ZEAL SCIENTIFIC PUBLICATION

World Journal of Advanced Pharmaceutical and Life Sciences

[illegible]: https://zealjournals.com/wjapls/

[illegible] 2799-0222 (Online)

(RESEARCH ARTICLE)

Comparative biocidal eff

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Comparative biocidal effect of B[illegible]*eva religiosa* extracts against the groundnut seed pest *Caryedon ser*[illegible]egal

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World Journal of Advanced Pharmaceutical and Life Sciences, 2024, 06(01), 028–038

Publication history: Received on 04 January 2024; revised on 11 March 2024; accepted on 14 March 2024

Article DOI: https://doi.org/10.53346/wjapls.2024.6.1.0022

Abstract

With a view to devising a strategy for protecting groundnut seeds against *Caryedon serratus*, we tested the biological impact of a product called BioArt made from the leaves of certain plants indigenous to Senegal (*Crataeva religiosa*, *Calotropis procera* and *Azadirachta indica*) and aqueous extracts of *Crataeva religiosa* on the external forms of *C. serratus*. The BioArt product caused the greatest mortality in adults. It induced maximum elimination (100%) of adults with the highest dose C1. Extracts of *C. religiosa* were less effective than BioArt on adults. They induced a maximum effect of 53.33% mortality with the highest dose C1. Females treated with BioArt laid fewer eggs than those treated with aqueous extracts of *C. religiosa*. With regard to the sex ratio of survivors, a comparative study of the different solutions showed that the BioArt product favoured females, while the *C. religiosa* extracts were equally distributed between males and females. The ovicidal activity showed almost equal embryonic and larval mortality and a slight difference in pupal mortality (32.41% with BioArt and 47.18% with *C. religiosa*). Monitoring of surviving eggs showed a lengthening or shortening of the various development times, with larval development, total development and life span being shorter with the BioArt product. The sex ratio was in favour of females for both products.

Keywords: Biocidal effect; BioArt; *Crataeva religiosa; Caryedo serratus*

1. Introduction

Groundnuts (*Arachis hypogaea* L.) play an important role in Senegal's production systems, accounting for over 40% of the income of small family farms. More than half of the arable land is used to grow groundnuts. It is also one of the crops that makes the greatest contribution to meeting the nutritional needs (particularly protein and calories) of the people of West Africa. However, it is attacked by a number of insects, the most dreaded of which is *Caryedon serratus* (Olivier), responsible for quantitative losses of up to 83% after a storage period of 4 months [1, 2]. The holes left by the larvae of *C. serratus* facilitate the attack of other insects which reduce the nutritional quality of the groundnut and encourage the development of a mould, *Aspergillus flavus*, which produces aflatoxin, which is highly carcinogenic.

The methods used to limit this damage are generally limited to the use of chemical insecticides, which can lead to chronic poisoning of farmers and consumers, a negative impact on the environment and resistance among pests. These effects have led several authors to rely on traditional insect control methods in their search for plant biocides capable of reducing insect-induced damage to crops without harming people or the environment [3, 4, 5, 6, 7].

To contribute to the search for alternative methods to the use of chemical insecticides hazardous to humans and the environment, we tested the insecticidal effect of the BioArt product and aqueous extracts of *Crataeva religiosa* on *Caryedon serratus*.

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2. Materials and methods

2.1. Harvesting and conservation of plant material

The groundnuts used for mass rearing were purchased at the Tillène market (Dakar). The groundnut seeds were taken to the Entomology and Acarology Laboratory of the Faculty of Science and Technology at Cheikh Anta Diop University in Dakar, where they were placed 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 any further infestation. The leaves of *C. religiosa* are harvested in the vicinity of the Animal Biology Department of the Faculty of Science and Technology at Cheikh Anta Diop University in Dakar. Harvesting is carried out early in the morning before sunrise. After harvesting, the leaves are freshly ground and used for aqueous extractions by maceration for biological tests.

2.2. Mass maturation

The original strain of *C. serratus* was obtained from groundnut pods collected in the locality of Keur Baka located 22 km south of Kaolack (14° 09' N-16° 04' W). The pods were collected and kept in the laboratory in plastic bags at room temperature for at least two months. Cocoons formed outdoors were isolated in Petri dishes. The adults that emerge from these cocoons are reared in the laboratory. Mass rearing is carried out in cylindrical glass jars (around 16 cm in diameter and 8 cm high), with perforated lids covered in muslin to allow the insects to breathe. Each jar is filled with peanut seeds until the base is completely hidden, with a sufficient number of male and female insects, and with paper folded in a zigzag pattern to allow the insects to move around easily inside the jar. The jars are then left at room temperature. After 48 hours, the seeds that have been laid are placed in glass Petri dishes, where the egg continues its development cycle until the adult emerges. Adult emergence was recorded and monitored every two days in order to maintain the cohort and avoid mixed batches of generations. Biological tests were carried out on adults (adulticide effect) and eggs (ovicide effect) of *C. serratus* from this farm.

2.3. Preparation and storage of test solutions

The method used is maceration with water as the solvent. For *C. religiosa*, 1kg of crushed fresh leaves were extracted in 5 litres of tap water, which was the solvent used at 50 degrees. The solution obtained is left at room temperature for a week and then filtered using a household sieve reinforced with muslin. The aqueous extracts are stored in one-litre bottles and used as required. C1 = 1 kg /5L = 0.2 kg /L is the concentration of the initial solution from which two other concentrations are obtained by dilution. C2 = C1/2 = 0.1 kg/L and C3 = C1/3 = 0.06 kg/L.

The BioArt product is synthesised by the GENGESPOP team from a combination of three plants (*A. indica*, *C. religiosa*, *C. procera*) using 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 insecticide and acaricide 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 results of a survey carried out in rural areas, which revealed that some farmers mixed shredded material from a range of plants with an insecticidal effect with their harvest, including these plants. In addition, these plants are very common in Senegal and easily accessible. Three different concentrations were obtained: C1 = 3 kg/ 21L = 0.14 kg/L is the concentration of the initial solution, from which two other concentrations were obtained by dilution; C2 = C1/2 = 0.07 kg/L and C3 = C1/3 = 0.04 kg/L.

2.4. Ovicidal tests

Females of *C. serratus* aged 48 hours from mass rearing were oviposited in pairs on healthy groundnut seeds. 24 hours after contact, the adults are removed from the seeds and the latter are observed under a monocular magnifying glass to see any 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 to avoid intraspecific larval competition.

In each Petri dish, 12 seeds, each containing one egg, were then sprinkled with a 1ml micropipette of each of the three concentrations of each given solution, and the dish was gently shaken so as to evenly impregnate the seeds. Three replicates and two controls (white control and solvent control) were made for each concentration (*C. religiosa*) and a white control (BioArt). For the white control, the seeds were not treated. For the solvent control, one millilitre (1ml) of tap water was sprayed on the peanut seeds. The next day, the seeds were placed in rectangular plastic boxes. Each box has 3 rows of 4 wells (logis) numbered by letters and numbers from 1 to 12. For each dose, three boxes are filled. All the boxes were placed on the laboratory bench and checked every day. The experiment was carried out 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 oviposition date corresponding to the day preceding the start of the experiment is given. The same applies to the dates of hatching, cocoon formation and emergence of the surviving adults. It is then easy to calculate certain biological parameters such as the percentages of egg and larval mortality, as well as the total mortality rate.

- Percentage of embryonic mortality

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

- The percentage of larval mortality

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

- Percentage of pupal mortality

$$\text{Pupal mortality} = \frac{\text{Number of unhatched cocoons}}{\text{Total number of cocoons}} \times 100$$

These mortalities are then corrected using Abott's formula, which gives the corrected mortality values as a percentage of the mortalities of the treated samples and the white control.

$$M_C = \frac{MT - MT0}{100 - MT0} \times 100$$

where
M_C: corrected mortality
M_T: mortality of treated insects
M_{T0}: mortality of untreated insects

2.4.1. Monitoring of "rescued" eggs

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

- Egg-laying to hatching time, which represents the stage of embryonic development.
- The time from hatching to weaving of the cocoon or larval development, which takes place mainly inside the seed.
- Weaving-emergence time or pupal stage.
- The oviposition-emergence period or total development phase covers the time between oviposition and adult emergence.
- The oviposition-to-death time of the adult or total lifespan covers the time between oviposition and the death of the adult.

2.4.2. Reproductive activity of "rescued" adults

These "rescued" *C. serratus* adults are monitored in order to assess the possible effect of the plant extracts tested on a certain number of their biological parameters, such as:

- The sex ratio of "rescued" adults
- The fecundity and fertility of these females and the lifespan of the 'rescued' adults.

The sex ratio, which corresponds to the ratio between the number of males that have emerged and the number of females, is determined for each test product. Emerging adults are sexed by observing the last abdominal segment, which is curved in males and elongated in females. 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 groundnut seeds; to determine the extent 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. In this way, infested seeds are replaced by perfectly healthy ones. It should be pointed out, however, that the conditions of absence of water and food are applied to these young emerging adults. The experiment was conducted at room temperature in the rearing room. The pairs were monitored until they died, enabling the total lifespan of *C. serratus* adults to be calculated [8].

2.5. Adulticide tests

The adults treated came from mass rearing carried out in the laboratory in glass jars; they were no more than 72 hours old. Each Petri dish contains 10 g of peanut seeds. The seeds were then infested with 10 *C. serratus* adults (5 males and 5 females). For each solution and each concentration, one millilitre (1 ml) was sprayed onto the peanut seeds in each box. This was then gently shaken for 2 to 3 minutes to ensure that the solution was distributed over the substrate. Three replicates and two controls (white control and solvent control) were carried out for each concentration given for the *C. religiosa* solution and a white control for the BioArt product. In the white control, adults were not in contact with the solutions and in the solvent control, one millilitre (1 ml) of tap water was sprayed onto the peanut seeds. The insects were exposed to the aqueous extracts for one week. Dead moths 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 solution tested. The results obtained are corrected using Abott's formula.

The number of eggs laid by treated adults and controls (fecundity) is also assessed.

2.6. Statistical analysis

Repeat averages and graphs were calculated using Excel 2013. The statistical analyses of the variables were performed using Rversion 3.5.1 software. The normality of the data was verified using the Shapiro-Wilk normality test. Most of the variables did not follow the normal distribution. We therefore used a non-parametric test, the most appropriate of which was the Kruskal-Wallis test. This allowed us to compare the means of the different doses used to determine whether or not there were significant differences at the 5% threshold.

Once the difference is significant, a multiple comparison between the doses will be made using the perwise test.

3. Results

3.1. Ovicidal effects of BioArt and aqueous extracts of *C. religiosa*

The results obtained by treating *C. serratus* eggs with BioArt and aqueous extracts of *C. religiosa* are presented in Table 1.

Table 1 Comparison of the effect of BioArt and *C. religiosa* on *C. serratus* eggs

Solutions	Embryonic Mortality	Larval Mortality	Pupal Mortality
BioArt	42.51^{a}±1.67	69.01^{a}±11.65	32.41^{a}±18.49
C. religiosa	40.74^{a}±1.6	69.29^{a}±10.81	47.18^{a}±39.23

Values are averages followed by the standard deviation. On a vertical line, means followed by the same superscript letter(s) are not significantly different (p > 0.05).

Generally speaking, the statistical analysis shows no significant difference between the products, whatever the parameter studied.

3.1.1. Monitoring of "rescued" eggs

In order to determine the biocidal efficacy of the BioArt product and *C. religiosa* extracts on the insect *C. serratus*, treated eggs were monitored in the laboratory. The study of the development cycle parameters carried out on the "rescued" eggs focused on the average laying/hatching, hatching/cocoon weaving, cocoon weaving/emergence, laying/emergence and lifespan of the "rescued" adult. The various results obtained from the experiments were listed in table form.

The results obtained from the biocidal action of the BioArt product and *C. religiosa* extracts on the average durations of the different development phases of the "rescued" eggs of the *C. serratus* insect are presented in Table 2.

Table 2 Comparison of the biocidal effect of the BioArt product and *C. religiosa* on the average duration (± standard deviation) of the different development phases of rescued eggs

Solutions / DM(Day)	Spawning/ Hatching	Hatching/ Cocoon	Weaving/ Emergence	Spawning/ Emergence	Lifespan (MP)
BioArt	7.85a±0.05	37.63a±4.9	25.78a±7.12	70.82a±2.76	74.53a±6.16
C.religiosa	8.75a±0.37	44.44b±0.38	27.08a±3.54	82b±2.64	100.06b±13.4

The durations are expressed in days; the values are averages followed by the standard deviation. On a vertical line, averages followed by the same superscript letter(s) are not significantly different (p > 0.05).

Comparative analysis of the effect of the BioArt product and *C. religiosa* extracts on the average duration of the various development phases of rescued *C. serratus* eggs gave the above results. There was no difference between the two products in terms of laying/hatching time. In terms of hatching/cocoon weaving time, larvae from eggs treated with BioArt had the shortest larval development time and were therefore the first to weave their cocoons. There was also no difference in weaving/emergence time. From oviposition to adult emergence, BioArt recorded the shortest total development time. We can also note that the "rescued" adults from eggs treated with the BioArt product have a shorter life span than those from eggs treated with aqueous extracts of *C. religiosa*.

3.1.2. Reproductive activity of "rescued" adults

Eggs previously treated with the BioArt product and aqueous extracts of *C. religiosa* and which reached the adult stage are referred to as "rescued" adults. We had planned to form pairs and then monitor them separately in order to assess the effect of the biocides on the reproductive activity of the females. However, our results did not allow us to form pairs, as we obtained a very low emergence rate and most of the survivors died just after emergence. The study of reproductive parameters carried out on "rescued" populations of *C. serratus* focused solely on determining the sex ratio. The percentages of offspring insects from eggs previously tested with the BioArt product and *C. religiosa* extracts and divided into male and female individuals enabled us to determine the sex ratio of the survivors. The results obtained are presented in Table 3.

Table 3 Comparison of the effects of BioArt and *C. religiosa* extracts on the sex ratio of male and female offspring from treated eggs

Solutions	Rescued individuals	Males	Females	Sex ratio
BioArt	11.11^{a}± 2.78	34.98^{a}± 41.01	$65{,}02^{a}$± 41.01	0.54^{a}± 2.23
C. religiosa	8.33^{a}±5.55	28.96^{a}± 34.41	$71{,}04^{a}$± 34.41	0.41^{a}± 1.09

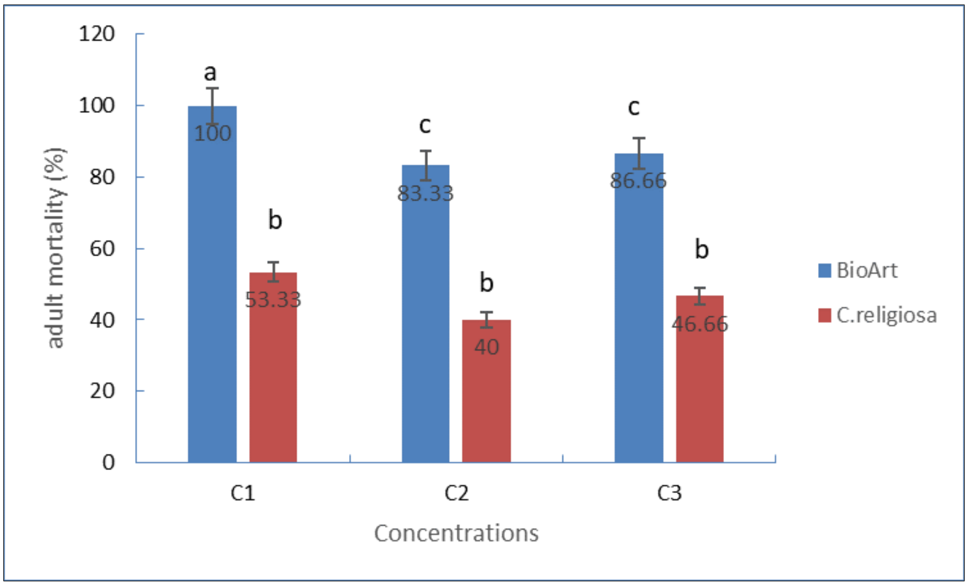
The values are averages followed by the standard deviation. In a column, means followed by the same superscript letter(s) are not significantly different from each other (p less than 0.05).

However, when we compare the data in relative terms, we can say that there is a slight difference between the rate of male offspring produced by BioArt (34.98%) and those produced by *C. religiosa* (28.96%). This slight difference in offspring rate was also observed in females, with 65.02% produced by BioArt and 71.04% by *C. religiosa*.

The highest sex ratio was observed with the BioArt product (0.54± 2.23) compared with 0.41± 1.09 with *C. religiosa* extracts, but still in absolute values.

3.2. Adulticidal effects of BioArt and *C. religiosa* extracts

The results obtained for the adulticidal activity of the BioArt product and the aqueous extracts of *C. religiosa* are presented in the form of histograms. Figure 1 compares the adulticidal effects of the two test products at the same concentration. For the same product, the diagrams followed by the same alphabetical letter are not significantly different at p ≥ 0.05.



C1 : Concentration1 ; C2 : Concentration2 ; C3 : Concentration3

Figure 1 Comparison of adult mortality between the two solutions

Generally speaking, we can see that the percentages of adult mortality induced by the BioArt product are significantly higher than those of *C. religiosa* extracts, whatever the concentration applied. However, we can also see that high doses act more effectively than low doses, whatever the product applied (figure 1).

3.2.1. Corrected mortality

BioArt is highly toxic to *C. serratus* adults. Thus, we note that all the doses gave more than 50% mortality and even 100% with the highest dose C1.

For aqueous extracts of *C. religiosa*, we can say that all doses gave mortalities of less than 50%. The highest dose, C1, gave higher mortality rates of 29.99%. The other doses, C2 and C3, gave mortality rates of 10% and 19.99% respectively. There was no significant difference between the three doses (Table 4).

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

Solutions	Concentrations	Adjusted mortality
BioArt	C1	$100^{b} \pm 0$
	C2	$81.47^{c} \pm 10.52$
	C3	$85.17^{c} \pm 4.77$
C.religiosa	C1	$29.99^{a} \pm 36.87$
	C2	$10^{a} \pm 12.5$
	C3	$19.99^{a} \pm 19.09$

Values are averages followed by standard deviation. On a vertical line, averages followed by the same superscript letter(s) are not significantly different (p less than 0.05).

3.2.2. Changes in adult mortality as a function of the dose applied and the duration of exposure

This treatment was spread over an interval of 10 days, after which no samples of dead individuals were taken. Figure 2 compares the adulticidal effects of the two test products at the same concentration. For the same product, the diagrams followed by the same alphabetical letter are not significantly different at $p \geq 0.05$.

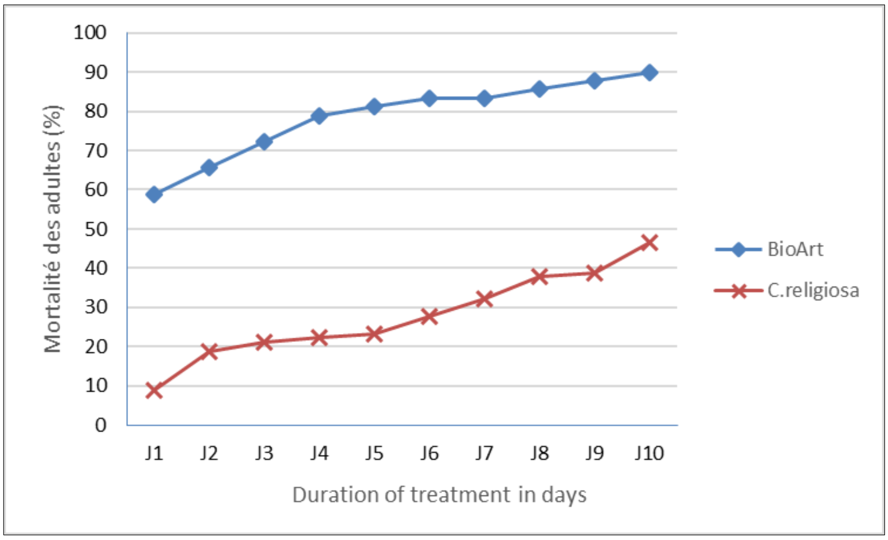


Figure 2 Comparison of adult mortality between the two solutions as a function of dose and duration of exposure

In this figure, we can generally see that, for an exposure period of 10 days, the BioArt product had a more marked adulticidal activity (90%) than that produced by *C. religiosa* (46.64%). We can also say that the highest mortality rates were obtained on the 1st day of treatment regardless of the test product, with 58.87% mortality with BioArt and 29.43% with *C. religiosa*.

3.2.3. Effect of aqueous extracts of C. religiosa and BioArt on the fecundity of treated females

The results obtained on the fecundity of *C. serratus* females treated with the BioArt product and *C. religiosa* extracts are presented in the following figures. For the same extract, the diagrams followed by the same alphabetical letter are not significantly different at $p \geq 0.05$.

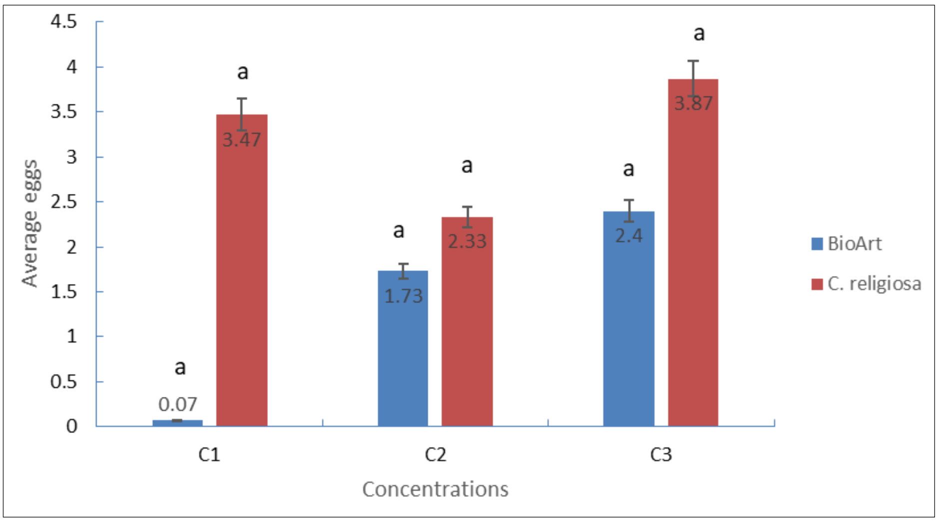


Figure 3 Comparison of the effect of BioArt and C. religiosa on the fecundity of treated females

The results of the graph generally indicate that the fecundity of females from *C. serratus* eggs treated with the two products did not vary according to concentration under the conditions of our work. However, in absolute terms, the BioArt product induced the greatest reduction in egg-laying in treated females, whatever the concentration applied.

3.2.4. Rescued adults

Adults previously treated with BioArt and *C. religiosa* and whose eggs have reached the adult stage are referred to as "rescued" adults. The study of reproductive parameters carried out on "rescued" populations of *C. serratus* focused on determining the sex ratio (Table 5).

Table 5 Comparison of the effects of BioArt and *C. religiosa* leaf extracts on the sex ratio of male and female offspring from treated adults

Solutions	Individus rescapés	Rescued individuals	Males	Females
BioArt	$0.55^a \pm 0.69$	$39.76^a \pm 52.07$	$60.24^a \pm 43.41$	$0.67^a \pm 0.19$
C. religiosa	$0.44^a \pm 0.51$	$50^a \pm 50.72$	$50^a \pm 38.49$	$1^a \pm 0.29$

The values are averages followed by the standard deviation. On a vertical line, values followed by the same superscript letter(s) are not significantly different (p less than 0.05).

In this table, the results obtained with the two products are generally significantly the same. However, when the data are compared in relative terms, there is a slight difference between the rate of male offspring produced by BioArt (39.76%) and those produced by *C. religiosa* (50%). This slight difference in offspring rate was also observed in females, with 60.24% produced by BioArt and 50% by *C. religiosa*.

The sex ratio varied from 1 (± 0.29) male to 1 female to 0.67 (± 0.19) male to 1 female. *C. religiosa* extracts produced the highest sex ratio (1± 0.29) and the BioArt product produced a sex ratio equal to 0.67± 0.19.

4. Discussion

The laboratory studies we carried out focused on the evolution of the ovicidal and adulticidal action of a product called BioArt and aqueous extracts of *C. religiosa* leaves on the most formidable peanut pest, *C. serratus*, under ambient conditions. The efficacy of the products varied according to their type and the dose applied.

Adulticidal activity showed mortality spread over time at all doses with the application of all solutions. Whatever the solution used, we noted that the effects induced increased 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 48 hours. *C. religiosa* proved less effective than BioArt, with mortality not exceeding 55% whatever the dose applied. Adult mortality induced by this plant ranged from 46.66% to 53.33%. The highest dose C1 proved more effective than the other two doses, whatever the solution applied. These results corroborate those of Thiaw [9] and Kébé [10] who both obtained 100% mortality on *C. serratus* adults with methanolic extracts of *Calotropis procera* and *Boscia senegalensis* respectively with a concentration of 0.1g/l within 24 hours of application. Faye [11] 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 *Callosobruchus maculatus* adults on day 10.

Evaluation of the fecundity of females treated with different doses of BioArt and *C. religiosa* showed a reduction in fecundity depending on the nature of the product and the dose applied. In absolute terms, BioArt induced the greatest reduction in egg-laying in treated females, irrespective of the concentration applied. The greatest reduction was obtained with the highest dose C1 (0.07 eggs). On the other hand, with *C. religiosa* extracts, the greatest reduction in fecundity was noted with dose C2, with an average fecundity of 2.33 eggs per female. These results are at odds with those of Thiaw *et al*. [12], who found that biocidal extracts of *Senna occidentalis* reduced the fecundity of females from treated eggs by percentages ranging from 27.29% (methanol extract) to 67.2% (ethyl acetate fraction) on the same insect. The work of Gueye [13] also showed a reduction in fecundity with *Lantana camara* extracts. This reduction could be explained by the short life span of the females due to the biocidal effect of the product. In fact, when it was 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 adults tested (the survivors) were only obtained with the low doses, in very low numbers. The high doses caused very high mortality from 24 hours after treatment, leaving the adults no time to mate. These results confirm those of Doumma *et al*. [14] who studied the action of ground *Boscia senegalensis* leaves on *C. maculatus*. They are also in agreement with those of Mazibur and Gerhard, [15] and Ketoh *et al*. [16]. With regard to the sex ratio, the comparative study between the different solutions shows that it is in favour of females for the BioArt product. With the *C. religiosa* extracts, we note an equal distribution of males and females. From these results, we can conclude that the predominance of females would increase the risk of populations increasing in stored seeds, hence the importance of damage in storage areas. The same trend was observed with Gningue *et al*. [17] and Thiaw [18], where the sex ratio was in favour of females with the respective application of *A. indica* and *C. procera* extracts on *C. serratus*.

An analysis of the ovicidal results shows that the BioArt product and *C. religiosa* extracts affect the viability of *C. serratus* eggs. They showed ovicidal efficacy of 42.51% and 40.74% respectively.

The larvicidal effect observed with the two products was almost the same (69.01% with BioArt, 69.29% with *C. religiosa*). This reveals the persistence of its biological activity during treatment, resulting in disruption or arrest of the insect's development at the larval stage.

With regard to pupal mortality, no significant difference was noted between the two products. However, in absolute terms, there was a slight difference between mortality induced by the BioArt product (32.41%) and that induced by *C. religiosa* (47.18%). These results corroborate those of Faye [11] who showed an ovicidal effect of 73.33% to 90% with fresh crushed leaves of *C. religiosa* and 33.3 to 45% with *S. occidentalis* leaves on *C. maculatus*. Gueye [13] showed low ovicidal activity with *Annona senegalensis* biocidal products; it was with the 0.01 g/ml concentration of the methanolic fraction that he obtained an activity of 33% and 23% with the 0.1g/ml concentration. Consequently, our results on the larvicidal effect are in disagreement with those of Thiaw *et al*. [12] who showed a larval mortality of 13.96 ± 4.85% with methanolic extracts of *S. occidentalis*, with the hexane and acetate fraction a mortality of 4.17 and 5.63 ± 2.52% respectively on *C. serratus*.

Under the conditions studied, our results show that the products affect the average duration of the different developmental stages of treated *C. serratus* eggs. Its action varied according to the solution. The laying/hatching times induced by the two solutions were significantly the same.

The BioArt product induced the shortest larval development time (37.63 days) while the *C. religiosa* extracts induced the longest larval development time (44.44 days). Ndiaye [19] 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 [20] reports that, under the usual conditions in Senegal, the egg hatches after about a week and the neonate larva perforates the pod, crosses the pericarp, pierces the tegument and penetrates the seed, which it consumes. He also points out that larval development lasts just over a month, after which the larva weaves a cocoon from which an adult emerges 15 days later. The same pupation period was observed by Robert [21] at 35°C. The work of Ndiaye [22] and Delobel & Tran [23] indicates that larvae develop between 40 and 58 days depending on temperature and relative humidity conditions. In his studies, Gueye [8] revealed a larval stage duration of around 45 days on average at 35°C. In contrast, our results showed pupal development of 25.78 ± 7.12 days with the BioArt product and 27.08 ± 3.54 days with *C. religiosa* extracts. These results confirm those of Thiaw [18], who showed pupal development times of 21.33 and 33.43 days with the extract and methanolic fraction of *Calatropis procera* and *Senna occidentalis* on the same insect. From oviposition to adult emergence, eggs treated with BioArt showed the shortest duration of 70.82 ± 3.35 days compared with 82 ± 2.64 days with *C. religiosa*. From oviposition to adult death, *C. religiosa* also showed the longest total lifespan of 100.06 ± 13.4 days compared with 74.53± 6.16 with BioArt. However, it should be noted that, in our studies, almost all the adults that emerged died shortly after emergence. This could be explained by the persistence of the biocidal action of the product, resulting in the immediate death of adults from treated eggs. As with most insects, the characteristics of larval development and the performance of adults depend mainly on temperature. Many authors have described a positive correlation between temperature and the speed of development or between temperature and performance in various insects [24, 25, 26]. In *C. serratus*, in particular, low temperatures (20°C) lead to an elongation in development time (183 days on average) [3].

Comparison of the average emergence of individuals from the first progeny from eggs treated with each of the two solutions showed no significant difference in the effect of the treatment on the size of the *C. serratus* population. The average emergence rate with the BioArt product was 11.11% ± 2.78. The same trend obtained with the BioArt product was observed with *C. religiosa*, with an average of 8.33 ± 5.56 survivors. These results do not confirm those of Thiaw [18], who showed higher emergence rates ranging from 30.55 to 52.78% with crude extracts and fractions of *C. procera* extracts.

Determination of the sex ratio shows that the proportions between male and female survivors from *C. serratus* eggs previously treated with the various BioArt biocidal products and from *C. religiosa* were modified depending on the solution used. This variation in the sex ratio could inevitably influence the reproductive activity of the offspring. Reducing the number of males would inevitably result in the release of unfertilised eggs due to the reduced copulation opportunities for these females. On the other hand, an increase in the number of males compared with females would favour the possibility of competition between males in the search for sexual partners. The effect of BioArt on the sex ratio favours females, which would increase the risk of population growth. The same trend was observed in the work of Gningue *et al*. [27], where the sex ratio was in favour of *C. serratus* females with the application of *A. indica* extracts. For *C. religiosa*, the sex ratio is also in favour of females. The opposite effect was observed in the work of Gningue *et al*. [17], where the sex ratio favoured males for doses C1 and C2, and females for dose C3 when *C. religiosa* extracts were applied to the same insect.

Numerous results show that by modifying the conditions of their development environment, certain insects and/or their parasites see the sex ratio of their offspring become unbalanced.

5. Conclusion

The aim of this study was to examine the efficacy of the BioArt product and *C. religiosa* extracts on the survival of *C. serratus* at the egg and adult stages.

The results show that these products have a biocidal effect on *C. serratus* eggs and adults that varies according to the solution used. The BioArt product induced high mortalities of *C. serratus* at the adult stage and considerable mortalities at the egg stage. The highest dose showed high adulticidal activity. The percentages of adult mortality induced by the BioArt product were significantly higher than those of *C. religiosa* extracts, whatever the concentration applied. It can also be noted that high doses acted more effectively than low doses, whatever the product applied.

Post-treatment monitoring to determine whether the treatment would have an impact on insect development times and the sex ratio of survivors showed an increase or decrease in development times and an imbalance in the sex ratio in favour of females.

Monitoring of adults treated with BioArt revealed a greater reduction in egg-laying by these females than those treated with *C. relgiosa*. As regards the sex ratio, the comparative study between the different solutions showed that the BioArt product favoured females, while with the *C. religiosa* extracts, there was an equal distribution of males and females.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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