



Sugar-Induced Modulation of Potato Tuber Moth Infestation: Field Evidence from Algeria

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Abstract: This study investigated the impact of foliar applications of sucrose, fructose and their combination (Suc + Fruc) on the infestation dynamics of *Phthorimaea operculella* in potato crops grown in Algerian fields. The experiment assessed the impact on the infestation rate, the number of mines, and the number of immature stages at the basal, median, and apical positions of the leaves. The treatments included sucrose (100 ppm), fructose (100 ppm), and Suc + Fruc (100 ppm). During the experimental treatments, the sucrose treatment resulted in the highest infestation rate ($62.50 \pm 13.64\%$), confirming its potent phagostimulatory effect. In contrast, the Suc + Fruc mixture led to the lowest infestation rate ($32.29 \pm 11.07\%$), which was significantly lower than the control rate. No significant differences in infestation were found between basal and apical leaves, but median leaves were significantly affected ($p < 0.05$), with sucrose increasing infestation. Mine numbers differed significantly at the basal stage ($p < 0.05$), with damage being reduced by the fructose and sucrose + fructose treatments. The abundance of immature *P. operculella* larvae varied significantly across treatments and leaf stages ($p < 0.001$), with the Suc + Fruc and fructose treatments reducing larval densities particularly effectively at the apical stage. The sucrose + fructose treatment was more effective at suppressing larvae than sucrose alone ($p = 0.006$). Abbott's efficacy analysis revealed that the Suc + Fruc treatment was the most effective (31.12-36.67%). These results imply that balancing sucrose with fructose is a promising, eco-friendly way to manage *P. operculella* in semi-arid environments, offering an alternative to traditional pest control methods.

Key words: Foliar sugars, biocontrol, *Phthorimaea operculella*, sustainable pest management, *Solanum tuberosum* L, treatments.

The potato tuber moth (*Phthorimaea operculella* Zeller, Lepidoptera: Gelechiidae) is one of the most destructive pests of potato (*Solanum tuberosum* L.) worldwide, causing substantial yield losses through larval damage to both foliage and tubers in the field and during storage (Rondon, 2010; Kroschel and Schaub, 2013). Infestation rates can reach 80-100% in untreated crops, particularly in warm temperate and subtropical regions (Sporleder *et al.*, 2017). Current control strategies rely heavily on chemical insecticides, which raise serious concerns regarding resistance development, environmental contamination, and non-target toxicity (Dent and Binks, 2023). Recent studies have documented resistance of *P. operculella* to multiple insecticide classes, necessitating the development of sustainable alternatives (Prasannakumar *et al.*, 2023).

Beyond microbial and nematode pathogens, insect pests present a distinct and critical challenge to potato cultivation. The potato tuber moth (*Phthorimaea operculella* Zeller) is one of the most destructive of these pests, attacking both foliage and tubers during growth in the field and storage. Larval feeding causes mining damage to leaves and create galleries in tubers, resulting in direct yield losses and a reduction in market quality. Reliance on synthetic insecticides for control raises concerns regarding the development of resistance, non-target toxicity, and environmental sustainability. Consequently, alternative ecological control strategies are increasingly being investigated. Recent advances in biocontrol research have highlighted the potential of plant-derived compounds to influence insect behaviour and plant defense responses.

Among these compounds, soluble sugars have emerged as potential resistance inducers or behavioural modifiers in plant-insect interactions (Mao *et al.*, 2025). Foliar-applied sugar microdoses, such as sucrose or glucose, have been shown to activate jasmonic acid (JA) and salicylic acid (SA) signalling pathways, thereby enhancing plant resistance to herbivores (Griffin *et al.*, 2025). In addition to their effects on plants, sugars may directly influence insect feeding behavior by altering

gustatory perception and chemosensory responses, thereby affecting larval survival and fecundity (Zhang *et al.*, 2024). Studies on other lepidopteran pests, such as *Helicoverpa armigera* and *Spodoptera frugiperda*, have reported reduced infestation levels following foliar sugar applications (Niassy *et al.*, 2024).

Regarding *P. operculella* specifically, recent studies have examined the use of plant volatiles and botanical extracts for oviposition deterrence. For instance, 4-ethylacetophenone, emitted by potato plants, has strong repellent effects on adult moths and significantly reduces oviposition (Ma *et al.*, 2025b). Similarly, extracts from non-host plants containing trans-2-dodecenal and trans-2-tridecenal, such as those from *Eryngium foetidum*, have been shown to mask host odours and deter oviposition (Ma *et al.*, 2025a). These findings support the broader concept of ecology-based pest management through modulation of host recognition cues. Within this framework, the application of foliar sugar microdoses is an innovative and relatively unexplored strategy for managing *P. operculella*. Although there is limited direct field evidence, this approach aligns with the broader principle of using plant-derived substances to modify pest behaviour and enhance plant defensive capacity (Mulugeta *et al.*, 2019; Ma *et al.*, 2025a; Ma *et al.*, 2025b). Unlike conventional insecticides, the aim of sugar microdoses is not to exert direct toxicity, but rather to modulate plant-insect interactions in an ecologically sustainable manner.

Despite these promising indications, the effectiveness of sugar microdoses against *P. operculella* in the field has not yet been systematically evaluated. Critical parameters such as the optimal concentration, effects on different canopies and potential impact on larval development are inadequately documented. Therefore, this exploratory field study was designed to evaluate the impact of foliar sugar treatments (sucrose, fructose and a mixture of both) on *P. operculella* infestation dynamics, larval abundance and oviposition-related damage. By evaluating this sugar-based approach within an integrated pest management framework, the study aims to contribute to the development of sustainable alternatives to chemical insecticides and support global objectives relating to food security and environmental preservation.

Materials and Methods

The following description provides a concise overview of the experimental site, which was located in an experimental plot in the Lambiridi region of Batna Province, Algeria (35°30'06.97"N, 6°03'30.73"E; altitude 1.34 km). Potatoes (*Solanum tuberosum* L., common variety 'Désirée') were planted on 15 August 2024, with 18 rows in total at a density of 17 plants per row. The 'Désirée' cultivar is characterised by its semi-erect, short-to-medium-height plants with thick, vigorous stems. The leaves exhibit dull grey-green pigmentation, and the tubers are oblong with pale yellow flesh.

Experimental design and treatments: The study employed a randomized complete block design (RCBD) with three replicates per treatment. Each replicate (elementary plot) consisted of three potato plants, resulting in a total of nine plants per treatment. Sugar treatments involved two sugars - fructose and sucrose (both sourced from Fluka Biochemica) - which were evaluated under different application modalities. The individual treatments were sucrose (T1-Suc) and fructose (T2-Fruc), both at a concentration of 100 ppm, while the combined treatment consisted of sucrose and fructose (T3-Suc + Fruc), also at a concentration of 100 ppm. The foliar spraying of sugars was carried out according to the methodology established by Derridj (2012) and recently validated by Naceri *et al.* (2025). Treatments were initiated upon the initial detection of the potato tuber moth in the pheromone traps that had been installed within the study plot. Foliar applications were conducted in the early morning (6:00 am) before photosynthetic activity began and when apoplastic intercellular sugar concentrations were low. A manual sprayer with a 5 L capacity was used for the applications, which were carried out at 15-day intervals between 1 September and 8 December 2024, as stated by Naceri *et al.* (2025). This made a total of eight applications. The following dates were identified for the 2024 cycle: 1 September, 15 September, 29 September, 13 October, 27 October, 10 November, 24 November and 8 December.

The solution was administered as a fine, non-drip V-jet foliar spray to all the potato plants to facilitate sugar absorption. The volume of the

spray was adjusted according to the phase of vegetative growth, to ensure adequate coverage of the foliage. Sugar solutions were added to the runoff to maximize the efficacy of the treatment. The three experimental treatments were then compared with an untreated control.

Leaf sampling was conducted at three canopy levels: Basal, median, and apical leaves were analysed separately due to well-documented differences in leaf age and physiology (Barton and Koricheva, 2010), pest colonization patterns (Shahbi and Rajabpour, 2017), biochemical composition including cuticular wax and sugar content (Trivedi *et al.*, 2019), microclimatic conditions (Agrios, 2005), and potential variation in sugar spray deposition. This approach was essential to determine whether sugar treatments exert differential effects across leaf developmental stages and canopy microhabitats, providing critical insights for optimizing application strategies. In fact, at each level, two leaves were randomly collected per plant; each elementary plot consisted of 2 plants, providing four leaves per plot, knowing that the number of block plots is 4. Each treatment was replicated three times, providing a total of 12 leaves per treatment, and 48 by block plots, at each canopy level, thus 144 leaves for three canopy levels. Since eight sampling dates were carried out during the whole experimental period, 1152 leaves were sampled by treatment and by the experimental period.

All developmental stages, including larvae and pupae, were systematically observed, documented and classified in accordance with standard entomological protocols. Morphological identification was performed using an optical magnifying lens and graph paper to determine larval instars, measure body size and record color characteristics of the different larval stages of the moth. In parallel, infestation intensity was assessed by counting the number of mines on infested leaves, enabling damage levels to be classified as low, moderate or high. Mine counts were conducted across three canopy strata - basal (lower), middle and apical (upper) - to account for vertical variation in infestation distribution within the plant. Treatment efficacy was assessed using Abbott's formula:

$$\text{Efficacy} = 100 \times ((T_0 - T_i) / T_0)$$

where T_0 : % total of leaflets affected in the control; T_i : % total of leaflets affected in the treated sugar modality (sugar treatment).

Abbott's formula uses the average infestation rates at different leaf stages for the treatments (T1-Suc, T2-Fruc and T3-Suc + Fruc) and the control, given that these rates have already been calculated to evaluate their effect on leaf stage infestation.

The global infestation rate data ($n = 1152$) and by foliar stage ($n = 384$), were analyzed using a two-way ANOVA to evaluate the effects of treatment, sampling date and their interaction. As infestation was expressed as a percentage, the data were arcsine square-root transformed prior to analysis to ensure normality and homogeneity of variance was met. Normality was assessed using the Shapiro-Wilk test and Q-Q plots, while homogeneity of variances was verified using Levene's test. When significant differences were detected, means were separated using the Tukey's HSD test at a 5% significance level. Statistical analyses were performed using SPSS software (version XX). Statistical significance was defined as follows: * $p < 0.05$: significant; ** $p < 0.01$: highly significant; *** $p < 0.001$: very highly significant.

Results and Discussion

Effect of treatments on global infestation rate

Figure 1 shows that the global leaf infestation rate was significantly influenced

by sugar treatments ($n = 1152$). Descriptive analysis revealed clear differences between the treatments. The highest infestation rate was observed in the sucrose treatment ($62.50 \pm 13.64\%$), followed by the control treatment ($46.88 \pm 12.98\%$) and the fructose treatment ($42.71 \pm 12.34\%$). By contrast, the combined sucrose and fructose treatment showed the lowest infestation rate ($32.29 \pm 11.07\%$). A two-way ANOVA performed on arcsine square-root transformed data indicated a very highly significant treatment effect ($p < 0.001$). Tukey's post hoc test confirmed that sucrose application resulted in significantly higher infestation rates than all other treatments. In contrast, the Suc + Fruc combined treatment significantly reduced infestation rates compared to the control and single-sugar treatments.

The elevated infestation observed under sucrose treatment can be explained by sucrose's well-documented role as a potent phagostimulant for many herbivorous insects. Sugars, particularly sucrose, enhance feeding behaviour and host acceptance, thereby increasing pest colonization (Simpson and Raubenheimer, 1993; Schoonhoven *et al.*, 2005). Furthermore, soluble sugars can modify primary plant metabolism and potentially alter the allocation of resources towards defence compounds (Bolton, 2009). Therefore, increased carbohydrate availability may enhance plant nutritional suitability for pests, promoting infestation. In contrast, the reduced infestation observed under the combined sucrose and

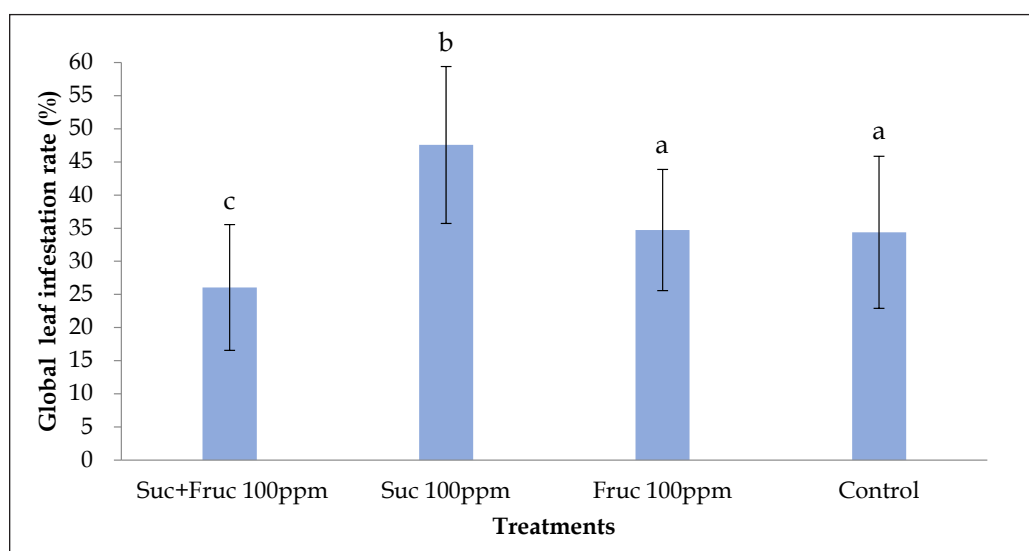


Fig. 1. Global leaf infestation rate (%) under different treatments. Values represent Mean $\pm$ SD ($n = 1152$).

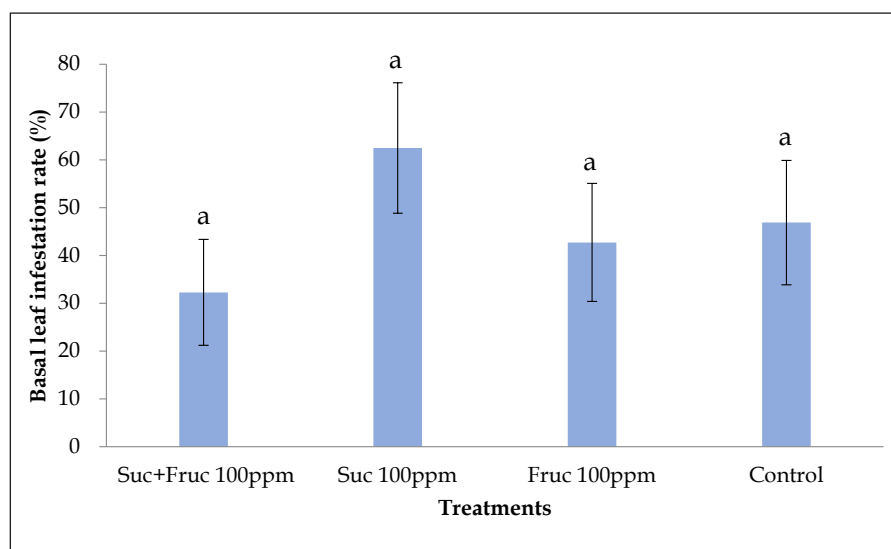


Fig. 2. Basal leaf infestation rate (%) under different treatments. Values represent Mean $\pm$ SD ($n = 384$), a: no significant variation between treatments.

fructose treatment suggests a more complex physiological response. Beyond their nutritional function, sugars act as signalling molecules that regulate gene expression and defence pathways (Rolland *et al.*, 2006). Sugar signalling interacts with hormonal defence networks, including jasmonic acid- and salicylic acid-mediated pathways, which play central roles in plant resistance mechanisms (Bolouri-Moghaddam and Van den Ende, 2013). The combination of sugars may have triggered defence-related metabolic adjustments, leading to reduced pest establishment.

Fructose alone produced intermediate levels of infestation, which may reflect its weaker phago-stimulatory effect compared to sucrose (Schoonhoven *et al.*, 2005). Overall, these findings emphasize the dual role of soluble sugars in plant-pest interactions: they act as nutritional substrates that may favor infestation, as well as signalling molecules capable of modulating plant defence responses.

Effect of treatments on basal, median and apical leaf infestation rate

Infestation dynamics in potato leaves varied according to canopy position and treatment. In basal leaves (Fig. 2), mean infestation ranged from $32.29 \pm 31.61\%$ under Suc + Fruc 100 ppm to $62.50 \pm 41.26\%$ under Suc 100 ppm, with intermediate values for Fruc 100 ppm ($42.71 \pm 32.77\%$) and control ($46.88 \pm 34.68\%$). No significant differences were observed among treatments ($p > 0.05$), likely due to the high

temporal variability inherent to polycyclic foliar diseases (Agrios, 2005). Basal leaves are typically the first canopy organs exposed to pathogens, benefiting from higher humidity and lower air circulation, which favour early infection and secondary inoculum amplification (Fry, 2015; Garrett *et al.*, 2006).

In median leaves (Fig. 3), infestation ranged from $23.96 \pm 26.30\%$ in the control to $56.25 \pm 34.96\%$ under Suc 100 ppm, with intermediate values for Fruc 100 ppm ($38.54 \pm 26.91\%$) and Suc + Fruc 100 ppm ($26.04 \pm 25.90\%$). Here, treatment effects were significant ($p < 0.05$), with sucrose application enhancing infestation. This may reflect the dual role of sugars as both metabolic substrates and signalling molecules regulating plant defence pathways (Bolouri-Moghaddam and Van den Ende, 2013; Bezruczyk *et al.*, 2018). Elevated sucrose in the apoplast can increase pathogen nutrition and promote colonization, particularly for hemi-biotrophic pathogens (Tausin and Giardina, 2014; Zhang *et al.*, 2024). The lower infestation under the Suc + Fruc treatment suggests that sugar balance modulates host defence signalling, as combinatorial sugar signals can influence defence gene expression differently than individual sugars (Bolouri-Moghaddam and Van den Ende, 2013; Su *et al.*, 2024).

In apical leaves (Fig. 4), infestation remained lower, ranging from $19.79 \pm 27.63\%$ under Suc + Fruc 100 ppm to $31.25 \pm 32.84\%$ in the control, with no significant differences among treatments ($p > 0.05$). The delayed

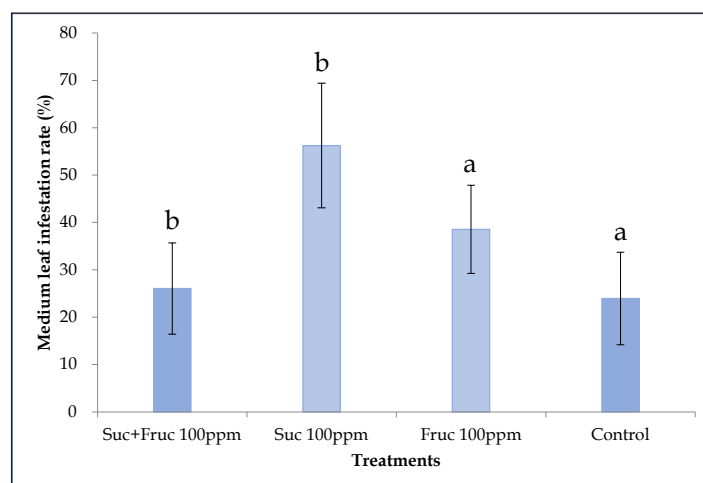


Fig. 3. Medium leaf infestation rate (%) under different treatments. Values represent Mean $\pm$ SD ($n = 384$), a: no significant variation between treatments.

onset of apical infestation reflects the vertical progression of polycyclic foliar epidemics, where infection originates in the basal canopy and spreads upwards (Agrios, 2005; Fry, 2015; Fry *et al.*, 2015). Upper canopy infection is more strongly influenced by environmental conditions such as temperature, leaf wetness duration, and humidity than by localized physiological changes induced by exogenous sugars (Garrett *et al.*, 2006; Wang *et al.*, 2023).

Treatments Efficacy: After calculating the T_0 and T_t values for the various treatments at different leaf stages (see Fig. 2, 3 and 4), Abbott's formula was applied to evaluate the efficacy of different sugar solutions. This showed that T3-Suc + Fruc at a dose of 100 ppm of each produced a significant level of Abbott effectiveness at both the basal and apical levels, with values of 31.12% and

36.67%, respectively. T2-Fruc at a dose of 100 ppm provided only 8.89% effectiveness at the basal level and 26.65% at the apical level. Additionally, the Abbott effectiveness of T1-Suc was 13.34% at the apical level. These results imply that fructose-based treatments are preferable for reducing infestation and that pure sucrose should be avoided in pest-prone environments. The study reveals a clear tripartite interaction between sugar treatments, infestation patterns and pest life stages. Sucrose (T1-Suc) was shown to act as a key stimulant for global infestation, likely via enhanced phago-stimulation and oviposition, consistent with the role of sucrose in promoting survival, longevity and fecundity in phloem-feeding pests (Schutze *et al.*, 2022). Conversely, T2-Fruc and T3-Suc + Fruc neutralised this effect (26.04-34.65%, $p = 1.000$ versus the control group), suggesting that

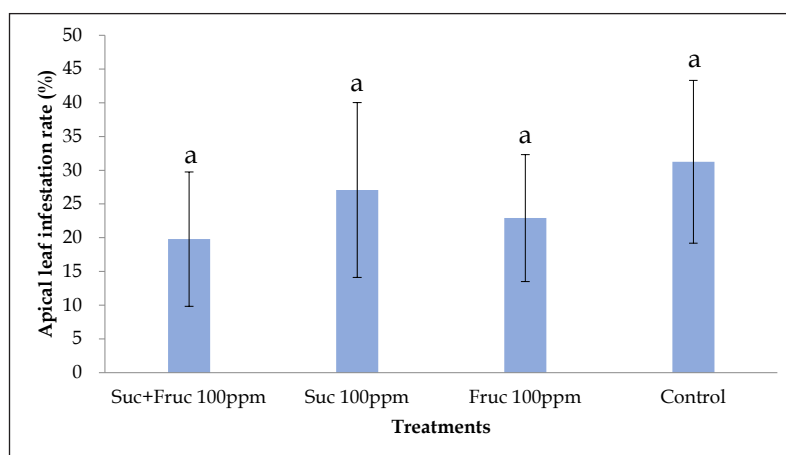


Fig. 4. Effect of treatments on apical leaf infestation rate (%). Values represent mean $\pm$ SD ($n = 384$), a: no differences between treatments.

Table 1. Average number of mines infesting different parts of the leaf by *P. operculella* (basal, middle and apical) in function of different sugar and their combination as treatment

Stage	Suc + Fruc 100 ppm	Suc 100 ppm	Fruc 100 ppm	Control	F	p
Basal	0.83 ± 1.03 b	2.92 ± 2.55 ab	0.71 ± 0.86 b	7.17 ± 6.20 a	3.42	<0.05
Medium	2.00 ± 2.05	3.58 ± 2.68	3.46 ± 2.86	2.67 ± 3.09	0.74	ns
Apical	0.38 ± 0.72	0.67 ± 0.96	1.75 ± 3.57	2.63 ± 2.60	1.28	ns

Different letters within a row indicate significant difference (Tukey, $p < 0.05$); ns = not significant. Values are Mean ± SD.

fructose may disrupt pest chemoreception or deter feeding (Mansour *et al.*, 2023).

Treatment effects on mine infestation by leaf stages: The number of mines varied significantly between treatments at the basal stage ($p < 0.05$). The control treatment recorded the highest infestation (7.17 ± 6.20 mines), which was significantly greater than the Suc + Fruc and Fruc treatments. The Suc treatment showed intermediate values. No significant differences were observed among the treatments at the medium and apical stages ($p > 0.05$). Overall, the effects of treatment were more pronounced at the basal canopy level (Table 1).

The significantly higher mine numbers observed in the basal control suggest that lower canopy leaves are more vulnerable to infestation. Basal leaves typically experience higher humidity and reduced air circulation - conditions that are favourable for insect oviposition and larval development (Agrios, 2005).

The reduced mine numbers under the Suc + Fruc and Fruc treatments at the basal stage suggest possible interference with host-insect interactions. Sugars play a central role in plant metabolic signalling and may modulate defense responses (Bolouri-Moghaddam and Van den Ende, 2013). Alteration of the carbohydrate balance can influence herbivore feeding behavior and performance (Bolton, 2009). The absence of significant differences in the medium and apical stages suggests that infestation dynamics are influenced more by environmental and dispersal factors than by localised metabolic

changes. Vertical stratification of infestation is common in canopy systems and reflects microclimatic gradients (Garrett *et al.*, 2006). Overall, treatment efficacy appears to be stage-dependent, with a stronger impact at the basal canopy, where initial colonization occurs.

Effect of treatments on the abundance of different larval stages

The abundance of the immature *Phthorimaea operculella* differed significantly among treatments at all leaf stages (Table 2). At the basal stage ($F_3 = 9.72$, $p < 0.001$), the control group had the highest density (0.28 ± 0.24), while the Suc + Fruc and fructose groups had the lowest similar values (0.05 ± 0.06). At the medium stage ($F_3 = 4.88$, $p = 0.006$), the control and sucrose had the highest means (0.23), while Suc + Fruc and fructose remained lower. At the apical stage ($F_3 = 12.41$, $p < 0.001$), the control group again had the greatest abundance (0.29 ± 0.18), while all sugar treatments strongly suppressed the immature stages, with fructose completely inhibiting them (0.00). Overall, the Suc + Fruc treatment consistently reduced immature densities compared with sucrose alone.

At the basal leaf stage, the control group exhibited the highest abundance of immature *P. operculella* stages (0.28 ± 0.24), which was significantly higher than the densities observed in the sugar treatments (Sucrose + Fructose and Fructose, both 0.05 ± 0.06). There were significant differences in abundance across the treatments ($p < 0.001$). This suggests that the combination of sucrose and fructose, as

Table2. Effects of different treatments (Sucrose + Fructose 100 ppm, Sucrose 100 ppm, Fructose 100 ppm) applied on the larval abundance stages of *P. operculella* in different parts of the leaf

Leaf stage	Suc + Fruc 100 ppm	Suc 100 ppm	Fruc 100 ppm	Control	ANOVA (treatment effect within stage)
Basal	0.05 ± 0.06 c	0.10 ± 0.10 bc	0.05 ± 0.06 c	0.28 ± 0.24 a	$F_3 = 9.72$, $p < 0.001$
Medium	0.10 ± 0.06 b	0.23 ± 0.18 a	0.14 ± 0.11 b	0.23 ± 0.20 a	$F_3 = 4.88$, $p = 0.006$
Apical	0.05 ± 0.06 b	0.03 ± 0.06 b	0.00 ± 0.00 b	0.29 ± 0.18 a	$F_3 = 12.41$, $p < 0.001$

Different letters within a row indicate significant difference (Tukey, $p < 0.05$); ns = not significant. Values are Mean ± SD

well as fructose alone, strongly deters larval establishment in the basal part of the leaf. Previous studies have suggested that sugars such as sucrose and fructose can affect insect feeding behaviour by altering the palatability or nutritional value of the host plant (González *et al.*, 2018). For *P. operculella*, such treatments may reduce the leaf's attractiveness or suitability for oviposition or larval feeding, thus decreasing survival rates.

At the medium leaf stage, the control and sucrose treatments exhibited the highest larval densities (0.23 ± 0.18), which were not significantly different from each other, but higher than those observed in the Suc + Fruc and fructose treatments. ANOVA results indicated that the treatment effect was significant at this stage ($p = 0.006$). While sucrose alone does not substantially reduce larval abundance, this suggests that the combination of sucrose and fructose, as well as fructose alone, can suppress the immature stages. However, the effects were less pronounced than at the basal stage. This differential response may be related to physiological changes in the plant as it matures, resulting in a slightly reduced response to sugar treatments at the medium leaf stage compared to the basal stage (Gupta *et al.*, 2020).

At the apical leaf stage, the control group again exhibited the highest abundance of immature stages (0.29 ± 0.18). All sugar treatments resulted in a significant reduction, with fructose completely inhibiting larval presence (0.00). These differences were statistically significant ($p < 0.001$), indicating that sugars have an even more pronounced inhibitory effect at the apical stage of leaf development. The complete suppression of larvae by fructose suggests a potent anti-feedant or deterrent effect, which may be due to changes in the leaf's chemical composition or direct physiological effects on the larvae (Steinitz *et al.*, 1997). These findings are consistent with previous research indicating that fructose may have a stronger impact than other sugars, possibly due to its unique biochemical interactions with plant tissues or insect digestive systems (Kuhar *et al.*, 2018).

Across all leaf stages, the combination of sucrose and fructose (Suc + Fruc at a concentration of 100 ppm) was found to

consistently reduce the abundance of immature *P. operculella* compared to sucrose alone, suggesting a synergistic effect between the two sugars. The sugar treatments, particularly fructose, were found to have a strong larval deterrent effect, as evidenced by the significant reduction in immature stages observed at the apical leaf stage. These findings highlight the potential of sugar-based treatments in integrated pest management strategies. Manipulating sugar availability or composition in the environment could suppress pest populations without the need for chemical insecticides, which can have negative ecological consequences.

Conclusions

In conclusion, this study demonstrates that sugar treatments significantly reduce the abundance of *Phthorimaea operculella* larvae across different leaf stages, particularly when sucrose and fructose are combined (Suc + Fruc). The Suc + Fruc treatment was particularly effective at suppressing the larvae in their immature stages, especially at the apical leaf stage, where the presence of larvae was completely inhibited by fructose. In contrast, sucrose alone induced higher infestation rates, confirming its role as a potent phagostimulant. These results imply that balancing sucrose with fructose could boost plant defense responses, providing an environmentally friendly alternative to chemical insecticides. The results highlight the potential of sugar-based treatments in integrated pest management strategies for controlling *P. operculella* in semi-arid environments.

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Declarations

The authors have no competing interests.

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About the Authors

Rahma Meradi research focuses on protecting apple trees against the codling moth (*Cydia pomonella*). She combines integrated pest management strategies (alternating alternative methods and insecticides) with the study of stimulating the tree's natural defenses through the foliar application of microdoses of sucrose. This overall approach is rooted in chemical ecology, aiming to better understand plant-insect interactions in order to reduce the impact of pests.

Smail Chafaa research focuses on the ecology and biodiversity of insects (entomofauna) in arid and semi-arid Algerian ecosystems. He is particularly interested in crop pests (olive, apple, tomato) in order to develop integrated pest management and biocontrol strategies. At the same time, he analyzes population dynamics in relation to climatic and environmental factors.

Mohamed Kebieche research focuses on environmental and pharmaceutical toxicology, studying the impact of pollutants (pesticides, heavy metals) and chemotherapies on oxidative stress, mitochondria, and brain toxicity (neurotoxicity) as well as liver toxicity (hepatotoxicity). At the same time, he explores the therapeutic potential of natural substances (polyphenols, medicinal plants, essential oils) for their antioxidant, antidiabetic, and antimicrobial properties, in order to counteract these toxic effects.

Nabil Berttela, affiliated with the University of Batna 1, centers his research on integrated crop and forest protection. His work spans biological control—specifically targeting the pest *Tuta absoluta*—forest entomology with a focus on cedar pests, and the chemistry of natural products derived from plants such as the dog rose.

Fateh Mimeche research focuses on aquatic ecology (ichthyology and fish dynamics), agricultural entomology (crop pests and beneficial auxiliaries), terrestrial fauna (beetles, rodents, and birds), and ecosystem management (wetlands, weed flora, and ethnobotany).

Hamadi Fetoui research focuses on environmental toxicology, where he investigates the mechanisms of oxidative stress induced by pollutants (pesticides, nanoparticles, heavy metals) and their deleterious impacts on the brain (neuroinflammatory toxicity), kidneys (fibrosis), and liver (apoptosis). Concurrently, his work evaluates the protective potential of natural compounds, particularly plant extracts, to counteract these oxidative damages and preserve the integrity of target organs.

