study was undertaken to contribute to the sustainable management of *Spodoptera frugiperda* Smith in cereal agrosystems, in this case, those of maize. It aims to evaluate the insecticidal efficacy of *Jatropha curcas* L. oil, a plant of the Togolese flora on *S. frugiperda* larvae. Two concentrations of *J. curcas* oil (10 and 20ml.l^{-1}) were tested by ingestion on the six larval stages of *S. frugiperda* grouped into (L_{1-2} (3-5 days of age); L_{3-4} (6-8 days of age); L_{5-6} (>10 days of age)). The insecticidal efficacy of the oil was determined in the laboratory and the phytosanitary protection tests on maize were carried out in the field.

In the laboratory, the concentration of 10 ml.l^{-1} with/without emulsifier caused a mortality rate of (87-92%) at stage L_{1-2}, (51-58%) at stage $L_{3-4,}$ and (57- 68%) at L_{5-6} stage after 72 hours of ingestion. 20 ml.l^{-1} concentration caused over 70% mortality whether applied with or without an emulsifier at all stages. Adult emergence is nil for L_{1-2} stages at 20 ml.l-1 and <10% for the other stages. Plots subjected to jatropha oil treatments (2l.ha^{-1} and 4l.ha^{-1} with or without emulsifier) were less infested like Emacot compared to control plots untreated. The present results show that jatropha oil has insecticidal potential against *S. frugiperda*.

Keywords: ingestion, potentiality, bio-insecticide, mortality rate, toxicity.

1. INTRODUCTION

Maize (*Zea mays* L.) is an important staple crop in West Africa [1]. The most produced cereal, maize, is used in human food, animal feed, and industrial uses. More than 70% of maize production is reserved for human consumption [2] in west Africa.

In Togo, maize is the main grain crop produced mainly for human and animal consumption. Yields obtained across Togo average 1.39 t/ha [3] against a potential yield of 5 t/ha (Ikenne) [4]. Maize cultivation experiences various factors that limit its yields such as the decline in soil fertility, poor cultivation practices, diseases, environmental stresses, and insect pests [5]. Pests, especially insects, incontestably play an important role in the loss of maize yield. On maize, lepidopteran stem borers and ear miners are the most damaging insects [6]. They are native pests and are responsible for 10 to 100% yield loss [7]. An exotic species, *Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae), also appeared in Africa in 2016 [8]. A pest of economic importance, *S. frugiperda* attacks maize and

various crops causing substantial damage [9]. These larvae feed on young tender leaves and sometimes on the ears in formation, which can cause more than a 10% loss of yield [10]. Faced with these scourges, chemical insecticides have been used to limit the spread of the pest [11]. However, although these chemical products have been effective [12], most of them constitute poisons for users, and the environment and are inaccessible to producers due to the cost which remains high [13].

Thus, it is important to find alternatives in terms of crop protection. The use of botanical species with pesticide effects presents itself as a possibility in the fight against insect pests [14]. These botanical pesticides, commonly called biopesticides, have a real advantage due to their low persistence, their low toxicity for humans, and their mode of action on pests [15]. Botanical pesticides have been effective against maize insects in Africa [2]. Indeed, [16] demonstrated the effectiveness of neem products against the stem borers *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) and *Eldana saccharina* Walker (Lepidoptera: Pyralidae). [2] demonstrated that neem oil has deterrent effects on the egg-laying of *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae). Among these plants with proven biocidal properties, *Jatropha curcas* L. (Euphorbiaceae) has significant insecticidal qualities. Indeed, the work carried out by [17] proved the insecticidal potential of the oil of *J. curcas*. Also, the insecticidal effect of *J. curcas* oil has been demonstrated on *M. nigrivenella* [2], millet borers [18], stored foodstuffs ([17, 19, 20] and insect pests of cowpea in the field [21].

Through this work, the effectiveness of the toxic molecules contained in *J. curcas* oil has been demonstrated on pests of stored foodstuffs (heevils) and those of crops in the vegetative phase (stem and pod borers, etc.). This study focuses on the toxic effect of *J. curcas* oil on crop pests in the vegetative phase and aims to determine the biocidal efficacy of the oil on the fall armyworm (*S. frugiperda*).

2. Material and methods

2.1 Material

Six stages larvae of *S. frugiperda* grouped into (L_{1-2} (3-5 days of age); L_{3-4} (6-8 days of age); L_{5-6} (>10 days of age)) were used for laboratory bioassays. The bio-insecticide *J. curcas* provided by IITA and synthetic insecticide, "EMACOT 50 WG" was used for testing.

2.2 Method

2.2.1 Breeding of *S. frugiperda*

Larvae were collected from maize plants at the Lomé Agronomic Experimentation Station and brought back to the laboratory for rearing. They are fed on fresh, tender maize leaves until the pupa stage. These pupae are then transferred to the adult breeding cage until the emergence of the latter. Upon emergence, cotton soaked in honey and the foot of young corn plants are introduced into these breeding cages for resting support for adults and egg-laying for females. The breeding cage is a rectangular cage made of aluminum (80 cm high and 50 cm wide) with an opening on one side. The opening is closed by a canvas in the form of a sleeve through which the manipulations are made. The upper side is made of fine mesh canvas to allow ventilation. In order to obtain age-matched larvae for testing, the egg masses laid are collected from the cages and incubated in the boxes. After hatching, the larvae of the same day of hatching (larvae of the same age) are fed on fresh and tender maize leaves and kept in culture for the tests. These sheets are renewed every 24 hours. Based on estimates of larval development time by Pitre and [22], larvae were grouped into L_{1-2} stages; L_{3-4}; and L_{5-6} with 3 to 5 respectively; 6 to 8 and 10 to 14 days of age.

2.2.2 Preparation of aqueous emulsion of *J. curcas* oil

Two concentrations of aqueous emulsions (10 and 20ml.l^{-1}) with and without emulsifier are prepared. Thus, the quantity of oil indicated is introduced into a beaker containing a 1% (g.l^{-1}) soapy solution as an emulsifier for solutions with an emulsifier. For solutions without an emulsifier, the oil is just mixed with water. In both cases, the mixture is stirred manually using a glass rod in order to obtain a suitable emulsion.

2.2.3 Laboratory test

The assessment was made by ingestion under ambient conditions between 28°C and 30°C. For each treatment, a sample of 10 larvae of the different stages was used and repeated four times each. Maize leaves cut into 5 cm in diameter are immersed in the various preparations for 2 minutes. These leaves are then removed and dried in the open air for 5 minutes in the laboratory before being used for the larvae in breeding boxes provided for the tests. The larvae are previously left empty for 6 hours before the introduction of treated leaves. The use of fasting larvae ensures that in contact with the treated leaves, they will feed.

2.2.4 Larval monitoring

The treated leaf is removed from the box after 24 hours and the larva is fed normally with the untreated leaves until it transforms into a pupa and from the pupa into adult insects. Mortality data was collected 24 and 48 hours after application. Observations were continued until adults emerged. A larva is considered dead when no part of its body moves when lightly touched with a brush. Observations continued on surviving larvae until the formation of pupae and the emergence of adults. The number of dead larvae and emerged adults per treatment made it possible to assess the mortality rate and the adult emergence rate.

2.2.5 Field evaluation of *J. curcas* oil against FAW

Maize variety "Ikenne " was planted at the SEAL field station on a plot size of 3.2 m×2 m, with spacing of 80 cm between rows and 20 cm between plants. The maize plot was fertilized with NPK15-15-15, fifteen (15) days after sowing at rate of 200 kg/ha and urea 45 days after sowing at rate of 100 kg/ha.

Treatment application : Treatments were applied using a hand-held sprayer at two-week intervals starting 15 days after planting until the appearance of male inflorescences. To avoid the risk of contamination, different sprayers were used for each formulation. 2 and 4 l/ha of jatropha oil were used with or without an emulsifier for the treatments. The control plots were not sprayed. Emacot, chemical insecticide was applied at rate of 1g/l. Randomized Complete Block Design (RCBD) with four replications was used for the experiment. Phytosanitary treatments were made by foliar application, mainly targeting the cornea of the plant.

Before the first application of the product, the number of egg masses, larvae per plant and infested plants were collected. After each application, the same data were collected until the emergence of male inflorescences. At each collection, destructive samples were taken to assess leaf scores using [23]. Therefore, each infested leaf is assigned a percentage of screening by the pest relative to the total leaf area of the leaf. The numerical scale of [23], was used to assess leaf damage ranging from 1 (no leaf damage) to 9 (severe leaf damage) which corresponds to the screening percentages.

2.3 Statistical analysis

The mortality data were corrected by the formula of [24]. Shapiro–Wilk's and Levene's tests were used respectively to test the normality and homogeneity of the data before any analysis. Data that does not follow a normal law or that is not homogeneous are subjected to statistical transformations to make them normal or homogeneous. Thus, percentage data such as adult mortality and emergence rate are transformed into Arsin√ (percent x/100) and those on the number of larvae are transformed by the logarithm (log (X+1). normal or homogeneous are subjected to the analysis of variance and the means separated with Tukey's multiple comparisons test at the 5% level. Data that are not normal or homogeneous are analyzed using the nonparametric Kruskal– Wallis The ranks are discriminated by the “all pairwise” method All these analyzes were carried out by the SPSS 26.0 software.

3. Results

3.1 Evaluation of the effectiveness of *J. curcas* oil in the laboratory on *S. frugiperda*

3.1.1 *J. curcas* oil on S. frugiperda larvae mortality.

The different doses based on jatropha oil produced lethal effects on the larvae of S. frugiperda. Based on the results of the analysis of variance, the mortalities vary according to the larval stages and the

doses. After 24 hours of ingestion, mortality is almost complete for treatment with the synthetic chemical insecticide (Emacot) at all larval stages (Figure 1). On the other hand, treatments based on jatropha oil caused variable mortality for the different larval stages. For the early stages (stage L_{1-2}), mortality varied from 49 to 67%. Statistical analysis reveals a significant difference in mortality between the different treatments (F= 53.69; P <0.001). Mortality is < 50% when the product is prepared with an emulsifier at a dose of 10 ml.l^{-1} and > 60% when the preparation is made without an emulsifier at a dose of 20 ml.l^{-1}.

The two jatropha oil preparations were more toxic to the first two instar larvae. On the L_{3-4} and L_{5-6} stage larvae of *S. frugiperda*, jatropha oil caused low mortality (8-23%) by ingestion with 10 ml.l^{-1} regardless of the preparation. The dose of 20 ml.l^{-1} with emulsifier had a lower lethal effect (48-45%), the same as the same dose without emulsifier (63-58%) on stages L_{3-4} (F= 40.49 ; P <0.001) and stages L_{5-6} (F= 26.66; P <0.001).

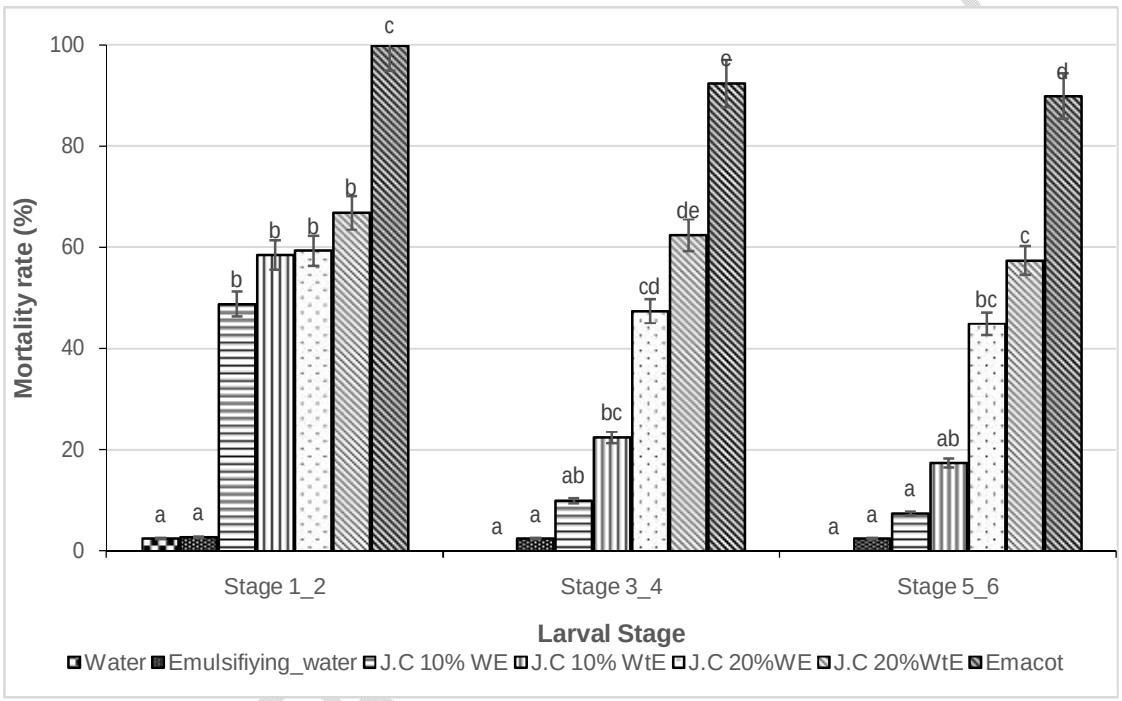

Figure 1: Mortality rate by ingestion of larvae of different larval stages of S. frugiperda subjected to different formulations based on jatropha oil after 24 hours. *The significant differences between the treatments are indicated by different letters (Tukey's test at the 5% threshold). J.C : J. curcas ; WtE : without emulsifier; WE : with emulsifier.*

After 48 hours of ingestion, the dose of 10 ml.l^{-1} with emulsifier caused a mortality < 40% on L_{3-4} (36%) and L_{5-6} (28%) stage larvae while on L_{1-2} stage larvae it caused 77% mortality (Figure 2). More than 80% mortality was recorded at all stages with the dose of 20 ml.l^{-1} without emulsifier. Statistical analysis reveals a significant difference between the oil-based products and the controls at all stages. Furthermore, at stage L_{1-2}, the oil-based preparations without emulsifier 10 ml.l^{-1} and 20ml.l^{-1} had practically identical toxic effects. The statistical analysis also shows that the dose of 20ml.l^{-1} without emulsifier has more effect on the larvae of stages L_{1-2} (98%) than L_{3-4} stages (87%) and L_{5-6} stages (84%).

In sum, jatropha oil showed different toxicities on *S. frugiperda* larvae. All larval stages showed a mortality of 8 to 59% after 24 hours of ingestion for preparations with an emulsifier and 18 to 67% for those without emulsifier. After 48 hours of ingestion, mortality increased from 28 to 87% with an emulsifier and from 44 to 98% for preparations without emulsifier. Furthermore, mortality increases with the concentration of *J. curcas* oil. After 48 hours of ingestion, stages L_{1-2} (on average 76% mortality due to preparations with emulsifier and 92% due to those without emulsifier) were more impacted by the various oil-based treatments followed by stages L_{5-6} (on average 58% mortality due to preparations with emulsifier and 70% due to those without emulsifier). Indeed, preparations with an

emulsifier caused between 74 and 77% mortality while those without emulsifier caused a mortality of 85 to 98% at these stages. The L_{3-4} stages, which are the most voracious, recorded on average 53 and 66% mortality respectively to preparations with emulsifier and those without emulsifier.

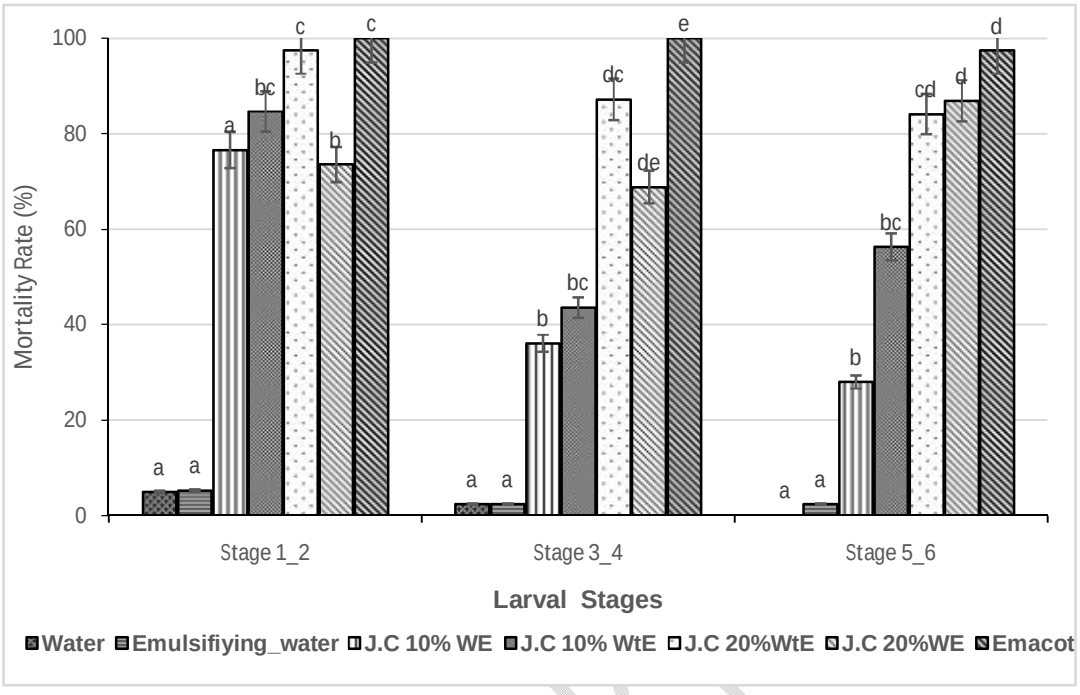

Figure 2: Mortality rate by ingestion of larvae of different larval stages of S. frugiperda subjected to different formulations based on jatropha oil after 48 hours. *The significant differences between the treatments are indicated by different letters (Tukey's test at the 5% threshold). J.C : J. curcas ; WtE : without emulsifier; WE : with emulsifier.*

3.1.2 *J. curcas* oil on *S. frugiperda* adult emergence

Little or no emergence of *S. frugiperda* adults is observed under conditions where the larvae are exposed to leaves treated with J. curcas oil (Figure 3). Jatropha oil with emulsifier at a dose of 10ml.l^{-1} allowed the emergence of 25% of adults for L_{3-4} stage larvae; L_{5-6} and 2.5% for those at stage L_{1-2}. Preparations without low dose emulsifier resulted in 7.5; 15 and 2.5% emergence of adults respectively for stages L_{1-2}; L3-4 and L5-6. The high dose without emulsifier impeded the emergence of adults at practically all stages, whereas that with the emulsifier only impeded the emergence of adults at the L1-2 stages. In general, emergence was zero with the application of Emacot for all stages. On the other hand, with jatropha oil, the emergence of adults was very low or even non-existent (<10%) at the L1-2 stage (df=6; $\chi 2$ =23.26; P<0.001), varying from 2.5 to 25% at stage L3-4 (df=6; $\chi 2$ =22.94; P<0.001). At stage L5-6, certain concentrations hindered the emergence of adults (df=6; $\chi 2$ =22.96; P<0.001).

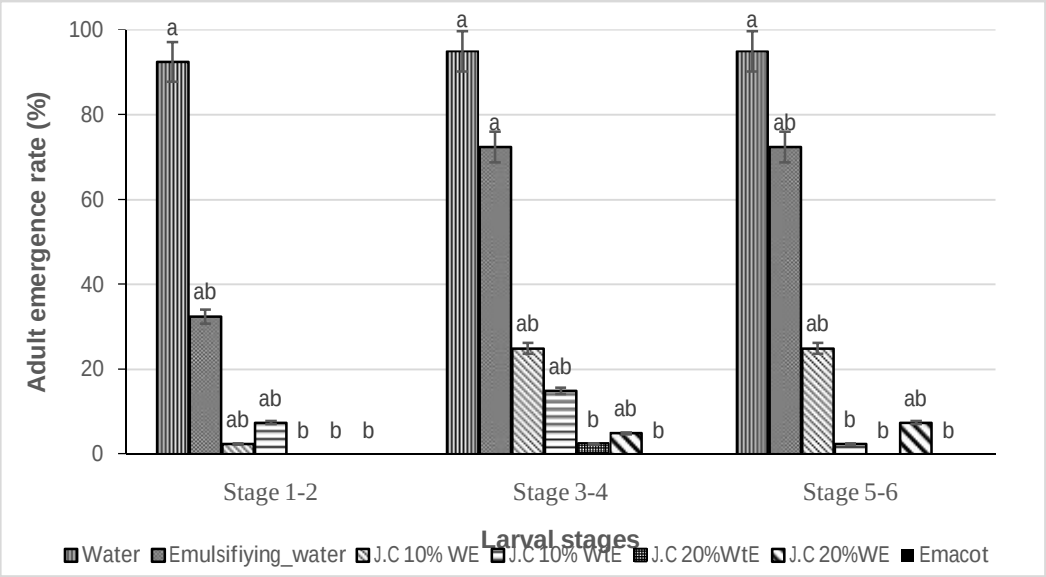

Figure 3: Emergence rate of *S. frugiperda* adults of different larval stages subjected to different formulations based on jatropha oil. *The significant differences between the treatments are indicated by different letters (Tukey's test at the 5% threshold). J.C : J. curcas ; WtE : without emulsifier; WE : with emulsifier.*

3.2 Evaluation of the effectiveness of *J. curcas* oil in the station on *S. frugiperda*

3.2.1 Effect of treatments on the evolution of the population of *S. frugiperda*

Population evolution of *S. frugiperda* larvae under the effect of different treatments is presented in Table 1. Fewer larvae were observed on the plots treated with Emacot and *J. curcas* oil compared to the plots without treatment (F= 6; P<0.001) but no significant difference is observed between concentrations of the oil.

Table 1: Effect of J. curcas oil on *S. frugiperda* larva population fluctuation

Traitement	Number of larvae per plant (mean ± SE)
J.C 10% WE	0,37±0,04bc
J.C 10% WtE	0,40±0,05b
J.C 20%WE	0,38±0,04b
J.C 20%WtE	0,32±0,05bc
Emacot	0,24±0,06c
Control	0,58±0,03a
Df	5 ; 88
F	6,00
P	<0,001

Values in a column followed by different lowercase letters are statistically different at the 5% level (Tukey test). *J.C : J. curcas ; WtE : without emulsifier; WE : with emulsifier.*

The density of *S. frugiperda* varies significantly with the date of collection (F = 10.85; P < 0.001). On the plots treated with J. curcas oil, the density is almost static at each collection.

3.2.2 Effect of oil on infestation, leaf damage of *S. frugiperda* and maize grain yield.

The infestation of the different plots by *S. frugiperda* was variable. It is more pronounced on the plots without treatment with 48% of infested plants (Figure 4a). This is less than 20% on plots that have received Emacot for treatment (15%). Regarding treatments with J. curcas oil, preparations made without emulsifier (respectively 35 and 30% at doses of 10 and 20 ml.l-1) recorded a different infestation rate from that whose preparations are made with an emulsifier (respectively 22 and 24% at doses of 10 and 20 ml.l-1). In general, the statistical analysis reveals a significant difference (df = 5; F = 3.43; P = 0.024). Between the different doses and the different formulations of the oil, no difference is observed. The severity of *S. frugiperda* on maize plants varied between plots with product application and those without product application. The results obtained show that the damage in general is low for all the treatments (2 ≤ score ≤ 3) according to the Davis scale. Statistical analysis indicates no significant difference between the *J. curcas* oil treatments and those of Emacot for the level of foliar damage. On the other hand, the difference in damage levels is significant between the control and the plots subjected to insecticide applications ($\chi 2$ = 40.56; P < 0.001; Df= 5).

Oil treatment influenced maize kernel production compared to controls (Figure 4b). The yield obtained under treatments where the product is applied with an emulsifier (yield ≤ 3 t.ha-1) is practically identical to that of Emacot. Analysis Statistical performance of different treatments was significant (F = 10.11; df = 5; P < 0.001). Effective in controlling the pest, jatropha oil without emulsifier was not efficient in obtaining yields. Thus, low yields were obtained under oil treatments without emulsifier (<2.5 t/ha). The yields obtained under Emacot and *J. curcas* oil with emulsifier were statistically identical at the 5% threshold.

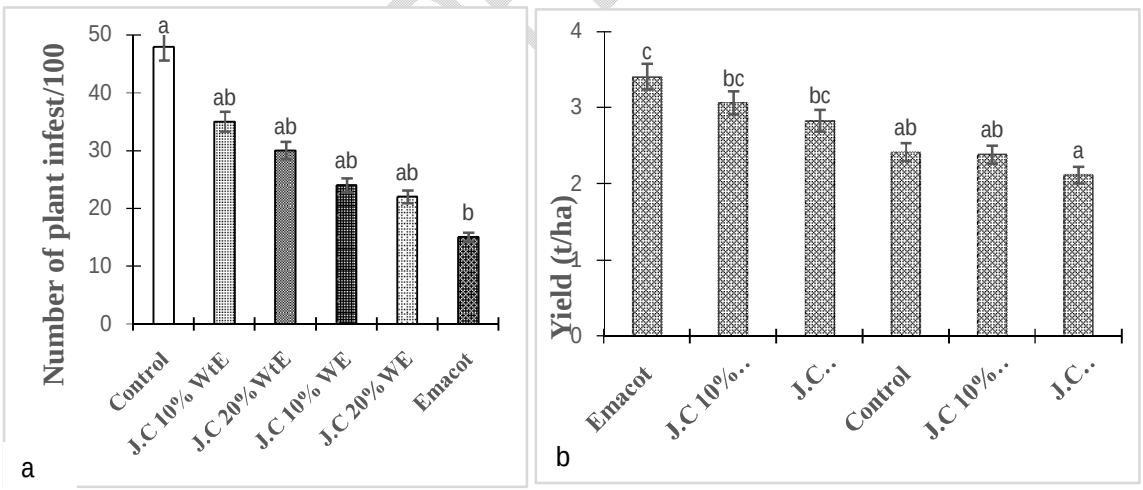

Figure 4: *S. frugiperda* infestation rate (a) and Yield of grain maize (b) according to the different formulations based on jatropha oil. *The significant differences between the treatments are indicated by different letters (Tukey's test at the 5% threshold). J.C : J. curcas ; WtE : without emulsifier; WE : with emulsifier.*

4. Discussion

The results of the biological tests in the laboratory show that the various products tested had effects on the larvae of S. frugiperda. Emacot used at 1g.l^{-1} had more effect on the larvae and caused almost 100% mortality of the larvae at all stages after 48 hours of exposure. These high mortalities are explained by the insecticidal power and the mode of action of chemical insecticides on the larvae.

Indeed, Emacot, a synthetic trans-laminar contact and systemic insecticide, induces an increase in cell apoptosis, DNA breaks leading to the rapid death of larvae [25]. Furthermore, [12] in Ethiopia proved the toxicity of synthetic chemical insecticides on S. frugiperda larvae in the laboratory. In their study, out of nine chemical insecticides tested, five caused more than 90% mortality after 72 hours of application. In pest control in the Americas, the use of chemical insecticides has been an important option [26]. Thus, [27] reported >60% mortality of *S. frugiperda* larvae after 16 h of application of Radiant (Spinetoram), Orthene (Acephate), and Larvin (Thiodicarb).

The mortality rate related to *J. curcas* oil after 24 hours of ingestion was ≤ 50% at 10 $ml.l^{-1}$ and > 50% at 20 $ml.l^{-1}$ on all larval stages. These mortalities show that the product poisoned the larvae. The results of this study confirm those of other authors who used the extracts of J. curcas seeds for biological tests on insect pests. Indeed, [28] demonstrated in Mexico the insecticidal potential of *J. curcas* grain extracts on L_3 stage larvae of *S. frugiperda.* [18] demonstrated that shredded *J. curcas* grains caused the death of the first stages of development of *S. calamistis* caterpillars. [21] demonstrated in the laboratory the effectiveness of J. curcas oil on the black bean aphid Aphis fabae Scop (Homoptera: Aphididae) after 24 hours of ingestion. These high mortality rates show the toxic nature of *J. curcas* oil. Indeed, the toxic nature of this oil is due according to [29] to the presence of phorbol esters. Phorbol esters are secondary metabolites of the family of diterpenes of the tigliane group [28] which act on biological membranes [14]. These insert into cell membranes and activate protein kinase (PKC) [30] leading to cell apoptosis [14]. At stages L_{3-6}, the mortality rate after 72 hours of ingestion is ≥ 50% at the dose of 10 $ml.l^{-1}$ and almost complete at the dose of 20 $ml.l^{-1}$. This proves that, 24 hours after ingestion, the effects of the product persist. These results are similar to those of [21] on *A. fabae* who showed that the mortality of these aphids increased up to 72 hours before stabilizing. According to these authors, mortality due to this oil increases with time. In addition, studies by [31] in 2018 demonstrated the toxic effect of jatropha oil on Hemiptera. According to the author, this toxic effect can be explained by the presence of a high quantity of curcin (toxalbumin) in the seeds of *J. curcas*.

J. curcas oil with emulsifier affected the emergence of adults without being able to prevent it when the larvae were over 5 days old. Conversely, the oil of *J. curcas* without emulsifier hindered the emergence of adults which it inhibits almost for all stages. This may in part mean that *J. curcas* oil takes a while to be at its most effective. These results corroborate those obtained by [21] who found that the biocidal effect of *J. curcas* oil increases during the hours following application to reach a maximum level after 96 hours.

Just as in the laboratory, jatropha oil made it possible to reduce the evolution of the population of *S. frugiperda* larvae compared to the control plot without product application. It also made it possible to reduce the infestation and the level of damage practically in the same way as the chemical insecticide Emacot but without being able to improve the yield of grain maize. This reduction can also be explained by the toxic nature of the oil conferred mainly by the esthers of phorbols. According to [32] phorbol esthers of the most toxic compounds in jatropha oil but which degrade very quickly and this degradation can be limited by adding an antioxidant. In this study, no antioxidant was added, so this reduction in the pest population would not be due solely to the effect of *J. curcas* oil but to other factors. However, similar reductions in the population of *M. nigrivella* in maize crops in Benin treated with this oil [2]. Also, [33] showed that the same oil reduced the population of major cowpea pests in Niger and therefore reduced the attacks of these pests. In Mali, crushed seeds of *J. curcas* resulted in a reduction in sorghum panicle bug damage [18].

5. CONCLUSION

It appears from the study that whatever the method of preparation, the oil of *J. curcas* has toxic effects on the fall armyworm. The insecticidal effect of *J. curcas* oil is comparable to the reference insecticide (Emacot) on L_{1-2} stage larvae under laboratory conditions. In the station, the oil of *J. curcas* had almost identical effects to that of Emacot but burns on leaves were observed on the plots having received the oil, especially those of 4 $l.ha^{-1}$. Jatropha oil could be a good bio-insecticide in FAW management.

REFERENCES

1. Agboka K., Schulthess F., Tamo M., Hell K., Stefan V. 2010. The importance of *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) as a post-harvest pest in different storage structures in Benin. Journal of Stored Products Research, 46: 81–86.

2. Agboka K, Agbodzavu K.M, Tamò M, Vidal S. 2009. Effects of plant extracts and oil emulsions on the maize cob borer *Mussidia nigrivenella* (Lepidoptera: Pyralidae) in laboratory and field experiments. International Journal of Tropical Insect Science 29: 185–194.
3. Direction des statistiques agricoles, de l'informatique et de la documentation (DSID). 2016. Données statistiques sur les superficies, les rendements et les productions du maïs depuis la campagne agricole 1990-1991 à celle de 2015-2016. 161p.
4. Ministère de l'Agriculture de la Production Animale et Haleutique (MAPAH). 2017. Ministère de l'Agriculture et de la Production Animale et Halietique. Catalogue officiel des espèces et variétés végétales du Togo. 7p.
5. Sétamou, M. 1999. Ecology and management of *Mussidia nigrivenella* Ragonot (Lepidoptera; Pyralidae) a cob borer of maize in West Africa. Thesis. Hannover University. Germany.131 p.
6. Polaszek, A. 1998. African cereal stem borers;economic importance, taxonomy, natural enemies and control. CAB International inassociation with the ACP-EU Technical Centre for Agricultural and Rural Co-operation (CTA). 530pp.s
7. Schulthess F., Bosque-Pérez N. A., Chabi-Olaye A.; Gounou S., Ndemah R., Goergen G.1997. Exchanging natural enemies species of lepidopterous cereal stemborers between African regions. *Insect Science and its Application*. 17: 97–108.
8. Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M. 2016. First report of outbreaks of the fall armyworm Spodoptera frugiperda (J E Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. PLoS ONE 11(10), e0165632. DOI: 10.1371/journal.pone.0165632
9. Midega C.A.O.; Pittchar J.O.; Pickett J.A.; Hailu G.W.; Khan Z.R. 2018. A climate-adapted push-pull system effectively controls Fall Armyworm, *Spodoptera frugiperda* (J E Smith), in maize in East Africa. *Crop Protect. 105*, 10–15.
10. Food and Agriculture Organization of the United Nations (FAO). 2018. Integrated management of the fall armyworm on maize: a guide for farmer field schools in Africa. 118p
11. Harrison R D, Thierfelder C, Baudron F, Chinwada P, Midega C, Schaffner U, Van den Berg J. 2019. Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management*. 243: 318–330.
12. Sisay B, Tefera T, Wakgari M, Ayalew G, Mendesil E. 2019. The Efficacy of Selected Synthetic Insecticides and Botanicals against Fall Armyworm, *Spodoptera frugiperda*, in Maize. *Insects*, 10: 45.
13. Midega C.A.O., Nyang'au I.M., Pittchar J., Birkett M.A., Pickett J.A., Borges M., Khan Z.R. 2012. Farmers' perceptions of cotton pests and their management in western Kenya. *Crop Protection*, 42:193–201.
14. Abdoul Habou Z. 2013. Entomofaune associée à Jatropha curcas L. au Niger et évaluation de l'activité insecticide de son huile (thèse de doctorat). Université de Liège-Gembloux Agro-Bio Tech, 126 p.
15. Glitho I. A., Ketoh K. G., Nuto P. Y., Amevoin S. K. et Huignard I. 2008. Approches non toxiques et non polluantes pour le contrôle des populations d'insectes nuisibles en Afrique du Centre et de l'Ouest. pp 207-217. In Regnault-Roger, C, Philogène, B.JR. et Vincent, C (éds). Biopesticide d'origine Végétale 2ème édition. Lavoisier, TEC & DOC, Paris, 550 p.
16. Bruce Y. A., Gounou S., Chabi-Olaye A., SmithH., and Schulthess F. 2004. The effect neem (*Azadirachta indica* A. Juss) oil on oviposition, development and reproductive potentials of *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) and *Eldana saccharina* Walker (Lepidoptera: Pyralidae). Agricultural and Forest Entomology. 6 (3), 1-10.
17. Solsoloy A.D., Solsoloy T.S.1997. Pesticidal efficacy of formulated product *J. curcas* oil on pests of selected field crops *In*: Gubitz G.M., Mithelbach M and Trabi M., Symposium on Biofuel and Industrial Products from *Jatropha curcas* and other Tropical Oil Seed Plants, February 23-27, Managua, Nicaragua.
18. Ratnadass A., Cissé B., Diarra A., Mengual L., Taneja S.L., Thiéro C.A.T. 1997. Perspectives de gestion bio intensive des foreurs des tiges de sorgho en Afrique de l'Ouest, Sci., 17 (2) :p. 227-233.
19. Adebowale K.O. & Adedire C.O., 2006. Chemical composition and insecticidal properties of the underutilized *Jatropha curcas* seed oil. African Journal of Biotechnology. 5 (10): 901-906.
20. Boateng B. A., Kusi F. 2008. Toxicity of Jatropha seed oil to *Callosobrochus maculatus* (Coleoptera: Bruchidae) and its parasitoid *Dinarmus basalis* (Hymenoptera: Pteromalidae). Journal of Applied Science Research 4(8), 945-951

21. Abdoul Habou Z., Haougui A., Mergeai G., Haubruge E., Adam T. & Verheggen F.J., 2011. Insecticidal effect of *Jatropha curcas* oil on the aphid *Aphis fabae* (Homoptera: Aphididae) and on the main insect pests associated with cowpeas (*Vigna unguiculata*) in Niger. Tropicultura, 29 (4) : 225-229.
22. Hogg D., Pitre H.N., Anderson R.E. 1982. Assessment of early-season phenology of the fall armyworm (Lepidoptera: Noctuidae) in Mississippi (*Spodoptera frugiperda*). *Environmental entomology*, 11: 705-710.
23. Davis FM, Williams WP, Wiseman BR. 1989. Methods used to screen maize and to determine mechanisms of resistance to the southwestern corn borer and fall armyworm, 101-108p.
24. Abbot W.S., 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265-267.
25. Wu X., Zhang L., Yang C., Zong M., Huang Q., Tao L.2016. Detection on emamectin benzoate-induced apoptosis and DNA damage in *Spodoptera frugiperda* Sf-9 cell line. Pesticide Biochemistry and Physiology .126 : 6–12
26. Andrews, K.L. 1988. Latin American Research on *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Florida. Entomologist. 71 : 630–653.
27. Belay D.K., Huckaba R.M., Foster J.E. 2012. Susceptibility of the Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), at Santa Isabel, Puerto Rico, to Different Insecticides. Florida. Entomologist, 95, 476–478.
28. Devappa R.K., Angulo-Escalante Miguel A., Makkar H.P.S., Becker K. 2012. Potential of using phorbol esters as an insecticide against *Spodoptera frugiperda*. Industrial Crops and Products, 38: 50– 53.
29. Makkar H. P. S., Becker K., Sporer F., and Wink M. 1997. Studies on Nutritive Potential and Toxic Constituents of Different Provenances of *Jatropha curcas*. J. Agric. Food Chem. 45,3152−3157.
30. Blumberg P.M., Nakadate T., Warren B., Dell Aquila M., Sako T., Pasti G., Sharkey N.A.B. 1987. Phorbol esters as probes of the modulatory site on protein kinase C. an overview, botanical journal of linean society 94, 1-2:p. 283-292.
31. Bourogâa F. 2018. Insecticidal properties of the physic nut tree *Jatropha curcas* L. (Euphorbiaceae) and potential use in pest management, thesis dissertation in Göttingen, Germany, 124p.
32. Devappa K. R., Bingham J-P., Khanal S. K. 2013. High performance liquid chromatography method for rapid quantification of phorbol esters in Jatropha curcas seed. Industrial Crops and Products, 49 : 211–219.
33. Abdoul Habou Z., Adam T., Mergeai G., Haubruge E., Verheggen F.J. 2014. Effet du mode de conservation de l'huile de *Jatropha curcas* L. sur son efficacité dans la lutte contre les principaux insectes ravageurs du niébé (*Vigna unguiculata* (L.) Walp.) au Niger, Tropicultura, 32(4) : 191-196.