

# Foliar sugar microdoses as a biocontrol approach against the tomato leaf miner *Tuta absoluta*: A sustainable pest management strategy

Original Article

## Abstract:

Tomato crops are highly susceptible to pests like *Tuta absoluta*, and current chemical control is detrimental to human health, the environment, and leads to resistance development. This study explores biocontrol by applying microdoses of sugars (fructose and sucrose) to tomato leaves to induce resistance against *Tuta absoluta* larvae. Tomato plants of the Saada variety received 100 ppm and 1000 ppm of sucrose, fructose, and their mixture. It was noted that the 1000 ppm sucrose-fructose association (applied one after another) provided initial protection during the first three weeks, while fructose alone and the mixture were better in the last three weeks. Fructose at 1000 ppm and the sucrose-fructose association maintained the infestation rate similar to the control. The mixture also inhibited the density of L1, L2, and L4 larvae, though L3 larvae were not inhibited. These observations underscore the promise of sugar-based therapies as biodegradable biocontrol agents, providing a green alternative to chemical pesticides.

## Key words:

*Solanum lycopersicum*, *Tuta absoluta*, sugar, induced resistance, exogenous apport

## Apstrakt:

**Mikrodoze šećera primenjene na lišće kao biološki pristup suzbijanju minera paradajzovog lista *Tuta absoluta*: Održiva strategija upravljanja štetočinama.**

Usevi paradajza su veoma podložni štetočinama kao što je *Tuta absoluta*, a trenutno hemijsko suzbijanje šteti ljudskom zdravlju, životnoj sredini i dovodi do razvoja otpornosti. Ova studija istražuje biološko suzbijanje primenom mikrodoza šećera (fruktoze i saharoze) na listove paradajza kako bi se indukovala otpornost na larve *Tuta absoluta*. Biljke paradajza sorte Saada tretirane su sa 100 ppm i 1000 ppm saharoze, fruktoze i njihove mešavine. Primećeno je da su saharoza i fruktoza primenjene zajedno (jedna za drugom) u koncentraciji od 1000 ppm obezbedile početnu zaštitu tokom prve tri nedelje, dok su čista fruktoza i mešavina bile efikasnije tokom poslednje tri nedelje. Fruktoza u koncentraciji od 1000 ppm i mešavina održavale su stopu infestacije sličnu kontroli. Mešavina je takođe smanjila gustinu larvi L1, L2 i L4 stadijuma, dok larve L3 stadijuma nisu bile inhibirane. Ova zapažanja ukazuju na potencijal šećernih tretmana kao biorazgradivih sredstava za biološko suzbijanje, pružajući ekološki prihvatljivu alternativu hemijskim pesticidima.

## Ključne reči:

*Solanum lycopersicum*, *Tuta absoluta*, šećer, indukovana otpornost, egzogeni doprinos

## Introduction

The micro lepidopteran, South American tomato borer, *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae), recently renamed *Phthorimaea absoluta* (Chang & Metz, 2021), has rapidly spread, invading several Afro-Eurasian countries (OEPP,

2021). The first outbreaks in Algeria were observed in the spring of 2008 in protected tomato crops in the Mostaganem region. It was later detected in various coastal areas, including the western, central, and parts of the eastern coast (OEPP, 2021). In recent years, this pest has severely affected tomato cultivation in greenhouses and open fields, with damage ranging

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from 50% to 100%.

The South American tomato borer is characterized by a high reproductive potential, with several overlapping generations per year, a strong dispersal capacity, and significant damage caused by the destruction of vegetative and reproductive organs by its larvae; damage can reach up to 100% in the absence of effective management methods. It has been classified as a serious economic threat to solanaceous crops and, to a lesser extent, a pest of other economically important solanaceous crops, including potatoes, eggplants, peppers, and tobacco (Biondi et al., 2018; Mansour et al., 2018; Guedes et al., 2019; Verheggen & Fontus, 2019; Sawadogo et al., 2020; Ponti et al., 2021).

The management of *Tuta absoluta* is highly dependent on chemical pesticides (Illakwahhi & Srivastava, 2017; Han et al., 2019), which present serious hazards to human health and environmental safety via bioamplification and bioconcentration (Hassaan & El Nemr, 2020). This has led to the overuse of pesticides, hence the development of resistance by the insect *T. absoluta* to several classes of pesticides, especially organophosphates and pyrethroids (Silva et al., 2016; Haddi et al., 2017; Zibae et al., 2018).

Given these challenges and the ongoing efforts to develop better intervention strategies while preserving the natural environment in an ecologically sustainable manner, the search for alternative pest control methods and products remains a priority. This pursuit is typically carried out within the phytopharmaceutical industry, which focuses on crop protection and enhancing plant defences against harmful organisms through the use of macro and microorganisms, chemical mediators, and natural substances of mineral, plant, bacterial, or animal origin (Isman, 2006; Mamy & Barriuso, 2022).

A large quantity of trials has been carried out in several countries such as France, Italy, Greece, and Algeria, which have suggested that foliar application of sucrose or fructose in low doses can serve as an alternative to pesticides for plant defence (Arnault et al., 2015; 2016; Brahim, 2022). These sugars have acquired critical regulatory roles and are increasingly being discovered as plant signalling molecules, modulating gene expression for metabolism, stress tolerance, and development. This also leaves open the possibility of priming—a physiological process that conditions plants for a faster and/or more intense defence response to subsequent stress at zero cost in terms of the entire metabolic cost of an induced defence response (Arnault et al., 2015; Ceusters et al., 2017). This new concept, "sweet immunity" or sugar-mediated

defence (Arnault et al., 2015), relies on foliar application of low-dose sugars to induce plant resistance to biotic stressors. The sweet immunity mechanism operates in a variety of phases: pre-attack, through the enhancement of basal resistance; during initial host recognition, through leaf surface interactions; upon pathogen challenge, through the induction of defence pathways (excluding insect responses) (Arnault et al., 2021).

This has been confirmed by Derridj et al. (2011) and Lambion & Marollien (2016), who demonstrated that the exogenous application of these phytohormones in sub-doses provided resistance in plants against insect oviposition. This resistance phenomenon is achieved through two mechanisms: a local effect in which the modification of the chemical composition on the leaf surface interferes with the oviposition behaviour of females, and the other, systemic effect, wherein the sugars initiate signalling pathways leading to changes in gene expression that provides a generalized effect in the stimulation of natural defences (Morkunas & Ratajczak, 2014; Formela-Luboińska et al., 2020).

Indeed, the application of sugars has been considerably beneficial in several cases: Apple and Pear/Codling Moth (*Cydia pomonella* L.), Vine/Downy Mildew (*Plasmopora viticola* Schwein.), Corn/Eastern Corn Borer (*Ostrinia nubilalis* Hbn.), Melon/Powdery Mildew (*Oidium neolycopersici* L. Kiss), Leek/Thrips (*Thrips tabaci* Linde.), and Tomato/Powdery Mildew (*O. neolycopersici* L. Kiss) (Ferré et al., 2008; Derridj et al., 2012; Arnault et al., 2021). However, regarding the effects of sugars on the tomato/leaf miner model, the field outcomes were variable after trials from 2016 to 2018 (Arnault et al., 2021). Given that *T. absoluta* is considered the most destructive pest of tomatoes, the findings from these trials should be considered preliminary.

This study tests the hypothesis that sucrose and fructose treatments at different concentrations (at 100 and 1000 ppm) applied alone, combined, or as mixtures will influence *Tuta absoluta* infestation levels by interfering with larval development and oviposition under laboratory conditions.

## Materials and Methods

### *Preparation of Tomato Seedlings and Infestation*

Laboratory experiments were conducted using tomato seedlings var—Saada, obtained from F1 hybrid seeds. Seeds were sown in plug trays filled with potting soil. After one week of germination, seedlings with two well-developed true leaves were transplanted into pots and kept under laboratory conditions; the plants became naturally infested by *T. absoluta*.

### Experimental Design

The experiment followed a completely randomized block design with three replications per treatment. Each replication consisted of a single tomato plant in a pot, totaling 21 pots arranged randomly. Two sugars, fructose and sucrose (both from Fluka Biochemika), were tested under the following conditions:

1. Individually at doses of 100 ppm and 1000 ppm,
2. In a mixture and in association, at a dose of 1000 ppm.

For the mixing modality, sucrose and fructose were each applied at a concentration of 1000 ppm and immediately in the same container after mixing them. In the case of the association modality, the sugars were applied one after the other at the same dose (1000 ppm) each.

### Foliar spraying

Following the methodology described by Derridj et al. (2009, 2011, 2012), Brahim et al. (2018), Arnault et al. (2015, 2021), and Brahim (2022), the treatments were initiated just after the first mine apparition. Early in the morning (at 6 a.m.), the foliar sprays were applied prior to the start of photosynthesis and when the sugar levels of the apoplastic intercellular spaces were low, with the manual sprayer (5 L). According to Arnault et al. (2021), the applications were carried out every 15 days, from May 15, 2023, to July 3, 2023. The total number of applications made during our experiment was four: May 15, 2023; May 29, 2023; June 12, 2023; and June 26, 2023. Arnault et al. (2021) indicated that trials conducted in his work in 2016 revealed that foliar application of sugars alone at a concentration of 100 ppm provides minimal or no protection. Consequently, the authors recommended a higher concentration of approximately 1000 ppm.

The solution was applied through foliar spraying in a non-dripping V-shaped jet across the entire plant to facilitate the absorption of sugar. The volume of the solution was adjusted to support vegetative growth, ensuring proper coverage of the foliage. The sugar foliar spraying was applied to the entire plant until runoff to maximize efficacy. These six experimental treatments were compared to a control.

### Sampling and Parameters Studied

In this study, we evaluated the effect of treatments on the infestation rate by the leaf miners on tomato leaflets and on the abundance of larval stages by sampling plants within our experimental design. Each week during the experiment, we carefully checked the plants to count, enumerate, and identify the following parameters:

- Monitoring infestation rates: The rate of infestation caused by leaf miner larvae on leaves was monitored throughout the experimental period.

- Leaflets evaluation: The total number of healthy and infested leaflets was counted. In particular, three levels of leaves: basal, median, and apical were considered to gain insight into the overall health of the plants and the intensity of infestation pressure.

- Identification of biological stages: The various biological stages of the leaf miner, including larval instars and pupae were recorded and documented. To ensure accuracy, plants were carefully re-examined using a handheld magnifying glass.

- Assessment of treatment effectiveness: Abbott's formula was applied to evaluate the final effectiveness of the treatments.

$$\text{Efficiency} = 100 \times ((T_0 - T_t) / T_0)$$

**T<sub>0</sub>**: % total of leaflets affected in the control treatment;

**T<sub>t</sub>**: % total of leaflets affected in the treated treatment.

### Statistical Analyses

All statistical analyses were conducted using the Statistica 8 software. The corresponding means were calculated for each variable studied, such as the average percentage of overall infestation, infestation by leaf levels, and the abundance of larval stages. A comparison of means was conducted using ANOVA. Beforehand, the conditions for using this test were verified (normality of the distribution through a Shapiro-Wilk test). A Fisher LSD post hoc test was applied to identify significant differences between groups, with a significance level set at  $p < 0.05$ .

### Results

#### Dynamics of the infestation caused by *Tuta absoluta* on tomato leaflets

During the eight weeks of observation, the collected data revealed that the larval infestations of *T. absoluta* on tomato plants exhibited temporal variations. The initial weeks were marked by relatively low infestation levels ranging from 0 to 14.94, followed by a gradual increase after the initial two weeks of treatment (from 14.94 to 34.43). More specifically, during the first three weeks, the combination of sucrose and fructose at a concentration of 1000 ppm each proved to be the least affected, with an infestation rate of only 1.29%. In contrast, all other modalities experienced more significant attacks, exceeding the reference rate of the control, which was 4.33% (Fig. 1). By the fourth week, all the infections showed a slight increase. The “association” and “mixing” modalities showed

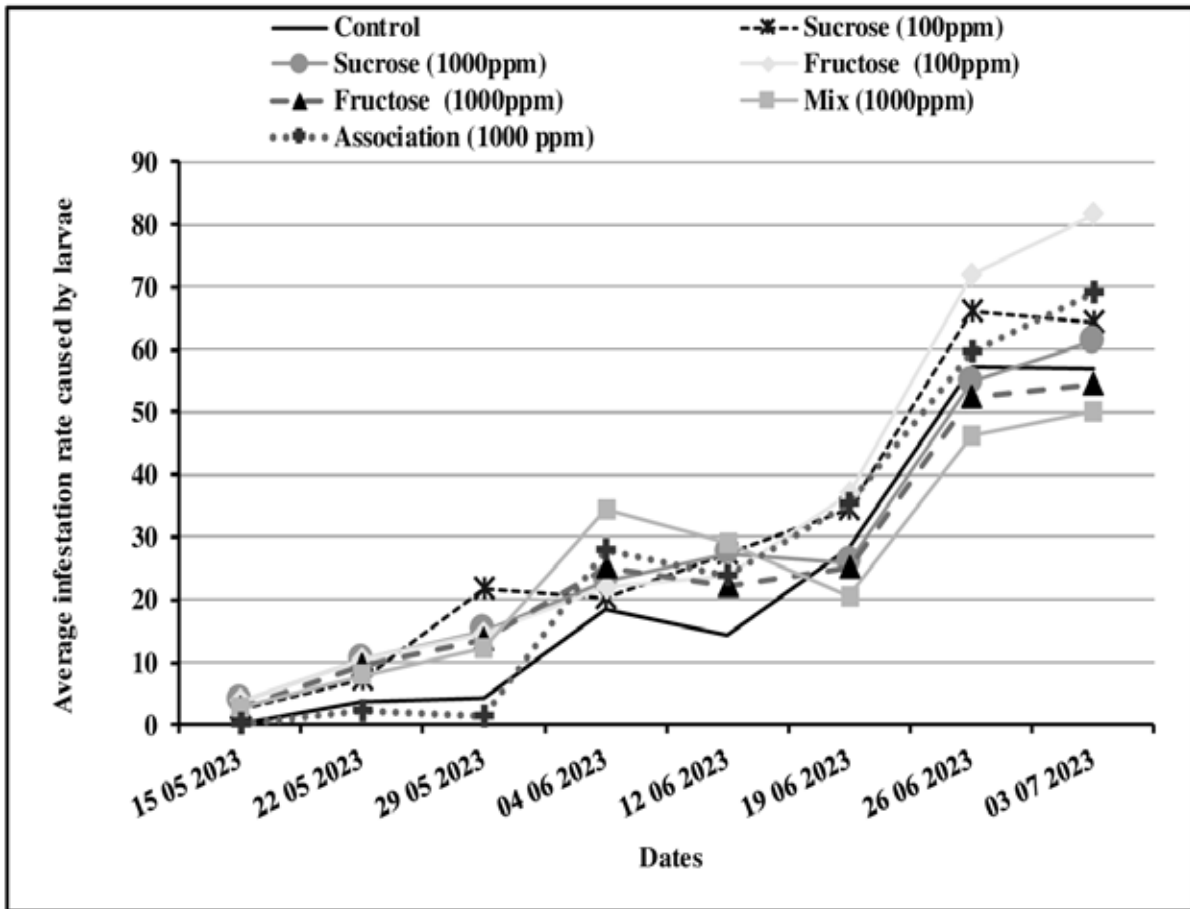


Fig. 1. Evolution of the infestation rate on tomato leaflets

particularly high infestation rates, reaching 28.04% and 34.43%, respectively, compared to 18.41% in the control group. However, from that date until the end of the trial (July 3rd), infestation levels declined in plants treated with a combination of sucrose and fructose at 1000 ppm and those treated only with fructose at 1000 ppm. These treatments ended up being the least affected, with final damage levels of 50% and 54.36% respectively.

In contrast, the treatment using fructose alone at 100 ppm showed a continued increase in infestation, resulting in a maximum rate of 81.69%. Sucrose at 100 ppm resulted in an infestation rate of 64.38%, while sucrose at 1000 ppm exhibited 61.34%. Fructose at 1000 ppm led to 54.36%, and the sucrose-fructose association yielded the highest rate at 69.2%. These values are relatively close to that of the control, which reached 56.84% (Fig. 1).

**Average infestation rate**

Foliar sprays of fructose at 1000 ppm, whether applied alone or in combination with sucrose at 1000 ppm, as well as sucrose at 1000 ppm alone or in combination with fructose at 1000 ppm, resulted in remarkably similar average infestation

rates. Specifically, the rates were 25.53±6.69%, 25.36±6.21%, 27.69±7.26%, and 27.43±9.39%, respectively. These values did not differ significantly from those observed in the control group ( $p>0.982$ ). In contrast, the application of sucrose or fructose at 100 ppm (33.12±10.20% and 30.47±8.40%, in order), when used alone, did not significantly differ from the control, which had an infestation rate of 22.89±8.13%. Furthermore, no statistically significant differences were observed between the different treatment modalities (Fig. 2).

**Infestation Rate by Layer**

Foliar application of fructose at 1000 ppm demonstrated a marked increase in leaflet protection, with infestation rates decreasing at the apical layer (7.11%±3.99 vs. 8.14%±4.45 for the control) but increasing substantially at the basal layer (44.76%±10.14 vs. 35.52%±10.74 for the control). This pattern was even more pronounced in the case of treatment with sucrose at 1000 ppm alone (9.00%±4.93), where infestation levels at the apical layer were comparable to those of the control, but significantly higher infestations were recorded at the basal level (Tab. 1). While basal infestation reached

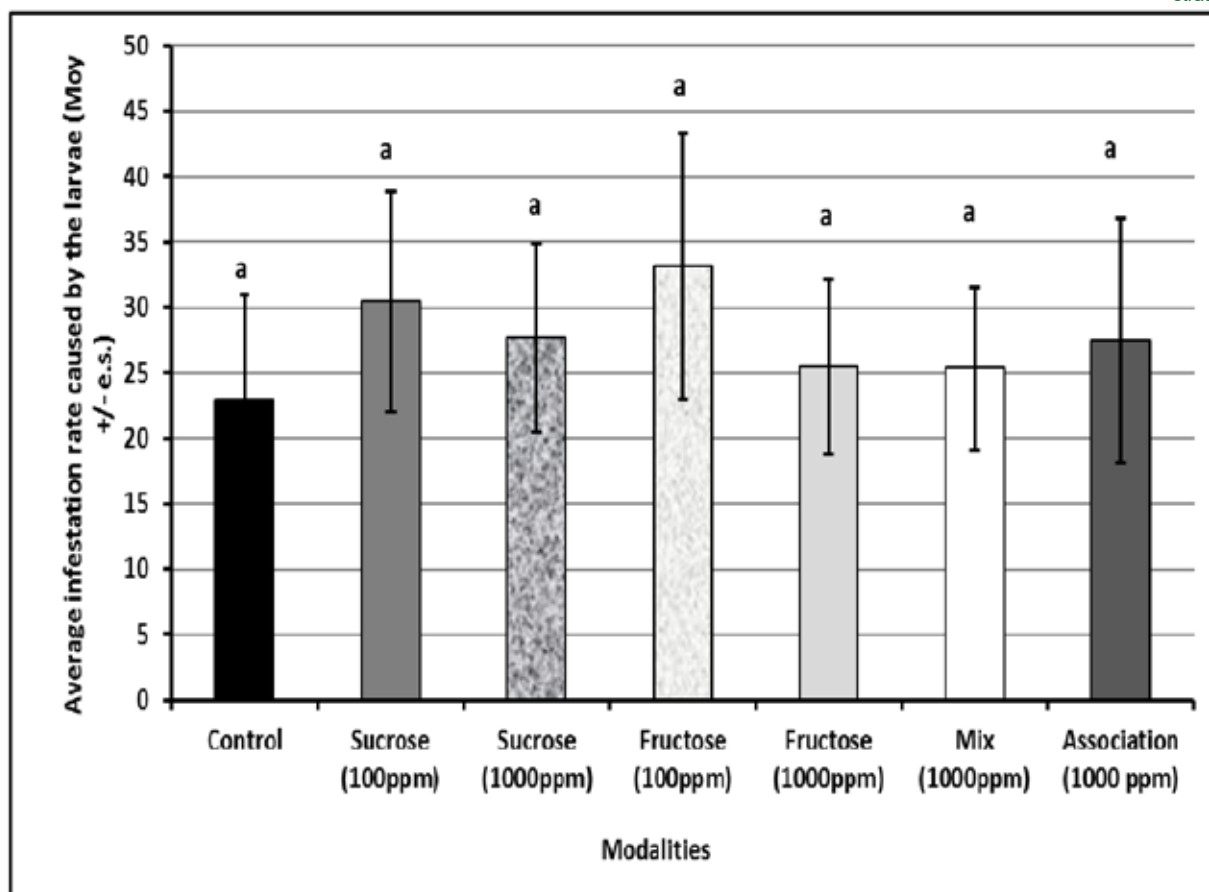


Fig. 2. Average total infestation rate caused by the *Tuta absoluta* larvae on tomato leaflets. ANOVA, Fisher's LSD tests,  $p < 0.05$ ; different letters show significant differences between treatments within each experiment

Table 1. Average rate of vertical infestation

Modalities	Basal layer	Medium layer	Apical layer
Control	35.52%±10.74 <sup>a</sup>	28.38%±9.80 <sup>ab</sup>	8.14%±4.45 <sup>b*</sup>
Sucrose (100 ppm)	42.73%±11.35 <sup>a</sup>	35.74%±8.58 <sup>a</sup>	17.12%±8.85 <sup>a</sup>
Sucrose (1000 ppm)	39.05%±11.29 <sup>a</sup>	38.47%±7.28 <sup>a</sup>	9.00%±4.93 <sup>b**</sup>
Fructose (100 ppm)	32.16%±11.90 <sup>a</sup>	39.77%±8.88 <sup>a</sup>	26.76%±10.49 <sup>a</sup>
Fructose (1000 ppm)	43.24%±11.04 <sup>a</sup>	31.53%±7.27 <sup>a</sup>	7.11%±3.99 <sup>b**</sup>
Mix (1000 ppm)	44.76%±10.14 <sup>a</sup>	31.09%±7.26 <sup>a</sup>	2.85%±1.57 <sup>b**</sup>
Association (1000 ppm)	37.04%±12.92 <sup>a</sup>	34.07%±10.86 <sup>a</sup>	13.40%±5.80 <sup>a</sup>

ANOVA, Fisher's LSD tests,  $p < 0.05$ ; different letters show significant differences between treatments within each experiment. \*\*:  $p \leq 0.01$  and\*:  $p < 0.05$

39.05%± 11.29 (vs. 35.52%± 10.74 for the control), in the case of the intermediate layer, only the fructose treatments applied at 1000 ppm (whether applied alone or in combination with sucrose at 1000 ppm), resulted in average infestation rates similar to the control (28.38%±9.80), with values of 31.53%±7.27 and 31.09%±7.26, respectively (Tab. 1).

The statistical analyses revealed significant, and

in some cases, highly significant ( $p < 0.01$ ) differences among the various leaf levels examined across the seven tested conditions. However, the apical level showed significant differences in the control group and highly significant differences for the treatments with sucrose at 1000 ppm, fructose at 1000 ppm, and the mixture at 1000 ppm, compared to the other levels studied.

**Table 2.** Effects of low-doses sugar spraying on the abundance of larval instar. ANOVA, Fisher's LSD tests,  $p < 0.05$ ; different letters show significant differences between treatments within each experiment.

\*:  $p < 0.05$

Modalities	L1	L2	L3	L4	Pupae
Control	0.37%±0.26 <sup>a</sup>	0.58%±0.35 <sup>a</sup>	0.33%±0.29 <sup>a</sup>	1.33%±1.04 <sup>a</sup>	0.13%±0.13 <sup>a</sup>
Sucrose (100 ppm)	0.58%±0.30 <sup>a</sup>	0.08%±0.08 <sup>a</sup>	0.62%±0.35 <sup>a</sup>	1.00%±0.91 <sup>a</sup>	0.00 <sup>a</sup>
Sucrose (1000 ppm)	0.28%±0.13 <sup>ab</sup>	0.83%±0.53 <sup>ab</sup>	0.58%±0.36 <sup>ab</sup>	1.96%±1.32 <sup>a</sup>	0.00 <sup>b*</sup>
Fructose (100 ppm)	0.20%±0.14 <sup>a</sup>	0.50%±0.46 <sup>a</sup>	1.13%±0.79 <sup>a</sup>	2.00%±1.48 <sup>a</sup>	0.04%±0.04 <sup>a</sup>
Fructose (1000 ppm)	0.33%±0.21 <sup>ab</sup>	0.29%±0.16 <sup>b*</sup>	0.62%±0.41 <sup>ab</sup>	2.00%±1.24 <sup>a</sup>	0.08%±0.05 <sup>b*</sup>
Mix (1000 ppm)	0.21%±0.11 <sup>a</sup>	0.25%±0.25 <sup>a</sup>	0.87%±0.83 <sup>a</sup>	0.54%±0.50 <sup>a</sup>	0.00 <sup>a</sup>
Association (1000 ppm)	0.45%±0.30 <sup>ab</sup>	0.71%±0.42 <sup>ab</sup>	0.54%±0.23 <sup>ab</sup>	2.75%±1.91 <sup>a</sup>	0.12%±0.06 <sup>b*</sup>

ANOVA, Fisher's LSD tests,  $p < 0.05$ ; different letters show significant differences between treatments within each experiment. \*:  $p < 0.05$

**Abundance of larval instar and pupae**

According to **Tab. 2**, almost all larval instars were present, though in variable abundance. An analysis of the average number of individuals at each developmental instar revealed that in the L1 instar, the lowest abundance of L1 larvae was observed when fructose alone was applied at 100 ppm, followed by application of mixture with respective values of 0.20±0.14 and 0.21±0.11. In contrast, the highest abundance occurred after foliar spraying of sucrose alone at 100 ppm.

In the case of L2 instar, the lowest L2 abundance was recorded in the sucrose at 100 ppm treatment (0.08±0.08), followed by fructose at 1000 ppm (0.29±0.16), and the mixture of the two sugars at 1000 ppm (0.25±0.25). On the other hand, the maximum average number of L2 was recorded in plants sprayed with sucrose alone at 1000 ppm (0.83±0.53), as well as in the association treatment at 1000 ppm. Considering the L3 instar, all the treatments exhibited higher abundances than the control's (0.33±0.29), reaching a maximum of 0.87±0.8 in the sucrose–fructose mixture at 1000 ppm, but no statistically significant differences were observed. Finally, in the L4 instar, the abundance was relatively low in the mixed treatment (0.54±0.50), while the other treatments showed L4 abundances that either exceeded or were close to those of the control. In the pupal stage, the average number of pupae forms was either zero or lower than that of the control for all treatments.

Statistical analysis of larval instar abundance revealed significant differences in specific treatments, particularly those with sucrose at 1000 ppm, fructose at 1000 ppm, and their combination at 1000 ppm. These differences allowed for the classification of

treatments into three distinct statistical groups: "a," "b," and "ab."

**Abbott Efficacy of Treatments**

Based on the results of our study across different treatment modalities, we observed that at the apical level, the application of fructose at 1000 ppm, when applied alone, as well as in combination with sucrose at 1000 ppm, reduced infestation rate to 7.11% and 2.85%, respectively, compared to the control group, which exhibited an infestation rate of 8.14%. These reductions correspond to Abbott efficacy gains of 12.65% and 64.98%. Regarding the basal level, fructose used alone at 100 ppm decreases the infestation rate by 32.16% compared to the control modality, which has an infestation rate of 35.52%, resulting in an Abbott efficacy of 9.45%.

**Discussion**

Several studies have actually proved that sugars such as sucrose and fructose, currently approved substances for controlling pests like the codling moth in apples and pears and the European corn borer can effectively enhance plant resistance. These sugars are believed to disrupt oviposition behaviour by modifying biochemical signals present on the leaf surface (Arnault et al., 2016; Brahim et al., 2018; Arnault et al., 2021; Brahim, 2022). Our study demonstrated their vertical distribution efficacy vs. *T. absoluta* on tomatoes, highlighting apical leaf targeting as a novel strategy for sustainable management.

However, this induced resistance may depend on various factors, including the type and concentration of sugar used, the developmental stage of the plant, the combination of sugars with other phytosanitary

products, the timing of application, and the level of pest pressure or infestation (Ferré et al., 2008; Derridj et al., 2011; Arnault et al., 2015; Lambion & Marollien, 2016; Arnault et al., 2021; Brahim, 2022).

Regarding the temporal progression of infestation, our results showed that during the first three weeks, the treatment consisting of a mixture of sucrose and fructose at 1000 ppm maintained the infestation level lower compared to those observed in the control group. The GRAB experiment on apples in 2017 (Lambion & Arnault, 2019), which tested the mixture of sucrose and fructose at 1000 ppm under field conditions, found that they provided moderate protection to fruits, particularly toward the end of the season. Our controlled trials on tomatoes revealed a vertical stratification of efficacy, likely due to host-specific leaf traits (e.g., trichome density) and cation gradients (Tiffrent, 2023). In a related study on maize, using three different sugars (glucose, sucrose, and fructose) at varying concentrations to mitigate borer-related injury, it was revealed that each elicited specific effects. For example, the application of sucrose at a concentration of 100 ppm was capable of reducing the development of *Botrytis* on tomatoes, while the application of sucrose at the same concentration was found to be less effective against *Botrytis* on beans (Ondet, 2010). These findings emphasize that each phytosanitary bio-aggressor requires a specific sugar and dosage for optimal effectiveness.

In general, our tests showed that sugar-based treatments did not significantly reduce the average total infestation rates on tomato leaflets independently of the modality tested. However, a vertical distribution effect was observed. At the basal level, fructose application at a concentration of 100 ppm caused a 9.45% reduction in the attack rate of leaf miner larvae, as measured by Abbott efficacy. However, no statistically significant differences were found compared to the control. At the median level, all treatment modalities exhibited relatively uniform infestation rates, with no significant differences and generally lower values compared to the basal level. On the other hand, at the apical level, foliar application of fructose at 1000 ppm and the mixture treatment of sucrose and fructose at 1000 ppm showed a protective effect on leaflets, achieving the lowest infestation rates with Abbott efficacy values of 12.65% and 64.98%, respectively. Conversely, at the basal level, these same treatments were not effective. Contrary to what has been demonstrated, female *T. absoluta* prefer the leaves of the apical part with lower calcium content for laying eggs rather than other parts of the tomato plant (Leite et al., 1999; Leite et al., 2004; Proffit et al., 2011; Cherif

& Verheggen, 2019). This contradiction could be explained by the effect of changes in the nutritional status of the leaves, particularly on the activity of the cations present on the leaf surface. In fact, Tiffrent (2023) has demonstrated that spraying glucose and fructose on apple trees increases the concentration of calcium present on the surface of apple leaves. The apical efficacy of sugars aligns with *T. absoluta*'s preference for low-calcium leaves (Leite et al., 2004), but our results suggest that sugars alter cation availability (e.g.,  $\text{Ca}^{2+}$ ) on treated organs (Tiffrent, 2023). Basal leaves, with thicker cuticles and lower sugar uptake, may resist this modulation.

Similarly, Derridj and Wu (1996) demonstrated that the corn borer lays its eggs on the leaf surfaces and levels of corn that are lowest in cations. Also, the variability observed across leaf levels may be attributed to differences in the developmental stage of the leaves and the severity of pest pressure. Indeed, apical leaflets, being younger, possess distinct morphological and chemical characteristics, such as the presence of trichomes and waxes, which influence the attraction or repulsion of biotic stressors compared to those of older layers. Ondet (2010) demonstrated that sucrose application on maize at a very early stage reduces the number of egg deposits by the corn borer.

Conversely, when the plant reaches the reproductive stage, this same foliar application increases the number of eggs laid by the corn borer. Lambion et al. (2018) reported through trials conducted in 2017 that the addition of fructose and sucrose to *Bacillus thuringiensis* Berliner at a concentration of 1 g/L enhanced its efficacy against *T. absoluta* under conditions of late and moderate attack. Fiala et al. (1993) proposed that the carbohydrate content in the phylloplane is correlated with that of foliar tissues, with monosaccharides appearing at the junctions of epidermal cells above the apoplastic regions. The adult lepidopteran insect *Ostrinia nubilalis* is sensitive to and responds to the detected sugar concentrations. These sugars are known to influence female host plant selection for oviposition, with fructose being the sugar most closely associated with female preference in host plant choice. According to Ondet (2018), and following the experiments conducted within the framework of the USAGE (2012-2015) and SWEET (2016-2019) projects aimed at controlling the apple codling moth, the efficacy of a mixture of fructose and sucrose at a concentration of 100 ppm was validated under conditions of pest pressure. Similarly, the study conducted by Brahim (2022) on the codling moth in Algeria supports these findings.

Foliar sprays based on sugars also led to significant variations in the abundance of the

different developmental stages of *T. absoluta*. Analysis of the tested treatment modalities revealed notable differences in larval instar abundance. The association treatment at 1000 ppm proved particularly effective, showing a significant decrease in the abundance of the larval instars L1, L2, and L4 compared to the control and other treatments. These results align with field trials conducted between 2006 and 2008 on apple trees by Anadiag, Innophyt, and ITCF, which evaluated the effectiveness of sucrose in combination with granulosis virus and in addition to classical phytosanitary products like Imidan 50 WP. Fructose alone at 100 ppm was only effective in reducing the abundance of L1, while sucrose sprayed alone at 100 ppm reduced the abundance of L2. These results support the idea that sugar-based treatments could be strategically applied to target the most vulnerable larval stages, particularly neonatal larvae, thereby optimizing plant protection timing (Ferré et al., 2008; Ondet, 2010). This is likely due to the very low number of chrysalises observed on the leaflets, which can be attributed to the generally low pupation rate of fourth-instar larvae on leaves. In fact, most pupation activity typically occurs in the soil. These findings are consistent with those reported by Barrientos et al. (1998) and Pereyra (2006), who found that pupation of the tomato leaf miner primarily takes place in the soil. The reduction in L1, L2, and L4 levels suggests that neonate larval development is interfered with, either through nutrient dilution (Spann & Schumann, 2010) or through induction of lignin/cellulose deposition (Tiffrent, 2023). These biochemical alterations must be measured in the future. In summary, though sugars may boost plant immunity to certain herbivores and pathogens, they may also act as oviposition disruptors by altering leaf surface biochemical cues. This could also raise interest regarding the feeding behavior of larvae in the case of the tomato/*T. absoluta* pair. In the field, we recommended 1000 ppm sucrose and fructose mixtures applied during the vegetative stage on apical leaves where *T. absoluta* oviposition is the highest. The integration of sugars with *B. thuringiensis* in IPM programs could potentially improve larval control at the cost of pesticides. Critical knowledge gaps are the effect of repeated sugar sprays on plant physiology (e.g., photosynthesis) and compatibility with *T. absoluta* natural enemies (e.g., *Trichogramma* spp.).

These findings make sugar sprays a sustainable control option for *T. absoluta*, as they are precise and have low environmental persistence. Future research directions include optimal application timing and testing field-scale efficacy against fluctuating pest pressure.

## Conclusion

In this study, our findings demonstrate that even micro-doses of sugar, specifically a combination of sucrose and fructose at 1000 ppm each, can evoke a synergistic effect, resulting in a reduction in infestation levels by the end of the experiment. However, this effect provides only limited protection against leaf miner larvae. Under field conditions, the efficacy of such treatments remains too low to justify their practical use as a standalone control method. Therefore, we strongly discourage the use of exogenous sugar treatments as the sole strategy for plant protection. A more effective approach would involve combining sugar applications with other phytosanitary products, whether biological or chemical. More broadly, given the growing need to reduce pesticide use, we suggest that sugars could be integrated into pest management programs as long as all interacting factors, application timings, and environmental conditions are carefully considered to optimize their use within an integrated pest management framework.

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