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Insecticidal activity of *Ricinus communis* L. seed extract against *Spodoptera frugiperda* J.E. Smith under laboratory and field conditions

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ABSTRACT

Insecticidal activity of the aqueous extract of the castor seed (*Ricinus communis* L.) against the Fall Armyworm (FAW), *Spodoptera frugiperda* (Lepidoptera: Noctuidae), one of the worst pests of maize crop, was assessed under laboratory and field conditions. In laboratory, the larvicidal activity of three concentrations of the extract that are 150 g/l, 200 g/l and 250 g/l and their effects on the development of FAW were evaluated through direct exposure and ingestion tests. The field experiment consisted of a randomized block design with two extract concentrations – 200 g/l and 250 g/l – and negative control consisted of untreated plots and positive control plots were treated with Emacot (Emamectin benzoate). Results of the laboratory experiments revealed considerable larvicidal activity of the extract through the ingestion test, inducing the larvae mortality of 75.8%, 60.3% and 46.5% for the extract concentrations of 250 g/l, 200 g/l and 150 g/l respectively, whereas positive (Emacot) and negative controls (emulsified water) recorded 100% and 3.3% of the larvae mortality, respectively. The field results showed 10% and 11% of infested plants in plots treated with 200 and 250 g/l, respectively, whereas Emacot-treated plots recorded 9.5% of infested plants. Untreated plots recorded the highest infested plants of 22.5%. The two-castor seed extract concentrations 200 g/l and 250 g/l reduced about 50% of maize plant infestation by FAW, thus could be a good candidate as alternative to chemical pesticides in controlling the pest.

Keywords: *Zea mays, Spodoptera frugiperda, Ricinus communis,* Seed extract, pest control.

INTRODUCTION

Maize, *Zea mays*, is one of the main crops in the Tropics. The Fall Army Worm (FAW) *Spodoptera frugiperda*, native to tropical subtropical regions of the Americas (Nagoshi et al., 2018) has become one of the most important arthropod pests of this important crop around the world. First reported in Sub-Saharan Africa in 2016 (Nagoshi et al., 2018), FAW has become a major threat of maize crop as to impact on food security in these countries. This invasive pest is a highly destructive leaf borer, causing severe damage

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to maize plants, although it can occasionally feed on stem and on maize crop (Fontaine et al., 2018; Prasanna et al., 2018). The FAW was reported to infest up to 68% of maize plots (Djima et al., 2020; Ndiaye et al. 2021), with potential yield loss estimated up to 53% (Pomalegni et al., 2019). The immediate response by the rural farmers was the use of the chemical pesticides from hazardous origins. Knowing the negative impact of the chemical pesticides on the environment and human health (Assogba-Komlan et al., 2007; Agboyi et al., 2015; Ngom et al., 2012; Otchere et al., 2020), along with the development of resistance in the pest and the non-target effects (Yehouenou et al., 2006), there was an urgent need to search fora sustainable and eco-friendly solution for the management of the FAW on maize. This study was embedded in the national research program in Togo, West Africa, to implement eco-friendly strategies for control of the FAW on maize.

Plant based insecticides as alternative to conventional chemically synthesized insecticides, with reduced adverse effects on human health and environment are wide documented. The potential of plant-based extracts in controlling pests have been demonstrated, and toxic, repellent, and antifeeding effects of the products were observed (Laba et al., 2012; Tounou et al., 2012; Bokobana et al., 2014; Diabaté et al., 2014; Nadio et al., 2015; Kolani et al., 2018; Sane et al., 2018; Toundou et al., 2020). Therefore, the identification of plants with potential biopesticide activity and locally available and affordable is of great interest. Castor, *Ricinus communis* L. is a Euphorbiaceous plant widely known for its pesticidal effects (Ramos-López et al., 2010; Hussein et al. 2016). Seed extract of *R. communis* was shown to inhibit adult emergence in mosquitos (Mandal, 2010) and insecticidal effect. Aqueous extracts of the seeds, leaves and even roots *R. communis* were shown to exhibit insecticidal activity larvae of *P. xylostella* (Tounou et al., 2011). Castor is an endemic plant, widely found in different parts of the country.

It is in that light that the objective of this study was to evaluate under laboratory and field conditions the efficacy of *R. communis* seed extract for control of *S. frugiperda*.

MATERIALS AND METHODS

Plant material

The mature seeds of *R. communis* were collected from the experimental Station of “Ecole Supérieure d’Agronomie”, University of Lomé (Togo). The maize variety IKENNE 9449 SR was used for the experiments.

Extract preparation

The castor seeds were washed with tap water and allowed to dry for 72 hours under room temperature in the dark. They were then crushed into a mortar until paste was obtained. The three solutions of the aqueous extract used in the experiment (250, 200 and 150 g/l) were then prepared by dissolving 250, 200 and 150 g of the paste, respectively, in one liter of soap solution (0.1% local soap "AKOTO" potassium palmitate), then macerated for 24 hours in order to dissolve the cellulosic membrane of seed cells. After the maceration, the mixture was filtered using a percale fabric, and the collected filtrate was stocked for use in the subsequent experiments.

Laboratory bioassay

In order to obtain a cohort of larvae of the same age for the tests, egg masses were collected from maize plants the same day at the ‘Station d'Expérimentations Agronomiques de Tchitchao’, transferred to the transparent plastic boxes (16 cm in diameter and 8 cm in height), and incubated in the laboratory. To ensure aeration, the lids of these boxes were pierced with an opening in their center, which was covered with a 3µm mesh. After hatching, the larvae were fed with fresh tender leaves of maize, replenished every 24 hours, and reared until the third larval stage (6-day old larvae).

The 6-day old larvae of *S. frugiperda* obtained were used for the laboratory experiments. Two tests were performed with the three different concentrations (150, 200 and 250 g/l) of the aqueous extract, one via direct exposure and the other through ingestion. Untreated individuals and those treated with Emacot (Emamectin benzoate) and water emulsified were used as controls. To avoid cannibalism (Prasanna et al., 2018), larvae were individually kept in experimental units consisting of 8.4 cm x 4.2 cm transparent plastic boxes covered above with a small-mesh cloth. The laboratory tests were conducted under room conditions at 28-30°C and 70-90% RH.

For direct exposure test, a drop (1 µl) of each tested concentration was directly applied with a syringe at the back of the larvae on the first segment following the head. For the ingestion test, 2 cm diameter leaf disks excised from maize young leaves were soaked in a 10 ml of the aqueous extract for 2 minutes and dried at room temperature for 5 minutes, before being placed in the experimental units to serve as food source for individual larvae. The larvae were starved for 6 hours before the introduction of treated leaf disks in the experimental units. The treated leaf disks were then removed from the experimental units after 24 hours and larvae were subsequently fed with untreated clean leaves until pupation.

Experimental units were observed daily to record individual survivorship and developmental time. In addition, emerged adults were observed to record any morphological discontinuity. Emerged adults were fed 10% sugar using soaked cotton suspended in the box.

Field experiment

The field assay consisted of a complete randomized block design, with four treatments, each repeated four times. Each block consisted of 3.5 m x 5.5 m plots, distant of about 2m from each other, while two successive blocks were 4 m apart. The field borders and the inter-block spaces were sown with two rows of maize two weeks before the sowing in the experimental plots to ensure the initiation of the FAW natural infestation and to avoid any crossed effects between the different treatments. Four treatments were tested under field conditions: 250 and 200 g/l of the aqueous castor seed extract (the two concentrations showing high efficacity under laboratory conditions), the pesticide Emacot (5%), and untreated plants as control. Maize in the experimental plots was planted at the density of 70000 plants/ha (70 cm x 30.5 cm). The two aqueous extract solutions were applied at 42 l/ha, and the pesticide Emacot at the recommended dose of 100 g/ha (Tounou et al., 2020). The first application was done on the 17th day after sowing (DAS), and the other applications at 14-day intervals until the appearance of the male flowers. Data were collected first on the 17th DAS (before the first application of the experimental products), then subsequently at 7 days interval for the assessment of the number of larvae, the percentage of infested plants, or at 14 days interval for the assessment of leaf damage score, and this until the appearance of the male inflorescence. For the evaluation of the first two parameters, 50 plants were randomly selected in each plot using the "W" sampling method (FAO, 2018). A plant is considered infested if at least one of the following was found on it: egg mass, alive larvae of *S. frugiperda* or fresh excrements of the larvae (Prasanna et al., 2018). Leaf damage score was assessed based on the scoring scale of Davis et al. (1989) by visual observation of 10 randomly selected plants per experimental plot. Leaf damage scores per individual plants were averaged to determine the leaf damage score of the plot. At maturity, maize was harvested and the yield was determined for each plot.

Statistical analysis

The data were subjected to statistical analysis using SAS version 9.2 (SAS Institute 2005). Percentages were arcsin-transformed and the numbers log-transformed before submitting to the analysis. A single factor ANOVA and Student-Newman-Keuls test (SNK) were used to test the effect of treatment on developmental time. Percentage data (larval and pupal mortality, and survivorship to adult stage) were compared among treatments using the Chi-Square test. For field data, firstly, the PROC MIXED procedure was used to test the effect of the two factors (treatment, date) on each of the parameters evaluated. Secondly, for each date, a single factor ANOVA followed by a SNK test was used to test differences among treatments for each of the variable assessed. Mean larval survival times (MST) were evaluated by the Kaplan-Meier Survivorship analysis of variance and the means were compared using the Chi-square test (SPSS Inc., 2002).

RESULTS

Insecticidal activity of the castor seed extract against larvae of *S. frugiperda* under laboratory conditions

There was a significant effect of treatment on larval mortality (P = 0.020) as well as on larval MST (P < 0.0001). Larval mortality was higher (76%) and the MST lower (4.6 days) for individuals fed with leaves treated with the aqueous extract at 250 g/l, followed by those fed with leaves treated with the aqueous extract at 200 g/l (60.3% and 5.3 days) and 150 /gl (46.5% and 6.1 days). None of individuals fed with Emacot-treated leaves survived, after a MST of about 1.1 days. Overall, larval mortality recorded in the direct exposure test was lower, and the MST slightly higher for all treatments compared to those recorded with the ingestion test (Table 1). In other tests, mortality recorded for untreated larvae or those treated with emulsified water was very low, ranging from 1.9 to 3.3% (Table 1).

Effect of the castor seed extract on the development of *S. frugiperda*

We found statistically-significant differences, in the average developmental time for both direct exposure and ingestion tests (P< 0.0001). Overall, larvae treated with the aqueous extract recorded slightly longer developmental time (Table 2), and lower pupae viability (Table 3). The average precents of individuals reaching adult stage was as low as 13.3% for individuals fed with leaves treated with extract at the concentration 250 g/l, and about 3-fold higher for those fed with leaves treated with extract at 100 g/l. Overall, higher percent of emerged adults were observed in the individuals of direct exposure test (Table 3). The castor seed extract also resulted in some morphological discontinuities of adults, such as wing malformations (Table 3). For some pupae, metamorphosis was incomplete with the formation of intermediates (nymph-adult).

Insecticidal activity of the castor bean extract against *S. frugiperda* under field conditions

Statistical analysis revealed significant effect of treatment on both larval density (P = 0.0002) and infestation rate (P < 0.0001). Densities of larvae recorded in plots treated with the aqueous extracts at 200 and 250 g/l were statistical similar at all DAS, but significantly lower than those recorded in untreated plots (from 24 DAS), and higher than those recorded in Emacot-treated plots (except for DAS 31 and 38) (Figure 1). A similar trend was observed for the infestation rate, as shown in Figure 2. Overall, the infestation rate was low during the experiment, the peak being about 23% on the 24^{th} DAS. Furthermore, estimated leaf damage scores based on Davis et al. (1989) scale ranged between 1.2 to 1.7, being significantly higher for untreated plants, but similar for plants treated with the extract or the pesticide Emacot (Figure 3).

Yield in maize grains

Yield in maize grains ranged from 3.5 to 4.1 t/ha (Table 4). Statistical analysis revealed no significant effect of the treatment on the yield (P = 0.4063).

Table 1: Mortality rates and Mean larval Survival Time of larvae of *S. frugiperda*.

Treatment	Larval mortality (%)		Mean survival time (Days)	
	Contact	Ingestion	Contact	Ingestion
150g/l_*R. communis*	27.59 Bb	46.55 Da	7.01 a	6.10 a
200g/l_ *R. communis*	32.76 Bb	60.35 Ca	6.90 a	5.37 b
250g/l_ *R. communis*	39.66 bB	75.87 bA	6.68 a	4.68 c
Emacot	84.48 a	100 aA	2.65 b	1.13 d
Emulsified water	1.97 Ca	0.00 eB	-	-
Control	3.33 Cb	3.33 eA	-	-
F	***3,61***			
P	***0,020***		***< 0,0001***	***< 0,0001***

Values in within a column followed by different lowercase letters and within a row followed by different uppercase letters are statistically different (α= 5%).

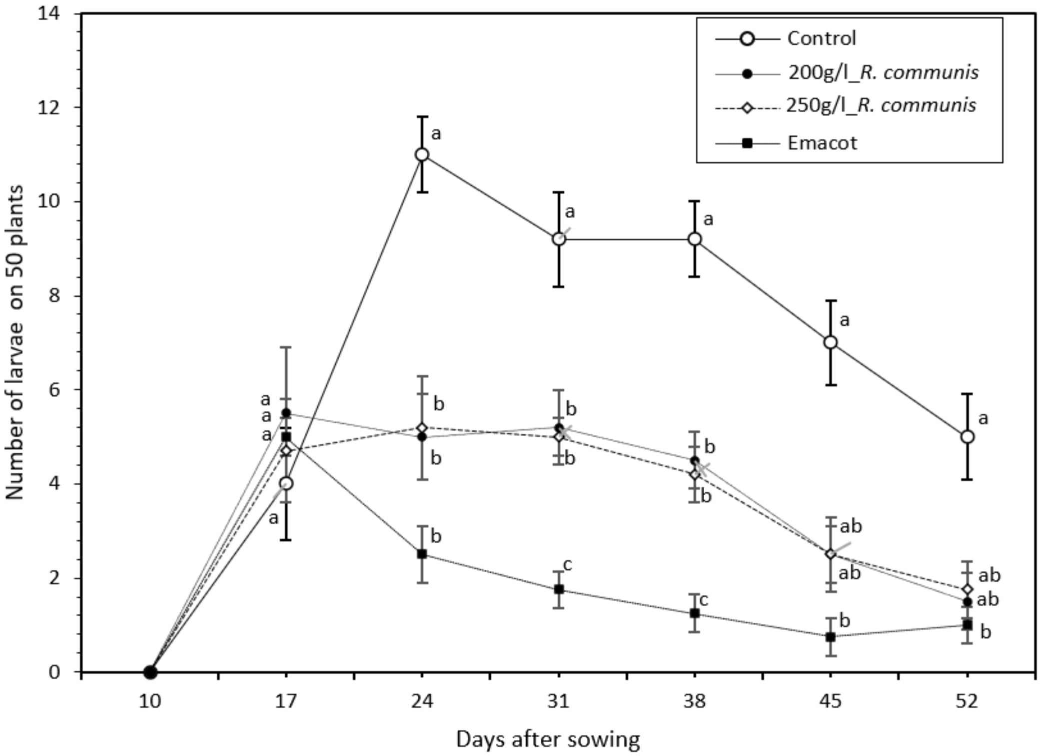

Figure 1: Mean number (Mean ± SE) of larvae of *Spodoptera frugiperda* recorded for the different treatments. Bars marked by different letters are significantly different (SNK test, P < 0.05).

Table 2: Developmental time (days) of *Spodoptera frugiperda* reared on different treatments.

Treatment	**Larval phase (days)**		**Pupal phase (days)**		**Larvae to Adulthood (days)**	
	Contact	**Ingestion**	**Contact**	**Ingestion**	**Contact**	**Ingestion**
150g/l_*R. communis*	7.61 ± 0.18 Aa	7.55 ± 0.23 Aa	9.95 ± 0.16 aA	9.96 ± 0.21 aA	18.47 ± 0.26 abA	18.44 ± 0,29 aA
200g/l_*R. communis*	7.41 ± 0.21 abA	8.09 ± 0.31 abA	9.80 ± 0.12 abA	9.82 ± 0.21 aA	18.37 ± 0.24 abA	18.71 ± 0.40 aA
250g/l_*R. communis*	7.86 ± 0.27 aA	7.50 ± 0.29 abA	9.88 ± 0.21 abA	9.75 ± 0.37 aA	19.04 ± 0.31 aA	17.88 ± 0.39 abB
Emacot	6.77 ± 0.22 b	-	9.89 ± 0.45 ab	-	17.77 ± 0.46 bc	-
Emulsified water	6.85 ± 0.85 bA	7.01 ± 0.93 bA	9.18 ± 0.11 bA	9.33 ± 0.92 aA	17.42 ± 0, 28 cA	17.51 ± 0.95 bA
Control	6.89 ± 0.11 bA	6.9 ± 0.11 bA	9.23 ± 0.14 bA	9.23 ± 0.14 aA	17.36 ± 0.11 cA	17.36 ± 0.11 bA
F	*4.72*	*6.83*	*3,70*	*0.17*	*9.80*	*8,30*
P	*< 0.0012*	*< 0.0003*	*< 0.0065*	*0.84*	*<0.0001*	*< 0,0001*

Values within a column followed by different lowercase letters and within a row followed by different uppercase letters are statistically different ($\alpha = 5\%$).

Table 3: Pupae viability, adult emergence and deformed adults' rates obtained from contact and ingestion tests of castor seed aqueous extract on *S. frugiperda* larvae.

Treatment	**Pupae Viability (%)**		**Adults (%)**		**Deformed Adults (%)**	
	Contact	Contact	Contact	Ingestion	Contact	Ingestion
150g/l_*R. communis*	90.40 ± 3.71 bA	76.24 ± 7.49 bA	68.30 ± 1.92 bA	40.00 ± 6.08 bB	2.6 b	7.14 b
200g/l_*R. communis*	89.70 ± 5.72 bA	75.42 ± 8.75 bA	58.33 ± 5.00 bA	28.33 ± 4.19 cB	2.5 b	27.08 a
250g/l_*R. communis*	68.75 ± 4.99 cB	70.83 ± 10.48 bA	40.00 ± 2.72 cA	13.33 ± 4.71 dB	25.0 a	12.5 b
Emacot	100.00 ± 0.00 a	-	15,00 ± 3.19 d	-	0 b	0 b
Emulsified water	100.00 ± 0.00 aA	100.00 ± 0.00 aA	98.33 ± 2.88 aA	100.00 ± 0.00 aA	0 b	0 b
Control	100.00 ± 0.00 aA	100.00 ± 0.00 aA	96.67 ± 1.92 aA	96.67 ± 1.92 aA	0 b	0 b
X^2	*24.4*	*90.7*	*90.7*	*93,6*		
P	*< 0.0001*	*< 0.0004*	*< 0.0001*	*< 0,0001*	*<0,0195*	<0,0001

Values within a column followed by different lowercase letters and within a row followed by different uppercase letters are statistically different (α = 5%).

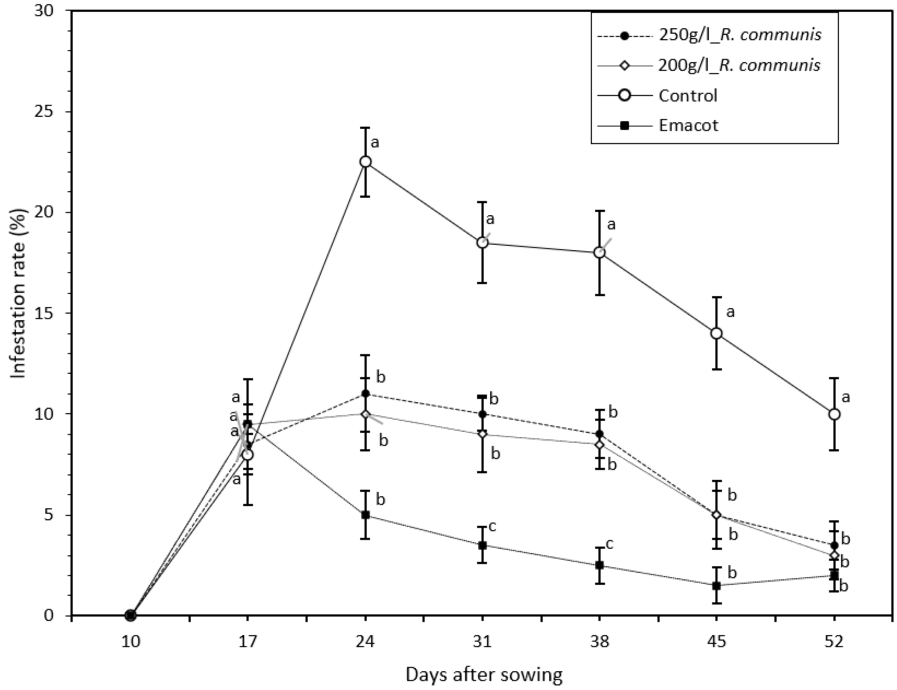

Figure 2: Mean percentage (Mean ± SE) of infested plants by *Spodoptera frugiperda* recorded for the different treatments. Bars marked by different letters are significantly different (SNK test, P < 0.05).

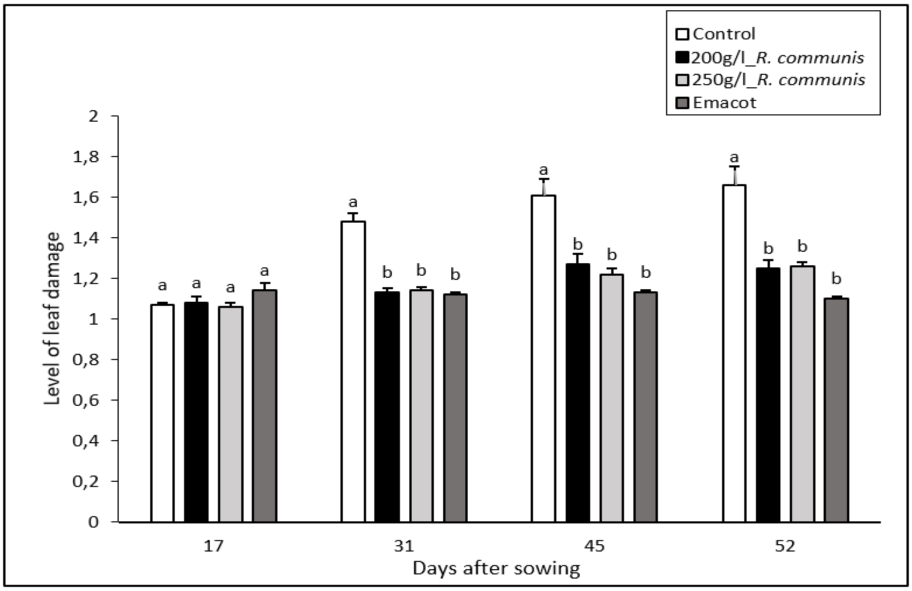

Figure 3: Mean leaf damage score (Mean ± SE) of infested plants by *Spodoptera frugiperda* determined for the different treatments. Bars marked by different letters are significantly different (SNK test, P < 0.05).

Table 4: Mean yield (M±SE) in maize grains of the different Treatments.

Treatment	Yield (t/ha)
250g/l_*R. communis*	3.9 ± 0.2 a
200g/l_*R. communis*	3.8 ±0.1 a
Emacot	4.0 ± 0.3 a
Control	3.5 ± 0.2 a

Average yields followed by the same letters within a column are not statistically different (P > 0.05).

DISCUSSION

Plant-based insecticides have shown to be attractive alternatives to currently used chemical insecticides for pest management, and reported to pose little threat to the environment and/or to human health as compared to synthetic pesticides, therefore potentially suitable for use in an integrated pest management program (Afouda et al., 2012; Wainwright et al., 2013; Yarou et al., 2017). The larval stage of FAW is the most destructive stage of this invasive pest, through defoliation of maize plants. The results of both laboratory and field experiments suggest the capacity and potential of castor seed extract to be considered as an alternative to chemical pesticides in the management of the FAW. In our experiments, the castor seed extract at 250 g/l was very effective, causing significant larval mortality (about 76%) via exposure by ingestion. Similarly, Tounou et al. (2011), showed that castor seed aqueous extract at a concentration of 20% induce about 67% mortality in caterpillars of *P. xylostella*. Castor seeds have been shown to contain toxins; mainly ricin and ricinine (Darby et al., 2001; Frederiksson et al., 2005), known to induce larval death (Rossi et al., 2012; Ramos et al., 2013; Manoj et al., 2017). Ramos-López et al. (2010) reported 100% mortality in *S. frugiperda* larvae subjected to ricinine at 1600 ppm.

In the experiments carried in this study, we observed delayed pupal developmental time for individual fed with extract-treated leaf disks, and a subsequent pupal mortality of 30%. Similarly, Ramos-López et al. (2010) reported the castor bean to cause a delay from 12.1 to 12.9 days in the developmental time and low pupal viability of *S. frugiperda* under laboratory conditions. We observed some serious morphological abnormalities of adults emerged from larva fed with leaf disks treated with the castor bean aqueous extract; wing malformations and intermediaries 'nymph-adult' being the main abnormalities observed. Tounou et al. (2011) reported similar effects of castor extract on *P. xylostella*. These results suggested that, besides its larvicidal activity, castor bean seed extract could induce negative impact on the biology as well as the morphology of the adult FAW.

In the field experiment, the extract induced a significant decrease in the number of FAW larvae as well as in the infestation rate. Except for DAS 31 and 38, both concentrations of the seed extract showed statistically similar insecticidal activity as the synthetic pesticide, suggesting the effectiveness of *R. communis* seed extract for the control of FAW under field conditions. The results of field experiment were in line with those of Tounou et al. (2011) who have shown that castor seed extract can control populations of cabbage moth, *P. xylostella* in semi-controlled conditions. Although an insecticidal effect of the extract and synthetic pesticide on the infestation rate percent plants infested by *S. frugiperda* was evident, surprisingly we found no significant effect on the yield in maize grains. Very small differences in maize grains were observed among extract-treated, Emacot-treated and control plots. This lack of significant effect does not agree with the works of Day et al. (2017), Kumela et al. (2018), Pomalegni et al. (2019) and Teixeira et al. (2020) who reported that FAW could induce a 15-67% reduction in yield. One possible explanation could be the overall low infestation rate observed during our experiment. However, a recent review by Overton et al. (2021) in relation to the impact of *S. frugiperda* on maize yield demonstrated that there is overestimation of yield lost due to this pest in many publications. This is explained by fact based on farmer survey or interviews instead of experimentally derived assessment; as did in our study. Moreover; in field experiments, Britz (2020) reported no relation between the damage by *S. frugiperda* and yield lost in maize. This suggests the need for further research to investigate for field experimentally assessment of the impact of *S. frugiperda* on maize grains yield, for the implementation of better management practices.

Conclusion

The present results revealed the effectiveness of the castor seed aqueous extract with high larvicidal activity in controlling the FAW. Also, the extract was found to induce a negative impact on the development of the insect pest by the low infestation of plants by the insect. Of great interest, was the ability of castor extract to induce morphological abnormalities in adults, such as wing distortions and intermediaries 'nymph-adult'. Thus, the castor seed extract can be a valuable candidate as alternative to chemical pesticides for the control of the *S. frugiperda*. However, further investigations to determine the compounds responsible for these abnormalities in the insect development are needed.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

EK designed the study. EK, ANN and AKT reviewed literature. EK, AT, AB and NFS implemented the study and collected data. EK, NFS analyzed the data. AKT, KS and OD supervised the study. EK, AT, NFS and AB wrote the manuscript.

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REFERENCES

Afouda L, Baimey H, Bachabi XF, Sero-Kpera HD, Balogoun R. 2012. Effet de l'Hyptis (*Hyptis suaveolens*), du Neem (*Azadirachta indica*), du Vernonia (*Vernonia amygdalina*) et de l'Amarante (*Amaranthus* sp.) sur les Nématodes à Galles (*Meloidogyne* spp.) en Cultures maraichères. *Agronomie Africaine,* **24**: 209-218. URL: https://www.ajol.info/index.php/aga/article/view/87010/76776

Agboyi LK, Djade KM, Ahadji-Dabla KM, Ketoh GK, Nuto Y, Glitho IA. 2015. Vegetable Production in Togo and Potential Impact of Pesticide Use Practices on the Environment. *International Journal of Biological and Chemical Sciences,* **9**(2): 723-736. DOI: 10.4314/ijbcs.v9i2.13

Assogba-Komlan F, Anihouvi P, Achigan E, Sikirou R, Boko A, Adje C, Ahle V, Vodouhe R, Assa A. 2007. Pratiques Culturales et Teneur en Eléments Anti Nutritionnels (nitrates et pesticides) du *Solanum macrocarpum* au Sud du Bénin. *African Journal of Food Agriculture and Nutrition Development,* **7**: 1-21. DOI: 10.18697/ajfand.15.IPGRI2-3

Bokobana ME, Koba K, Amen YN, Poutouli W, Akantetou PK, Laba B, Nadio NA, Raynaud C, Sanda K. 2014. Insecticidal Activities of *Ocimum canum* Sims Essential Oil on Termites *Macrotermes subhyalinus* Rambur (Isoptera: Termitidae). *Journal of Essential Oil-Bearing Plants* **17**: 726–733. DOI: https://doi.org/10.1080/0972060X.2014.929045

Britz C. 2020. Relationship between *Spodoptera frugiperda* (Lepidoptera: Noctuidae) Damage and Yield Loss in Maize. PhD Thesis, North-West University, South Africa. URL: http://hdl.handle.net/10394/34749

Darby SM, Miller ML, Allen RO. 2001. Forensic Determination of Ricin and the Alkaloid Marker Ricinine from Castor Bean Extracts. *Journal of Forensic Sciences,* **46**: 1033-1042. DOI: 10.1520/JFS15097J

Davis FM, Williams WP, Wiseman BR. (1989). Methods used to screen maize for and to determine mechanisms of resistance to the Southwestern corn borer and fall armyworm. In *International*

Symposium on Methodologies for Developing Host Plant Resistance to Maize Insects. URL: https://agris.fao.org/agris-search/search.do;jsessionid=7827192896D554359A3F25376C5B663F?request_locale=zh_CN&recordID=QY19910011490&query=&sourceQuery=&sortField=&sortOrder=&agrovocString=&advQuery=&centerString=&enableField=

Diabaté D, Gnago JA, Koff K, Tano Y. 2014. The Effect of Pesticides and Aqueous Extracts of *Azadirachta indica* (A. Juss.) and *Jatropha curcas* L. on *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrididae) and *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) found on Tomato Plants in Côte d'Ivoire. *Journal of Applied Biosciences,* **80**: 7132-7143. DOI:10.4314/jab.v80i1.14

Djima K, Agboka K, Adanka KD, Osae M, Tounou AK, Adjevi MKA, Fening OK, Meagher RL. 2020. Maize Infestation of Fall Armyworm (Lepidoptera: Noctuidae) Within Agro-Ecological Zones of Togo and Ghana in West Africa 3 years after its Invasion. *Environmental Entomology,* **20**: 1-6. DOI: 10.1093/ee/nvaa048

FAO. 2018. Gestion Intégrée de la Chenille Légionnaire D'automne sur le Maïs, un Guide pour les Champs-Ecoles des Producteurs en Afrique.URL: http://www.fao.org/3/I9124FR/i9124fr.pdf. Accessed October 02, 2021.

Fontaine R, Clain C, Franck A. 2018. *Spodoptera frugiperda* la Chenille Légionnaire D'automne. Fiche phytosanitaire FDGDON & CIRAD. URL: https://plateforme-esv.fr/sites/default/files/2020-09/Fiche-phytosanitaire-S-frugiperda-R%C3%A9union%20-%20finale-compr.pdf.

Frederiksson S-A, Hulst AG, Artursson E, de Jong ADL, Nilsson C, van Baar BLM. 2005. Forensic identification of neat ricin and of ricin from crude castor bean extracts by mass spectrometry. *Analytical Chemistry,* **7**(6): 1545-1555. DOI: 10.1021/ac048756u

Hussein HM, Ubaid JM, Hameed IH. 2016. Insecticidal Activity of Methanolic Seeds Extract of *Ricinus communis* on Adult Of *callosobruchus maculatus* (coleopteran: brauchidae) and Analysis of Its Phytochemical Composition. *International journal of pharmacognosy and phytochemical research*, **8**(8): 1385-1397. URL: https://www.researchgate.net/profile/Imad-Hameed/publication/305930531_

Kolani L, Sanda K, Agboka K, Mawussi G, Koba K, Djouaka R. 2016. Investigation of Insecticidal Activity of Blend of Essential Oil of *Cymbopogon schoenanthus* and Neem Oil on *Plutella xylostella* (Lepidoptera: Plutellidae). *Journal of Essential Oil-Bearing Plants,* **19**: 1478- 1486. DOI: https://doi.org/10.1080/0972060X.2016.1221742

Kumela T, Simiyu J, Sisay B, Likhayo P, Mendesil E, Gohole L, Tefera T. 2019. Farmers' Knowledge, Perceptions, And Management Practices of the New Invasive Pest, Fall Armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya. *International Journal of Pest Management*, ***65***(1): 1-9. DOI: 10.1080/09670874.2017.1423129

Laba B., Nenonéné A. Y., Adjrah Y., Koba K., Poutouli W. and Sanda K. (2012). Efficacy of *Cymbopogon schoenanthus* L. Spreng (Poaceae) Extracts on Diamondback Moth Damaging Cabbage. *Journal of Biofertilizers and Biopesticides,* **3**: 1-4. DOI: 10.4172/2155-6202.10000119

Mandal S. 2010. Exploration of Larvicidal and Adult Emergence Inhibition Activities of *Ricinus Communis* Seed Extract Against Three Potential Mosquito Vectors in Kolkata, India. *Asian Pacific Journal of Tropical Medecine,* **3**(8): 605-609. DOI: https://doi.org/10.1016/S1995-7645(10)60147-2

Manoj K. (2017). A Review on Phytochemical Constituents and Pharmacological

Activities of *Ricinus communis* L. Plant. *International Journal of Pharmacognosy and Phytochemical Research*, **9**: 466-472. DOI: 10.25258/phyto.v9i2.8116

Nadio NA, Poutouli WP, Akantétou P, Laba B, Tozou P, Bokobana ME, Koba K, Raynaud C, Sanda K. 2015. Propriétés Insecticides et Répulsives de L'huile Essentielle d'*Ocimum sanctum* L. envers *Dysdercus voelkeri* Schmidt (Heteroptera ; Pyrrhocoridae). *Revue du Conseil Africain et Malgache pour l'Enseignement Supérieur* **3**: 65-72.

Nagoshi Rodney N, Goergen G, Tounou AK, Agboka K, Koffi D, Meagher RL. 2018. Analysis of Strain Distribution, Migratory Potential and Invasion History of Fall Armyworm Populations in Northern Subsaharan Africa. *Scientific reports* **8**: 3710. DOI: 10.1038/s41598-018-21954-1

Ndiaye, A., Faye, M., Ba, I., Diallo, I., & Sembene, P. M. (2021). The Fall Armyworm Spodoptera frugiperda (JE Smith), a New Pest of Maize in Africa: Monitoring, Damage Evaluation and Identification of Natural Enemies on Production Areas of Senegal. *International Journal of Biological and Chemical Sciences*, **15**(6): 2247-2260. DOI: 10.4314/ijbcs.v15i6.1

Ngom S, Traore S, Thiam MB, Anastasie M. 2012. Contamination des Produits Agricoles et de la Nappe Phréatique par les Pesticides dans la zone des Niayes au Sénégal. *Revue des Sciences et de la Technology*, **25**: 119-130. URL: https://www.ajol.info/index.php/srst/article/download/117245/106812

Otchere KG, Adam JI, Larbi JA, Basil SA, Banunle A. 2020. Analysis of Insecticide Residues in Cabbage (*Brassica oleracea* var. Capitata) From Three Major Markets in Kumasi. *Annals of Environmental Science and Toxicology*, **4**(1): 19-23. DOI: 10.17352/aest.000021

Overton K, Maino LJ, Day R, Umina AP, Bett B, Carnovale D, Ekesi S, Meagher R, Reynolds LO. 2021. Global Crop Impacts, Yield Losses and Action Thresholds for Fall Armyworm (*Spodoptera frugiperda*): A review. *Crop Protection*, **145**: 105641. DOI: https://doi.org/10.1016/j.cropro.2021.105641 .

Pomalegni SBC, Ahoyo Adjovi NR, Kpadé CP, Gbemavo DSJC, Allagbé CM, Adjanohoun A, Mensah GA. 2019. Capitalisation des études et autres travaux sur les chaînes de valeur du maïs au Bénin. URL: http://www.slire.net/download/2500/capitalisation_cva_mai_s.pdf.

Prasanna BM, Huesing JE, Eddy R, Peschke VM. 2018. *La chenille légionnaire d'automne en Afrique: Un guide pour la lutte intégrée contre le ravageur*, (1ere édn). Mexico, CDMX: CIMMYT. URL: https://repository.cimmyt.org/handle/10883/19458.

Ramos-López AM, Pérez S, Rodríguez-Hernández GC, Guevara-Fefer P, Zavala-Sanchez MA. 2010. Activity of *Ricinus communis* (Euphorbiaceae) against *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *African Journal of Biotechnology*, **9**: 1359-1365. DOI: 10.5897/AJB10.1621

Ramos V, Alves D, Braga M, Carvalho G, Santos C. 2013. Extraction And Isolation of Anti-Tryptic Castor-Bean (*Ricinus communis* L.) Substances and their Effects on *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae). *Chilean Journal of Agricultural Research*, **73**: 128-135. DOI: http://dx.doi.org/10.4067/S0718-58392013000200007

Rossi GD, Santos CD, Carvalho GA, Alves DS, Pereira LLS, Carvalho GA. 2012. Biochemical Analysis of a Castor Bean Leaf Extract and its Insecticidal Effects against *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae). *Neotropical Entomology*, **41**: 503-509. DOI: https://doi.org/10.1007/s13744-012-0078-0

Sane B, Badiane D, Gueye MT, Faye O. 2018. Évaluation de l'Efficacité Biologique d'Extrait de Neem (*Azadirachta indica*

Juss.) comme Alternatif aux Pyréthrinoïdes pour le Contrôle des Principaux Ravageurs du Cotonnier (*Gossypium hirsutum* L.) au Sénégal. *International Journal of Biological and Chemical Sciences*, **12**(1): 157-167. DOI: 10.4314/ijbcs.v12i1.12

SAS. 2005. SAS Institute, version 9.2 Inc., Cary.

Sharma S, Vasudevan P, Madan M. 1990. Insecticidal Value of Castor *(Ricinus communis)* Against Termites. *International Biodeterioration*, **27**: 249-254. DOI: https://doi.org/10.1016/0265-3036(91)90053-T

SPSS Inc. 2002. SPSS: Statistical Program for the Social Science. Version 11.5, Chicago: SPSS Inc.

Teixeira SCL, Paiva LA, Correa F, Silva FC, Pelosi AP, da Silva AM, de Sousa AAC, Jesus FG. 2020. Interaction between Corn Genotypes with Btprotein and Management Strategies for *spodoptera frugiperda* (Lepidoptera: Noctuidae). *Fla. Entomol.*, **102**: 725–730. DOI: https://doi.org/10.1653/024.102.0409

Toundou O, Palanga KK, Simalou O, Abalo M, Woglo I, Tozo K. 2020. Biopesticide Plants Species of the Mining Area of Tokpli (South-Togo) Effects on Okra (*Abelmoschus esculentus*) Protection against *Aphtona* spp. *International Journal of Biological and Chemical Sciences*, **14**(1): 225-238. DOI**:** 10.4314/ijbcs.v14i1.19

Tounou AK, Mawussi G, Amadou S, Agboka K, Gumedzoe YMD, Sanda K. (2011). Bio-Insecticidal Effects of Plant Extracts and Oil Emulsions of *Ricinus communis* L. (Malpighiales: Euphorbiaceae) on the Diamondback, *Plutella xylostella* L. (Lepidoptera: Plutellidae) under Laboratory and Semi-Field Conditions. *Journal of Applied Biosciences*, **4**: 2899-2914. URL: www.biosciences.elewa.org

Tounou AK, Govgovor YS, Kounoutchi K. 2020. Guide de reconnaissance et de gestion durable de la chenille légionnaire d'automne. Lomé, FAO. DOI: https://doi.org/10.4060/cb0694fr

Wainwright H, Wanyamay C, cherotich N. 2013. Biopesticides and their Commercialization in Africa. Proceedings of The First International Conference on Pesticide Plants, 21-24 January 2013, Egerton University and ICIPE, Nairobi, Kenya, 189 – 191.

Yarou BB, Silvie P, Assogba-Komlan F, Mensah A, Alabi T, Verheggen F, Francis F. 2017. Plantes pesticides et protection des cultures maraichères en Afrique de l'Ouest (synthèse bibliographique). *Biotechnology, Agronomy and Society and Environment* **21**: 288-304. DOI: 10.25518/1780-4507.16175

Yehouenou APE, Lalèyè P, Boko M, van Gestel AMC., Ahissou H, Akpona S, van Hattum B, Swart K, van Straalen MN. 2006. Contamination of Fish by Organochlorine Pesticide Residues in the Ouémé River catchment in the Republic of Benin. *Environment International*, **32**: 594-599.
DOI: 10.1016/j.envint.2006.01.003