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Research Article
Infestation Differences and Control of the Clearwing Moth (*Synanthedon myopaeformis* Borkh.) in Apple Orchards, Egypt

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Abstract
Background and Objective: The clearwing moth (*Synanthedon myopaeformis* Borkh.) is considered one of the most dangerous pests infesting apple orchards in Egypt, causing the destruction of apple trees and a significant reduction in tree vigour and yield. Therefore, controlling it has become an important issue. The present study aimed to investigate the differences in *S. myopaeformis* infestation in apple orchards in different geographical regions and the infestation rates to different agricultural operations. **Materials and Methods:** The infestation percentages of *S. myopaeformis* in different geographical regions under varying agricultural operations were determined. Additionally, the amounts of chemical components (e.g., phenols, proline and total carbohydrates and proteins) in the stems and leaves of both infested and healthy apple trees were determined. Finally, the efficacy of seven different materials of varying types to control the borer was tested by painting the trunks of the apple trees. **Results:** The highest numbers of *S. myopaeformis* were recorded in July at locations with varying agricultural operations: Melig (25.88 adults), Kafer-Aleim (20.30 adults) and Al-Khatatba (13.02 adults). The emergence percentages recorded at the abovementioned locations were 44.55, 33.40 and 22.05%, respectively. The infested trees contained high amounts of proline and phenols in both stems and leaves, whereas total carbohydrate and protein contents were low. The highest reduction in the emergent population was recorded with the use of the pesticide Ranous (82.16%) and the application of used motor oil on the trunk (78.15%). **Conclusion:** The proposed treatment of infested apple trees is painting the trunks during the summer months, when *S. myopaeformis* activity is high, with motor oil and the pesticide Ranous. The accumulation of phenol and proline in the infested trees indicated a type of direct defense mechanism against *S. myopaeformis* attacks.

Key words: Apple clearwing moth, infestation variance, chemical components, agricultural operations, control

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The invasive clearwing moth, *Synanthedon myopaeformis* Borkh. (Lepidoptera: Sesiidae), poses a huge threat to the apple orchards in Egypt and other countries[1-3]. These borer insect attacks result in severe damage, leading to the destruction of apple trees and a significant reduction in tree vigour and yield[2,4]. Their larvae develop and live inside the main trunk and branches of the trees, moreover, the moths have a long emergence period, making their control challenging. In addition, this borer infests pome and stone fruit trees such as *Sorbus* spp., *Pyrus* spp., *Crataegus* spp. and *Prunus* spp.[5,6].

In Egypt, the apple (*Malus domestica* Borkh.) cultivation area extends from the Nile Delta to some newly reclaimed lands[7]. Therefore, the apple crop ranks highly in Egyptian fruit production[8]. Nevertheless, the continuous presence of *S. myopaeformis* and other borers (e.g., *Zeuzera pyrina*, *Hypothenemus eruditus*, *Scolytus amygdali* and *Chlorophorus varius*) in apple orchards at different locations indicate differences in apple tree infestation[9].

Strategies for controlling the clearwing moth have usually depended on the use of synthetic pesticides. However, the use of these pesticides is accompanied by detrimental impacts on the environment and human health[10], therefore, new and safe materials are needed to control the clearwing moth.

Previous studies have investigated the damage caused by this pest and reported on its ecology, biology and control. For example, Abd El-Rheem and Batt[9] surveyed the insects in Menoufia Governorate and found that the highest infestation percentages (26.08 and 21.33%) of *S. myopaeformis* were recorded at Abo-Mashour and El-Khatatba, respectively. Ateyyat[11], Judd *et al.*[12] and El-Ashry *et al.*[13] evaluated the efficacy of *Bacillus thuringiensis*, various organic and nematode products and synthetic insecticides for controlling *S. myopaeformis*.

The present study aimed to investigate the differences in *S. myopaeformis* infestation in apple orchards in different geographical regions and the infestation rates to different agricultural operations. Moreover, the study aimed to highlight the changes in the chemical components between healthy and infested trees as well as at different heights of the infested trees. Finally, different materials were tested to evaluate their efficacy to control and reduce the *S. myopaeformis* population and consequently reduce the use of hazardous pesticides by using alternative materials to achieve the same pest control results, ultimately preserving the environment and human health.

MATERIALS AND METHODS

Infestation percentages of *S. myopaeformis* in different geographical regions and differences in agricultural operations: Three locations with apple tree cultivation were chosen in three different geographical regions: Meleig, Shebin El-Kom district (30.5968258°N, 31.0410349°E), Kafer-Aleim, Berket El-Sabaa district (30.636967°N, 31.100151°E) and Al-Khatatba, Sadat district (30.33938°N, 30.70440°E).

Three apple orchards infested with *S. myopaeformis* (with varied agricultural operations) were periodically examined for the infestation at three different heights above the ground surface (i.e., 0-50, 50-100 and 100-150 cm) during the last week of December, 2020.

Fifty infested trees were chosen from each apple orchard in the different regions (each of which followed different agricultural systems) to study the differences in an infestation. The protrusive exuviae of pupae from infested trees were recorded monthly. The infestation percentages of *S. myopaeformis* at different locations were determined from the beginning of January to December, 2021.

Chemical components of the leaves and stems of infested and healthy apple trees: Leaf and stem samples of healthy and infested trees (at different heights above the ground, i.e., 0-50, 50-100 and 100-150 cm) were collected. The samples were transferred to the Plant Physiology Laboratory, Menoufia University, for analysis of the chemical components: Total phenol, carbohydrate and protein contents were determined according to the methods described by Ainsworth and Gillespie[14], Niaz *et al.*[15] and Sarkar *et al.*[16], respectively, whereas, total proline content was determined using the method described by Ábrahám *et al.*[17].

Treatment of apple tree trunks with different materials

Tested materials: The seven materials used in different groups were illustrated in Table 1: Prev-Am (6% orange oil), 25% palmetto gold (0.5% citronella oil+5% jasmine oil+15% mineral oil), top perfect (80% jojoba oil), fluence (5% bifenthrin), ranous (25% bifenthrin), aqua (10% novaluron) and used motor oil (The Mobil Super XHPTM, Exxon Mobil Egypt, 15 W-50).

Application site and orchard conditions: The apple orchard at Kafer-Aleim was chosen for analysis. The apple trees were approximately 15 years old and infested with *S. myopaeformis*. This orchard was abandoned and free of pesticide application.

Table 1: List of materials used for controlling *S. myopaeformis*

Trade name	Active ingredient	Concentration (%)	Formula	Application rate /1 L
Prev-Am	Orange oil (d-limonene)	6	SL	4 cm
Palmetto gold	Citronella oil 5%	25	OD	60 cm
	Jasmine oil 5%			
	Mineral oil 15%			
Top perfect	Jojoba oil	80	EC	2.5 cm
Fluence	Bifenthrin	10	EC	1.1 cm
Ranous	Bifenthrin	25	EC	0.5 cm
Aqua	Novaluron	10	EC	6 cm
Used motor oil	The Mobil Super XHP™ , ExxonMobil Egypt , 15W-50			

Application and treatments: The chosen infested apple trees were grouped for treatments into seven groups according to the materials used. The trees were examined and exuviae protruding from the bark were removed by pulling out with forceps after counting.

The treatment application was conducted during the active period of emergence (early June to late August, 2021). Twenty trees in each group were painted three times at 1 month intervals with the same tested materials under evaluation.

Twenty other trees were left without treatment during the abovementioned periods as parallel controls. Continual observations were recorded and the new exuviae were counted 1 month after each painting treatment.

The percentage reduction in the population of emerged moths affected by different treatment materials was determined according to the following equation:

$$\text{Reduction (\%)} = \frac{\text{Number of exuviae in check-}\atop\text{Number of exuviae in treatment}}{\text{Number of exuvaie in check}} \times 100$$

Statistical analysis: The infestation percentages of *S. myopaeformis* at different geographical regions with varied agricultural operations as well as the data obtained from the application of the tested materials were statistically analyzed by (SAS program computer). The variance and the values were compared by t-test, f-test ($\alpha = 0.05$).

RESULTS

Infestation percentages at various locations in Menoufia Governorate: Substantial differences in the infestation percentages of *S. myopaeformis* were observed through the continuous monitoring of apple orchards at different geographical locations in Menoufia Governorate (Melig, Kafer-Aleim and Al-Khatatba). Figure 1 shows that, according to the infestation percentages recorded at 0-50 cm in late 2020, the highest infestation percentage was recorded at Melig (25.85%), followed by Kafer-Aleim (18.45%) and then Al-Khatatba (11.88%). At 50-100 cm, the infestation percentages at Melig, Kafer-Aleim and Al-Khatatba were 12, 7.08 and 4.38%, respectively. However, at 100-150 cm, the lowest infestation percentages were recorded (8.92, 4.85 and 0%, respectively) at the abovementioned locations. Therefore, the presence of differences at various locations in this study is interesting to note. These differences may be due to variations in irrigation, fertilization, the distance between trees, weather factors, intercropping, weeds, soil type and groundwater level.

Monthly variations in an emergent population at different locations: The number of *S. myopaeformis* pupal exuviae protruding from the infested trees at Melig, Kafer-Aleim and Al-Khatatba, Menoufia Governorate, during 2021 was shown in Table 2. The highest numbers of emerged *S. myopaeformis* adults were recorded in July at Melig (25.88 adults), Kafer-Aleim (20.30 adults) and Al-Khatatba (13.02 adults), whereas the lowest numbers of emerged *S. myopaeformis* adults were recorded in January at the abovementioned locations (4.04, 2.92 and 1.12 adults, respectively). The recorded percentages of annual emergence were 44.55, 33.40 and 22.05% at Melig, Kafer-Aleim and Al-Khatatba, respectively.

Highly significant differences were observed in adult emergence during months at Melig (LSD = 1.03, for 9 statistical groups), Kafer-Aleim (LSD = 0.86, for 11 statistical groups) and Al-Khatatba (LSD = 0.79, for 10 statistical groups). The monthly emergence averages revealed three statistically significant groups for the different locations (Table 2).

Infestation status of *S. myopaeformis* at different geographical regions with varied agricultural operations: Wide variations in the infestation status of *S. myopaeformis* in the apple tree orchards at Melig, Kafer-Aleim and Al-Khatatba was given in Table 2. Table 3 shows that, these locations had varied agricultural operations, including differences in irrigation (flood and drip irrigation), soil type (clay, sandy and

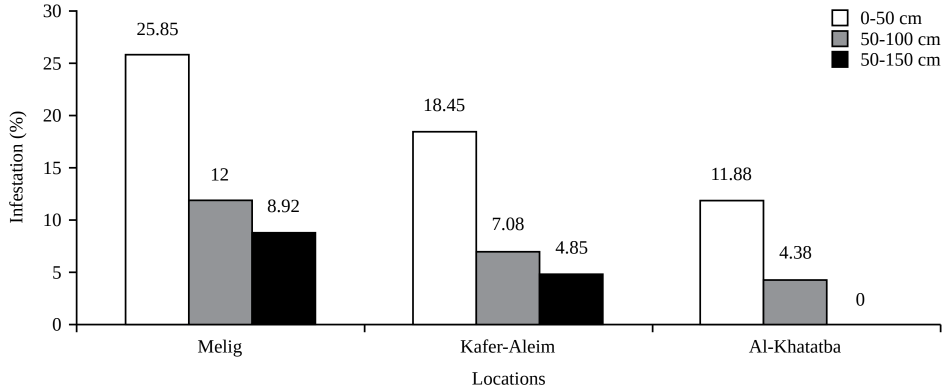

Fig. 1: Infestation percentages of *S. myopaeformis* at different heights in apple trees cultivated at Melig, Kafer-Aleim and Al-Khatatba in Menoufia Governorate

Table 2: Monthly averages of *S. myopaeformis* pupal exuviae protruding from the infested trees at Melig, Kafer-Aleim and Al-Khatatba in Menoufia Governorate during 2021

	Melig		Kafer-Aleim		Al-Khatatba			
Months	Range	Av±SE	Range	Av±SE	Range	Av±SE	LSD	F-test
January	0-9	4.04±0.25^{Ja}	0-6	2.92±0.21^{Kb}	0-4	1.12±0.13^{Jc}	53.73	0.56
February	0-12	5.96±0.41^{Ia}	0-8	4.18±0.28^{Jb}	0-6	1.88±0.21^{IJc}	44.45	0.12
March	2-13	7.56±0.39^{Ha}	2-11	6.54±0.32^{Hb}	0-9	3.98±0.34^{Gc}	27.72	0.99
April	6-18	10.52±0.36^{Ga}	4-12	8.14± 0.26^{Gb}	1-12	5.65±0.31^{Fc}	61.47	0.87
May	10-21	14.22±0.30^{Ea}	6-17	11.04±0.33^{Eb}	3-15	8.72±0.29^{Dc}	81.62	0.85
June	13-24	19.14±0.44^{Ca}	10-19	14.48± 0.37^{Cb}	4-15	10.64±0.27^{Cc}	134.79	1.02
July	14-33	25.88±0.69^{Aa}	13-27	20.30± 0.44^{Ab}	7-18	13.02±0.29^{Ac}	164.09	1.41
August	19-27	23.32±0.25^{Ba}	13-22	17.72±0.28^{Bb}	8-15	11.98±0.24^{Bc}	482.32	0.72
September	13-23	18.06±0.32^{Da}	6-17	12.98±0.37^{Db}	3-13	8.24±0.40^{Dc}	180.35	1.02
October	7-17	12.94±0.29^{Fa}	5-13	9.58±0.29^{Fb}	1-10	6.78±0.34^{Ec}	99.94	0.86
November	4-12	8.20±0.26^{Ha}	2-9	5.58± 0.24^{Ib}	0-7	3.08±0.22^{Hc}	114.75	0.67
December	2-10	6.64±0.27^{Ia}	0-8	3.86±0.26^{Jb}	0-6	2.36±0.27^{Ic}	65.20	0.75
Annual number	156.48		117.32		77.45		351.25	
Emergence (%)	44.55		33.40		22.05		100.00%	
F Test	373.63		330.09		205.67			
LSD	1.03		0.86		0.79			

Letters A-K: Statically groups for different months, Letters a-c: Statically groups for different locations

muddy soils), fertilizers used (organic and mineral), the distance between trees, bearing (intercropping), pruning, weed types and mechanical control. Accordingly, the agricultural operations at Al-Khatatba resulted in the lowest infestation percentage, as evidenced by the lowest emergence percentage of adults (22.05%), whereas, the agricultural operations at Melig resulted in the highest infestation percentage, as evidenced by the highest emergence percentage of adults (44.55%), Table 2.

Differences in chemical components

Differences in chemical components in the stems and leaves of healthy and infested apple trees: Table 4 showed the differences in the chemical components in the stems and leaves of healthy apple trees and apple trees infested with *S. myopaeformis*.

Highly significant differences were observed in phenols, proline and total carbohydrates and proteins in both healthy and infested apple trees. The stems and leaves of infested trees contained high amounts of total phenols (44.24 and 38.22 mg caticolo 100 g^{-1} dry weight) and proline (404.93 and 971.66 μg g^{-1} fresh weight), respectively, whereas, the amounts of total carbohydrates and proteins were higher in the healthy trees than in the infested trees. In the stems and leaves, the recorded total carbohydrate values were 102.51 (dry weight) and 186.42 mg 100 g^{-1} (dry weight) and the total protein values were 13.20 and 12.14%, respectively.

Table 3: Effects of differences in agricultural operations on trees and infestation at different locations

	Locations		
Agriculture operations	Melig	Kafer-Aleim	Al-Khatatba
Irrigation	Flood	Flood	Drip
Soil type	Clay	Clay	Sandy
Distance among trees	2×4 m	2.5×5 m	5×5 m
Intercropping	Vegetables	Citrus trees	-
Pruning	Winter (December)	Winter (December)	Winter (December) Summer (June)
Mechanical control	-	Hoeing-ploughing	Mechanical control - Lime painting of tree trunks
Fertilization	1-Organic: (Animal dung) during December 4 pick/tree	1-Organic (Animal dung) during December 4 pick/ tree 2-Mineral: • MAP compound (12N:61P_2O_5:0K) during mid-January • 850 g ammonia sulfate/tree during March • 250 g potassium sulfate+150 g ammonia nitrate/tree during May • 750 g ammonia sulfate /tree during August	1-Organic: (Compost) during February and July 2-Mineral: • Zinc sulfate foliar spray during mid- • December 2 kg/100 L water • 25 g phosphoric acid + 250 g ammonia sulfate+ 125 g potassium sulfate/1 m^3 water during mid-January • 125 g ammonia sulfate + 250 g potassium sulfate + 25 g magnesium sulfate/1 m^3 water during April • Chelated calcium 1% spray during May • 250 g ammonia sulfate+75 g potassium sulfate + 25 g magnesium sulfate/1 m^3 water during August
Weeds	• Nutsedge (*Cyperus rotundus* L.) • Scutch grass (*Cynodon dactylon* L.) • Wild oat (*Avena fatua* L.) • Endive (*Cichorium endivia* L.) • Field bindweed (*Convolvulsar vensis* L.) • Bishop's Weed (*Ammim ajus* L.)	• Nutsedge (*Cyperus rotundus* L.) • Scutch grass (*Cyperus rotundus* L.)	• Scutch grass (*Cynodon dactylon* L.)

Table 4: Chemical components in the stems and leaves of healthy apple trees and trees infested with *S. myopaeformis*

Treatments	Healthy (Av±SE)	Infected (Av±SE)	T-Test	p-value
Stem				
Total phenols (mg caticolo 100 g^{-1} dwt.)	20.87±0.44	44.24±0.82	-19.06	0.00002**
Proline (µg g^{-1} fwt.)	217.82±0.54	404.93±0.79	-163.66	0.00001**
Total carbohydrate (mg 100 g^{-1} dwt.)	102.51±0.46	86.44±0.67	14.69	0.00006**
Total protein (%)	13.20±0.06	9.02±0.08	15.51	0.00005**
Leaf				
Total phenols (mg caticolo 100 g^{-1} dwt.)	14.47±0.85	38.22±0.17	-22.52	0.00001**
Proline (µg g^{-1} fwt.)	336.58±1.14	971.66±0.72	-390.34	0.00001**
Total carbohydrate (mg 100 g^{-1} dwt.)	186.42±0.71	122.20±0.31	68.75	0.00001**
Total protein (%)	12.14±0.13	7.08±0.49	8.19	0.0006**

**Highly significant, $p \leq 0.01$

Table 5: Chemical components in infested apple tree stems at different heights above the ground surface

	Height above ground surface (cm)					
Treatments	0-50 (Av±SE)	50-100 (Av±SE)	100-150 (Av±SE)	F-test	p-value	LSD
Total phenols (mg caticolo 100 g^{-1} dwt.)	44.24±0.82	42.75±0.74	41.75±0.80	1.76	0.250^{Ns}	-
Proline (µg g^{-1} fwt.)	404.93 ± 0.79^{a}	400.81 ± 1.05^{b}	396.48 ± 0.56^{c}	23.74	0.001*	2.99
Total carbohydrate (mg 100 g^{-1} dwt.)	86.44 ± 0.67^{b}	95.57 ± 0.19^{a}	97.91 ± 0.68^{a}	68.45	0.0001**	2.53
Total protein (%)	9.02±0.08	9.38±0.12	9.71±0.14	1.79	0.246^{Ns}	-

LSD: Least significant difference, *Significant, $p \leq 0.05$, **Highly significant, $p \leq 0.01$, ^{Ns}: Non-significant and data followed by the same letter were not significantly varied at $p \leq 0.05$

Table 6: Efficiency of different materials against *S. myopaeformis* moths in three applications on apple trees

	First treatment			Second treatment			Third treatment		
	No. of emerged moths			No. of emerged moths			No. of emerged moths		
Tested materials	Range	Av±SE	R (%)	Range	Av±SE	R (%)	Range	Av±SE	R (%)
Prev-Am	23-33	28.40 ± 0.75^{a}	8.24	21-31	27.15 ± 0.65^{a}	15.29	18-29	26.5 ± 0.62^{a}	26.69
Palmetto gold	19-30	26.5 ± 0.56^{ab}	13.41	18-27	24.60 ± 0.48^{b}	23.24	13-25	22.4 ± 0.67^{b}	38.04
Aqua	18-29	25.4 ± 0.60^{bc}	17.93	14-26	22.30 ± 0.80^{c}	30.42	13-22	18.5 ± 0.65^{c}	48.82
Top perfect	15-30	24.05 ± 0.86^{c}	22.29	14-23	20.70 ± 0.56^{d}	39.74	11-21	16.35 ± 0.61^{d}	54.77
Fluence	15-28	21.15 ± 0.81^{d}	31.66	12-20	16.85 ± 0.60^{e}	47.43	7-16	12.15 ± 0.62^{e}	66.39
Used motor oil	13-26	18.85 ± 0.67^{e}	39.1	10-19	12.70 ± 0.57^{f}	64.39	6-13	7.90 ± 0.34^{f}	78.15
Ranous	11-23	16.9 ± 0.81^{e}	45.40	7-15	10.80 ± 0.61^{g}	68.42	3-9	6.45 ± 0.38^{f}	82.16
Cheek	26-41	30.95±0.83	-	28-43	32.05±0.92	-	32-47	36.15±79	-
F-test	35.38			113.19			187.25		
LSD	2.06			1.70			1.59		

LSD: Least significant difference, R (%): Reduction and data followed by the same letter were not significantly varied at $p \leq 0.05$

Differences in the chemical components present in the infested apple tree stem at different heights above the ground surface: Table 5 shows that, the chemical analysis of infested apple tree stems at different heights revealed that the total phenol content decreased slightly from 44.24 mg caticolo 100 g^{-1} (dry weight) (at 0-50 cm)-41.75 mg caticolo 100 g^{-1} (dry weight) (at 100-150 cm). The total protein content slightly increased from 9.02% (at 0-50 cm)-9.71% (at 100-150 cm). Hence, no significant differences were observed in phenol and protein contents at different heights.

There were highly significant differences in proline and carbohydrate contents at different heights (F test = 23.74 and 68.45, respectively). The proline content decreased from 404.93 µg g^{-1} fresh weight (at 0-50 cm)-396.48 µg g^{-1} fresh weight (at 100-150 cm). These values demonstrated three statistically significant groups. The total carbohydrate content increased from 86.44 mg 100 g^{-1} dry weight (at 0-50 cm)-97.91 mg 100 g^{-1} dry weight (at 100-150 cm). These values demonstrated two statistically significant groups. (Table 5).

Efficacy of apple tree trunk treatment with seven materials for the control of *S. myopaeformis*: The obtained data were represented by the number of exuviae protruding from the bark of the trees that were treated with different materials (Table 6). The effect of the tested materials varied in terms of the emergence of *S. myopaeformis* moths during three successive treatments at 1 month intervals.

Evaluation after the first treatment: The highest average number of exuviae protruding from the apple tree bark (Table 6) was 28.40 for the trees painted with Prev-Am, followed by palmetto gold (26.5), aqua (25.4), top perfect (24.05), fluence (21.15) and used motor oil (18.85). The lowest average number of exuviae was recorded for ranous (16.9).

The highest percentage reduction in the *S. myopaeformis* moth population emerging from infested trees was 45.40% (Ranous), showing its efficacy against emerging adult moth infestation, followed by used motor oil (39.1% reduction) and Fluence (37.16% reduction). The lowest percentage reduction was observed with Prev-Am (8.24% reduction) and Palmetto Gold (13% reduction).

Evaluation after the second treatment: The second treatment with different materials (Table 6) reduced moth emergence more effectively than the first treatment. The highest percentage reduction in moth population was recorded for Ranous (68.42%), followed by used motor oil (64.39%), fluence (47.43%), top perfect (39.74%), aqua (30.42%) and palmetto gold (23.24%). The lowest percentage reduction was observed with Prev-Am (15.29%).

Evaluation after the third treatment: Table 6 shows that, the highest percentage reductions in moth emergence were 82.16 and 78.15% with the use of ranous and used motor oil, respectively, without a significant difference between them, followed by fluence (66.39%), top perfect (54.77%), aqua (48.82%) and palmetto gold (38.04%). The lowest percentage reduction was observed with Prev-Am (26.69%).

Statistical analysis of the obtained data from the emerged moth population (determined by counting the number of exuviae protruding from the bark of infested trees treated with different materials) demonstrated significant differences between the three applications of different materials (F test = 35.38, 113.19 and 187.25 for the 1st, 2nd and 3rd applications, respectively). The LSD values between the averages of emerged moths during the different applications of tested materials revealed five, seven and six statistical groups in the 1st, 2nd and 3rd applications were shown in Table 6, respectively.

DISCUSSION

The small red-belted clearwing moth *S. myopaeformis* has impacted fruit production since ancient times. Although several studies have been conducted on this borer insect, a significant increase in the *S. myopaeformis* population has been observed in recent years, with consequential increases in its harmful effects on apple trees. This underscores the need for continuous data collection in apple orchards and conducting more studies on the borer.

The current study reported the infestation percentages of *S. myopaeformis* at different locations in Menoufia Governorate, Egypt (Melig, Kafer-Aleim and Al-Khatatba) that follow different agricultural practices. Results indicated that during 2020, the highest percentages of moth emergence from infested apple trees at 0-50 cm above the ground (basic stem region) were recorded at three geographically distinct apple orchards. These results were consistent with those reported by Batt and Abd El-Raheem[3] and Hashim[18], who reported that *S. myopaeformis* was abundant at 50 cm above the ground on the stem of both apple and plum trees. These results further confirmed that *S. myopaeformis* larvae attack the main trunks of apple trees rather than the main and sub-main lateral branches[19].

The highest number of *S. myopaeformis* adults emerged in July at the different locations under investigation. Batt and Abd El-Raheem[3] reported that the highest percentage of emerged *S. myopaeformis* moths in Menoufia Governorate, Egypt, was recorded in August. Hashim[18] reported that the highest flight activity of *S. myopaeformis* moths in pear orchards in Beheira Governorate, Egypt, was recorded during August. Moreover, Al-Antary and Ateyyat[20] showed that in Jordan, the flight activity of *S. myopaeformis* moths occurred from May to September, with a population peak in June. In Europe, high numbers of flying clearwing moths are observed between the middle of June and the end of July[21,22]. The differences in the flight activity of adults between June and August may be due to the differences in the geographical locations and climatic conditions in the areas under study as well as the differences in the methodologies used for counting the emergence percentage (trapping or counting the protrusive pupal exuviae from infested trees).

Concerning the infestation status of *S. myopaeformis* in different geographical regions with varied agricultural operations, our results indicated that the highest infestation and adult emergence percentages were recorded at Melig. This may be due to negligence toward the orchard and the adoption of outdated operational and fertilization systems as well as the spread of several weeds (Table 3). In contrast, the lowest infestation and adult emergence percentages were recorded at Al-Khatatba, which may be attributed to the modern agricultural systems and irrigation and fertilization management approaches adopted in this orchard as well as the absence of harmful weeds (Table 3).

Regarding the differences in the chemical components (especially total phenols and proline) present in the stems and leaves of healthy apple trees and those infested with *S. myopaeformis* (when considering the infestation area to be the trunk above the ground surface), the present data confirmed that the infested trees contained high total proline and phenol contents in both stems and leaves, whereas total carbohydrate and total protein contents were low. Moreover, 0-50 cm of the main trunk above the ground surface was considered the main infestation area in apple trees. Proline accumulated in high amounts at this height and its accumulation decreased at higher heights, with a concomitant decrease in infestation rates. Furthermore, both proline and phenols accumulated in high amounts in the leaves of the infested trees rather than in the leaves of the healthy trees, which explains the role of proline and phenols in the defense mechanism against the attacks of these borers. The defense mechanisms of plants against insects are wide-ranging and both direct and indirect. Most defense compounds are produced in response to plant stress or damage from phytophagous insects, which in turn repel the feeding and survival of attacking insects[9,23,24]. The current explanation was supported by Othmen *et al.*[25], who detected physiological and biochemical changes in host plants induced by insect feeding and observed a positive correlation between the number of feeding psyllid nymphs and the accumulation of both proline and total phenols in the leaves of carrot plants. Moreover, Hanley *et al.*[26], Sharma *et al.*[27], War *et al.*[28] and Moctezuma *et al.*[29] reported that phenolic compounds are secondary metabolites produced as a direct defense mechanism by plants against phytophagous insects. Additionally, Stratmann[30] and Bidart-Bouzat and Imeh-Nathaniel[31] mentioned that some phenolic compounds are induced as a result of attacks by herbivores.

Similarly, the accumulation of proline, a tissue-repairing metabolite, in plants occurs in response to different types of biotic and abiotic stresses or attacks by phytophagous insects and pathogens[32-34]. The findings of the present study are consistent with these reports. Khattab and Khattab[35] mentioned that the levels of proline and phenol oxidase increased after insect feeding on eucalyptus leaves, whereas carbohydrate and total soluble protein contents decreased. Rehman *et al.*[36] stated that the presence of proline in the cultivar Alankar helped in avoiding aphid attacks. Similar results were reported by Khattab[37], who found that cabbage leaves infested with aphids had higher free proline content than noninfested cabbage leaves, demonstrating the biotic stress experienced by cabbage plants. Kaur *et al.*[38] reported that phytophagous insects can induce proline accumulation in infested plants.

The current study investigated the control of *S. myopaeformis* using seven different materials applied on the trunks of apple trees (Table 1). Recently, the Egyptian Ministry of Agriculture has banned many pesticides previously used to combat wood borers. Therefore, we relied on the use of pesticides containing active ingredients showing good efficacy against many insects (i.e., fluence, ranous and aqua). Some pesticides of plant origin were also used (i.e., Prev-Am, palmetto gold and top perfect) as well as motor oil. Although ranous and fluence have the same active ingredient (bifenthrin), ranous controlled *S. myopaeformis* more effectively than fluence, perhaps due to its long residual period. The efficacy of used motor oil could be attributed to its negative effects on the survivability of *S. myopaeformis* larvae as well as their ability to pupate and emerge. In addition, it may prevent females from laying their eggs on the treated trunks, an explanation supported by previous studies[39-41].

The application of used motor oil on the trunks of apple trees proved to be an effective, low-cost method that is safe for mammals and reduces the potential for developing pest resistance. The results are supported by Erler[42], who mentioned that coating apple tree trunks with used motor oil could potentially control *S. myopaeformis* because it reduced the mean number of adults caught in the second year of treatment by 81.3%. Furthermore, Deligeorgidis *et al.*[22] stated that the population of *S. myopaeformis* substantially decreased after coating the trunk with a combination of paraffinic oil, fenoxycarb and chlorpyrifos. Finally, Ateyyat and Al-Antart[19] showed that painting apple tree trunks with copper sulfate, petroleum oil and the insecticide Dursban (chlorpyrifos) decreased the survival of *S. myopaeformis*.

CONCLUSION

The highest emergence rate of the clearwing moth *S. myopaeformis* was recorded in July. Attending carefully to the apple orchards, freeing them of harmful weeds and adopting modern agricultural systems reduces the infestation of apple trees by this borer. The infested trees accumulated high amounts of proline and phenols, which constitute one of the direct defense mechanisms against *S. myopaeformis* attacks. Further studies are warranted to determine how to apply these compounds in the field to reduce *S. myopaeformis* infestation. Finally, treatment with ranous and used motor oil was recommended during the activity period of emergence to decrease the population density of emerged *S. myopaeformis*.

SIGNIFICANCE STATEMENT

This study discovered that the pesticide Ranous and used motor oil have a good impact against the clearwing moth that can be beneficial for integrated management programs for this borer. Also, the infested trees indicate a type of direct defense mechanism against the borer attacks by the accumulation of phenol and proline compounds in the leaves and stems of apple trees which reinforces that new theories on the phytochemical can be used as an alternative to pesticides soon. This study will help the researchers to uncover the critical areas of finding alternative methods to control the clearwing moth.

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