

## Integrated management of yellow aphid (*Melanaphis sacchari* Zehntner) in sorghum (*Sorghum bicolor* L.) Moench in Guerrero, Mexico

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### Abstract

Sorghum is cultivated in tropical and subtropical regions of the world and is an important cereal for Mexico. However, it is affected by different pests, especially the yellow aphid. The objective of the research was to evaluate the effectiveness of biological, botanical and chemical insecticides in reducing *Melanaphis sacchari* populations in sorghum plants under greenhouse conditions. Planting was conducted in a greenhouse, using the sorghum hybrid 945-M. Pests, diseases and weeds management were implemented. The incidence of the yellow aphid was induced artificially. A total of 13 treatments were applied. The following variables were assessed: the number of aphids per leaf, the biological effectiveness of the treatments, plant height, diameter of the plant stem, number of leaves, and the weight of fresh and dry plants. An analysis of variance was conducted for each variable under study, as along with a comparison of means using the Tukey method ( $\alpha=0.05$ ) and

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correlation analysis using the SAS 9.4 software. The chemical, biological and organic insecticide that exhibited the greatest control of the yellow aphid (more than 95%) were: Toretto® (sulfoxaflor), PHC® Meta Tron® (*M. anisopliae*), Bio-Die® (Argemonein, Berberine, Ricinin and a-Terthienyl). Adequate management strategies are needed to avoid health problems in people, environmental contamination and resistance or multiple resistance.

**Keywords:** artificial infestation; control; damage; greenhouse conditions; incidence; pest

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## Introduction

Sweet sorghum (*Sorghum bicolor* L.) Moench (Poaceae) is grown in tropical and subtropical regions of the world and can be used as a dual-purpose crop because it has several advantages, such as being tolerant to water stress, presenting excellent nutritional quality and being able to be grown on grazing land, as well as being a crop for silage and grain harvest (Demanet and Canales, 2020). It is an essential cereal for the elaboration of balanced feed, especially in dairy, beef and pork production, as well as for poultry feed and egg production (Alejandro, 2019); in addition, the grain is used to make flour for use in baking and is also a raw material in the industry to produce starch, alcohol, acetone and butanol (Rodríguez, 2018). In the 2021 cycle, sorghum production worldwide was 61,364,996.82 Mt (FAOSTAT, 2023).

The yellow sorghum aphid *Melanaphis sacchari* (Zehntner) (Hemiptera: Aphididae) is of African origin and has been reported in Asia, Australia, the Middle East, Central and South America in crops such as maize (*Zea mays* L.), sugarcane (*Saccharum officinarum* L.), wheat (*Triticum* spp.), rice (*Oryza sativa* L.), and barley (*Hordeum vulgare* L.) (Poaceae). It causes direct damage, such as leaf lesions, stunting and delayed flowering, as well as indirect damage such as the proliferation of fumagina (*Capnodium* spp.) and the transmission of viral diseases (Perales, 2019). Currently, *M. sacchari* is found in 20 states of the Mexican Republic, where it causes yield losses ranging from 30 to 100%. In the 2013 cycle, the presence of the invasive pest identified as *M. sacchari* was observed for the first time in northern Tamaulipas (Silva-Martínez *et al.*, 2019), causing total losses to producers.

Adults and nymphs directly suck large amounts of sap from the leaves of the plant and inject toxins that alter its hormonal balance, causing serious damage, such as brown coloration on leaves, chlorosis, necrosis, stunting and delayed flowering, all of which decrease yield. Although this damage depends on the insect population, the phenological stage, the time it takes the pest in the crop, and the climatic conditions (Silva-Martínez *et al.*, 2019), once infested the plant can have up to 30,000 aphids (Valverde, 2018). This represents a great threat because the aphids life cycle is 14 to 28 days (Fortoul, 2019); it reproduces parthenogenetically and rapidly colonizes the plant (Valverde, 2018). On the other hand, the control of *M. sacchari* is based on the application of chemical insecticides with active molecules such as: imidacloprid, sulfoxaflor, spirotetramat, thiamethoxan and methamidophos. This method is currently the most used by farmers because of its effectiveness in controlling this pest, although the irrational use of these products causes resistance in the aphid, damages the environment and eliminates predatory and parasitoid insects of the Braconidae, Aphelinidae, Hemerobiidae, Chrysopidae, Chamaemyiidae, Coccinellidae and Anthocoridae families (Fortoul, 2019; García-Burgos *et al.*, 2020). However, currently there are new insecticides that have the advantage of being selective against the target pest and affecting beneficial insects less (Koch *et al.*, 2019); some of them are sulfoxaflor, spirotetramat and flupyradifurone, which cause high aphid mortality rates and have low toxicity on predators and are recommended for the management of *M. sacchari* in commercial grain sorghum crop (Haar *et al.*, 2019).

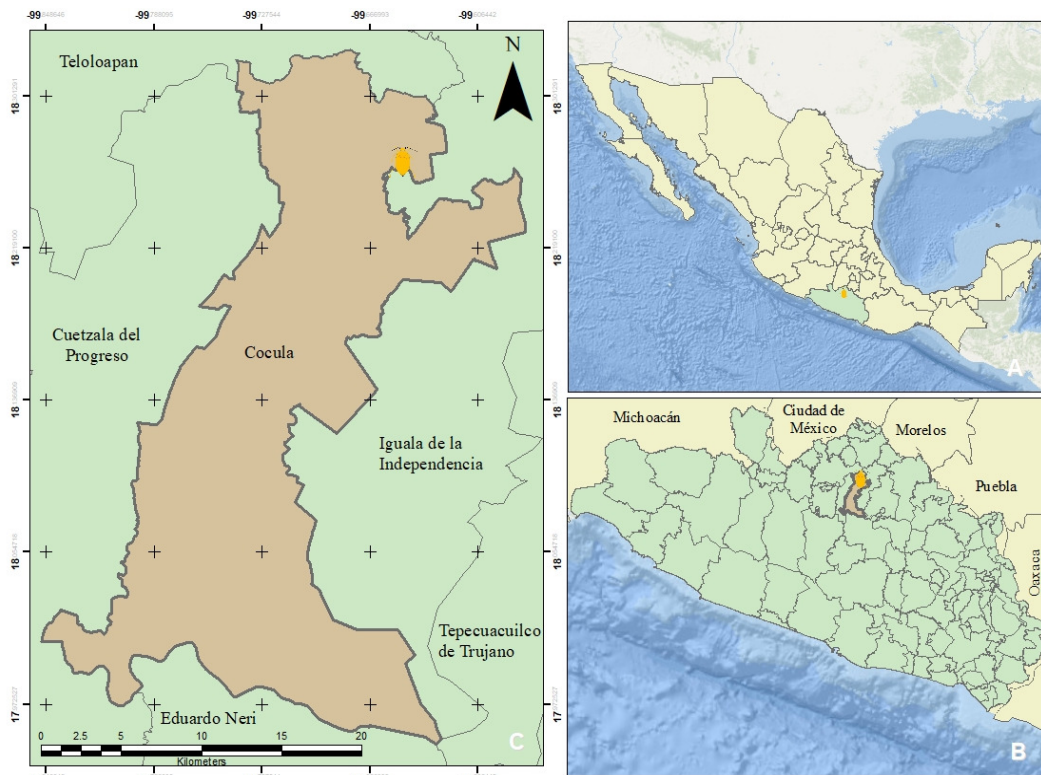
In order to prevent collateral damage, reduce aphid populations and minimize plant damage, integrated management through economic thresholds is recommended, along with new aphid-resistant sorghum varieties, seed insecticide treatment and foliar insecticide sprays; these measures provide the basis for integrated pest

management programs (Szczepaniec, 2018; Haar *et al.*, 2019; Lahiri *et al.*, 2019). Also, eliminating host plants that act as a reservoir (Maya and Rodriguez-del-Bosque, 2014) and integrating chemical control in combination with biological and botanical control. Biological control with commercial products formulated with entomopathogenic fungi, such as *Beauveria bassiana* (Balsamo), Vuillemin (Cordycipitaceae) and *Metarhizium anisopliae* (Mechnikov), Sorokin (Clavicipitaceae), is considered an alternative to the use of agrochemicals, because it is a natural method compatible with ecosystems (Fortoul, 2019). Likewise, the use of botanical insecticides is one of the biorational alternatives to reduce, replace or complement chemical control. Therefore, the objective of the research was to evaluate the effectiveness of biological, botanical and chemical insecticides in reducing *Melanaphis sacchari* populations in sorghum plants under greenhouse conditions.

## Materials and Methods

### Study area

The research was conducted in the greenhouse of the Colegio Superior Agropecuario del Estado de Guerrero (CSAEGRO), located in Cocula, Guerrero, Mexico (Figure 1), at the geographical coordinates 18° 19' north latitude and 99° 39' west longitude, at an elevation 640 meters above sea level.



**Figure 1.** Geographic location of the experiment. A) Mexico, B = State of Guerrero, C = Cocula (CSAEGRO)

### Genetic material

The hybrid sorghum genotype 945-M, from GENEXMR<sup>®</sup>, was used in the experiment; the characteristic of this material is that it has high yields in rainfed and irrigated crops.

*Agronomic management*

Planting was done on February 18, 2022 and two seeds were planted in the center of the 5 kg pot (previously sieved compost and loam soil were used as substrate, which were mixed in a 2:1 ratio). Watering was done daily in the morning and in the middle of the day (0.5 L of water/pot/watering). In fertilization, two applications were made of 5 g per pot of the 150N-70P-90K treatment (the normally used dose per ha). The first application occurred at 12 days after planting (DAP), using a mixture of ammonium sulfate (20.5% of N), diammonium phosphate (DAP) (46% of P<sub>2</sub>O<sub>5</sub>, 18% of N) and potassium chloride (60% of KCl). The second fertilization was applied at 44 DAP using 2 g of urea per experimental unit (All Pronamex<sup>®</sup> fertilizers). At 19 days, foliar fertilization was applied and the product Nutri-Humus<sup>®</sup> (containing humic, fulvic and humic acids) at a dose of 5 mL per L<sup>-1</sup> of water. Weed control was conducted manually every three days. At 19 DAP, Coragen<sup>®</sup> (chlorantniliprole) was applied at a dose of 0.38 mL per L<sup>-1</sup> for controlling the fall armyworm *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae).

*Artificial infestation of M. sacchari infestation on sorghum plants*

To achieve artificial infestation of the plants, leaves of Johnson grass *S. halepense* and sorghum infested with yellow aphid were collected, chopped at 50 DAPL and pieces were placed on the leaves of healthy sorghum plants. Monitoring was conducted on the intermediate leaves of the plant, 24 h after the induced infestation, to try to ensure that the infestation was close to or greater than the economic threshold of 50 aphids per leaf.

*Treatments and variables*

Table 1 shows the pesticides and doses evaluated (before application, a leaf of the plant was selected and the number of insects present was counted.). The treatments were applied at 52 DAPL with 0.100 L of water sprayed on the foliage of the six replicates of each treatment.

**Table 1.** Treatments, products and doses evaluated in this study

No.	Treatments*	Active ingredient (%)	Doses <sup>2</sup>	Symbology
T1	Toretto <sup>*1</sup>	Sulfoxaflor (21.8%, equivalent to 240 g)	50 mL*	TOD1
T2			100 mL**	TOD2
T3	Movento <sup>®</sup> 150 OD <sup>1</sup>	Spirotetramat (15.30%, equivalent to 150 g)	350 mL*	MOD1
T4			500 mL**	MOD2
T5	Allium liquid <sup>*1</sup>	Garlic extract (87%)	5 L*	ALD1
T6			7.5 L**	ALD2
T7	Bio-Dic <sup>*1</sup>	Argemonin (3.50%), Berberine (2.20%), Ricinin (2.80%) and a-Terthienyl (3.50%).	5 L*	BID1
T8			7.5 L**	BID2
T9	Atento <sup>*1</sup>	<i>Beauveria bassiana</i> (7.0%, equivalent to 5.3 × 10 <sup>9</sup> conidia/70 g)	350 g*	ATD1
T10			500 g**	ATD2
T11	PHC <sup>®</sup> Meta Tron <sup>*1</sup>	<i>Metarhizium anisopliae</i> (3%, equivalent to 1.2 × 10 <sup>12</sup> conidia / 240 g)	350 g*	PHD1
T12			500 g**	PHD2
T13	Control	Water	-	TES

<sup>1</sup>= Commercial product, <sup>2</sup>= 0.100 L of water was used to apply each treatment, \* = Low dose, \*\* = High dose

*Variable evaluation*

Number of aphids per leaf: Seven evaluations were made. First a pre-evaluation was made (evaluation 1), then six evaluations were made at 1, 2, 3, 8, 13 and 18 days after application of the treatments (DAT), at 52 DAPL. In each evaluation, the number of live aphids was counted on a randomly selected leaf in the middle part of the plant.

Biological effectiveness of the treatments: It was determined with the following formula of Abbott (1925): % Biological Effectiveness =  $[(A - B)/A]*100$ , where: A= Value of the control and B= Value of the treatment with pesticide.

Plant height (cm): It was measured with a tape measure from the stem collar to the tip of the panicle of the plant.

Plant stem diameter (mm): The diameter was measured with a digital vernier on the surface of the substrate.

Number of leaves: The number of complete leaves per plant was counted.

Weight of fresh plants (g): The two plants were extracted with the whole root, weighed on the scale and the fresh weight per pot was obtained.

Weight of the dried plants (g): The two plants were cut into small pieces, put in paper bags, placed in the oven at 70 °C for 72 h for a faster and more uniform drying; they were weighed on the scale to obtain the dry matter weight.

#### *Statistical analysis*

With the data of the variables, an analysis of variance was conducted using a randomized complete block design, as well as a means comparison using the Tukey test ( $\alpha=0.05$ ). A linear regression analysis was performed on the variable “number of aphids per leaf”, and a correlation analysis was conducted for all variables using SAS 9.4 software.

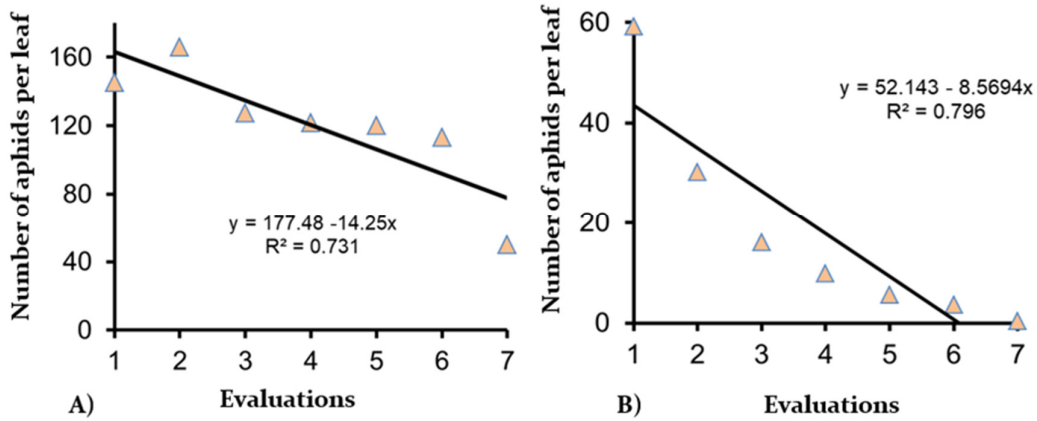
## **Results and Discussion**

### *Number of aphids per leaf*

In the six evaluations carried out DAT, it was found that the treatments caused highly significant effects ( $p<.0001^{**}$ ) in presence of the pest, due to the heterogeneous distribution of the insect in the experimental units. However, the highest population of aphids was found in the control treatment, which gradually decreased from evaluation 1 (145.33) to 7 (49.83), presenting a dynamic that adjusted to the simple linear regression model ( $R^2= 0.71$ ), where it was determined that there was a decrease of 14.35 insects between evaluations, on average (Figure 1A).

On the other hand, it was found that the population dynamics of aphids on plants treated with insecticides also adjusted to the simple linear regression model ( $R^2=0.79$ ), which determined that there was a reduction of 8.56 insects, on average, between evaluations (Figure 1B).

From the second date, it was determined that treatments T1 and T2 with Sulfoxaflor (Toretto<sup>®</sup>) applied at low (50 mL per ha<sup>-1</sup>) and high (100 mL per ha<sup>-1</sup>) doses, were the most effective, and from day 2 DAT they suppressed 100% of the incidence of yellow aphid. On the other hand, Szwarc *et al.* (2021) reported that thiamethoxam + lambda-cyhalothrin, alfacipermethrin + acetamiprid, imidacloprid and sulfoxaflor + lambda-cyhalothrin were more than 70 % effective (Table 2), which coincides with the results obtained in the present investigation with the chemical insecticides sulfoxaflor and spirotetramat as active ingredient.



**Figure 1.** Linear regression. A) = Linear regression of the number of aphids in the control treatment and B) = Linear regression of the number of aphids in the treatments

**Table 2.** Number of aphids per leaf per treatment in the different evaluations carried out in the study

Tr.	Eva. 1	Eva. 2	Eva. 3	Eva. 4	Eva. 5	Eva. 6	Eva. 7
	(pre-evaluation)	(day 1, DAT)	(day 2, DAT)	(day 3, DAT)	(day 8, DAT)	(day 13, DAT)	(day 18, DAT)
TOD1	29.67 b	0.00 c	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b
TOD2	28.17 b	1.67 bc	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b
MOD1	76.83 ab	42.17 bc	22.17 b	18.00 b	5.83 b	1.17 b	0.00 b
MOD2	78.50 ab	16.83 bc	4.67 b	8.17 b	0.67 b	0.00 b	0.00 b
ALD1	95.67 ab	47.50 bc	14.67 b	4.50 b	1.50 b	0.00 b	0.00 b
ALD2	62.00 ab	34.50 bc	17.50 b	10.00 b	7.33 b	7.33 b	1.17 b
BID1	60.67 ab	35.67 bc	8.00 b	6.83 b	4.33 b	0.00 b	0.00 b
BID2	36.33 b	13.67 bc	6.00 b	1.17 b	2.50 b	3.00 b	0.00 b
ATD1	86.83 ab	76.17 b	44.83 b	40.00 b	28.00 b	22.50 b	2.33 b
ATD2	57.33 ab	24.17 bc	30.67 b	13.50 b	12.50 b	9.33 b	0.67 b
PHD1	49.67 ab	34.83 bc	20.67 b	8.50 b	2.83 b	0.83 b	0.00 b
PHD2	48.50 b	34.83 bc	24.50 b	7.83 b	2.50 b	0.00 b	0.00 b
TES	145.33 a	166.00 a	127.17 a	121.67 a	120.00 a	113.33 a	49.83 a
Prob.(F)	0.0075**	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**
HSD	96.491	74.959	66.304	50.254	44.059	42.562	17.415

Tr.=Treatments. TOD1= Toretto<sup>®</sup> at 50 mL. TOD2= Toretto<sup>®</sup> at 100 mL. MOD1= Movento<sup>®</sup> 150 OD at 350 mL. MOD2= Movento<sup>®</sup> 150 OD at 500 mL. ALD1=Allium liquid<sup>®</sup> at 5 L. ALD2= Allium liquid<sup>®</sup> at 7.5 L. BID1=Bio-Die<sup>®</sup> at 5 L. BID2=Bio-Die<sup>®</sup> at 7.5 L. ATD1= Atento<sup>®</sup> at 350 g. ATD2= Atento<sup>®</sup> at 500 g. PHD1= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 350 mL. PHD2= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 500 mL. TES= Control (water). Eva. = Evaluation. Mean values with equal letters in the same column are not statistically different (Tukey,  $\alpha=0.05$ ). HSD = Tukey's honest significant difference. DAT= After the application of the treatments.

*Biological effectiveness of treatments*

Evaluation one (day one DAT)

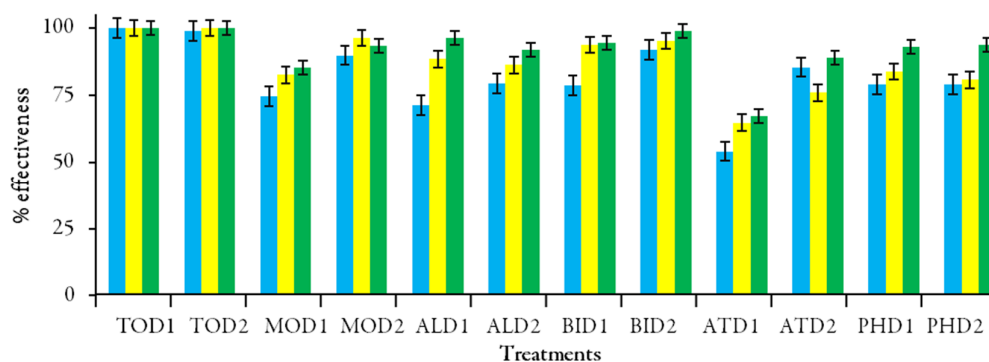
During evaluation one, it was determined that the active ingredient sulfoxaflor (Toretto<sup>®</sup> 50 and 100 mL per ha<sup>-1</sup>) presented 100 % biological effectiveness against yellow aphid, while *B. bassiana* (Atento<sup>®</sup> 350 g per ha<sup>-1</sup>) was the least effective (54 %), while in the other treatments it was 71 to 99 % (Figure 2).

Evaluation two (day two DAT)

On this date, sulfoxaflor insecticide (Toretto<sup>®</sup>) in the two doses was again the treatment that presented 100 % of biological effectiveness, unlike Atento<sup>®</sup> (*B. bassiana* 350 g per ha<sup>-1</sup>), which had the lowest percentage of effectiveness (65 %), and in the rest of the treatments the effectiveness fluctuated from 76 to 99 % (Figure 2).

Evaluation three (day three DAT)

The same tendency as in the two previous evaluations was observed because the two doses of sulfoxaflor (Toretto<sup>®</sup>) presented 100% effectiveness and *B. bassiana* (Atento<sup>®</sup> 350 g per ha<sup>-1</sup>) was the treatment that registered the lowest percentage of effectiveness (67%); the rest of the treatments ranged from 85 to 99%. On the other hand, Zambrano-Gutierrez *et al.* (2019) found that *B. bassiana* presented infection levels of 6.0 to 10.0% of *M. sacchari* in sorghum. Likewise, Lorenzo (2021) reported that the effectiveness of *B. bassiana* can be reduced due to several factors such as inhibition of germination and death of conidia when immersed in water at temperatures below 25 °C, as well as oxygen concentrations that can affect viability and virulence, and finally, high and low temperatures (Figure 2).



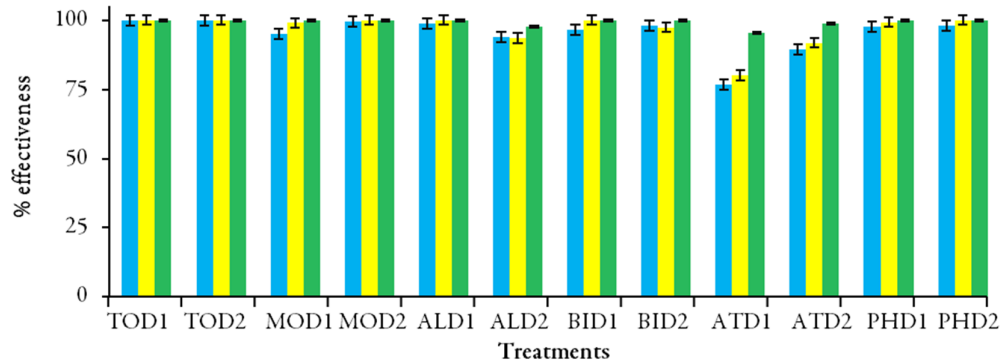
**Figure 2.** Biological effectiveness of the application of treatments in study on the incidence of *M. sacchari* in three evaluations carried out every 24 h

Blue color= Evaluation 1 (day 1 DAT), yellow color= Evaluation 2 (day 2 DAT), green color= Evaluation 3 (day 3 DAT). TOD1= Toretto<sup>®</sup> at 50 mL. TOD2= Toretto<sup>®</sup> at 100 mL. MOD1= Movento<sup>®</sup> 150 OD at 350 mL. MOD2= Movento<sup>®</sup> 150 OD at 500 mL. ALD1=Allium liquid<sup>®</sup> at 5 L. ALD2= Allium liquid<sup>®</sup> at 7.5 L. BID1= Bio-Die<sup>®</sup> at 5 L. BID2= Bio-Die<sup>®</sup> at 7.5 L. ATD1= Atento<sup>®</sup> at 350 g. ATD2 = Atento<sup>®</sup> at 500 g. PHD1= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 350 mL. PHD2= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 500 mL.

Evaluations four, five and six (days 8, 13 and 18 DAT)

In the three evaluations carried out at 5-day intervals, it was found that the chemical insecticides Toretto<sup>®</sup> (at doses of 50 and 100 mL) and Movento<sup>®</sup> 150 OD (at a dose of 500 mL) were 100% effective against the yellow aphid. Likewise, it was determined that the treatments liquid Allium (at a dose of 5 mL), Bio-Die<sup>®</sup> (at a dose of 5 L) and PHC<sup>®</sup> Meta Tron<sup>®</sup> (at a dose of 500 mL) showed 100% effectiveness in evaluations 5 and 6. In addition, in the three evaluations it was found that the biological insecticide Atento<sup>®</sup> (at a dose of 350 g) presented the lowest percentages of effectiveness (Figure 3). While chemical pesticides exhibit rapid action, surpassing biological and organic pesticides (such as plant extracts), the latter are known for their longer-lasting effects. Nevertheless, the continuous and inappropriate use of chemical pesticides can lead to various problems, including pollution, health issues for humans, environmental degradation, and the development of resistance (Ha, 2014). According to Cerna-Chavez *et al.* (2022), the fall armyworm had developed resistance to 33 active ingredients in different parts of the world by 2022.

The above results are different from those obtained by Rojas-Gutierrez *et al.* (2017), who found that native strains *B. bassiana* and *M. anisopliae* caused averages of 82.3-75.0 and 66.7% aphid mortality, respectively. On the other hand, Rodríguez-del-Bosque and Terán (2018) mentioned that the insecticides, sulfoxaflor (12 g of a.i. per ha<sup>-1</sup>) and spirotetramat (45 g), presented effectiveness greater than 95%, due to the systemic and translaminar effect they present.

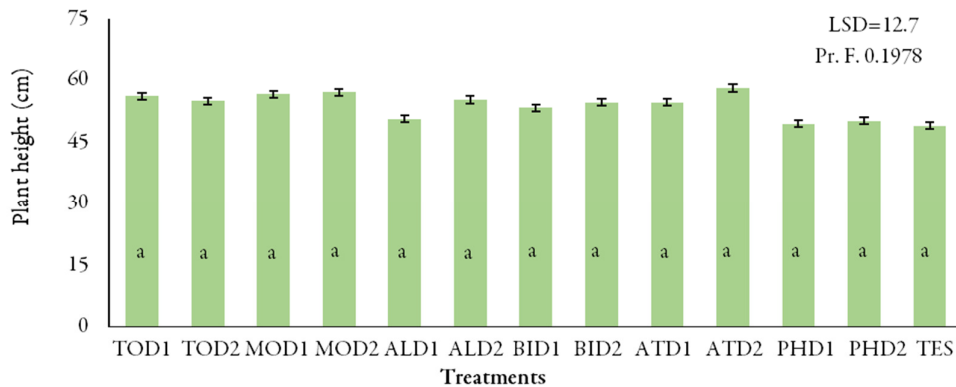


**Figure 3.** Biological effectiveness of treatments in study on the incidence of *M. sacchari* in three evaluations, carried out every 5 days

Blue color= Evaluation 1 (day 8 DAT), yellow color= Evaluation 2 (day 13 DAT), green color= Evaluation 3 (day 18 DAT). TOD1= Toretto<sup>®</sup> at 50 mL. TOD2= Toretto<sup>®</sup> at 100 mL. MOD1= Movento<sup>®</sup> 150 OD at 350 mL. MOD2= Movento<sup>®</sup> 150 OD at 500 mL. ALD1=Allium liquid<sup>®</sup> at 5 L. ALD2= Allium liquid<sup>®</sup> at 7.5 L. BID1= Bio-Dic<sup>®</sup> at 5 L. BID2= Bio-Dic<sup>®</sup> at 7.5 L. ATD1= Atento<sup>®</sup> at 350 g. ATD2 = Atento<sup>®</sup> at 500 g. PHD1= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 350 mL. PHD2= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 500 mL.

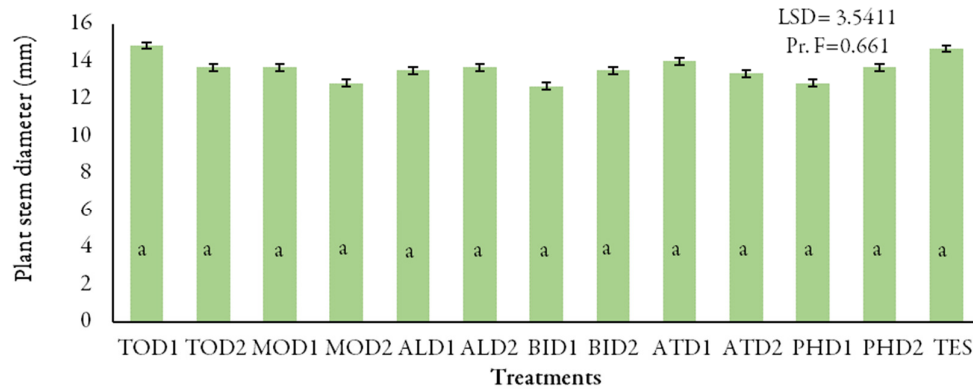
*Plant height, plant stem diameter and number of leaves per plant*

The results obtained for plant height, plant stem diameter and number of leaves per plant did not show significant differences between treatments ( $p=0.1954$ ,  $p=0.661$ ,  $p=0.652$ ) (Figures 4-6).



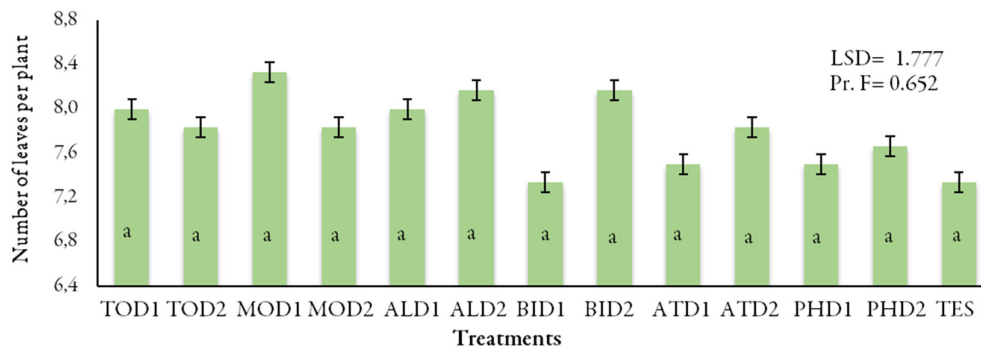
**Figure 4.** Effect of the application of chemical, organic and biological treatments under study on plant height.

TOD1= Toretto<sup>®</sup> at 50 mL. TOD2= Toretto<sup>®</sup> at 100 mL. MOD1= Movento<sup>®</sup> 150 OD at 350 mL. MOD2= Movento<sup>®</sup> 150 OD at 500 mL. ALD1=Allium liquid<sup>®</sup> at 5 L. ALD2= Allium liquid<sup>®</sup> at 7.5 L. BID1= Bio-Dic<sup>®</sup> at 5 L. BID2= Bio-Dic<sup>®</sup> at 7.5 L. ATD1= Atento<sup>®</sup> at 350 g. ATD2 = Atento<sup>®</sup> at 500 g. PHD1= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 350 mL. PHD2= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 500 mL. TES= Control (water). LSD= Minimum significant difference. Pr. F.= Probability of Fc. Values with the same letters are not statistically different (Tukey at 0.05).



**Figure 5.** Effectiveness of treatments on the stem diameter of the sorghum plants

TOD1= Toretto<sup>®</sup> at 50 mL. TOD2= Toretto<sup>®</sup> at 100 mL. MOD1= Movento<sup>®</sup> 150 OD at 350 mL. MOD2= Movento<sup>®</sup> 150 OD at 500 mL. ALD1=Allium liquid<sup>®</sup> at 5 L. ALD2= Allium liquid<sup>®</sup> at 7.5 L. BID1= Bio-Die<sup>®</sup> at 5 L. BID2= Bio-Die<sup>®</sup> at 7.5 L. ATD1= Atento<sup>®</sup> at 350 g. ATD2 = Atento<sup>®</sup> at 500 g. PHD1= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 350 mL. PHD2= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 500 mL. TES= Control (water). LSD= Minimum significant difference. Pr. F.= Probability of Fc. Values with the same letters are not statistically different (Tukey at 0.05).

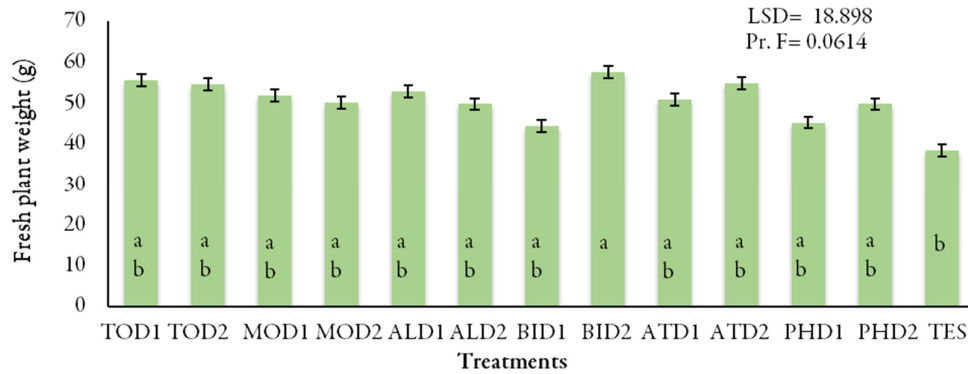


**Figure 6.** Effectiveness of the application of chemical, organic and biological of treatments on the number of leaves per plant

TOD1= Toretto<sup>®</sup> at 50 mL. TOD2= Toretto<sup>®</sup> at 100 mL. MOD1= Movento<sup>®</sup> 150 OD at 350 mL. MOD2= Movento<sup>®</sup> 150 OD at 500 mL. ALD1=Allium liquid<sup>®</sup> at 5 L. ALD2= Allium liquid<sup>®</sup> at 7.5 L. BID1= Bio-Die<sup>®</sup> at 5 L. BID2= Bio-Die<sup>®</sup> at 7.5 L. ATD1= Atento<sup>®</sup> at 350 g. ATD2 = Atento<sup>®</sup> at 500 g. PHD1= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 350 mL. PHD2= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 500 mL. TES= Control (water). LSD= Minimum significant difference. Pr. F.= Probability of Fc. Values with the same letters are not statistically different (Tukey at 0.05).

#### *Fresh plant weight*

In this variable, significant statistical differences were found ( $p=0.0500^*$ ); however, it was determined that the plants treated with Bio-Die<sup>®</sup> at a dose of 7.5 L ha<sup>-1</sup> presented the greatest weight with an average of 57.7 g (which means the increase of 50% with respect to the average of 38.5 g of the control plants). The increase in plant weight in the other treatments ranged from 15.6 to 44.7% with respect to the weight of the control plant (Figure 7). In the experiment conducted by Perales (2019), the authors noted that despite the damage caused by *M. sacchari*, there were not significant differences in fresh plant weight, which ranged between 60.52 and 78.59 g, higher values than those obtained in the present investigation.

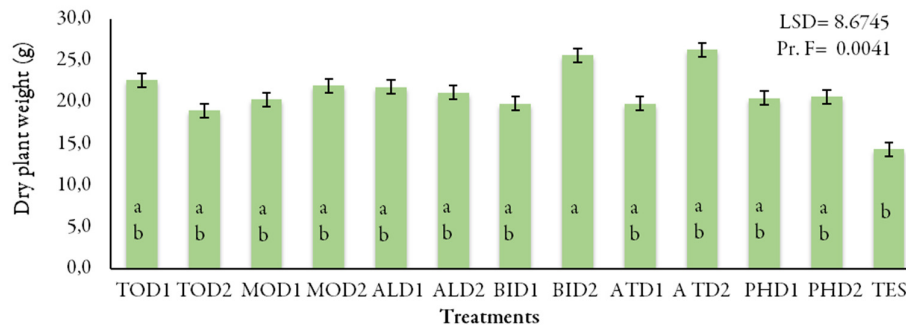


**Figure 7.** Effect of treatments on fresh plant weight at the end of sorghum crop

TOD1= Toretto<sup>®</sup> at 50 mL. TOD2= Toretto<sup>®</sup> at 100 mL. MOD1= Movento<sup>®</sup> 150 OD at 350 mL. MOD2= Movento<sup>®</sup> 150 OD at 500 mL. ALD1=Allium liquid<sup>®</sup> at 5 L. ALD2= Allium liquid<sup>®</sup> at 7.5 L. BID1= Bio-Die<sup>®</sup> at 5 L. BID2= Bio-Die<sup>®</sup> at 7.5 L. ATD1= Atento<sup>®</sup> at 350 g. ATD2 = Atento<sup>®</sup> at 500 g. PHD1= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 350 mL. PHD2= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 500 mL. TES= Control (water). LSD= Minimum significant difference. Pr. F.= Probability of Fc. Values with the same letters are not statistically different (Tukey at 0.05).

### Dry plant weight

In this variable there were highly significant statistical differences ( $p=0.0041$ ) because the plants treated with the *B. bassiana* treatment (Atento<sup>®</sup> at a dose of 500 g) presented the greatest weight with a mean of 26.3 g (which means an increase of 84% compared to the mean of the control treatment of 14.3 g). In contrast, it was found that plants treated with Toretto<sup>®</sup> at a dose of 100 mL ha<sup>-1</sup> had the lowest dry biomass weight, with a mean of 19 g, which is 32.9% lower than the average recorded in the control plants. In the other treatments, increases between 38.5 and 79.7% were obtained with respect to the weight of the control plant (Figure 8).



**Figure 8.** Effect of treatments on dry plant weight at the end of sorghum crop

TOD1= Toretto<sup>®</sup> at 50 mL. TOD2= Toretto<sup>®</sup> at 100 mL. MOD1= Movento<sup>®</sup> 150 OD at 350 mL. MOD2= Movento<sup>®</sup> 150 OD at 500 mL. ALD1=Allium liquid<sup>®</sup> at 5 L. ALD2= Allium liquid<sup>®</sup> at 7.5 L. BID1= Bio-Die<sup>®</sup> at 5 L. BID2= Bio-Die<sup>®</sup> at 7.5 L. ATD1= Atento<sup>®</sup> at 350 g. ATD2 = Atento<sup>®</sup> at 500 g. PHD1= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 350 mL. PHD2= PHC<sup>®</sup> Meta Tron<sup>®</sup> at 500 mL. TES= Control (water). LSD= Minimum significant difference. Pr. F.= Probability of Fc. Values with the same letters are not statistically different (Tukey at 0.05).

### Correlation analysis

This statistical analysis showed positive and significant correlations between the different response variables (Table 3). It was found that plant height correlated negatively and significantly with the number of aphids per leaf ( $r= -0.22$ ), as well as with collar diameter ( $r= -0.27$ ); that is, as the yellow aphid population increased, plant height and collar diameter tended to decrease due to the damage caused by the pest feeding. A

similar trend in leaf number was also determined with the number of aphids per leaf ( $r = -0.17$ ), meaning that the number of leaves decreased as aphid incidence increased.

**Table 3.** Correlation analysis between the variables under study

Variable name	Plant height	NLP	NAL	PSD	FPW	DPW
Number of leaves per plant (NLP)	0.14750 <sup>ns</sup>					
Number of aphids per leaf (NAL)	-0.22154*	-0.17015*				
Plant stem diameter (PSD)	-0.27684*	-0.09015*	0.10158 <sup>ns</sup>			
Fresh plant weight (FPW)	0.11864 <sup>ns</sup>	0.07665 <sup>ns</sup>	-0.31069*	0.30740**		
Dry plant weight (DPW)	0.12497 <sup>ns</sup>	0.14478 <sup>ns</sup>	-0.30673*	0.11434 <sup>ns</sup>	0.55192**	
Biological effectiveness	0.16670 <sup>ns</sup>	0.05994 <sup>ns</sup>	0.11633 <sup>ns</sup>	0.06834 <sup>ns</sup>	0.03495 <sup>ns</sup>	0.00706 <sup>ns</sup>

ns= non-significant positive correlation ( $p > 0.05$ ), \* = Negative correlation, \*\* = Significant positive correlation

Similarly, the number of aphids per plant was negatively and highly significantly correlated with both fresh ( $r = -0.31$ ) and dry ( $r = -0.30$ ) plant weight, which indicated that as the pest population increases, it will cause more damage that translates into reduced plant weight and, therefore, forage yield. The results obtained show that yellow aphid incidence directly reduces biomass accumulation in sorghum plants grown under dry tropical conditions, due to direct (sap sucking) and indirect (for example fumagina) damage caused by this sucking stinging insect. It is reported that the feeding of the yellow aphid causes stress to the plant, which becomes more serious when there is an exponential increase in the population, because the insect feeds on the sap of the leaves and stem and causes a delay in growth and development, so that fewer leaves are produced on the affected plant (Perales, 2019).

## Conclusions

The chemical, biological and organic insecticide with the greatest control of the yellow aphid (more than 95%) were: Toretto® (sulfoxaflor), PHC® Meta Tron® (*M. anisopliae*), Bio-Die® (Argemonein, Berberine, Ricinin and  $\alpha$ -Terthienyl). Adequate management strategies are needed to avoid health problems in people, environmental contamination and resistance or multiple resistance.

## Authors' Contributions

JLAV Conceptualization and prepared the draft and, BGG Methodology, SAS, KVDR Reviewed and improved the paper, DACZ, WZM Data curation, MATR, MVH, EDDN Formal analysis, JFDN Supervision. All authors have read and approved the final manuscript.

## Ethical approval (for researches involving animals or humans)

Not applicable.

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## Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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