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Biocidal effect of bio art biological product against *Caryedon serratus* (Olivier, 1789), seed pest in peanut stocks in Senegal

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Abstract

In order to design an integrated pest management strategy, the insecticidal activity of the product BioArt on eggs and adults of *Caryedon serratus* (Ol.) was studied in the laboratory at different concentrations. The main results revealed that BioArt affected the survival of treated stages, depending on the concentration applied. It caused 44.44% embryonic mortality in C1 and C2 and 82.22% larval mortality in C1. This bioactivity is also expressed by a modification of the development times and an imbalance of the sex ratio in favour of females. The adulticidal activity showed mortality spread over time for all doses. The BioArt product showed a remarkable adulticidal efficacy of 100% mortality in C1, 83.33% in C2 and 86.66% in C3. A reduction in the fecundity of females treated with the C1 dose was also noted, as well as a balance in the sex ratio of survivors to treated adults. BioArt must be used to protect the groundnut stocks.

Keywords: *Caryedon serratus*; Peanut stock; BioArt; Biocide

1. Introduction

Generally considered to originate from South America, the groundnut, with its scientific name *Arachis hypogaea* L., is a legume that was introduced in West Africa, mainly in Senegal, towards the end of the 16th century [1]. It currently occupies a predominant place in the economic system of Senegal, where its cultivation covers more than half of the cultivable area. This legume remains the country's main export crop and brings in about 80 billion CFA francs each year, which represents 40% of the country's total exports [2]. Very rich in protein and calories (50% lipids, 25% proteins), this oilseed is also a very important nutritional supplement for local populations [3].

After harvesting, very few insects are able to attack the groundnut in the shell. Of these insects, *Caryedon serratus* (Olivier, 1790) is the most formidable. It can inflict quantitative crop losses of 83% on this commodity during 4 months of storage [3].

In addition, the holes left in the hull by the larvae of this pest favour the attack of other pests and facilitate the development of a mould (*Aspergillus flavus* Link.) producing a carcinogenic substance: aflatoxin. All these losses at all stages, from harvest to consumption, are not only detrimental to farmers but also very costly to the national economy [4]. Faced with the threat of insect pests in stocks, farmers often resort to synthetic insecticides which have many harmful effects. Among these effects, we can list the selection of resistant strains [5], intoxication and pollution of the environment, but also the reluctance of consumers to consume products treated with pesticides [6]. These effects force several authors to rely on traditional methods of insect control to search for plant biocides capable of reducing insect-induced damage to crops without harming people and the environment [7, 8, 9,10, 11]. This study is part of the effort to

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improve the protection of groundnut seeds in order to reduce quantitative and qualitative losses of seeds with non-polluting methods such as the use of plants with insecticidal effects against *C. serratus*. To this end, we tested in the laboratory the biocidal effect of the BioArt product, which is a combination of three plants (*Azadirachta indica*, *Crataeva religiosa*, *Calotropis procera*), on the eggs and adults of *C. serratus*.

2. Material and methods

2.1. Mass rearing

The groundnut used for mass rearing was purchased at the Tilène market (Dakar). These peanut seeds were brought to the Entomology and Acarology laboratory of the Faculty of Science and Technology of the Cheikh Anta Diop University of Dakar where they were put in bags and kept in the freezer for 96 hours at 4 °C to eliminate any hidden infestation. The seeds were then brought to room temperature and placed in glass jars 16 cm high and 8 cm in diameter, hermetically sealed to prevent further infestation.

The original strain of *C. serratus* came from groundnut pods collected in the locality of Keur Baka (14° 09' N-16° 04' W) 22 km south of the Kaolack region. They are collected and kept in the laboratory in plastic bags at room temperature for at least two months. The cocoons formed outside are isolated in Petri dishes. Adults emerging from these cocoons are reared in the laboratory. Mass rearing is carried out in cylindrical glass jars (about 16 cm in diameter and 8 cm high) with a perforated lid covered with muslin cloth to allow the insects to breathe. Each jar is filled with peanut seeds until the base is completely hidden, a sufficient number of male and female insects, paper folded in a zigzag pattern that allows the insects to move easily inside the jar and cotton wool soaked in distilled water. The jars are then left at room temperature. After 48 hours, the seeds that had received eggs were placed in glass Petri dishes where the egg will continue its development cycle until the adult emerges. Adult emergence was recorded and monitored every two days in order to respect the cohort and avoid mixed batches of generations. Biological tests were carried out on adults (adulticidal effect) and eggs (ovicidal effect) of *C. serratus* from this farm.

2.2. The Bio Art product

The BioArt product is synthesized by the GENGESPOP team from a combination of three plants (*Azadirachta indica*, *Crataeva religiosa*, *Calotropis procera*) in a dosage known to the manufacturer. It was developed after some fifteen years of research combining knowledge of bio-aggressors and ancestral knowledge and techniques. The insecticidal and acaricidal action of this ecological product is obtained by infiltration through the respiratory stigmas and by blocking the respiration of arthropod pests. The reasons for this choice are based, on the one hand, on the results of a survey carried out in rural areas, which revealed that some farmers mixed the shredded material of a number of plants with an insecticidal effect with their harvest, and these plants were among those chosen. In addition, these plants are very common in Senegal and easily accessible. Three different concentrations were obtained: C1 = 3kg/ 21L = 0.14kg/L is the concentration of the initial solution and from which two other concentrations are obtained by dilution; C2 = C1/2 = 0.07kg/L and C3 = C1/3 = 0.04kg/L.

2.3. Ovicidal test

The 48-hour-old female *C. serratus* from the mass rearing were placed in pairs to lay eggs on healthy peanut seeds. 24 hours after contact, the adults were removed from the seeds and the seeds were observed under a monocular magnifying glass for eggs deposited on them. If a seed receives more than one egg, only one is left and the others are peeled off with fine tweezers so that there is no intraspecific larval competition.

In each Petri dish, 12 seeds containing one egg each are then sprayed with a 1ml solution of each concentration and the dish is gently shaken to evenly impregnate the seeds. For each concentration, three replicates and a blank control were made. For the blank control, the seeds were not treated. The next day, the seeds were placed in rectangular plastic boxes. Each box has 3 rows of 4 wells numbered by letters and numbers in the index from 1 to 12. For each dose, three boxes were filled. All the boxes were placed on the laboratory bench and checked every day. The experiment was conducted at room temperature between 29 °C and 35°C and 47-92% relative humidity. This study device allows the eggs to be monitored individually. For each seed, the date of oviposition corresponding to the day before the start of the experiment is mentioned. The same applies to the dates of hatching, cocoon formation and the emergence of the surviving adults. It then becomes easy to calculate certain biological parameters such as the mortality percentages of eggs, larvae and the total mortality rate.

Percentage of embryonic mortality

$$\% \text{ Embryonic Mortality } = \frac{\text{Number of unhatched eggs}}{\text{Total number of eggs}} \times 100$$

Percentage of larval mortality

$$\% \text{ Larval mortality } = \frac{\text{Number of dead larvae}}{Total\ number\ of\ larvae} \times 100$$

Total mortality percentage

$$\text{Total Mortality } = \frac{\text{NNo.of unhatched eggs + No.of dead larvae}}{Total\ number\ of\ eggs} \times 100$$

These mortalities were then corrected by Abott's formula (Abott, 1925), which gives the corrected percentage mortality values based on the mortalities of the treated samples and the blank control.

$$\text{MC } = \frac{\text{MT} - \text{MT0}}{100 - \text{MTO}} \times 100$$

Where;
CM: corrected mortality
MT: mortality of treated insects
MTO: mortality of untreated insects

2.4. Monitoring of "rescued" eggs

The study of the parameters of the development cycle carried out on the rescued eggs of *C. serratus* focused on

- The duration of egg-laying and hatching, which represents the stage of embryonic development.
- The time from hatching to the weaving of the cocoon or larval development, which takes place mainly inside the seed.

2.5. Weaving-emergence time or pupal stage.

The oviposition-emergence duration or total development phase covers the time between oviposition and adult emergence.

The oviposition-death of the adult or total life span covers the time between oviposition and death of the adult.

2.6. Reproductive activity of "survivor" adults

The monitoring of these "rescued" *C. serratus* adults is carried out in order to evaluate the possible effect of the extracts of these plants tested on a certain number of their biological parameters, such as

- The sex ratio of the "rescued" adults
- The fecundity, fertility of these females and the life span of the "rescued" adults

The sex ratio, which corresponds to the ratio of the number of emerged males to the number of females, is determined for each test product. Sexing of the emerging adults is done by observing the last abdominal segment which is curved in the male and elongated in the female. Mating between males and females was then carried out. Each pair was placed alone in a numbered petri dish with an oviposition substrate. The oviposition of the "surviving" females of *C. serratus* was monitored on healthy peanut seeds; for the importance of oviposition, the number of eggs laid on the walls of the jars and on the seeds by each female was counted every day under a binocular magnifying glass. Thus, infested seeds are replaced by perfectly healthy ones. It should be noted, however, that the conditions of no water and no food are applied to these emerging young adults. The experiment is conducted at room temperature in the rearing room. The monitoring of the pairs is interrupted when they die, thus allowing the total life span of the adults of *C. serratus* to be calculated [12].

2.7. Adulticide tests

The treated adults come from the mass rearing carried out in the laboratory in glass jars; they are at most 72 hours old. In each Petri dish, 10g of peanut seeds are placed. The seeds are then infested with 10 adults of *C. serratus* (5 males and 5 females). For each concentration, 1ml was sprayed onto the peanut seeds in each box. This was then gently shaken for 2-3 minutes to ensure distribution of the solution on the substrate. For each given concentration, three replicates and a blank control were performed. In the blank control, adults were not in contact with the solutions at all. The insects were exposed to the aqueous extracts for one week. Dead hives were counted every 24 hours and the eggs laid were also counted. The proportion of dead adults (number of dead/total number x 100) was calculated for each concentration of the solution tested. The results obtained were corrected using the Abott (1925) formula.

The number of eggs laid (fecundity) and the sex ratio of the offspring was also evaluated.

2.8. Statistical analysis

Repeat mean calculations and graphs were performed in Excel 2013. The Statistical analyses of the variables were performed with R software. The normality of the data was checked by the Shapiro-Wilk normality test. Most of the variables did not follow the normal distribution. Thus, we used the non-parametric test and the most suitable was the Kruskal-Wallis test. It allowed us to compare the means of the different doses used to see whether or not there were significant differences at the 5% level. Once the difference is significant, a multiple comparisons between the doses will be made using the pairwise test.

3. Results

3.1. Ovicidal effects of Bio Art

The overall analysis of the results shows that BioArt reduces egg hatchability in absolute terms compared to the control. The two high doses caused the same embryonic mortality rate (44.44%). This decreased with the lowest dose C3 (41.66%) (Table 1).

Although there was no significant difference between concentrations, the mortality rate of the larvae varied from 60.18% to 82.22%. The C1 dose causes the highest mortality (82.22), this rate decreases considerably when the dose is reduced; it is 64.64% in C1 and 60.18 in C3.

As for pupal mortality, we found that the mortality rate obtained with the white control (83.33%) is significantly higher than those obtained with the three doses with respectively 11.11% in C1, 44.44% in C2 and 41.66% in C3.

Table 1 Ovicidal effect of BioArt: mean (standard deviation)

Solution	Concentrations	Embryonic Mortality	Larval Mortality	Mortality Nymphal
BioArt	C1	44.44 ^{a}± 17.35	82.22 ^{a}± 16.78	11.11^{a}±19.24
	C2	44.44^{a} ± 12.73	64.64 ^{a}± 6.01	44.44 ^{b}± 9.62
	C3	41.66^{a} ± 17.99	60.18 ^{a}± 13.13	41.66^{b}±14.43
	TB	27.77^{a} ± 17.35	61.09^{a} ± 3.47	83.33^{c}± 28.87

The values are averages followed by the standard deviation. On a vertical line, means followed by the same superscript letter(s) are not significantly different from each other ($p > 0.05$). C1= concentration1, C2= concentration2, C3= concentration3, TB= white witness

3.2. Monitoring of "rescued" eggs

The results obtained from the biocidal action of the BioArt product on the average duration of the different developmental phases of the "rescued" eggs of the *C. serratus* insect are presented in Table 2.

The BioArt product induced a mean oviposition/hatching time of 7.85 ± 0.05 days, with a minimum time of 7.8 ± 0.05 days with C1 and a maximum time of 7.9 ± 0.58 days with C2.

The average duration of larval development was 37.63 ± 4.89 days, with a minimum duration of 33 ± 6.05 days in C2 and a maximum of 42.75 ± 0.96 days in C1. The lowest dose C3 induced a mean duration of larval development of 37.13 ± 5.74 days. The average weaving/emergence time was 25.78 ± 7.12 days, with a maximum of 31 ± 7.45 days in C3 and

a minimum of 17.67 ± 67 days in C1. An elongation of the duration of the total development phase is noted, it is respectively 67, 67; 72 and 72.8 days for treatments C1, C2 and C3 (66 days for the white control).

As for the average lifespan, an increase in the lifespan of the adults was noted; it was of the order of 74.53 ± 6.16 days, with a minimum duration of 67.67 ± 1.15 days in C1 and a maximum of 79.6 ± 14.64 days in C3 (66 days for the control).

Table 2 Effect of the BioArt product on the average duration (± standard deviation) of the different development phases of the rescued eggs

Average duration (Days)	Concentrations			
	C1	C2	C3	TB
Laying/hatching	7.8^{a} ± 0.2	7.9^{a} ± 0.58	7.86^{a} ± 0.74	7.62^{a} ± 0.4
Hatching/cocoon weaving	42.75^{a}± 0.96	33^{a} ± 6.05	37.13^{a} ± 5.74	39.9^{a} ± 6.61
Weaving/emergence	17.67^{a}±1 .15	28.67^{b}± 4.93	31^{b} ± 7.45	24.5^{ab} ± 0.71
Laying/emergence	67.67^{a} ±1.15	72^{ab} ± 6.05	72.8^{b} ± 3.35	66^{a}± 0
Lifespan	67.67^{a}± 1.15	76.33^{b} ± 5.77	79.6^{ab}± 14.64	66^{a}± 0

The durations are expressed in days; the values are averages followed by the standard deviation. On a horizontal line, the averages followed by the same superscript letter(s) do not differ significantly from each other (p > 0.05).; C1= concentration1, C2= concentration2, C3= concentration3, TB= white witness

3.3. Reproductive activity of "rescued" adults

Table 3 Effects of BioArt on the sex ratio of male and female offspring from treated eggs

Solution	Concentrations	Individual survivors	Individuals Males	individuals females	Sex-ratio
BioArt	C1	8.33^{a} ± 8.33	0.00^{a}	100^{a} ± 1	0.00^{a}
	C2	11.11^{a}±4.81	24.81^{a}±0.58	75.19^{a} ± 0	0.33^{a}± 0.58
	C3	13.89^{a}±9.62	80.12^{b}±0.58	19.88^{a}±0.58	4.03^{a} ± 1.15
	TB	5.55^{a} ± 9.62	0.00^{a}	100^{a}± 1.15	0.00^{a}

The values are averages followed by the standard deviation. On a vertical line, means followed by the same superscript letter(s) are not significantly different from each other (p less than 0.05) ; C1= concentration1, C2= concentration2, C3= concentration3, TB= white witness

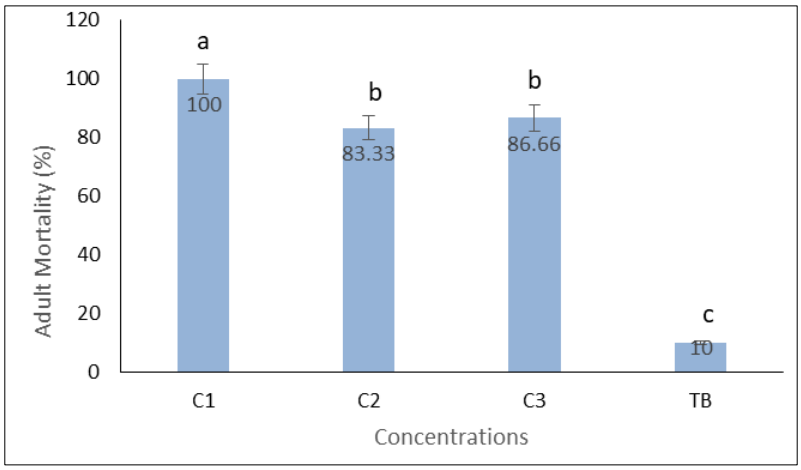
Table 3 shows that the percentages of surviving individuals are significantly the same. The average of the percentages obtained in C1, C2 and C3 is 11.11 ± 2.78 for the control 5.55 ± 9.62. In males, the results obtained show a total absence of males in C1. The lowest dose C3 gives the highest number of males which is equal to 80.12± 0.58 significantly higher than those obtained with the two other doses and the white control. In females, the results obtained with BioArt are generally significantly the same. However, when comparing the data in relative terms, it can be said that there is a difference between the rate of female offspring produced by the three doses (100% in C1, 75.19% in C2 and 19.88% in C3) but also between the low doses C2 and C3 and the white control (100%).

The results in Table 3 also show that the lowest dose C3 causes the highest sex ratio 4.03 ± 1.15. While the C2 dose induces a ratio between males and females that is equal to 0.33± 0.58.

3.4. Adulticidal effects

Fig. 1 allows the comparison of the effects between concentrations. The diagrams followed by the same alphabetical letter are not significantly different at $p \geq 0.05$.

In the graph above, we note that all concentrations induce high mortality of *C. serratus* adults compared to the control. Thus, the highest dose (C1) shows average mortality of 100% which is significantly higher than that of the other concentrations and much higher than the control (10%). The other concentrations C2 and C3 induced mortalities of 83.33% and 86.66%, respectively. There was also a significant difference between the two low doses and the white control (Fig. 1).



C1= concentration1, C2= concentration2, C3= concentration3, TB= white witness

Figure 1 Mortality of adults treated with BioArt

3.5. Corrected mortalities

The BioArt product has very high toxicity toward *C. serratus* adults. Thus, we note that all doses gave more than 80% mortality and even 100% with the highest dose C1 (Table 4).

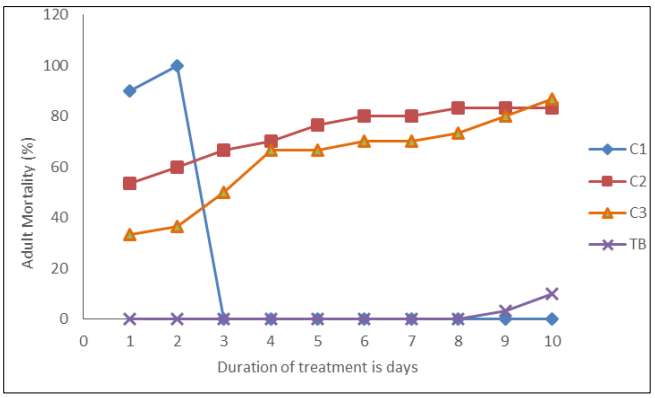
Table 4 Percentage of corrected mortality of *C. serratus* adults induced by the product BioArt

Solutions	Concentrations	corrected mortality
BioArt	C1	100 ^{b}± 0
	C2	81.47 ^{c} ±10.52
	C3	85.17 ^{c} ± 4.77

The values are averages followed by the standard deviation. On a vertical line, means followed by the same superscript letter(s) are not significantly different from each other (p less than 0.05); C1= concentration1, C2= concentration2, C3= concentration3, TB= white witness

3.6. Evolution of adult mortality as a function of the dose applied and the duration of exposure

This treatment was spread over a 10-day interval, after which no dead individuals were collected.



C1= concentration1, C2= concentration2, C3= concentration3, TB= white witness

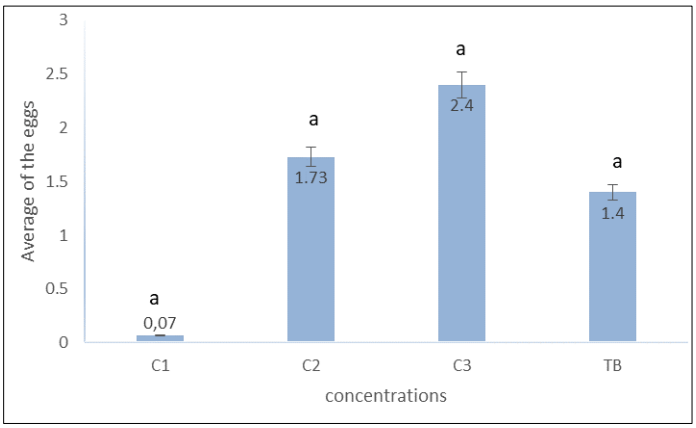
Figure 2 Mortality of adults treated with BioArt as a function of dose and duration of exposure

When we evaluated the level of mortality of adults of *C. serratus* as a function of the duration of exposure, we noted that for a duration of exposure of between 1 and 2 days after treatment, the C1 dose of the BioArt product showed a more marked adulticidal activity than that produced by the C2 and C3 doses, which was 100%. We can also see that the highest mortality was obtained on the first day after treatment regardless of the concentration, 90% in C1, 53.33% in C2 and

33.33% in C3. The white control did not cause any mortality before the 9th day of treatment with a very low mortality rate of 3.3% (Fig. 2).

3.7. Effect of BioArt on the fecundity of treated females

The results obtained on the fecundity of *C. serratus* females treated with BioArt are presented in Fig. 3 below. The diagram followed by the same alphabetical letter is not significantly different at p ≥ 0.05.



C1= concentration1, C2= concentration2, C3= concentration3, TB= white witness

Figure 3 Effect of BioArt on the fecundity of treated females

Evaluated after 10 days of treatment with BioArt, the average fecundity of *C. serratus* females varies with the dose applied. Thus the highest dose (C1) has an almost zero average fecundity of 0.07 eggs per female compared to the white control which is 1.4 eggs; while the low doses have no influence on the fecundity of the "surviving" females, the fecundity is higher than the control batch. We can therefore say that it decreases as the dose increases (Fig. 3).

"Rescued" adults

Table 5 Effects of BioArt on the sex ratio of male and female offspring from treated adults

Solution	Concentrations	Individual survivors	Individuals Males	individuals females	Sex-ratio
BioArt	C1	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
	C2	$1.33^{a}\pm2.31$	$24.81^{a}\pm0.58$	$75.19^{a}\pm1.73$	$0.33^{a}\pm0.19$
	C3	$0.33^{a}\pm0.58$	$100\ ^{a}\pm 0.58$	0.00^{a}	0.00^{a}
	TB	$1^{a}\pm 1.73$	$33.33^{a}\pm0.58$	$66.67^{a}\pm1.15$	$0.49^{a}\pm0.28$

Values are averages followed by the standard deviation. On a horizontal line, means followed by the same superscript letter(s) are not significantly different from each other (p less than 0.05); C1= concentration1, C2= concentration2, C3= concentration3, TB= white witness

The results presented in Table 5 indicate that the percentages of surviving males and females varied according to the concentration. For each parameter studied, the statistical analysis shows that the values obtained are significantly the same. For the survivors, we note a total absence with the highest dose C1. The average obtained in C1, C2 and C3 is equal to 0.55 ± 0.69 and for the white control, 1 ± 1.73. The distribution of the surviving individuals according to sex gives 100% males in C3 and 24.81% in C2. Among the females, we note a presence only with the C2 dose, which is equal to 75.19%. We also note a ratio between males and females of 0.33±0.19 with the C2 dose and 0.49±0.28 with the white control.

4. Discussion

The laboratory studies we conducted focused on the evolution of the ovicidal and adulticidal action of a product named BioArt on the most serious peanut pest *C. serratus* under ambient conditions. The product showed differentiated efficacy depending on the dose applied.

By analysing the ovicidal results, we can note that the product BioArt affects the viability of *C. serratus* eggs, compared to the white control. All doses reduced the hatching of *C. serratus* eggs. Thus, it showed an ovicidal efficacy between 41.66 and 44.44% with the application of all doses. Statistically, we note equal effectiveness of the effect of all doses at $p < 0.05$. Thus, the highest doses (C1 and C2) show the same percentage mortality of 44.44% in *C. serratus* eggs.

The larvicidal effect observed with BioArt reported mortalities that ranged from 60.18% to 82.22%. Thus, we can see that they increase with concentration. The highest dose was more effective with 82.22% mortality; the low doses C2 and C3 caused 64.64 and 60.18% of the larvae, respectively. This reveals the persistence of its biological activity during the treatment leading to a disruption or a stop of the development of the insect at the larval stage.

Concerning pupal mortality, the highest dose showed a significantly lower mortality rate than the low doses (11.11%). This could be explained by the high mortality rate recorded on the larvae (82.22%). The low dose C2 and C3 gave mortality rates of 44.44% and 41.66%, respectively. These results corroborate the work of Faye [13] who showed an ovicidal effect of 73.33% to 90% with freshly crushed leaves of *C. religiosa* and 33.3 to 45% with *Senna occidentalis* leaves on *Callosobruchus maculatus*. Gueye [14] showed low ovicidal activity with *Annona senegalensis* biocides; he obtained 33% activity with the 0.01 g/ml concentration of the methanolic fraction and 23% with the 0.1g/ml concentration. Therefore, our results on the larvicidal effect of BioArt are not in line with those of Thiaw [15] who showed the highest larval mortality rates with the lowest dose C3 of 16.67 and 6.25% obtained with the methanol fraction and the crude methanolic extract respectively. The ethyl acetate fraction considered as the one of intermediate polarity gave a larval mortality rate of 2.08%. The C3 concentrations of the apolar extracts (ether and hexane) did not induce any mortality in the surviving eggs. Thiaw *et al.* [16] showed larval mortality of 13.96 ± 4.85% with methanolic extracts of *S. occidentalis*, with the hexane and acetate fraction mortality of 4.17 and 5.63 ± 2.52%, respectively on *C. serratus*.

Under the study conditions, our results show that BioArt affects the average duration of the different developmental stages of treated *C. serratus* eggs. Its action varies according to the doses applied. The average oviposition/hatching time is almost the same with all doses 7.8 in C1 and C3, 7.9 in C2. The duration of larval development induced by BioArt varies from 33 ± 6.05 to 42.75 ± 0.96 days, with a maximum duration in C1 and a minimum in C2. Ndiaye [17] reports that the incubation period lasts 6 to 8 days, and the development time from egg to resulting adult is 45 to 47 days. Delobel [18] reports that, under the usual conditions in Senegal, the egg hatches after about a week and the neonate larva punctures the pod, passes through the pericarp, pierces the seed coat and enters the seed, which it consumes. He also specifies that larval development lasts a little over a month; at the end of this time, the larva weaves a cocoon from which an adult will emerge 15 days later. This same duration of pupation was noted by Robert [19] at 35°C. The work of Ndiaye [3] and Delobel and Tran [20] indicates a development of the larvae between 40 and 58 days depending on the temperature and relative humidity conditions. Gueye [12] reveals, in his studies, a larval stage duration of about 45 days on average at 35° C. On the other hand, our results showed a pupal development that varied from 17.67 ± 1.15 to 31 ± 7.45 depending on the dose. These results confirm those of Thiaw [15] who showed a duration of pupal development varying between 21.33 and 33.43 days with the extract and the methanolic fraction of *Calatropis procera* and *Senna occidentalis* on the same insect. From oviposition to adult emergence, the treated eggs showed a duration varying from 67.76 ± 1.15 to 72.8 ± 3.35 days. From oviposition to adult death, they showed a total life span varying from 67.67 ± 1.15 to 79.6 ± 14.64 days. It should be noted, however, that in our studies almost all of the emerged adults died shortly after emergence. This could be explained by the persistence of the biocidal action of the product, which led to the immediate death of the adults from the treated eggs. These results are in line with those of Delobel [21] who indicates a complete development of the egg of about two months. However, they are not in line with those of Thiaw [15], which show a lifespan that varies from 117.33 to 140.93 days. An elongation of the lifespan of surviving adults was recorded with extracts of *L. camara* and *A. senegalensis* [14].

The average emergence rate of adults from *C. serratus* eggs previously treated with BioArt was 11.11% with a maximum of 13.89% in C3 and a minimum of 8.33% in C1. Indeed, these low emergence rates can be explained by the high embryonic, larval and pupal mortality rates. This work is not in line with that of Thiaw [15], which shows higher emergence rates ranging from 30.55 to 52.78% with crude extracts and extract fractions of *C. procera*.

The sex ratio is in favour of females except for the lowest dose C3 where males are more numerous, which would increase the risks of population growth and competition between males in the second case. The same trend is observed with the work of Gningue *et al*. [22], where the sex ratio is in favour of females of *C. serratus* with the application of *A. indica* extracts.

The adulticidal activity showed temporally spread mortalities of all doses. Thus, we note that the effects induced increase over time for each dose applied. The BioArt product thus showed remarkable adulticidal efficacy (between

83.33 and 100%) with the application of all doses. Its efficacy on adults is a function of the doses applied, killing more than 78% of *C. serratus* adults in 4 days. Moreover, the highest dose C1 induced 100% mortality in 48h. These results corroborate those of Thiaw [23] and Kébé [24] who both obtained 100% mortality on *C. serratus* adults with methanolic extracts of *Calotropis procera* and *Boscia senegalensis* respectively with the concentration of 0.1g/l in 24 hours of application. Faye [13] obtained an efficacy of 87.25% in C1 (0.2g/cm3) and C2 (0.13g/cm3) and 74.87% in C3 (0.1g/cm3) with the aqueous extract of *C. religiosa* leaf powder on *C. maculatus* adults at day 10.

The evaluation of the fecundity of females treated with different doses of BioArt showed a reduction in fecundity depending on the dose applied. Compared to the control, BioArt reduced fertility only with the highest dose C1 (0.07). These results are not in line with the work of Thiaw *et al*. [16] who found that biocidal extracts of *S. occidentalis* showed percentages of reduction in fecundity of females from treated eggs ranging from 27.29% (methanol extract) to 67.2% (ethyl acetate fraction) on the same insect. The work of Gueye [14] also showed a reduction in fecundity with *Lantana camara* extracts. This reduction could be explained by a low longevity of the females due to the biocide effect of the product. Indeed, when applied to adults, we found that a few minutes after treatment, the insects were dead or paralysed. This means that the females have not had time to lay eggs or are unable to lay eggs due to paralysis.

The offspring of the tested adults (the survivors) were only obtained with the low doses in very low numbers. The high doses caused very high mortality within 24 hours of treatment, leaving no time for the adults to mate. These results confirm those of Doumma *et al*. [25] who studied the action of ground *Boscia senegalensis* leaves on *C. maculatus*. They are also in agreement with those of Mazibur and Gerhard [26] and Ketoh *et al*. [27]. Regarding the sex ratio, the results obtained show that it is in favour of females for the C2 dose and for the white control. From these results, we can conclude that the predominance of females would increase the risks of population increase in stored seeds, hence the importance of damage in storage areas. The same trend is observed with Gningue *et al*. [22], where the sex ratio is in favour of females with the application of *A. indica* extracts on *C. serratus*.

5. Conclusion

The results show that BioArt induces high mortality of *C. serratus* at the adult stage and medium mortality at the egg stage. The ovicidal and adulticidal effects varied according to the dose used. Thus the highest dose showed high adulticidal activity while all three doses showed almost the same ovicidal effects. Post-treatment monitoring to see if these will have an impact on insect development times and sex ratio of survivors showed a lengthening or shortening of development times and an imbalance in sex ratio in favour of females. Follow-up of BioArt-treated adults revealed a reduction in fecundity of these females only with the highest dose and a balance in the sex ratio of the survivors.

In the light of the laboratory tests, this work could therefore be continued with a view to the practical use of this product for the protection of groundnut stocks and seeds in the farming environment. It would also be possible to carry out a series of trials in a real environment to better determine the optimal application doses and to test the germination of treated seeds.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest on this research work.

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