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Original Article

Sustainable management of the codling moth *Cydia pomonella* (Lepidoptera: Tortricidae) using sugar in Northeast of Algeria

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Abstract:

The research aimed to test whether foliar sugar sprays are effective in promoting Anna apple tree resistance to the codling moth (*Cydia pomonella* L.), a key pest in Algeria. The sucrose, fructose, and blend mixture (100 ppm) treatments at low concentrations were evaluated in an experiment conducted in Batna from 2017 to 2019. Treatments were applied 21 days apart, starting after flowering and continuing until harvest, to stimulate trees' innate immunity through "sugar immunity." Results indicated a significant reduction in infestation levels, from 42.62% to 12.24%, with sucrose alone being the most efficient (11.57%–14.91%). Reductions were also obtained with fructose and the mixture. Infestation levels were lower in 2018 and 2019 compared to 2017, which is attributed to climatic factors. The study emphasizes the effects of climate change on pest ecology and encourages the use of sugar-induced immunity rather than chemical insecticides, recognizing the need to carefully manage application times and dosages amid global warming challenges

Key words:
Anna variety, biocontrol, enhanced defence, infestation rate, sugar signalization

Apstrakt:

Održivo suzbijanje jabukinog smotavca *Cydia pomonella* (Lepidoptera: Tortricidae) primenom šećera u severoistočnom Alžiru

Istraživanje je imalo za cilj da ispita da li folijarne aplikacije šećera mogu da povećaju otpornost stabala jabuke sorte Anna na jabukinog smotavca (*Cydia pomonella* L.), jednog od glavnih štetočina u Alžiru. Tretmani saharozom, fruktozom i njihovom mešavinom (100 ppm) pri niskim koncentracijama ispitani su u ogledu sprovedenom u Batni od 2017. do 2019. godine. Tretmani su primenjivani na svakih 21 dan, počev od završetka cvetanja pa sve do berbe, u cilju stimulacije urođene imunosti stabala putem „šećerne imunosti". Rezultati su pokazali značajno smanjenje nivoa infestacije, sa 42,62% na 12,24%, pri čemu je saharoza pokazala najveću efikasnost (11,57%–14,91%). Smanjenje infestacije zabeleženo je i kod fruktoze i mešavine. Niži nivoi infestacije u 2018. i 2019. godini u poređenju sa 2017. pripisuju se klimatskim faktorima. Studija ističe uticaj klimatskih promena na ekologiju štetočina i podstiče upotrebu imunosti indukovane šećerom umesto hemijskih insekticida, uz naglašavanje potrebe za pažljivim upravljanjem vremenom i dozama primene u uslovima globalnog zagrevanja.

Ključne reči:
sorta Anna, biološka kontrola, pojačana odbrana, stopa infestacije, šećerna signalizacija

Introduction

The domesticated apple tree, *Malus domestica* Borkh., is one of the most cultivated fruit species in the world, second only to citrus in demand and third only to bananas and grapes in production, with a production of 87.82 million tons in 2019 (FAO, 2021). Apple cultivation in Algeria covered an area of 32,989 hectares in 2019, yielding an output of 5,588,300 quintals (FAO, 2021). Apple cultivation around the Batna region was increased from 3,288.27 hectares in 2009, to 4,537.01 hectares during 2019, whereas production increased from 167,094 to 1,012,240 quintals over the same period (DSA, 2020). From nearly 6,000 cultivated apple varieties, six make up 90% of the national production in Algeria (MADR, 2019).

Despite the expansion of cultivated areas, production levels have remained low due to factors such as cultivation practices, orchard age, fertilization practices, soil management, and pest control. Apple trees are affected by numerous diseases and insect pests, among which the codling moth (*Cydia pomonella* L.) is the most damaging pest of apples worldwide (Boivin et al., 2001; 2003; McGuffin et al., 2014; Reyes et al., 2015). If left unchecked, codling moth can cause yield loss of up to 100% (Beers et al., 2003; Sauphanor et al., 2009). The larvae damage the fruit by boring into it, resulting in the loss of marketable apples, and even more than 1% damage is considered unacceptable in commercial orchards (Benoît et al., 2009; Belkair, 2018).

Fruit growers are forced to treat their orchards annually for pest management and rely solely on chemical management with 7 to 8 applications per year on average. The overuse of insecticides has led to immense loss of biodiversity of beneficial insects (Ismail & Albittar, 2016). Further, synthetic pesticides have been found to be responsible for neurological diseases, and it has become a concern whether they affect health or contribute to environmental problems (Baldi et al., 2013; Choinard et al., 2016). Therefore, it is a critical necessity to develop management strategies that provide sustainable, biocompatible, and effective alternatives for chemical pest control.

Innovative methods for stimulating the plant's natural defenses are also being developed. Although this view has become quite popular, researchers have chosen the path of indirect defense by either empowering plants to defend themselves or changing the plant's own defense processes against the aggressor. An elicitor representing the newly explored and promising avenue is sucrose, which acts in the insecticidal action by stimulating plant immunity and defense mechanisms (Bolouri Moghaddam & Van den Ende, 2013; ITAB, 2018). The use of these water-soluble plant-derived compounds (such as sugars) allows them to penetrate the leaf and serve as genuine signals that trigger a cascade of defensive reactions in the plant. Furthermore, these molecules present in the plant can cross the cuticle and, at the plant's surface, act as signals perceived by insects through contact, thereby influencing their behavior and host plant selection for oviposition (Derridj et al., 2011a). The concept of "sweet immunity" or "sugar-enhanced defense" is based on accumulating evidence that endogenous sugars may function as signaling molecules activated by stress exposure, thereby triggering a more rapid and robust amplification of defense mechanisms, immunity, and stress tolerance (Tarkowski et al., 2019). In recent years, sugars like glucose, fructose, and sucrose have developed several significant regulatory roles and hence are increasingly recognized as signaling molecules in plants, modulating the expression of genes related to plant metabolism, resistance to stress, and development. This creates an opening for soft priming, a defined physiological process preparing plants for a quicker and/or stronger defense response to future stress conditions without incurring the costs of implementing a fully induced defense response (Arnault et al., 2015; Ceusters et al., 2017). This introduces a new concept of sugar-related defense (Arnault et al., 2015). Foliar spraying of low doses of sugars induces a response in the plant, resulting in increased resistance to biotic stressors. The application of sugars has shown promising results in apple and grapevine models (Arnault et al., 2015; 2016; 2021).

The objective of this study is to test the effect of ultra-low doses of commercial sugar sprays during the period from 2017 to 2019, in order to reduce attacks by the codling moth on apples and pears, as well as to decrease the number of *C. pomonella* larvae in an apple orchard of the Anna variety, located in the Tilatou region (Batna province, Algeria).

Materials and Methods

The experiment was conducted in an apple orchard (Anna variety) located in the Tilatou region (35°19′57.30″ N, 5°47′57.23″ E), about 45 km southwest of Batna province, at an altitude of 900 meters above sea level. The study lasted three years, from 2017 to 2019. The region is characterized by an arid climate ($Q2=34.68$), with average annual rainfall ranging from approximately 169 to 338.8 mm, and average temperatures from -1.5 °C to 38.0 °C.

According to the orchard owner, codling moth infestations have been observed since 2013, with damage reaching an average of 80% in this untreated orchard. In addition to apple trees, the orchard includes plots of pear trees, apricot trees, olive trees, pomegranate trees, and a small number of fig trees.

The experiment was conducted from 2017 to 2019, using a randomized complete block design (Fisher) with four replications. The four treatments were randomly assigned within each block, and each block contained 12 trees. The four tested modalities and the doses applied for each modality are presented in **Table 1**. It should be noted that the sugars used are sourced from Cevital company (Algeria).

The choice of this dose is based on studies of sugar sprays (sucrose, fructose, glucose) applied to crops at concentrations ranging from 0.1 g to 10 g/100 L, targeting various bioaggressors such as the corn borer (*Ostrinia nubilalis* Hbn.), codling moth (*C. pomonella* L.), melon powdery mildew (*Oidium*

Table 1. Tested modalities and doses used

Year	Modalities	Active substance	Formula	Dose
2017-2019	1	Control	Water	/
	2	Commercial sucrose (SucC)	Sugar	100 ppm
	3	Commercial frucrose (FrucC)	Sugar	100 ppm
	4	Mixture (SucC+ FrucC)	Sugar	100 ppm +100 ppm

neolycopersici L. Kiss), and gray rot (*Botrytis cinerea* Pers.). These studies have shown greater activity at extremely low concentrations compared to those above 100 ppm. It should be noted that increasing the dose beyond 100 ppm (10 g per 100 L) does not enhance resistance induction effects and may even negate them (Ferré, 2008; Derridj et al., 2009; 2012). In addition, higher doses may cause side effects, such as altering insect feeding behavior and potentially affecting the epiphytic flora or the epiphytic phase of certain pathogens prior to contamination, as well as impacting bioaggressors on the plant surface (Derridj et al., 2011a; Arnault et al., 2016).

Applications began at the end of flowering (April) in all three blocks and were repeated every 21 days until harvest in August (Ondet & Gorski, 2015; Arnault et al., 2016; 2021). This interval is based on trials conducted in France on two lepidopteran species (*Ostrinia nubilalis* and *Cydia pomonella*) (Derridj et al., 2009; 2012; Ondet & Gorski, 2015; Arnault et al., 2015; 2016; 2021). A total of six treatments were applied each year (**Table 2**). Treatments are conducted very late in the day, starting at 5:00 PM, because at that time the leaves naturally contain less sugar (the apoplast or intercellular space is poor), which facilitates penetration and modifies the balances on the surface of the plant, inducing systemic resistance through a "sugar" signal. The female codling moth poorly recognizes the treated plant and does not lay her eggs on it (Derridj et al., 2011b).

The treatments were applied using a 16 L backpack sprayer (main material: plastic; power source: pressure; type: hand compression; non-drip spraying) with four sprayers used, one for each modality, to avoid the risk of sugar contamination), attempting to spray the entire tree. Spraying on the bark should also allow for the penetration of sugar into the plant (Derridj et al., 2009). 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 water is suited for vegetative development to ensure proper wetting of the vegetation. The sugars were put into solution and dissolved just before pulverization (Ferré et al., 2008). The observations focused on counting the fruits attacked by the codling moth and were conducted on the fruits in each elementary plot (the fruits examined on the tree as well as the fruits that fell to the ground). The fruits examination was conducted every 7 days until harvest. During the season, the fallen fruits under the identified trees were examined, and after each examination, these fruits were removed from the trial because the apples rot, and the damage caused by the codling moth can no longer be seen (Derridj et al., 1999). For all the remaining fruits on the tree, the assessment was carried out at harvest.

Table 2. Treatment dates

Treatment no.	Year		
	2017	2018	2019
1	13.04.	26.04.	13.04.
2	03.05.	06.05.	03.05.
3	23.01.	27.06.	23.05.
4	12.01.	17.07.	12.06.
5	02.11.	06.08.	04.07.
6	22.01.	10.08.	24.07.

Bands of corrugated cardboard (15 cm wide, 60 cm long) were placed in May of each study year on tree trunks to trap larvae (L5), males, and females coming down to the base of the tree to enter diapause. Each band consisted of two superimposed sheets of corrugated cardboard covered with a polyethylene mesh. The three layers were secured with wire, and the mesh was designed to prevent birds from feeding on the larvae. The trap bands were positioned around the base of the experimental tree trunks, close to the ground. Bands were removed at the end of October each year, coinciding with the end of the third generation of this pest in the area (Brahim, 2010; SRPV, 2017).

All analyses were performed using STATISTICA 08 software. For each modality, we compared the means of each variable, the overall mean infestation rate, average number of larvae captured, and the

Abbott efficacy treatment. The Abbott efficacy equation (1925) is:

$$\textbf{Efficacy} = 100 \times [(T_o - T_t)/T_o]$$

where T_o is the total percentage of damaged fruits in the control block, and T_t is the total percentage of damaged fruits in the treated block. Comparisons were made using analysis of variance (ANOVA), followed by post hoc analysis with Fisher's LSD test. Prior to analysis, the assumptions for using this test were verified, including the normality of distribution with the Shapiro–Wilk test.

Results

Infestation rate caused by C. pomonella

The infestation rate caused by the codling moth in 2017 was higher compared to that recorded in 2018 and 2019, ranging from 42.62%±5.75 to 12.24%±2.14, regardless of the treatment modality tested on the Anna variety (**Table 3**). The attack rate in treated plots was reduced and appeared to be two to three times lower than that recorded in the control. Among the treatments, the SacC (100 ppm) modality consistently showed the lowest infestation rate across all study years, with values ranging from 11.57%±2.02 to 14.91%±2.43, compared to the FrucC modality at 100 ppm (13.46%±2.35 to 18.14%±2.93) and the mixture (100 ppm) modality, which recorded rates between 16.16%±2.77 and 21.57%±3.10. Analysis of variance (ANOVA) followed by Fisher's LSD test ($p<0.05$) for the average percentages of attacked and fallen fruits showed a highly significant difference for all three years studied (**Table 3**).

Estimation of diapausing larvae

The data analysis reveals several significant trends. Sucrose showed a more pronounced inhibitory effect than fructose during 2017–2018, as evidenced by the values for males in 2017 (2.75±0.48 vs. 2.25±0.75, $p<0.05$) and females in 2018 (6.0±2.45 vs. 8.75±2.10, $p<0.01$). However, this difference was greatly diminished in 2019 (8.75±2.39 vs. 7.25±1.11, $p>0.1$). The sugar mixture had an intermediate profile, leaning more towards fructose in 2017 (2.0±0.91 vs. 2.25±0.75, $p>0.05$) and more towards sucrose in 2019 (10.25±1.65 vs. 8.75±2.39, $p>0.05$). The pupal stage appeared to be particularly sensitive, with almost complete inhibition under sucrose in 2017 (0±0 vs. 1.25±0.48, $p<0.001$) and a paradoxical effect of the mixture in 2018 (3.0±1.15 vs. 1.75±0.63, $p<0.05$). Low standard errors (±0 to ±1.15) attest to the reproducibility of these observations (**Fig. 1**).

Abbott efficacy treatments

The results obtained for this parameter show a relatively moderate to high efficacy for all tested modalities on the Anna variety, ranging from 21.87%±4.27 to 44.71%±7.60. It is noteworthy that all tested modalities achieved their highest effectiveness in 2017. Among these, SacC (100 ppm) demonstrated the greatest efficacy, while the mixture modality (100 ppm) showed the lowest effectiveness over the three years of study (**Fig. 2**). Analysis of variance (ANOVA) followed by Fisher's LSD test ($p<0.05$) for the total number of attacked fruits on the Anna variety revealed a significant difference in effectiveness between the study years only in 2019 for the mixture modality (**Fig. 2**).

Discussion

The present study evaluated the efficacy of very low concentrations (100 ppm) of industrial sugars (sucrose, fructose, and their mixture) in providing rapid sugar-induced immunity against the codling moth through foliar treatments applied at 21-day intervals from post-flowering to harvest over three growing seasons (2017, 2018, and 2019) in the Tilatou area (Batna, Algeria). Results showed significant year-to-year fluctuations in codling moth infestation intensity, which were strongly associated with certain climatic conditions and were more evident in 2018 and 2019 compared to 2017. Infestation intensity declined considerably following the application of the test treatments, with medium to high efficacies (44.08% to 68%) compared to the control ($p<0.05$, ANOVA followed by Tukey's test). The wide confidence intervals (±7.02 in 2017) indicate extreme variance. These results confirm

Table 3. Average infestation rate caused by larvae on apple fruit

Years	Control	Sucrose (100ppm)	Fructose (100ppm)	Mixture (100ppm)
2017	42.62%±5.75[a]	14.91%±2.43[b****]	18.14% ± 2.93[b****]	21.57 % ±3.10[b****]
2018	34.09% ± 5.05[a]	11.57% ±2.02[b****]	13.46% ± 2.35[b****]	17.14% ± 2.80[b****]
2019	25.54% ± 3.99[a]	12.24% ±2.14 [b****]	13.84% ± 2.46[b****]	16.16 % ± 2.77[b****]

ANOVA, Fisher's LSD tests, $p<0.05$; different letters show significant differences between treatments within each experiment. ****: $p\leq0.0001$

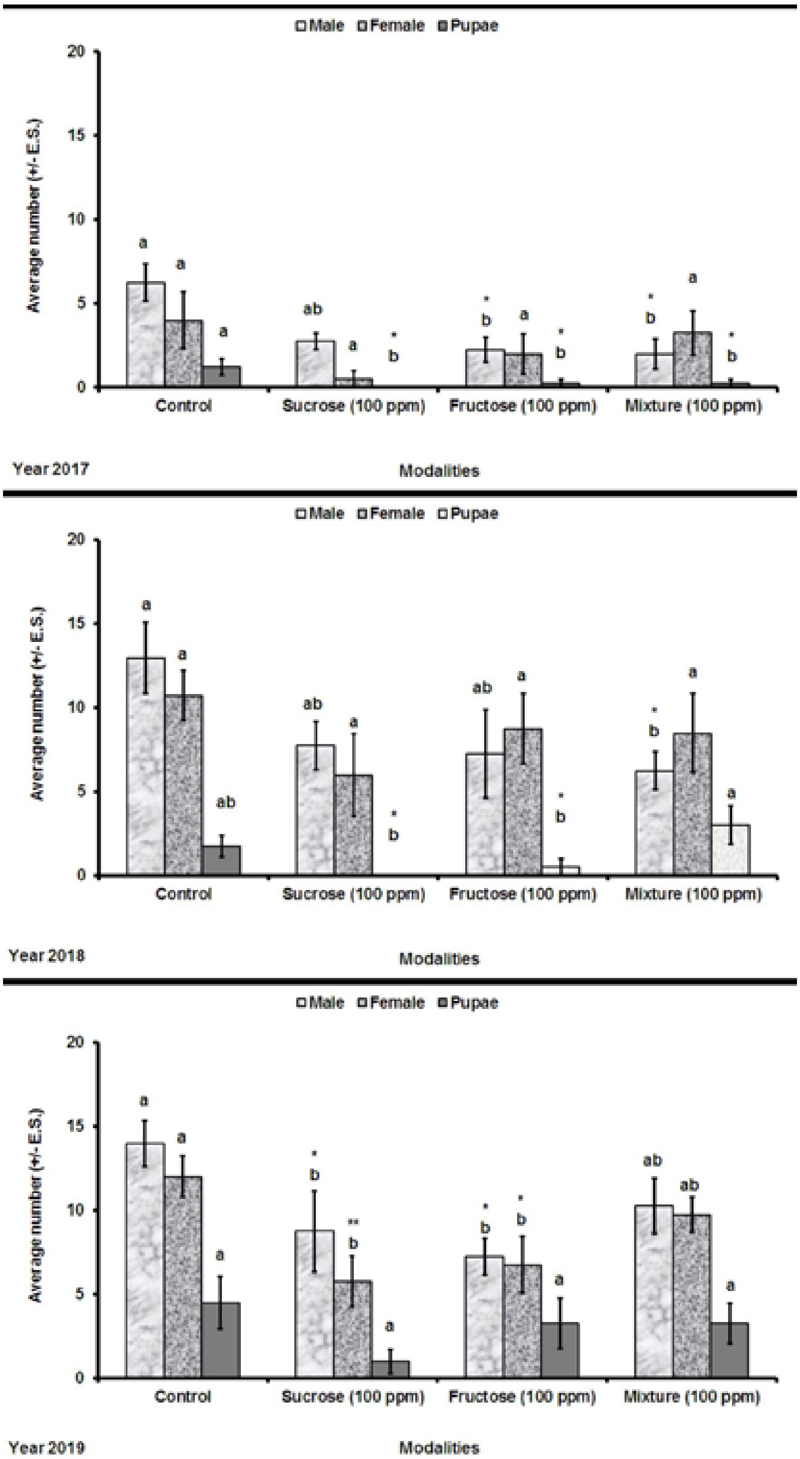

Fig. 1. Average number of captured larvae and pupae. ANOVA, Fisher's LSD test, $p<0.05$; different letters indicate significant differences between treatments within each experiment (*$p<0.05$, **$p<0.01$)

the viability of sugar immunity as an integrated pest control strategy, potentially reducing the use of chemical pesticides.

In 2017, the region experienced a wet and chilly spring followed by a hot summer, with maximum temperatures exceeding 35 °C for 51 days, resulting in a codling moth infestation rate of 42.62%±5.75. Spring rains likely created favorable conditions for larval development, while summer heat accelerated their life cycle. This supports the observations of Hermans (2018), who stated that warmer and longer summers lead to higher pest pressure. In contrast, 2018 experienced moderate temperatures, with a maximum of 27 °C and only 44 days exceeding 35 °C, leading to a lower infestation rate of 34.09% ± 5.05. This finding is consistent with Kleckova & Klecka (2016), who reported that moderate temperatures limit pest reproduction. In 2019, the region recorded 71 days with temperatures above 35 °C, while spring rains occurred less frequently than in 2017, resulting in an intermediate infestation rate of 25.54%±3.99. This reflects the combined influence of higher temperatures and lower rainfall. Additionally, milder winters can hinder fruit tree vernalization, making them more susceptible to pests and diseases, as noted by Coureau (2020), who found that weather-stressed trees were more vulnerable to pests such as the codling moth. Hermans (2018) also observed that climate change accelerates codling moth generations, thereby increasing infestation levels.

The findings showed that sucrose was the most efficient treatment, reducing infestation rates to 11.57%–14.91%, followed by fructose (13.46%–18.14%) and the sugar blend (16.16%–21.57%). These results align with those of Bounahouche (2017) and Dafri (2017), who recorded high infestations of 77%–80% on another apple variety (Royal Gala) under similar conditions, further highlighting the influence of climatic and yearly variations on pest pressure. Notably, the lowest infestation levels were observed in 2018 and 2019, while the conditions in 2017 favored codling moth development, leading to higher infestations.

Sugars applied as foliar sprays have a dual effect: enhancing plant defenses and disrupting codling moth larval feeding. Cabbanat (1999) demonstrated

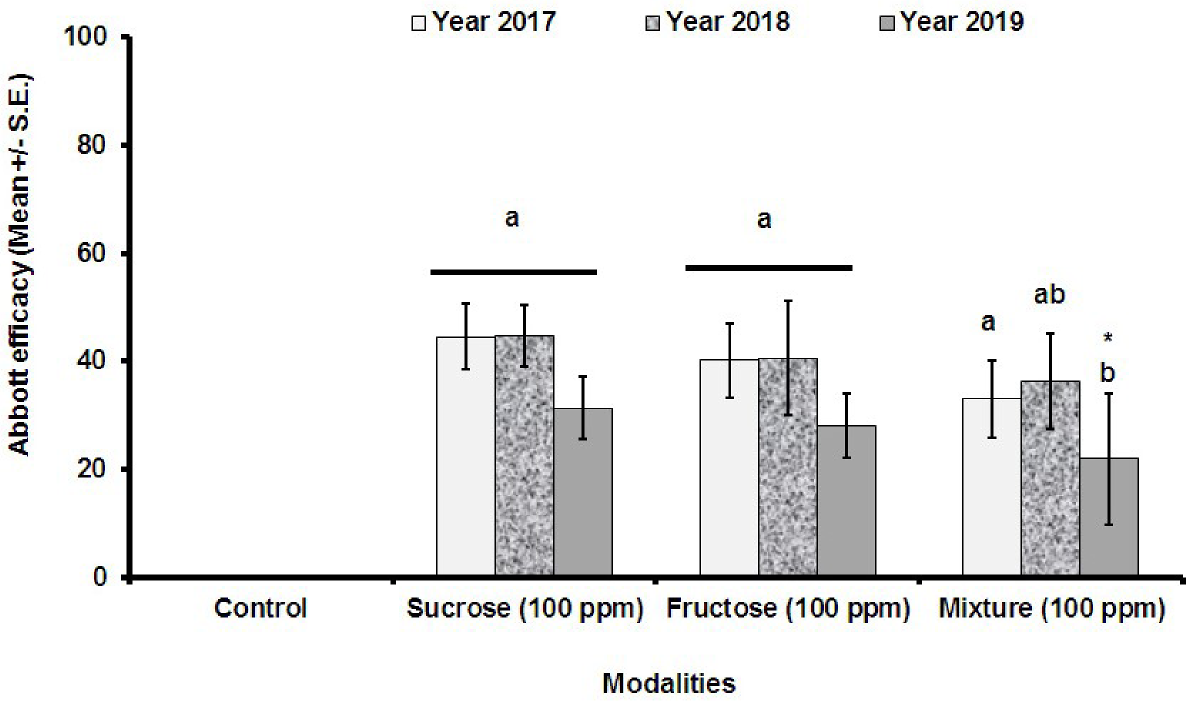

Fig. 2. Abbott efficacy of treatments. ANOVA, Fisher's LSD test, $p<0.05$; different letters indicate significant differences between treatments within each experiment (*$p<0.05$)

that polyols and sugars affect *C. pomonella* larval feeding by inhibiting their ability to penetrate fruit. Similarly, Ondet (2019) reported reduced codling moth infestations on the Akane variety in France following sugar applications. Recent studies, such as Ceusters et al. (2016), have examined sugar-induced immunity mechanisms, showing that sucrose and fructose activate defense genes and strengthen plant resistance. Additionally, Derridj et al. (2012) found that sugars disrupt insect perception of plants and their oviposition behavior, confirming their role as anti-phagostimulants that limit crop damage. The study also revealed a significant reduction in the number of codling moth larvae captured in corrugated cardboard trap bands treated with sucrose and fructose compared to the control. Inhibitory activity analysis showed notable differences between sugars, with sucrose outperforming fructose in 2017 and 2018, as indicated by male counts in 2017 (2.75±0.48 vs. 2.25±0.75, $p<0.05$) and female counts in 2018 (6.0±2.45 vs. 8.75±2.10, $p<0.01$). However, this difference diminished in 2019 (8.75±2.39 vs. 7.25±1.11, $p>0.1$), indicating annual fluctuations in larval response. The sugar mixture showed an intermediate pattern—similar to fructose in 2017 (2.0±0.91 vs. 2.25±0.75, $p>0.05$) and to sucrose in 2019 (10.25±1.65 vs. 8.75±2.39, $p>0.05$). Overall, statistical analyses confirmed significant inhibitory effects of sugar solutions (most p values <0.05), pronounced interannual variability requiring improved experimental controls, and complex interactions between sugars, such as a potential antagonistic effect in mixtures and a loss of specificity in 2019.

This shows the possibility of sugar-based systems managing pest infestations as captures were significantly lower in treatment than control in 2017. This shows that the sugars could be affecting larval behavior or ability to pupate. This agrees with Knight & Light (2005), who showed that sugars affected codling moth larval movement and feeding and reduced survival. However, effectiveness of sugars treatment also appears to decline with years, as evidenced by the increase in captures for 2018 and 2019, either due to larval adaptation or environmental factors on the effectiveness of treatment. Witzgall et al. (2008) have indicated a long-term trend towards reduced control operation effectiveness based on repellent or attraction regimes and claimed that an integrated approach would have to be employed to effectively manage codling moth infestations. The use of a blend of sugars in 2019 was effective with sub-control captures, demonstrating synergism between components, concurring with Varela et al. (1993) that blends of components increase the efficiency of treatment by acting on different insect behavior. This research confirmed that sugar control was able to effectively suppress the population of codling moths but its efficiency is dependent on local condition and treatment duration. Chouinard et al. (2016) further included that traps and bands supplemented by attractants or repellents such as sugars monitor and control effectively orchard insect's pests.

These results illustrate the complexity of interaction between different types of sugars and their variation in effect from year to year, but together supporting the greater inhibitory effect of sucrose over fructose throughout the first two years of study. Arnault et al. (2021) evaluated the effectiveness of biocontrol strategies, including sweet immunity, within an integrated pest management program. Results of their evaluation show that the use of sugar in combination with other biocontrol strategies had the potential to effectively control codling moth infestations and reduce environmental degradation. The results of this study carry promising potential in the context of climate change, where pests become more resistant to conventional means of control, thereby making sustainable pest control possible. Sweet immunity as a method of biocontrol is an efficient alternative to chemical pesticides and is safe for human health and the environment.

Conclusion

This research demonstrates that treating apple trees (Anna variety) with low doses of a sucrose and fructose mixture enhances their resistance to *Cydia pomonella*, effectively reducing infestation rates and larval populations under dry conditions. The findings validate the feasibility of sugar-induced immunity as a green pest management strategy that helps conserve biodiversity. Sucrose proved to be the most effective treatment and the most attractive to farmers, as it is cost-effective, easy to apply, and environmentally friendly. However, treatment efficacy is influenced by climatic conditions, underscoring the role of climate change in shaping pest dynamics. This approach offers a pathway toward integrated crop management strategies that combine induced resistance with sustainable agricultural practices to address present and future agricultural challenges. Nevertheless, the observed interannual variability highlights the need to develop protocols tailored to local climatic conditions, which should be a priority for the large-scale adoption of this technique.

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