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EFFICIENCY AND COST OF BIOLOGICAL CONTROL OF *Strymon megarus* (GODART) (LEPIDOPTERA: LYCAENIDAE) WITH TRICHOGRAMMATIDAE PARASITOIDS (HYMENOPTERA)

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Abstract: The fruit borer, *Strymon megarus* (Godart) (Lepidoptera: Lycaenidae) is an important pest in pineapple crops and is mainly controlled by pesticides. The objective of this study was to compare the efficiency of biological control in relation to chemical control of fruit borer, and to investigate their economic aspects. The experiments consisted of two treatments: the release of parasitoids from the family Trichogrammatidae and the spraying of chemicals from the group of pyrethroids and organophosphates, both of which were carried out in areas where flowering occurred naturally and in areas of artificial floral induction. Thus, the work was carried out in a 2x2 factorial scheme with two control methods and two types of crop flowering, in addition, the study was performed in two seasons. In the first, two parasitoid species *Trichogramma pretiosum* Riley and *Trichogrammatoidea annulata* De Santis (Hymenoptera: Trichogrammatidae) were released in the amount of 200,000 /ha, 50% of this value referring to each species. In the second crop season, 400,000 parasitoids of a single species, *T. pretiosum*, were released per hectare. Both treatments were applied to areas with artificially induced flowering and in areas of natural flowering. In the first crop season, the biological and chemical controls showed the same efficiency in areas with the same type of induction. In the second crop season, the biological control was less efficient than the chemical one in artificial floral induction areas, but it showed the same efficiency in natural induction areas. The costs of biological control in the first crop season were lower than in the chemical control, however, in the second crop season, the cost of both was similar due to the increased dose of parasitoid release. The biological control share similarity in relation to the efficiency to the chemical.

Keywords: Ananas comosus, Trichogramma, organic production, integrated pest management, sustainability.

INTRODUCTION

Pineapple is an important crop worldwide and according with FAO (2020), have been the second mos-important fresh tropical fruits in relation to export. In Brazil, fruit production occurs in almost all the national territory and between the last few years it has reached almost 12 billion fruits produced (IBGE, 2019). The fruit is greatly appreciated due to its organoleptic characteristics such as its remarkable odor and taste. Moreover, from the fruit, it is possible to produce processed products such as sweets and other foods (CRESTANI et al., 2010). The occurrence of pests made it difficult to expand its cultivation, and one of the most important pests is the fruit borer, *Strymon megarus* (Godart) (Lepidoptera: Lycaenidae) (SANCHES, 2013).

Fruit borer, *S. megarus*, it is a butterfly that when in adult phase, the female lays eggs in places near the inflorescence of the plant, so when hatching from the egg, the caterpillar initially feeds on external parts of the flowers, through which it manages to pierce and enter into the fruit. When inside the fruit, the caterpillar feeds on plant tissues where it grows until it becomes pupae, a phase that occurs in the soil. The feeding on the forming tissues allows the caterpillar to build galleries in the fruit, which is the main damage associated with this pest, because a fruit attacked by only one caterpillar can be completely injured and lose its commercial value. Moreover, it is estimated that under strong attack, the producer may lose up to 80% of production (MATOS, 1999). The attacked fruits have a twisted aspect and may contain a type of resin in the holes that is the result of the feeding (MATOS, 1999; SANCHES, 1999; NORONHA et al., 2016).

This pest is efficiently managed by chemical control, however, the number of required sprays varies with the number of weeks the plant takes from the opening of the first flower to the closing of the last (NORONHA et al., 2016). That is, the average number of sprays that were performed is high when considering the sustainability of the agro-ecosystem and ranges from 6 to 15 sprays depending on pest infestation, in addition, currently there is only one registered product for the pest (Imunit® - alpha-cypermethrin + teflubenzuron) which makes it difficult for the producer, who ends up using unregistered products (MAPA, 2020). For these reasons, it is important that other tools be used in the management of this pest, such as biological control, that has potential in pest management in fruit crops (WANG et al., 2019). The use of different tactics in pest management is a practice advocated by Integrated Pest Management (IPM), this model propose the integration of several control tactics, instead of being based on control through the exclusive use of insecticides (KOGAN, 1998; BURNIER, 2003). In addition, pest control through the use of MIP strategies favors the conservation of natural enemies that are responsible for the natural death of pests, because through this strategy the environment is manipulated in several ways, in addition to taking care with the use of selective insecticides to the beneficial fauna of the systems (GALVAN; KOCH; HUTCHISON, 2006).

Examples of natural enemies used in applied biological control programs are egg parasitoids of the family Trichogrammatidae (Hymenoptera). These small insects are responsible for the control of Lepidoptera around the world (PARRA e ZUCCHI, 2004; WANG et al., 2014; KARIMOUNEA et al., 2018). Embryonic development occurs within the eggs of the pest, where the parasitoid feeds on the host embryo until it is completely destroyed (PINTO, 1997), so the host species does not hatch, which explains its success in controlling the pests. Another factor that is linked to the success of the use of these parasitoids is the relative ease of rearing in large quantities under laboratory conditions through the use of alternative hosts (PARRA, 2010). In addition, many species belonging to the family have the potential to be used in pest control on fruit crops (NAVA et al., 2007).

The use of several parasitoid species have the potential to contribute to the efficiency control of fruit pests due to the biological characteristics of the parasitoids (WANG et al., 2019), and also due to the fact that minor crops do not have products registered in the Ministry of Agriculture, Livestock and Supply (Ministério da Agricultura, Pecuária e Abastecimento —MAPA) for pest control (NAVA et al., 2007), for example, as previously mentioned, there is only one product registered for S. megarus, and this is a mixture of molecules from the chemical groups of the pyrethroids and benzoylurea, whose first group is considered a broad spectrum molecule, that is, it reaches not only pests but also natural enemies, that is, they are not selective. This fact is aggravating in view of the fact that some producers abandon the crops due to the problems that appear during the harvest (WYCKHUYS et al., 2013), or even fail to commercialize the products due to inconsistencies in the limits of residues allowed in the products, which is not a problem when biological control is used, as this control method leaves no residue and is not harmful to the health of the environment and man.

In addition, another factor that could contribute to biological control in pineapple culture is related to flowering induction. Floral induction is a physiological process that takes place in pineapple and stimulates emission of the inflorescence. This induction may occur naturally according to climate conditions favorable to the plant, or it may be artificially induced with the use of specific products (SANCHES, 2013). Producers carry out this process to anticipate part of the harvest at a time of favorable trade. However, part of the plants do not receive this induction treatment. The plants in these areas do not flower uniformly, and serve as a focus for maintaining the pest in the field. For that reason, biological control would be of great value to producers since the natural enemy finds the pest in the field, so it is important to know the plague the culture and in a sustainable way to know how to position different tactics in each situation (HAN-MING et al., 2019).

Thus, the objective was to evaluate the efficiency of controlling *S. megarus* with the release of Trichogrammatidae parasitoids in field conditions, compared to the control with insecticides used in the pineapple crop, in addition to evaluating the cost of pest management to provide information and subsidies to farmers.

MATERIALS AND METHODS

EXPERIMENTAL AREA AND TYPES OF FLORAL INDUCTION

The trials were carried out in two consecutive crop seasons (2016/2017) on commercial farm using pineapple cv. Smooth Cayenne with thirteen months of planting, in double lines and 1,0 x 0,5 x 0,3 m spacing between plants. The biological control was used in areas of natural floral induction and in areas of artificial floral induction, and the same occurred with chemical control, applied in both types of area in order to compose an experiment in factorial.

The farm was located in the municipality of Bauru, State of São Paulo, Brazil (22°20'30.2" S, 49°12'43.0"), and the experimental areas of each treatment, biological and chemical control in induced and natural flowering plant areas, were one hectare in size. The entire experimental area was naturally infested with *S. megarus*. Both biological and chemical control were performed in the early hours of the day due to milder temperatures.

In order to evaluate the influence of floral induction types on both controls executed for *S. megarus* (biological and chemical), treatments in all harvests were carried out in natural and artificial induction areas. The experimental design adopted in the study was a randomized block design (RBD) composed of five repetitions represented by areas of 400 square meters, in a factorial scheme (2 control methods of *S. megarus* X 2 types of floral induction).

STRYMON MEGARUS CONTROL

Biological and chemical treatments were used to controls *S. megarus* in both crop seasons. Biological control was carried out through the inundative release of Trichogrammatidae parasitoids (PINTO et al, 2003). In the 2016 crop, *Trichogramma pretiosum* Riley and *Trichogrammatoidea annulata* De Santis (Hymenoptera: Trichogrammatidae) parasitoids were released in the field in the amount of 200,000/hectare by release, at the proportion of 50% of each species. The biological control in the second crop season (2017) was performed with the release of *T. pretiosum*, using the in the amount of 400,000 /hectare. The parasitoids were released in cardboard cells deposited in the specific plant inflorescences (Figure 1). The points selected for release were zigzagged and were chosen according to the 10-m range of action of the parasitoids (BUENO et al., 2009). The parasitoids used during the study were produced and supplied by the company BUG Agentes Biológicos.

The chemical control was performed using the conventional one used by the farmer in both crops, consisting of

Figure 1: Cardboard cell with parasitoids deposited in inflorescences.

products with active ingredients such as cypermethrin, deltamethrin, belonging to the group of pyrethroids, and also chlorpyrifos and dimethoate from the group of organophosphates (Table 2).

FIST SEASON

Six releases of parasitoids were performed in the first crop season in the artificial floral induction areas, and seven releases in the natural floral induction areas. The releases were made weekly, that is, every seven days, and the amount of releases made in each area corresponds to the time in weeks that the plants take from opening the first flower to closing the last as the attack of the pest occurs through this structure.

SECOND SEASON

The biological control strategy of the second crop season was carried out through six releases in the artificial floral induction area and nine releases in the natural floral induction area. The frequency of release was the same as that adopted in the first year, and occurred weekly.

EVALUATION OF THE TREATMENTS

The effect of the treatments in both crop seasons was evaluated in two occasions. The first evaluation followed the sampling indicated by Matos et al. (2006), and occurred at ten points per plot, where each treatment had five plots. Each point corresponded to a planting line and consisted of twenty plants randomly chosen by walking in zigzag. Each plant was evaluated for the presence/absence of pest attack symptoms, and the evaluation occurred prior to fruit bagging and at a time when the fruits were sufficiently developed for late symptom evaluation.

The second evaluation was performed at harvest, so it was possible to obtain the total number of fruits per area and percentage of fruits attacked by the pest. Both evaluations were performed to validate the sampling method used in the study. All data obtained in the experiments in both crop seasons were submitted to normality tests and analysis of variance (ANOVA) using SISVAR 5.6 software, and the means compared by the test of Tukey at 5% of significance.

ECONOMIC EVALUATION

Cost surveys were performed in both years of the experiment on all treatments. The surveys include cost spent in material, biological and chemical control and equipment.

RESULTS AND DISCUSSION

FIRST SEASON

The type of floral induction (artificial or natural) interfered among the areas within the same control (Figure 2). Biological control was most effective in areas where fruits were artificially induced in relation to areas where fruits underwent natural floral differentiation. When not artificially induced, plants flourish with less uniformity when compared to those induced with the ethylene-based phyto regulator, thus, these areas have fruits with no open flowering until the fruits with all flowers closed, that is, there is a difference in the floral phenology of these plants. For this reason, in the 2016 crop, it was necessary to add a release in these areas, considering that when the experiment was set, the number of releases was the same for all treatments.

This result was also observed in the conventional chemical control used by the farmer (Figure 2). In addition, the chemical control was more effective in artificial induction areas in relation to areas of natural induction. Again, the pattern of non-uniformity in flowering of naturally induced areas was observed, and similar to the biological control, the number of sprays performed by the farmer increased in these areas so that all plants could be covered in order to avoid infestation.

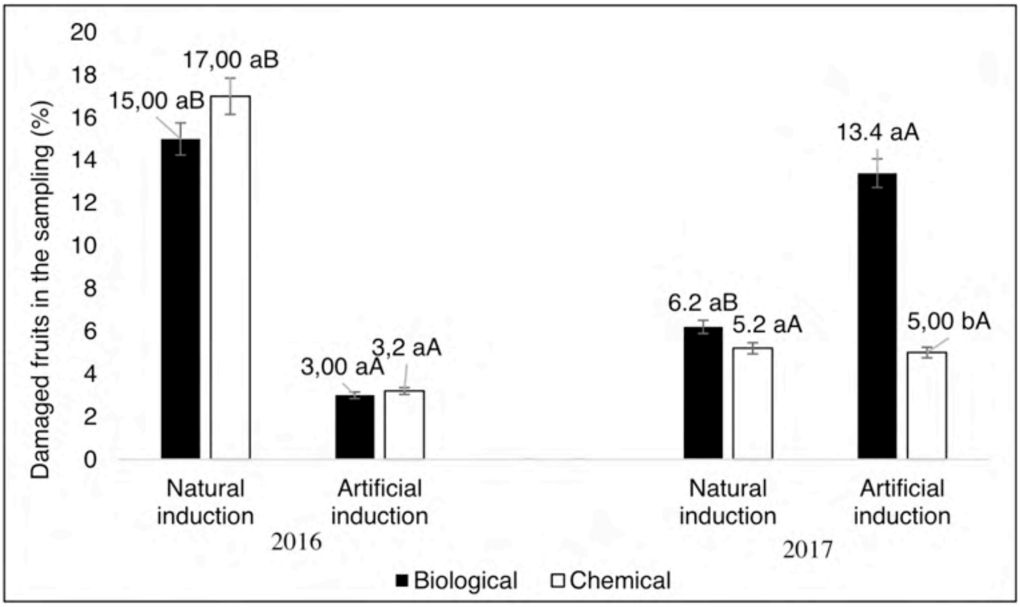

Figure 2: Efficiency of the treatments in the experimental areas in 2016 and 2017. Statistical explanation (subtitle): Means followed by the same letter, lower case in the treatment (biological and chemical) and upper case between areas (natural and artificial), do not differ statistically from each other by the Tukey test (P> 0.05).

Despite the difference in the effectiveness of biological control between natural and artificial areas, the control method did not differ from the chemical control when compared within areas with the same type of induction (Figure 2).

SECOND SEASON

According to the results obtained in the first year of the experiment, it was possible to change the methodology to investigate more precisely the efficiency of *S. megarus* biological control. One change was the use of only one species, *T. pretiosum* besides the increase in the release rate from 200,000/hectare in 2016 to 400,000/hectare in 2017. In addition, because of the non-standardized flowering in natural floral induction areas, it was necessary to increase the number of releases to nine, while in the area of artificial floral induction, the number of releases made was six.

It could be stated from the sampling that both biological and chemical controls were effective in areas with natural floral induction (Figure 2). Regarding control methods within artificial floral induction areas, chemical control was more effective than biological control, thus the results obtained in the second year of the experiment did not follow the same pattern found in the first crop.

In the 2017 crop, unlike the previous crop, no difference was found between the areas of the two types of floral induction for chemical pest control, that is, this control method was equally efficient in both natural and artificial induction areas (Figure 2). However, that fact is not true for biological control, which was less effective in artificially induced areas than in naturally induced areas. To explain what happened, the climatic data of the seasons in both years was provided (Figure 4). However, the climate in the period did not show significant differences that could explain what happened, for this reason, a hypothesis is that the difference found in the areas treated with biological control can be explained due to the pressure of the attack of the pest being different in both areas.

SAMPLING VALIDATION

Besides sampling, evaluation of total fruits at harvest was carried out to confirm the results obtained in the treatments. The results found in the second evaluation confirm those obtained through sampling and validate the methodology used for this study in both harvests (Figure 3). Similarly, the difference found in 2016 was in relation to the effectiveness of the same type of control for *S. megarus* between areas with distinct floral induction type, that is, both biological and chemical control were more effective in floral induction areas than in the natural floral induction ones (Figure 3). Within the same type of floral induction, both pest control methods were equally effective, results similar to those found by sampling (Figure 2 and 3).

Regarding the second harvest, the results obtained through the evaluation of total fruits at harvest were the same as those found in the sampling, which shows that the sampling method is reliable and faithful to the total results. The highest percentage of damage was found in the artificial induction area treated with biological control. On the other hand, the same area treated with chemical control showed only 1.92% of damage (Figure 3). In natural induction areas, both controls were equally effective, however, similar to the data found in the sampling, biological control was more effective in natural induction areas than in the artificial induction ones.

As observed in the results o btained in the experiments, the difference between the treatments was caused by the lack of uniformity in the flowering of plants in areas where the floral induction occurred naturally. As flowering period was standardized in

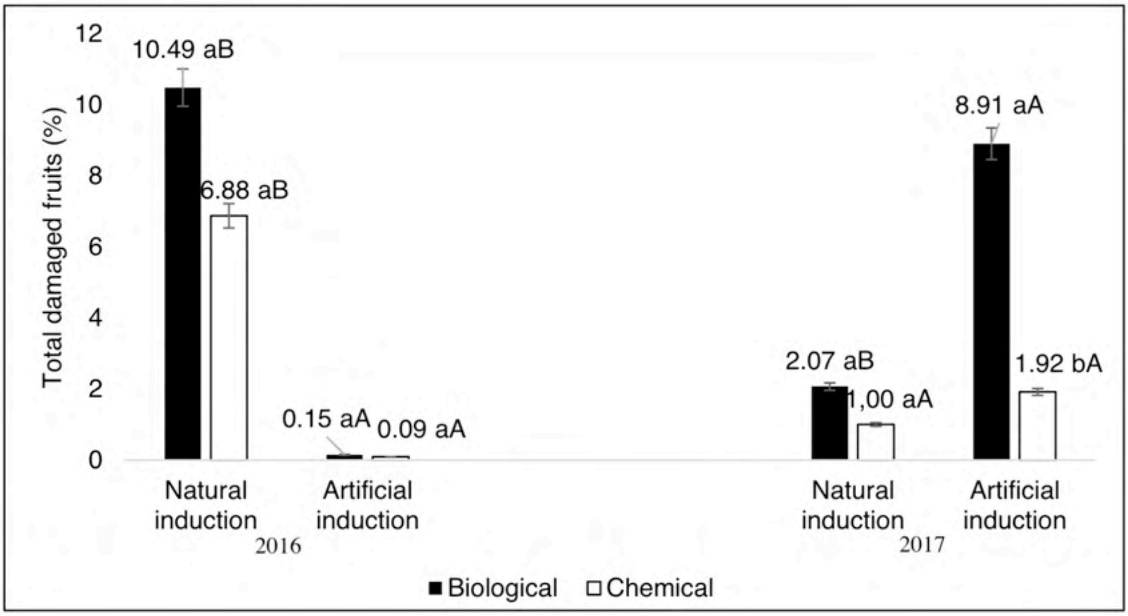

Figure 3: Treatment efficiency in 2016 and 2017. Total fruit analysis at harvest. Statistical explanation (subtitle): Means followed by the same letter, lower case in the treatment (biological and chemical) and upper case between areas (natural and artificial), do not differ statistically from each other by the Tukey test (P> 0.05).

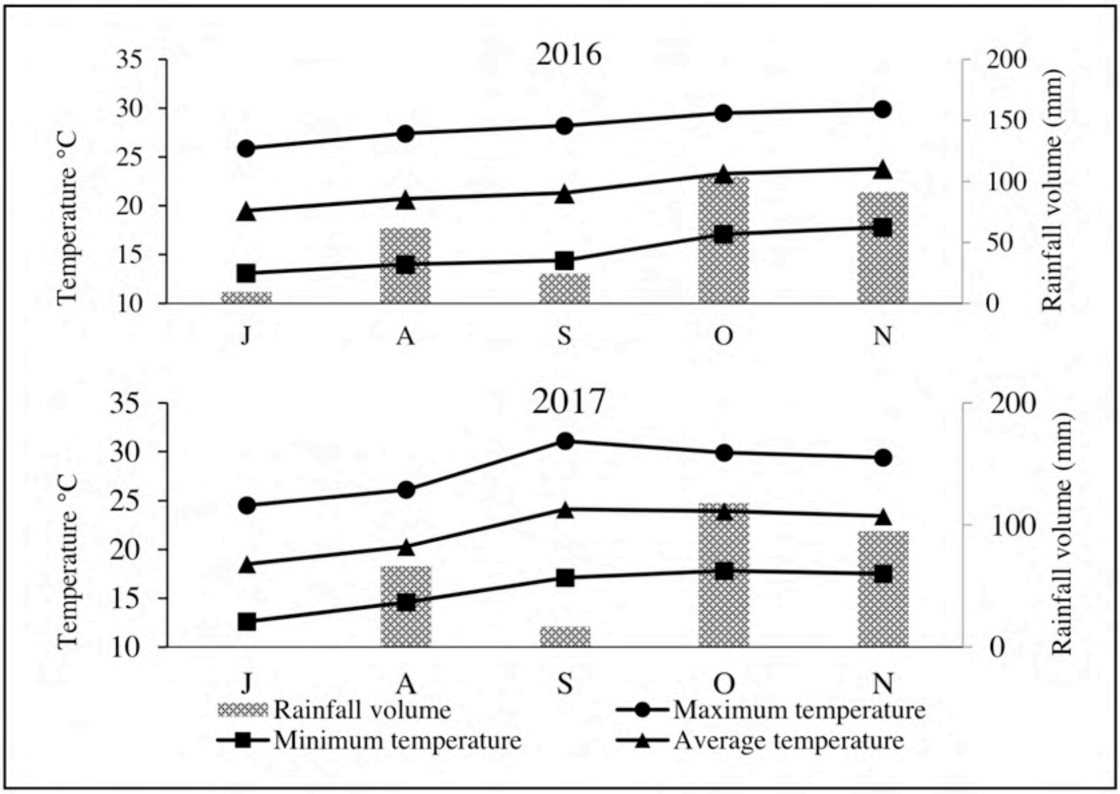

Figure 4: Climatic data of the months where the treatments were applied in 2016 and 2016.

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one area, the critical period for the plant in relation to pest attack decreases, that is, the time the caterpillar is able to penetrate the fruit through the flowers decreases and consequently the time required for the flowering may be reduced, similar to what had happened in the results found in the experiment since in the area where standardization occurred, six releases were required while in non-standardized areas, the number of sprays increased to seven. For this reason, when referring to biological control for the pest under study, several factors must be taken into account regarding the number and even the quantity of releases.

The distinct results found in the 2017 crop resulted from changes in the methodology. The biological control was more effective in areas of natural floral induction in that year due to the expressive increase from seven to nine releases. The increment in the releases provided sufficient time to protect plants against pest attack, even in an area where there is no flowering standardization. Therefore, investigating the optimal number of releases for each case is essential.

Another important change that occurred between crop seasons and may have influenced the results was the use of only one of the parasitoid species in 2017. It is known that each species has preferences and specificities over pest species, for example, *T. annulata* has high potential for use in fruit pest control, such as avocado (NAVA et al., 2007). In surveys conducted in Paraná, levels of up to 40% parasitism of *Stenoma catenifer* Walsingham (Lepidoptera: Elachistidae) by the species (HOHMANN et al., 2003) were reported. However, there are no studies reporting which of the two species would be more suitable for *S. megarus*. Therefore, only *T. pretiosum* was chosen to be used because this parasitoid is generalist and very aggressive with a large number of known pest-lepidopterans. In addition, because it is a well-known and widely used parasitoid, it can be more easily obtained by producers, as in addition to effectiveness, a biological control program must be affordable and cost-effective.

Besides the changes in the methodology, climate factors such as rainfall and temperature (BUENO et al., 2009) may influence the effectiveness of parasitoids. However, these variables were analyzed in the months when the experiments were being conducted in both years, and there were no sudden changes that could have affected the results achieved in the experiment.

Regardless of the results found in both harvests, it is possible to observe that biological control is as efficient as the chemical control for *S. megarus* control. The data contained in this study are novel since the parasitoid species have not been previously tested by other researchers for the pest under study. Nevertheless, these parasitoids were previously used in studies on fruit, such as the use of *T. pretiosum* to control *Grapholita molesta* (Busck), *Bonagota salubricola* (Meyrick) and *Adoxophyes orana* (Fischer von Rösslerstamm) (Lepidoptera: Tortricidae) in apple orchards (HASSAN et al., 1988; PASTORI et al., 2008). Similar to the control of *S. megarus*, biological control for pests in the crop season presented a potential of up to 70%, while the highest potential observed in the results of this work is 99%, a value found in artificially induced areas in the first year of experiment.

In addition to studies on apple trees, *T. pretiosum* showed viability in the control of citrus ferret, *Ecdytolopha aurantiana* (Lima) (Lepidoptera: Tortricidae) when tested under laboratory conditions, evaluating parasitism and viability in this host (MOLINA et al., 2005). Unfortunately, rearing *S. megarus* in laboratory for tests in controlled environment requires the development of study for mass rearing of the pest insect.

ECONOMIC ASPECTS

In relation to the economic aspects raised over this study, values related to inputs were investigated. The value of the treatments varied according to the crop season and the type of area where they were applied. The sum of areas with artificial (six releases) and natural (seven releases) floral induction totaled thirteen releases of parasitoids, *T. pretiosum* + *T. annulata* (200 thousand / ha), performed in the first year. The number of sprayings of phytosanitary products carried out in all areas was ten. When the costs of both treatments were compared in the first crop, it was observed that the value of biological control was less expensive in relation to chemical control (Table 1 and 2). Expenses with labor in the field, related to the release of the parasitoid and tractor driver for spraying were not considered in both values. Only the values of the products and machinery for application in the conventional case were regarded.

Because of the modification in the methodology, the value of biological control increased in the second crop. Fifteen releases of parasitoids, *T. pretiosum* (400 thousand/ ha) were carried out, six in artificially induced areas and nine in naturally induced areas. In the second year the total of eight sprays were performed on chemical control (Table 1 and 2).

CONCLUSION

It is concluded that the biological control and chemical control share similarities in the control of the fruit borer, however, for better results, the area of release, number of parasitoids and species to be released should be better investigated. In addition, the costs according to the methodology were lower or equal to the cost of conventional control.

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Crop/area	Product	No. of releases	Parasitoids /ha	Costs (USD)*
1 / artificial	*T. pretiosum*	6	100	26,90
	T. annulata	6	100	26,90
	Total			53,75
1 / natural	*T. pretiosum*	7	100	31,35
	T. annulata	7	100	31,35
	Total			62,70
	Total spent in the first crop season			116,40
2 / artificial	*T. pretiosum*	6	400	107,50
	Total			107,50
2 / natural	*T. pretiosum*	9	400	161,20
	Total			161,20
	Total spent in the second crop season			268,65

*Average commercial dollar value in the study periods = U$ 3.35.

Table 1: Biological control costs at all crop seasons.

Product	a.i./ G.q	No. of applications	Dose/ha	Cost (USD)		Total
				Product	Tractor	
Cyptrin®	Cypermethrin/ Pyrethroid	2	330	11.35 (x2)	20.00 (x2)	62.70
Keshet®	Deltamethrin/ Pyrethroid	2	330	4.05 (x2)	20.00 (x2)	48.10
Lorsban®	Chlorpyrifos/ Organophosphate	4	660	4.75 (x4)	20.00 (x4)	98.90
Dimexion®	Dimethoate/ Organophosphate	2	660	6.65 (x2)	20.00 (x2)	47.30
	Conventional control total – 2016					257.02
Cyptrin®	Cypemethrin / Pyrethroid	2	1000	41.18 (x2)	67 (x2)	64.60
Keshet®	Deltamethrin/ Pyrethroid	2	500	20.59 (x2)	67 (x2)	52.30
Lorsban®	Chlorpyrifos/ Organophosphate	2	2000	48.03 (x2)	67 (x2)	68.70
Dimexion®	Dimethoate/ Organophosphate	2	2000	37.03 (x2)	67 (x2)	62.10
	Conventional control total – 2017					247,66

* Average commercial dollar value in the study periods = U$ 3.35.

Table 2: Chemical control costs at all crop seasons.

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