STUDIA UNIVERSITATIS BABEŞ-BOLYAI BIOLOGIA, 70, 1, 2025 (p. 133-152)
doi:10.24193/subbbiol.2025.1.07

The control of *Cydia pomonella* (L.) (Lepidoptera, Tortricidae) population using sugars under semi-arid climate (Batna, Algeria)

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Article history: Received 30 August 2024; Revised 2 April 2025; Accepted 26 May 2025; Available online 25 June 2025

Abstract. The codling moth remains the main pest of apples in the Batna region of Algeria and causes heavy damage to apple orchards. This paper aims to show the possibility of using insecticide (Thiacloprid which may provide selective control tools) and sugar (which may induce multiple systemic resistances) to control *Cydia pomonella*. The field trials were carried out on the "Anna" apple tree cultivar in Tilatou (Batna, Algeria). The efficacy of sucrose and fructose (100 ppm), in comparison to Thiacloprid (25 mL ha^{-1}), was assessed based on the proportion of fruits that larvae destroyed, the quantity of larvae gathered in corrugated cardboard, and the quantity of male moths trapped in pheromone traps. This study showed that all tested products reduced fruits damaged by *Cydia pomonella*. Treatments by sucrose and fructose provide percentages of damaged fruits at rates of 8.44±0.64 and 7.57±1.25, respectively, vs. 36.35±3.00 for untreated trees. The treatments also affected the number of larvae caught in bands of corrugated cardboard. Foliar spraying in the morning with sugar (every 20 days) can be an alternative method to manage the codling moth population. The use of sugars is a novel method in the plant protection strategy. These results constitute an interesting alternative to classical approaches offered by the opportunity to reduce the rate of chemical insecticides required for effective pest management.

Keywords: codling-moth, fruit damage, apple, sucrose, fructose.

Introduction

The majority of control techniques used in apple orchards aim to combat the codling moth (*Cydia pomonella* L.). The cryptic *Cydia pomonella* (*C. pomonella*) larvae live inside the fruit throughout their feeding stages, leaving an unattractive hole that may encourage internal rotting (Unruh *et al.*, 2016; Garczynski *et al.*, 2019; Nelson *et al*., 2021; Ju *et al*., 2023). Besides apples, they also infest pears, apricots, and walnuts. If left unchecked, it can result in extremely large yield losses of more than 95% (Unruh *et al.*, 2016; Damos and Soulopoulou, 2019; Shayestehmehr *et al.*, 2021; Mahendiran *et al.*, 2022). Consumers will not allow even minimal surface damage to apples or pears, and fruit that has been infected cannot be sold. Control measures are necessary when the estimated cost of treating a pest is lower than the cost produced by the potential damage (Baranek *et al*., 2021; Cahill *et al*., 2022; Eliceche *et al.*, 2023). The increasing reliance on chemicals has been associated to a number of issues, including hazards for farmers and consumers health; outbreaks in secondary pests controlled by natural enemies under toxic pesticides; environmental pollution; biodiversity reduction and pesticide resistance (Arnault *et al*., 2016; Baranek *et al*., 2021; Rani *et al*., 2021; Ali *et al*., 2023). Insecticide resistance is a major issue in the control of *C. pomonella* all over the world. Insecticide efficacy reductions on codling moths have been tested in pome fruit production locations across Europe, the Middle East, North America and South America (Chouinard *et al*., 2016; Unruh *et al.*, 2016; Kadoić Balaško *et al*., 2020; Gomez *et al*., 2023; Kaplan, 2023; Shayestehmehr *et al.*, 2021).

Sugars can function as signaling molecules in the same way that classical plant hormones routinely do, modulating gene expression and development processes of plants (Ahmad, 2019; Choudhary *et al*., 2022; Xu *et al*., 2022; Guo *et al*., 2023; Xie *et al*., 2023). However, the regulatory networks underlying are still not clear due to many cell signaling pathways involved. Environmental stresses, including pathogen infection and wounding, induce a series of defence responses that also interfere with carbohydrate metabolism and sugar-responsive genes (Moghaddam and den Ende, 2012; Saddhe *et al*., 2021).

It was discovered a long time ago that damaged plants had a higher sugar tolerance or high sugar resistance. More research is being done about the role of sugar signaling in plant defense mechanisms against fungi (Trouvelot *et al*., 2014; Tun *et al*., 2023). This has led to the sweet-immunity and sugar-enhanced defense concepts (Moghaddam and den Ende, 2013; Arnault *et al*., 2016; Tarkowski *et al*., 2019). Moghaddam and den Ende (2012) reported that the concept of sweet immunity predicts specific key roles for saccharides in the control of biotic and abiotic stresses. Few researches have been done on sugar and sugar polyols on the leaf surface that Lepidoptera females use as signals when identifying the plant where they should lay their eggs (Bertea *et al*., 2020; Formela-Luboińska *et al*., 2020). It was therefore hypothesized that sugar spraying may also increase plant resistance, and indeed, several studies showed such positive effects. Spraying soluble carbohydrates (sucrose, fructose, glucose, and trehalose) on the leaves of maize, tomato, potato, bean plants, and apple trees could induce resistance to pests and diseases (Ahanger *et al*., 2013). Furthermore, soluble carbohydrates sprayed at low doses can penetrate the cuticle and end up on the plant surface, constituting signals perceived by the insect through contact, then influencing its behavior and selection of the host plant to lay eggs (Derridj *et al*., 2011). Sucrose and fructose have also been shown to have some potential in the management of different parasites under low to moderate pest loads and on perennial crops (vineyards, arboriculture). In organic orchards, they reduce *C. pomonella* larval attack by 55% (Costantini and La Torre, 2022; Eliceche *et al*., 2023). The objective of the present study is to show the possibility of using sucrose and fructose to control *C. pomonella* in one of the important apple tree-growing regions of Algeria. The efficacy of these two sugars (100 ppm) was assessed for control of *C. pomonella* in an Algerian apple orchard cultivated with the "Anna" cultivar.

Materials and methods

Field experiments

This study was conducted in 2019 in Tilatou (Batna, Algeria) in an apple orchard (864 m^2) "Anna" cultivar. Tilatou is situated in the south-west of Batna (35°19'57.30" N 5°47'57.23"E) located in a semi-arid bioclimatic zone with a cold winter and an average altitude of more than 760 m above sea level (Fig. 1).

Observations were made on one apple cultivar "Anna". Differences in the percentage of *C. pomonella* larval damage and the efficacy of sucrose, fructose and thiacloprid treatments were observed in this cultivar. Four blocks of sucrose-treated trees, 4 blocks of fructose-treated trees, 4 blocks of thiacloprid-treated trees and 4 blocks of untreated trees. Each block comprises 4-7 trees. All modalities are then randomly distributed within each block (4) and each block comprises 4 to 7 trees (Table 1).

Figure 1. Exploitation and study orchard plan (Anna variety, Tilatou region)

Table 1. Experimental plan

Line 1	Line 2	Line 3	Line 4
I 1	II 3	III 2	IV 4
I 2	II 1	III 4	IV 3
I 3	II 4	III 1	IV 2
I 4	II 2	III 3	IV 1

Roman numbers represent different blocks; Arabic numbers correspond to the modalities. Were : (1) : Untreated modality, (2) : Sucrose, (3) : Fructose and (4) : Thiacloprid.

Foliar spraying

When the first codling moth males were captured in the pheromone traps that had been set up in the research orchard on April 25, 2019, the entire experimental plan was treated. An untreated orchard was used as a reference (Fig. 2), located in the same study region, Tilatou (35°26'52.26''N5°58'26.52''E).

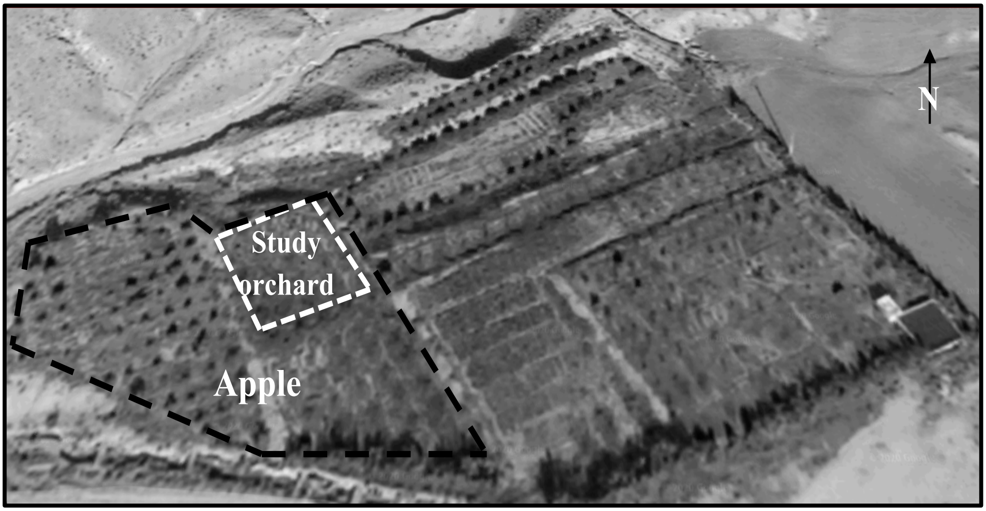

Figure 2. Exploitation and untreated orchard plan
(Golden delicious variety, Tilatou region)

In this orchard, *C. pomonella* dynamic flights were monitored by delta traps (Russell IPM, Algeria) baited with a standard pheromone capsule containing one mg of codlemone, installed at an approximate height of 1.70 m within the canopy of the tree, and checked every three days.

Treatment (= one foliar spray) was carried out very early in the morning, at the start of photosynthesis (Preininger *et al*., 2018), throughout the season during three insect generations, and until the harvest. The sucrose and fructose were sprayed every 20 days, and two applications with thiacloprid were done throughout the season on the whole tree (June 6th and 28th).

The sucrose used was from Fluka Biochemika (99% purity) used at 100 ppm (10 g 100 L^{-1}) dose. Previously weighted and brought into tubes for the amount of water sprayed. The use of sugar in the morning promotes its penetration when the apoplast (intercellular space) is poor. The chemical insecticide used is thiacloprid (Calypso480 SC, Bayer Crop Science), with a rate of 250 mL ha^{-1}. It is a specialty belonging to the chemical family of chloronicotinyls and neonicotinoids class. This insecticide was chosen because farmers in the region of Batna commonly use it. It is a systemic insecticide that acts by contact and ingestion on the insect nervous system (Gupta *et al*., 2019). This class of insecticide acts as agonists to acetylcholine, binding to postsynaptic nicotinic acetylcholine receptors, and causes paralysis and death of the insect, often within a few hours (Windley *et al*., 2017).

To perform different treatments, we used three backpacksprayers (Lion Mark), one sprayer for each modality, to avoid the risk of sugar contamination. The main material of the sprayer: plastic; power source: pressure, type; hand compression; pressure: 0.2-0.4 Mpa, (not dripping spray), capacity of 20 L (to spray the whole tree). To provide optimum security and prevent risks of intoxication during the execution of treatment with thiacloprid, personal protective equipment was used, including nitrile gloves, waterproof coveralls with hoods, boots, and a mask. The four modalities tested, as well as the doses administered for each modality, are represented in the Table (2).

Table 2. Modalities tested and doses used in the trial

Modalities	Formulated product	Active constituent	Dose
1	Untreated	Untreated	Untreated
2	Sugar	Sucrose	100 ppm (10g $100L^{-1}$)
3	Sugar	Fructose	100 ppm (10g $100L^{-1}$)
4	Calypso 480 SC	Thiacloprid	250 mL ha^{-1}

Estimation of diapausing larvae

On the tree trunk, bands of corrugated cardboard were positioned on May 6, to catch the larvae that were descending to overwinter under the tree (four to seven bands per block). These strips consist of two overlapping sheets of corrugated cardboard covered with a polyethylene mesh. The three layers are attached with wire. The mesh is designed to prevent birds from feeding on larvae. Trap bands are arranged around the base of the trunks of 76 experimental trees, close to the ground. Bands were removed on November 12.

Estimation of infested fruits

It consists of observing fallen and damaged fruits per tree during the fruiting period and damaged fruit at harvest per tree (August 7). Every week, the fallen fruits were collected from the ground and removed to distinguish those damaged by *C. pomonella* from those due to other causes. Observation and confirmation of codling moth damages on apples are made in the laboratory to distinguish between active, scarred or stopped damages.

Statistical analysis

The number of diapausing larvae and percentage of damaged fruit per tree were examined using ANOVA and Fisher's LSD test at $p<0.05$, respectively, to determine significant differences between means. Percentages of damaged fruits by larvae in the orchard were compared using the Abbott efficacy equation (Abbott, 1925):

$$\text{Efficacy} = 100 \times [(T0 - Tt)/T0].$$

where T0 is the total percentage of damaged fruits in the control block and Tt is the total percentage of damaged fruits in the treated block. All analyses were performed using STATISTICA 8 software v. 2008 (Stat Soft).

Results

The dynamic of C. pomonella flights

Flight of the codling moth began in first week of May in both these orchards (Fig. 3). In both the study and untreated orchard, catches in the *C. pomonella* pheromone traps dropped below detection levels after early November (Fig. 3). At these sites the codling moth went through three full generations and part of a fourth generation, and at least six moths co-existed during most months of research. In the studied test-orchard and the following non-sprayed one we confirmed the importance of catch for the first generation.

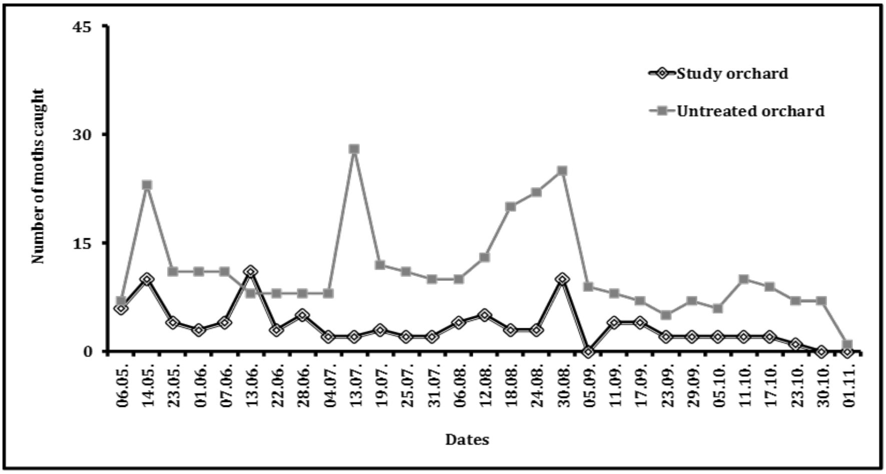

Figure 3. The dynamic of *C. pomonella* flights in the research orchard and the control orchard.

The first flight took place from May to the end of June; the second started in July and ran through the second week of August; and the third flight, began in second decade of August and runs until the first week of October. From there we can consider that the development of a fourth generation stopped. The dynamic of *C. pomonella* populations was related to the different phenological stages of the host plant (Fig. 4).

Estimation of diapausing larvae

A total of 205 larvae were observed and removed from bands of corrugated card board installed at the beginning of the experiment. Most of the larvae were located in untreated trees.

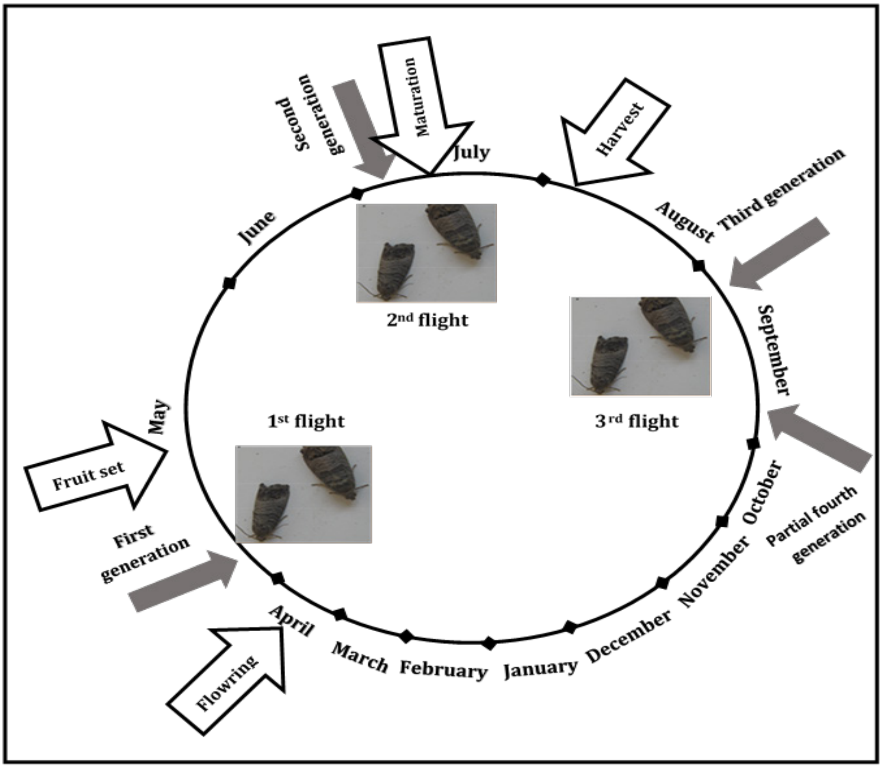

Figure 4. Life Cycle of the codling moth in an orchard that cultivates the "Anna" variety.

The greatest number of larvae per tree in treated blocks with thiacloprid, fructose and sucrose was, on average, 9.75%±0.69; 8.03%±0.77; and 9.25%±0.55, respectively. The average number of larvae collected in untreated blocks was 15.25±0.79. The numbers of larvae per tree band were similar for fructose and sucrose; there were highly significant differences between them and those untreated and treated with thiacloprid (ANOVA, Tukey's L.S.D. tests, $p < 0.05$) (Fig. 5).

On the other hand, the number of diapausing larvae captured in bands of trees sprayed with sucrose and fructose was approximately five and three times (in order) lower than those observed in untreated trees and, respectively, three and two times lower than those treated with thiacloprid (Fig. 5).

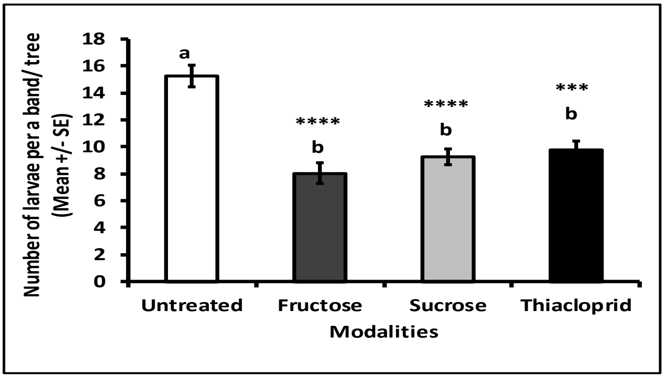

Figure 5. Average (±Standard Error) number of caterpillars per band or tree.
*ANOVA, Fisher's LSD tests, p<0.05; different letters show significant differences between treatments within each experiment. ****: p< 0.0001 and ***: p = 0.005.*

Damaged fruits

The counting at the end of the three generations on the attacked fruits of the trees of the experimental plan allows estimating the levels of efficiency of the tested modalities. The first falls were recorded in June. The losses increased over time and the most common attacks were caused by the second-generation caterpillars.

The percentage of damaged fruit at the end of the first generation was high. It reached 38.10%±9.33 in the untreated block, while the other modalities had a lower percentage of damaged fruit. Fructose, sucrose and thiacloprid showed a significant reduction in infestation levels of 14.01%±1.54, 13.38%±1.60 and 16.74±5.34% respectively, compared to the untreated modality (ANOVA, Fisher's tests, p< 0.001) (Fig. 6a).

For the second generation, the same assessments are recorded. Compared to the untreated trees we noted a higher significant reduction in the percentage of damaged fruit on trees treated with fructose (26.84%±9.53) and sucrose (28.33%±7.01). The application of thiacloprid showed also reduction in apple fruit damages, reaching 33.06%±4.39 compared to the untreated trees (59.77%±12.35) (ANOVA, Fisher's tests, p< 0.001) (Fig. 6a, 6b).

As for the first two generations, the third (partial) generation shows the same observations. Nevertheless, infestation levels are lower than those reported in the first (38.10%±9.33) and second generations (59.77%±12.35), where the latter has the highest percentage of infestation. The count at the end of the third generation shows an infestation level of 26.20%±5.77. Note that the tested modalities reduce the percentage of damaged fruits to 17.36%±4.62, 18.43%±3.20, and 19.88%±5.21 recorded by fructose, sucrose, and thiacloprid, respectively (Fig. 6c).

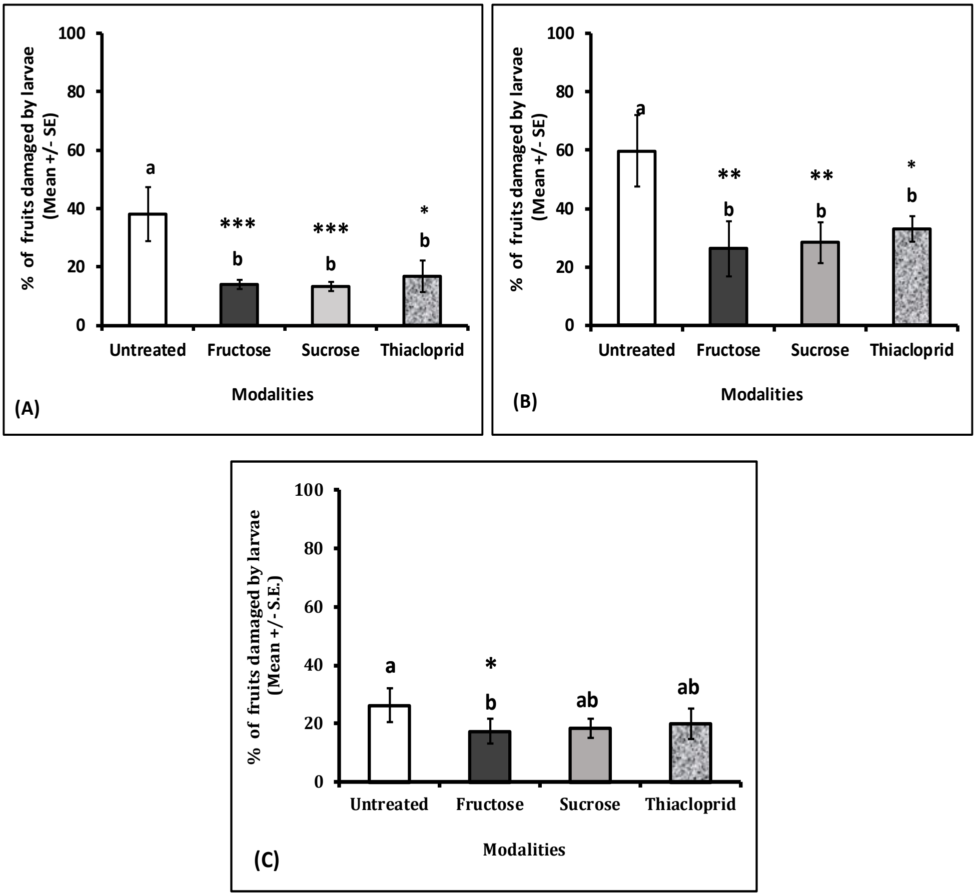

Figure 6. Mean (± SE) percentage of fruits damaged at the end of the first generation (A), the second generation (B), and the third generation (C) by larvae on "Anna" cultivar. *ANOVA, Fisher's LSD tests, p<0.05; different letters show significant differences between treatments within each experiment. *: p<0.05, **: p<0.01 and ***: p< 0.001.*

Fruit damage types

There were three types of fruit damage at harvest: scared, stopped, and active. The sucrose and fructose treatments had similar and significantly different percentages from trees that had not been treated ($p < 0.0001$) and from trees that had been treated with thiacloprid ($p < 0.01$) (Fig. 7a). For fallen fruit rates, they were similar and not significantly different between fructose and sucrose for any type of fruit damage and significantly different from untreated and thiacloprid-treated trees for scared and active fruit damage. For stopped fruit damages, all modalities did not differ significantly. Treated trees with thiacloprid showed more active and scarred damages than treated trees with fructose and sucrose, whatever damaged or fallen fruits at harvest (Fig. 7b).

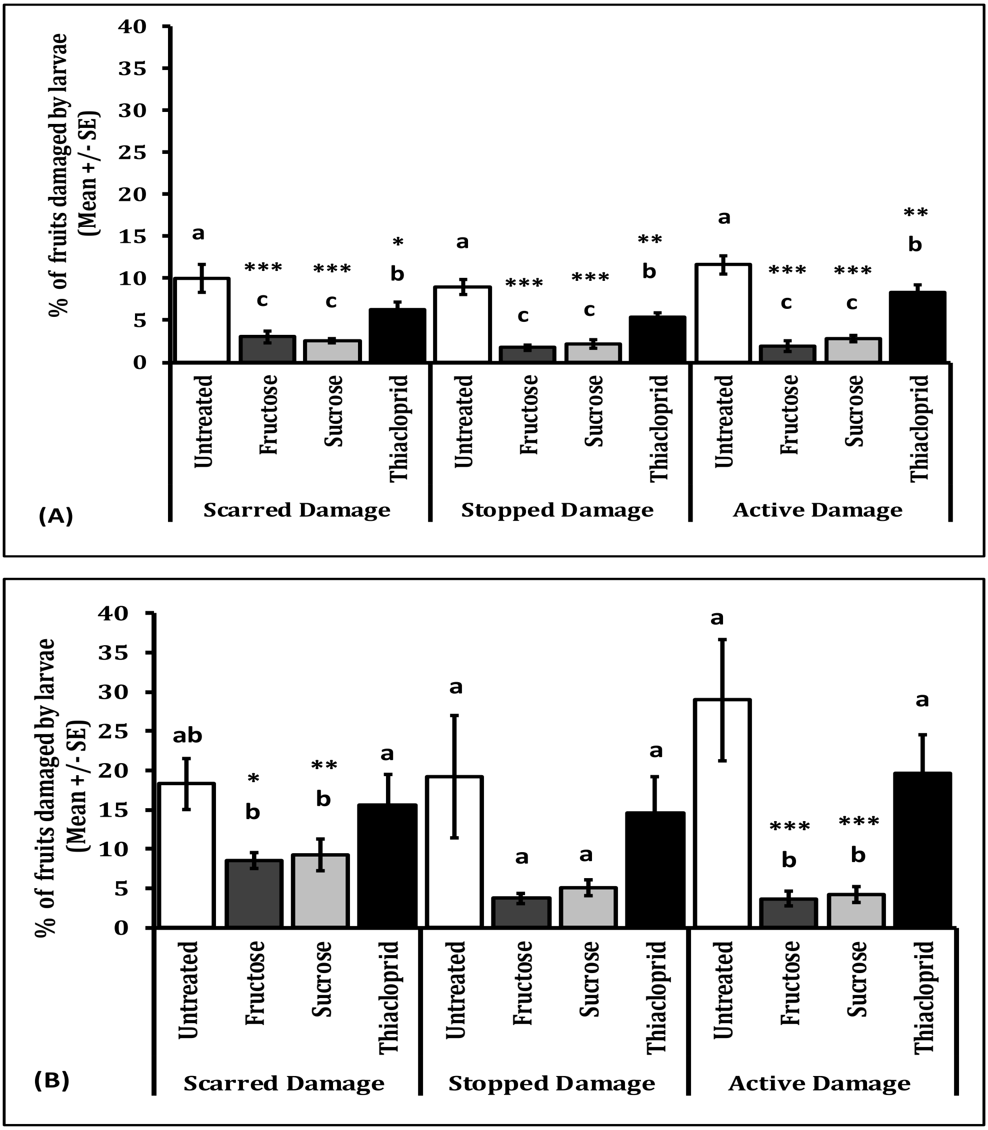

Figure 7. Mean (± SE) percentage of different fruits damaged at harvest (A) and fallen fruits (B) by larvae on "Anna" cultivar. *ANOVA, Fisher's LSD tests, $p<0.05$; different letters show significant differences between treatments within each experiment. ***: $p<0.001$, **: $p \leq 0.01$ and *: $p<0.05$.*

Abbott efficacy

For the three generations, treatments based on infra-doses of sucrose, fructose, and thiacloprid allow to obtain a low to very important and significant efficiency between 22.95%±3.75 and 80.82%±2.59. Take note that thiacloprid, fructose, and sucrose all provide the best mean Abbot efficacy regardless of the generation. Figure (8) shows that the best results are recorded in the first generation by fructose (78.65%±2.17) and sucrose (80.82%±2.59), while thiacloprid has the highest efficiency in the second flight (32.3%±6.17) ($p<0.0001$, ANOVA, Fisher's L.S.D. tests, $p< 0.05$).

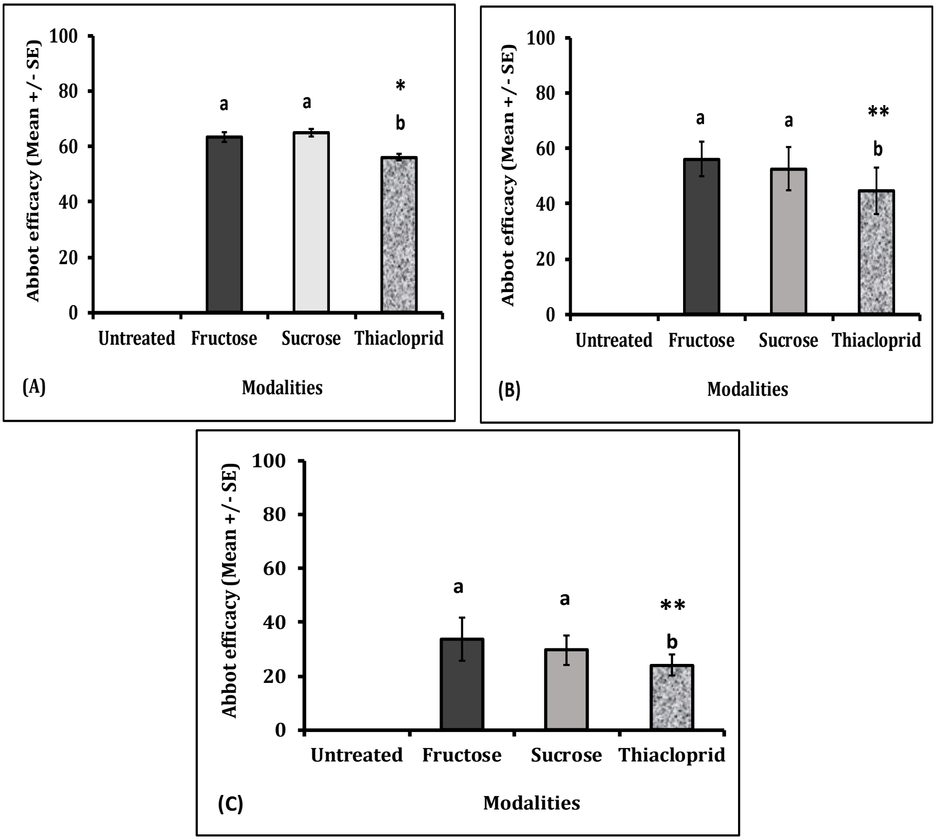

Figure 8. Mean Abbott effectiveness levels for sugar, insecticides (chemical and bio-insecticides), and damaged fruits at the end of the first generation (A), the second generation (B), and the third generation (C) by larvae on the cultivar "Anna" (Efficacy level in percent vs. untreated control damage level). *ANOVA, Fisher's LSD tests, $p <0.05$; different letters show significant differences between treatments within each experiment. *: $p<0.05$, and **: $p \leq 0.01$ are all present.*

Discussion

The dynamic of C. pomonella flights

The codling moth in Batna has three full generations and a partially developed a fourth generation, according to monitoring of its flight patterns conducted in two distinct orchards. In the research orchard, where male pheromone trap captures showed a total of 101 individuals and 322 individuals in the untreated orchard, the codling moth population density was rather low, according to the results that have been provided. The catches per trap were higher in the untreated orchard, confirming the permanent risk of this insect over the years. Work in most areas of Batna indicates that *C. pomonella* has two to three generations per year. For example, in Tazoult (altitude 1000 m) and Lambiridi (altitude 1075 m), there are three generations per year. In the Tizi-Ouzou area, there are three generations per year (Guermah and Medjdoub-Bensaad, 2016). And four generations in Morocco, with two full generations and two partial generations (El Iraqui and Hmimina, 2016a).

According to El Iraqui and Hmimina (2016b), the generation number changes depending on the altitude and is also related to temperature, which decreases by 3 degrees every 100 m of altitude (Gutiérrez-Gamboa *et al.*, 2021). And it also comes from the spatial-temporal equation, related mainly to photoperiod and nutrition (El Iraqui and Hmimina, 2016a; 2016b; Hill *et al.*, 2021).

Estimation of diapausing larvae

The sugar treatments and significantly reduce codling moth larval populations. Reduced codling moth larvae on corrugated cardboard bands suggests a decline in the adult population during the next few years. And its importance should not be underestimated given the role of these bands in the decreasing populations of codling moths (Arnault *et al.*, 2015; 2016). It has been demonstrated that when the codling moth population density is relatively low, the sucrose and fructose treatments may be successful at controlling the pest.

The lower number of larvae in band traps, in both, tested modalities compared to the untreated modality indicates that they had a significant effect on larval populations. The reduction of the number of hibernating larvae in the two biological strategies is an encouraging result.

Damaged fruits

Chemical treatments (Calypso 480 SC Chloronicotinyls) showed that this product has a greater effect on reducing damage. In Morocco, a comparative study of thiachlorpid with other active ingredients showed a reduced sensitivity of the field population for thiacloprid and deltamethrin, followed byazinphos-methyl and diflubenzuron (El Iraqui and Hmimina, 2016a).

The number of damaged fruits has decreased due to the application of sugars, whose effectiveness is enhanced when applied during the day.. It was also sufficient to preserve the fruits from attacking when the majority of the first-generation larvae emerged (Xi *et al*., 2021).

The induction of changing surface signals is necessary for host recognition and *C. pomonella* egg-laying. Foliar sprayings of maize with low concentrations of sucrose (1 to 10 mg L^{-1}) have a systemic impact on the plant and decrease *Ostrinia nubilalis* egg-laying (Derridj *et al.,* 2012). This could reduce the damage caused by *C. pomonella* and lepidopterans, to an apple. The trials conducted under semi-field circumstances revealed that the apple trees leaf surface composition and even the codling moth's egg distribution changed 20 days after being treated with sugar at 10 ppm (10 mg L^{-1}). Also, sugar-modified leaf surface signal recognition by the codling moth females and ABBOTT efficiency average on 4 years of experiments is 40+/-16.0% on the apple infests. Sugars can also reduce powdery mildew in melon cultures (Arnault *et al*., 2015). The significant reduction in larval damages can probably be explained by the fact that the sugar-induced systemic resistance vs. *C. pomonella* is due to the modification of metabolites present at the surface of leaves and fruits, some of which are signals for the insect that disrupt host recognition and egg-laying. According to the chemical examination of the metabolites on apple tree leaves, the sucrose treatment mostly caused changes (in terms of amounts and ratios) in metabolites, which altered the signals for the insect's host acceptance and egg-laying (Arnault *et al*., 2016).

Fruit damage types at harvest

Whatever damaged or fallen fruits were at harvest, the fructose treatments showed that scarred damages were much higher than stopped or active ones . Reporting that on an infected host, this delay may allow for continued feeding and producing healed fruits. According to Cabanat (1999), sucrose and fructose are phagostimulants that increase feeding by larvae at a dose of 100 ppm. In contrast, glucose has a repellent activity that diminishes at 100 ppm and induces a phagoinhibitory effect. In our case, we can say that the spraying of sugars alone, in mixtures, and in alternation induces a repellent activity on the larvae, which is reflected in a high percentage of stopped attacks.

In general, regardless of the type of damage and the fallen or harvested fruits, the reduction in infestation rates is explained by the fact that certain groups of plant-derived molecules. serve as signals perceived by the pest on the surface of the plants, influencing its behavior, stimulating oviposition in females, and affecting the feeding behavior of adults and larvae in several insects (Cabanat, 1999; Vrieling and Derridj, 2003; Derridj *et al.,* 2011). Additionally, the penetration of soluble substances (soluble sugars and polyols) in water deposited on the surface of the plant can stimulate defense reactions within the plant.

Few studies revealed that sugar foliar spray alone has interesting effects and when combined with chemical plant protection products, it allows reducing their doses while keeping a good efficiency. Sugars activate defense pathways but not always in the same way (Arnault *et al*., 2021).

Abbott efficacy

Regardless of any damaged or fallen fruit at harvest, sugar and the chemical treatments (Calypso 480 SC Chloronicotinyls) recorded Abbott's best average efficacy. This can be explained by several experiments conducted to test the efficacy of these modalities for the control of *C. pomonella* in apple orchards. Research results widely differ from one study to another, but generally, the application of the insecticide allows a significant decrease in the population of codling moths, as well as crop damage (Arnault *et al*., 2015).

The outcomes are in line with those of Arnault *et al*. (2016), who reported the findings of seven studies performed in apple orchards in Algeria and France between 2013 and 2014. After applying sucrose at 0.01%, the number of contaminated apples decreased. Sucrose had a mean Abbott effectiveness of 41.0%±10.0. Also, it was demonstrated that when sucrose was combined with the insecticide thiacloprid, it increased the effectiveness of the thiacloprid treatment by 18%. The researchers concluded that the interaction between sucrose and thiacloprid is not additive but rather synergistic and potentiating.

Conclusions

The employment of sucrose and fructose treatments as biological controls in agriculture holds a lot of promise for the environmentally friendly management of insect pests. According to the results, these two sugars can be used as a substitute for controlling codling moth populations and fruit damage levels in apple orchards. We also observed that it is an easy and safe method that benefits humans, wildlife, and the environment. By misting plants with little amounts of sugar, we were able to create plant resistance to *C. pomonella* behavior (antixenosis) (only 100 ppm). The occurrence appears to be widespread and repeatable. Additionally, it is administered easily with a standard sprayer, just like a chemical insecticide. This method of management should have the benefit of preventing plant damage brought on by neonate larvae. New directions in crop protection research will open up with the findings of the induced processes.

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