Evaluation of botanical insecticides in controlling the population of fall armyworms (*Spodopterafrugiperda Smith*) present on corn crops (*Zea mays*) located in Santa Cruz, Guanacaste

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Abstract. Botanical insecticides manufactured under the name of spinetoram, Solaris 6 SC® (75 ml.ha-1) and Capsoil 9,82 EC® (*Capsicumm annum* + mustard (*Sinapis alba*) + garlic (*Allium sativum*) (2 l.ha-1) were evaluated by comparing them with two homemade extracts: garlic extract + neem (*Azadirachtaindica*) + detergent (20 ml.l-1 water) and garlic extract + oregano (*Origanumvulgare*) + juanilama (*Lippia alba*) + rosemary (*Rosmarinusofficinalis*) (20 ml.l-1 water); and a control with the objective to evaluate the effectiveness of non-chemical alternatives to treat the *Spodopterafrugiperda* in the corn crops of the test field in Santa Cruz, Guanacaste which is owned by the University of Costa Rica. Results show that the best insecticide to control the immature fall armyworm is Solaris 6 SC®, followed by the insecticide made of garlic extract, neem, and detergent. Also, the natural parasitism of the *S. frugiperda* on the area not treated with pesticides reached values of 60% where the *Chelonus* sp. was the parasitoid that was present at all times. The performance of the areas treated with pesticides range from 153 and 180 quintals of fresh corn by hectare where the insecticide made of garlic extract, neem, and detergent (20 ml.l-1 water) reflected the higher production. The areas treated with Solaris 6 SC® had the less quantity of corn damaged by *S. frugiperda* and *Helicoverpazea* while the area treated with garlic extract + oregano + juanilama + rosemary had the greatest loss during this evaluation. Thus, the insecticide made of garlic extract, neem, and detergent is recommended because of its high capacity to kill S. frugiperda and other pests that affect the corncob, its higher performance it is more cost efficient for small farmers.

1. Introduction

Corn has long been a staple agricultural crop across the Americas thanks to its many beneficial uses. This grain has been established as the third most widely grown product in the world after wheat and rice [1]. The countries that have the highest production of corn are The United States, The People's Republic of China, and Brazil; those three countries hold 73% of the annual world production [2].

Corn, as well as many other crops, has a direct relationship with its natural predators that raise their population densities, when favorable environments are found, to the point they become pests of high agricultural importance [3]. Corn plants can be attacked by many different insects, which can damage their structures and directly interfere on the yield and quality of the grain, if they are not well controlled.

The fall armyworm, *Spodopterafrugiperda* Smith (Lepidoptera: Noctuidae) is a pest with polyphagous habits that cause economicloss in many crops such as corn, sorghum, rice, and other grasses [4]. Despite being an insect that can reproduce in almost all grasses, it has an affinity for corn crops where it is considered the most frequent pest due to the adapt ability this insect presents in a variety of climate conditions where corn is grown [5].

Most of the treatments that are used to control the fall armyworm are chemical products that can affect people's health and the environment [6]. Additionally, the constant use of chemicals causes a reduction of natural enemies in the field which in turn generates an imbalance in the agricultural ecosystem as well as the emergence of pest populations resistant to the applied pesticides [7].It is estimated the chemical pest control methods currently used in corn production account for 10% to 12% of the production direct costs [6]. Of these, 6% comes from the chemical control of *S. frugiperda*[8]. For this reason, pest control is considered one of the most expensive components of corn production in the area and in the world.In order to improve corn production systems, an initiative using natural pesticides to control *S. frugiperda* arose, to provide more alternatives in pest control for small and organic farmers.

2. Materials and Methods

The research was carried out at the Test Field of the University of Costa Rica in Santa Cruz, Guanacaste, 10° 15'06" North latitude and 85° 41'07" West longitude. This canton is part of a dry tropical forest with an altitude of 54 m.a.s.l., annual rainfall of 1 834 mm, an average annual temperature of 27.9 °C and a relative humidity of 75%.

2.1. Experimental Material

White corn seed (Hybrid HS5G) from Monsanto was used. This hybrid is tolerant to drought and also to late lodging when it is not broken. Additionally, this corn has a reputation as a hardy variety that provides good quality of grains for the industry.

Table 1 shows the treatments used to controlS. *frugiperda* in corn, as well as the composition, and the application doses.

Table 1. Description of the botanical pesticides used to controlS. *frugiperda* in a corn plantation located in Santa Cruz, Guanacaste.

Treatment	Treatment's Description	Trade name	Doses
T1	Control treatment	Not applicable	Water
T2*	garlic extract + neem + detergent	Not applicable	20 $ml.l^{-1}$ water
T3*	garlic extract + oregano + juanilama + rosemary	Not applicable	20 $ml.l^{-1}$ water
T4	Hot chili extract + mustard + garlic	Capsoil 9.82EC®	2 $l.ha^{-1}$
T5	spinetoram	Solaris 6SC®	75 $ml.ha^{-1}$

*T2 and T3 were artisanal formulations, while T4 and T5 were commercial formulations.

2.2. Extracts' Formulations

In the formulation of each extract equal parts (meaning weights) of each component were used: oregano (*Origanumvulgare*), rosemary (*Rosmarinusofficinalis*), juanilama (*Lippiaalba*), neem (*Azadirachtaindica*), garlic (*Allium sativum*) (weight of the cloves in relation to the foliage), and detergent (1/8 of grated blue soap bar). The materials were deposited in a 4 gallon plastic bucket and molasses was added in a 1:1 proportion. Once the solids and the liquid were mixed, the bucket was closed with a double water bag (with cover function that prevents the contact of the mixture with the spores of the environment) for 15 days. After that, the water seal was removed, and each of the extracts were filtered.The newly formulated pesticides were packed in dark plastic bottles, labeled, and stored in the refrigerator at 5°C.

2.3. Experimental Design

Fifty plots of 28 m^2 (3.5 m x 8 m) each were established, consisting of 5 grooves with 3 m spacing between them. A discretionary random design was used. The design consisted of 5 treatments and 10 repetitions. Two seeds per hole were planted with a distance between rows of 0.7 m and 0.2 m between plants, for a density of 71 428 plants per ha^{-1}. The three central furrows were considered useful for the experiment while the furrows located in the edge were considered useless as well as the plants that were at the beginning and at the end of the furrow.

2.4. Data Collection

Initial and subsequent samplings were carried out to determine thedamage level of *S. frugiperda* as well as the effect of the treatments on the pest. Fifteen plants per plot were gathered and the affected leaf area was evaluated using the Peralta visual scale (2014) in which only the damage of the bud and the first fully expanded leaf of each plant were considered.Weekly samplings were carried out in all the plots in order to determine the incidence and development of the pest. In each sampling, 15 plants were randomly selected and the presence of larvae *S. frugiperda*and larval instar were quantified. In addition, the presence of predators and natural enemies of the fall armyworm was recorded.
Two treatment applications directed at the foliagewere carried out with a backpack sprayer having a 16 lt capacity and a hollow-cone nozzle. The pesticides' applications were carried out in two periods. The first one, 15 days after the emergence (DAE) and the second one when the 60% of the plants were in bloom.After each application, the number of live and dead larvae of *S. frugiperda* was quantified. The live larvae were collected in the field and brought to the entomology laboratory for individual breeding. The breeding process was carried out in plastic glasses of 120 ml with a cheese cloth cover to allow for good airing. The feed of the larvae was based on corn leaves that were changed every day until the larvae had completed their life cycle or until the parasitoid emergence.
The two times the larvae were raised in laboratories, the percentage of natural parasitism was determined by using the following equation:

$$\%\ \text{of Parasitism:}\ \left(\frac{\text{Parasitaized Larvae}}{\text{Total Larvae}}\right)*100$$

Total larvae are defined as the sum of immature *S. frugiperda* collected in each of the treatments. On the other hand, the parasitized larvae were quantified by the pupae of the parasitoids regardless of whether the adult emerged or not.
With the aim of evaluating the damage of the fall armyworm in the corncob ears, in each experimental unit, 10 corncobs without husks were harvested and separated into two categories: healthy corncobs and corncobs damaged by the fall armyworm or any other pest. In this case, for both categories, fresh corncobs were weighed. The yield in $kg.ha^{-1}$ was quantified by means of the total number of corncobs per plot and 10 fresh healthy corncobs per plot were harvested and weighed. In other words, the fresh weight of 50 healthy corncobs per treatment was quantified in order to extrapolate yield to one hectare of crop.

3. Data Analysis

Data was analyzed by a Kruskal Wallis non-parametric test ($p < 0.05$) and a non-parametric multiple range test with the objective of determining statistical differences between the mean with a program called InfoStat [9].

4. Results and Discussion

4.1. First Application

The intensity of the damage of *S. frugiperda*before the application of treatments was non-significant ($p < 0.8822$) for all plots. Subsequent to the application, Solaris® significantly ($p < 0.0001$) reduced the damage of *S. frugiperda* in comparison to the control (Figure 1) with a reduction in plant damage from 32% to 1.3%. [10] found out that using a dose of 0.10 l ha^{-1} of spinetoram reduced the infestation of the fall armyworm in the corn plots by 6%. For the *S. frugiperda*damage level to the crops receiving the remaining treatments, no significant differences were found between them, but the three of them significantly differed from the control by decreasing*S. frugiperda* damage by 50% when compared to the control.

4.2. Second Application

The damage level increased as a result of five weeks in which there were no applications of any kind after the first application of pesticides. There were no significant differences ($p < 0.0537$) between treatments due to the fact that the residual effect of the botanical pesticides was relatively short and the time period between applications was long. That allowed the new establishment of the pest in the plots.

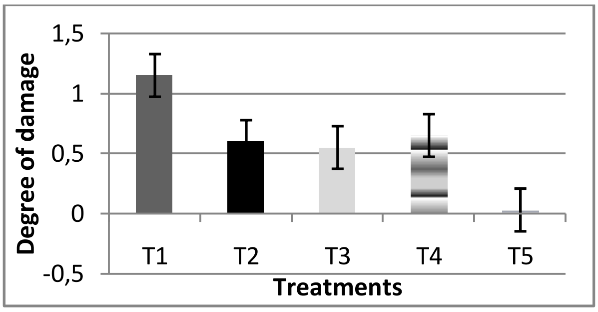

Figure 1. Damage level after treating the areas to kill*S. frugiperda* in corn plantations, Santa Cruz, Guanacaste.

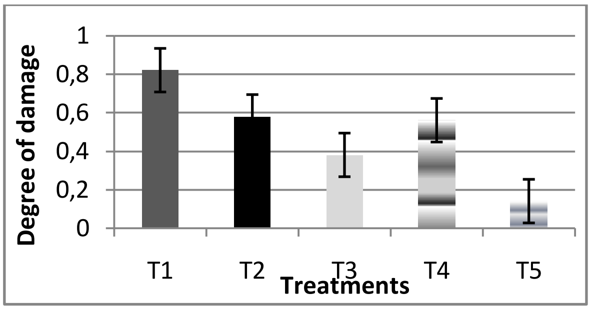

Figure 2. Damage level after II treatmentapplication to kill*S. frugiperda* in corn plantations, Santa Cruz,Guanacaste.

Explanation:
Different letters show significant differences according to the Krusal Wallis Test ($p < 0.05$).
T1 =control;
T2 = garlic+neem+detergent;
T3 =garlic+ oreganum+juanilama+romerum;
T4 =Capsoil®;
T5 =Solaris®

The pattern of damage shown in Figure 1can be explained by the residual activity of the pesticide because there is a direct relationship between the persistence of the product in the field and the action it has on the pest. In the case of applying spinetoram, Its effect lasts for two weeks, which is reflected in a lower presence of *S.frugiperda*[11]. This is followed by the application of Capsoil® which lasts in the environment for about 10 days, and lastly, the protection of the pesticide made out of neem can last from 5 to 7 days. However, that period of time can be shortened because ofclimate conditions like high humidity or ultraviolet rays, which can decompose the pesticide's active ingredient in the 14hoursfollowing its application [12].

The second application showed significant differences ($P < 0.0001$) between the spinetoram, the control, and the other pesticides (Figure 2) which reinforces the results from the first application. So, this proves that the pesticide can be used during all the instars of the development of the crops with similar results. However, the best pest management was obtained when the larvae was found in its first instar, before it went into the bud of the plant, because once the insect is inside, the pesticide doesn't have direct contact with it, which most probably reduces the effect of the pesticide.

Just as in the first application, the T2, T3, and T4 treatments did not show significant differences in the averages.Even so, a positive effect on reducing the damage level was found when compared to the control. Between these two, there were significant differences in the averages which lead one to infer that their use in the field is a feasible measure to fight*S.frugiperda*.

4.3. *S.frugiperda* and its natural enemies on the field

Figure 3 shows larvae behaviour of *S. frugiperda* in the corn plots treated with botanical pesticides. There are two noticeable drops in the numbers of the pest (sampling 2 and 8) that coincide with the treatment application date. This proves that natural pesticides used in this research do affect, in one way or another, the larvae's life cycle because they reduced the quantity of larvae on the crops both times they were used. In the beginning, applications had a similar effect on fall armyworms where the time to restore the insect population was what changed. Taking this into account, big differences among the T1, T2, T4 and T3 behaviour can be seen. These follow a pattern similar to the first application ones, which proves the significance among these pesticides. Moreover, Solaris® showed a separation between the lines under all the other treatments and it lasts even for 3 consecutive samplings, which equals three weeks. From the fifth sampling on, *S.frugiperda* populations were similar in all treatments, even for T1, which reduced populations notoriously maybe because of the rains.

Seven natural enemies of *S. frugiperda* were found: predators like *Zelus*spp. (Hemiptera:Reduviidae), *Podisus*spp. (Hemiptera:Pentatomidae),*Hippodamiaconvergens*Guérin-Méneville and*Coccinellasanguinea* L. (Coleoptera: Coccinellidae); and parasitoids like *Sarcophaga*sp. (Diptera: Sarcophagidae), *Chelonus*spp. (Hymenoptera: Braconidae), *Archytasmarmoratus*(Townsend)(Diptera: Tachinidae). These were efficient enough to control immature fall armyworms by parasitism and predation.

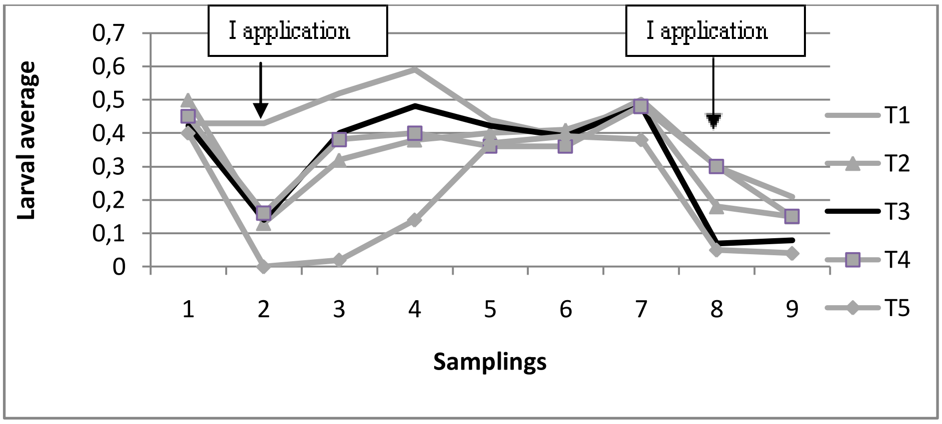

Figure 3.*S. frugiperda's p*opulation dynamics during the life cycle of corn plantations,Santa Cruz, Guanacaste.

4.4. Natural Parasitism

Natural parasitism of T1 reached 60% and showed that natural treatments could be an advantage in fighting *S.frugiperda* if a fighting methodology is designed based on botanical pesticides that will not kill natural enemies. Other treatments did not show a negative effect on natural parasitism.

Even though there are many other biological enemies of the fall armyworm, *Chelonus*spp. was the only one found in important numbers. *Chelonus*spp. is a parasitoid with a high reproductive rate, which parasitizes the *S.frugiperda's* eggs and continues to develop inside its host until the IV larval instar, where it kills its host to be able to complete its life cycle [13]. Being an endoparasite could explain the increase of natural parasitism in the II sampling in relation with the I one, because in the II sampling the quantity and number of larvae instars of the fall armyworm favour the gathering of a higher number of parasitized larvae.This increase possibly happens due to the growth of weeds in the lots since the pollen and nectar are important factors in feeding and also in the life cycle of the target adults [14].

4.5. Yield

All treatments showed a high yield, in the range of 153qq to 180 qq ("quintal": 100 lbs) of fresh corncobs by hectare, which is similar to the one obtained at a national level (MAG 2010). T2 showed a higher yield by hectare, with significant differences with T4 ($p < 0.0177$) while the other treatments did not differ significantly among themselves ($p < 0.1853$).

4.6. Economic Analysis of Yield

Lower economic losses were obtained by applying T5. The loss using this treatment was ₡86 570.13, being an acceptable loss margin for farmers because even though the loss is somewhat high, it still allowed them to make a profit of ₡ 664 846.9 for selling healthy corncobs. The application cost was lowest for T2 (₡ 11571), followed by T3 (₡19 943), T5 (₡20 201) and T4 (₡37 949)(Table 2).

Table 2. Economic analysis of yield while applying four botanical pesticides to kill *S. frugiperda*, Santa Cruz, Guanacaste.

Treatment	Total Yield (corncobs)	High Quality Corncobs	Rejected Corncobs	Expected Profits (₡)	Loss (₡)	Actual Profit (₡)
T3	7314.2	4411.4	2902.8	731 418.0	290 281.4	441 136.6
T1	7555.4	4844.4	2711.1	755 544.0	271 107.0	484 437.0
T4	7057.0	5034.2	2022.8	705 704.0	202 282.7	503 421.3
T5	7514.2	6648.5	865.7	751 417.0	86 570.1	664 846.9
T2	8285.6	6631.6	1653.9	828 559.0	165 394.3	663 164.7

5. Conclusion

Applying the pesticide Solaris 6 SC® with a dose of 0.075 $l.ha^{-1}$showed the best results in killing fall armyworm in corn plantations.Corn plots treated with garlic + neem + detergent showed the highest yield in this research. In turn, this treatment showed a proper result in killing the pest during the vegetative and production phase since it reduced the loss of fresh corncobs to quantities close to the ones obtained with the best pesticide (Solaris 6 SC®.) Nevertheless, it is recommended to increase the application frequency so that the corncob loss is minimized. Capsoil 9.82 EC® provides an intermediate pest control but it is an expensive option to recommend for farmers.Garlic extract + oregano + juanilama + rosemary treatment showed the highest loss of all treatments, including the control treatment. This treatment does not provide any benefit to the farmers at this application rate; that is why it is recommended to reduce the time period between applications to compensate for its relatively short residual activity in the field.Natural parasitism by*Chelonus* spp. reached values of 60%, for this reason, the conservation of natural enemies plays an important role in killing *S. frugiperda*.

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