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Evaluation of chemical and biological control tactics for managing *Unaspis euonymi* (Hemiptera: Diaspididae) in urban green spaces

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Abstract

The euonymus scale, *Unaspis euonymi* (Comstock) (Hemiptera: Diaspididae), is a destructive armored scale pest of *Euonymus* shrubs in urban landscapes, causing aesthetic and physiological damage that is difficult to control due to its protective waxy cover. This study evaluated the performance of multiple control tactics applied in sequence for pest management in Tehran's urban green spaces, Iran. The efficacy of winter emulsifiable oil (0.5-2%) and seven insecticide treatments alone and combined with the oil was tested alongside augmentative releases of the predator *Chilocorus bipustulatus* L (Coleoptera: Coccinellidae). Results showed that winter oil efficacy was concentration-dependent, with 2% providing the highest control (41.76%). Among insecticides, the combination of pyriproxyfen (an insect growth regulator) with emulsifiable oil was the most effective treatment, maintaining the highest efficacy (65.81%) over 14 days, highlighting enhanced efficacy when combined. In contrast, imidacloprid was the most ineffective compound. Furthermore, releases of *C. bipustulatus* provided substantial and increasing suppression, with efficacy rising from 33.33% at seven days after release (DAR) to 74.76% at 21 DAR. The study concludes that a dormant-season application of 2% emulsifiable oil, the targeted use of pyriproxyfen with oil if necessary, and augmentative releases of *C. bipustulatus* can provide a scientific basis for developing an integrated management strategy against *U. euonymi*. Further research is needed to optimize release rates and evaluate long-term efficacy under field conditions.

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Introduction

Euonymus spp. (spindle tree) plays a vital role in urban green spaces due to its aesthetic versatility, durability, and ecological benefits. As a slow-growing evergreen shrub, it is widely used in hedges, topiaries, and formal gardens, enhancing urban landscapes with structured greenery and year-round visual appeal (Dirr, 2011). Its tolerance to pruning and pollution makes it particularly suitable for cities, where it contributes to air purification, microclimate regulation, and biodiversity support by providing habitat for small fauna (Cameron et al., 2012). However, its susceptibility to insect pests requires integrated management strategies to sustain its ecological and horticultural benefits in urban ecosystems (Sadof & Neal, 1993; Rebek & Sadof, 2003; Erbas & Ulgenturk, 2022).

The euonymus scale, *Unaspis euonymi* (Comstock) (Hemiptera: Diaspididae), is a major armored scale pest of *Euonymus* spp., causing significant aesthetic and physiological damage to host plants in urban and ornamental landscapes (Matadha et al., 2005; Gholamzadeh-Chitgar et al., 2018; Van Driesche, 2022). The pest feeds by piercing leaf and stem tissues, extracting cell contents and disrupting nutrient transport, which leads to chlorosis, premature leaf abscission, branch dieback, and, in severe infestations, plant mortality (Rebek & Sadof, 2003; Van Driesche, 2022). The pest typically has two to three generations per year, overwinters as mated adult females, and produces mobile crawlers in spring and summer, which are the most vulnerable stages for chemical and biological control (Savopoulou-Soultani, 1996; Ozyurt & Ulgenturk, 2007).

Unaspis euonymi undergoes a sessile life cycle after the initial crawler stage. Upon hatching, mobile crawlers locate feeding sites before settling and secreting a protective, waxy cover. Sexual dimorphism influences settlement preferences, with males predominantly colonizing leaves and females favoring twigs (Savopoulou-Soultani, 1996; Van Driesche, 2022). This waxy covering, along with their cryptic behavior, complicates chemical control by shielding the insects from contact insecticides (Dennis, 1969; Sadof & Sclar, 2000). Consequently, effective management is challenged by the scale's resistance to conventional insecticides and its impact on already stress-prone urban *Euonymus* plantings (Rebek & Sadof, 2003; Gholamzadeh-Chitgar et al., 2018). To mitigate these challenges, an integrated approach combining biological control, cultural practices, and selective chemical treatments is essential for sustainable pest suppression while minimizing environmental impacts (Deguine et al., 2021; Erbas & Ulgenturk, 2022; Van Driesche, 2022).

Emulsifiable oils are a valuable tool for managing armored and soft scale insects on trees and shrubs. Their mode of action is primarily physical; the oil spray suffocates the pests by penetrating their protective waxy covers and disrupting gas exchange (Khaghaninia, 2009; Gholamzadeh-Chitgar et al., 2018; Jafari, et al., 2025; Rezaei et al., 2025). Application timing and concentration are critical: higher rates (1–2%) during the dormant season target overwintering stages with robust covers, while lower rates (0.1–0.5%) in the summer are effective against vulnerable crawlers and newly settled nymphs (Sadof & Sclar, 2000; Zareiyan & Hesami, 2021; Jafari et al., 2025; Rezaei et al., 2025). A key advantage of oils is their compatibility with biological control. Once the spray has dried, the residual toxicity is minimal, allowing natural enemies to colonize the plants and suppress any remaining scale populations, thereby providing sustained and compatible pest suppression in urban green spaces (Sadof & Sclar, 2000; Toorani et al., 2017).

The efficacy of emulsifiable oils has been demonstrated against a range of sucking insect pests. Successful control has been reported for the euonymus scale, *U. euonymi* (Sadof & Sclar, 2000; Gholamzadehs-Chitgar et al., 2018), as well as for psyllids such as *Euphyllura olivine* (Costa) and *E. pakistanica* Loginova (Hemiptera: Psyllidae) (Khaghaninia, 2009; Zareiyan & Hesami, 2021). However, a significant limitation arises when managing scales on dense ground covers. In these habitats, the pests are often concealed within the foliage canopy, which prevents adequate spray coverage and reduces direct contact. This challenge of incomplete foliar penetration is a noted constraint in euonymus scale management (Sadof & Sclar, 2000), underscoring the necessity of integrating oil applications with other control methods for effective pest suppression.

Within a comprehensive management approach, insecticides are not a first resort but a carefully deployed component used when pest populations exceed actionable thresholds and threaten plant health (Dennis, 1969; Rebek & Sadof, 2003; Deguine et al., 2021). The objective is to select targeted products and apply them in a manner that minimizes harm to the environment and conserves beneficial insects (Toorani et al., 2017; Rezaei & Moharramipour, 2019). Consequently, insecticides play a critical, yet circumscribed, role in achieving sustainable pest management. Previous studies have reported varying efficacy of different insecticides against *U. euonymi*, with some products providing effective control while others have shown limited success (Rebek & Sadof, 2003; Sadof & Sclar, 2000; Gholamzadeh-Chitgar et al., 2018). However, compatibility with natural enemies is a key consideration when using these chemical tools (Rebek & Sadof, 2003; Toorani et al., 2017; Rezaei & Moharramipour, 2019).

Biological control represents a sustainable strategy for managing *U. euonymi* by conserving its native and introduced natural enemies (Jefferson et al., 1995; Jaihoni et al., 2008). Several predatory beetles are effective specialists, including *Chilocorus kuwanae* Silvestri (Coleoptera: Coccinellidae) and *Cybocephalus nipponicus* Endrödy-Younga (Coleoptera: Cybocephalidae), which prey on both crawlers and settled stages of the scale (Matadha et al., 2003). *Chilocorus kuwanae*, deliberately introduced in the United States for this purpose, has successfully established in regions such as New Jersey and Virginia (Jefferson et al., 1995; Matadha et al., 2003). However, the success of such introductions is not guaranteed and can be influenced by local ecological factors. For instance, while *Chilocorus renipustulatus* (Scriba) (Coleoptera: Coccinellidae) demonstrated high predatory efficacy in laboratory studies, it failed to establish in Ankara, Turkey, likely due to climatic incompatibility and parasitism by native parasitoids (Erbas & Ulgenturk, 2022).

The ladybird beetle *Chilocorus bipustulatus* L. (Coleoptera: Coccinellidae) is a well-studied predator of scale insects, recognized for its potential in augmentative biological control programs (Jaihoni et al.,

2008; Atrchian et al., 2016; El Aalaoui et al., 2019). Its notable voracity has been demonstrated against various pests. For example, when preying on the olive scale (*Saissetia oleae* Olivier), *C. bipustulatus* consumed significantly more eggs and nymphs than other coccinellid species, displaying a unique capacity to handle second-instar nymphs that are often inaccessible to other predators (Santos et al., 2009). Similarly, against the cactus mealybug, *Dactylopius opuntiae* (Cockerell), it was among the most effective species in consuming high numbers of eggs and first instars (El Aalaoui et al., 2019). These traits suggest *C. bipustulatus* is a strong candidate for managing *U. euonymi*. However, the success of augmentative releases in urban landscapes hinges on the concurrent reduction of broad-spectrum insecticide use (Jaihoni et al., 2008; Erbas & Ulgenturk, 2022; Van Driesche, 2022).
An integrated approach, combining biological control with compatible cultural practices and selective insecticides, is therefore essential for the sustainable management of *U. euonymi*. Accordingly, this study evaluated the efficacy of three control tactics, winter oil, selected insecticides, and augmentative releases of *C. bipustulatus*. The specific objectives were to: (1) assess the efficacy of various concentrations of winter emulsifiable oil during the dormant season; (2) evaluate the performance of several insecticides, including their combinations with oil, during the growing season; and (3) determine the pest suppression potential of augmentative releases of *C. bipustulatus*. The findings are expected to provide a scientific basis for developing a practical management strategy against *U. euonymi*.

Materials and Methods

Efficacy of winter emulsifiable oil

The efficacy of a winter emulsifiable oil (L 80% formulation; 92% sulfonation degree) was evaluated against *U. euonymi* populations under urban green space conditions. The oil was tested at concentrations of 0.5, 1, 1.5, and 2% (v/v), selected according to recommended rates for dormant applications against armored scales (Sadof & Sclar, 2000; Gholamzadeh-Chitgar et al., 2018). The experiment was conducted in the first week of March 2022 in Janbazan Park, located in District 20 of Tehran Municipality, Iran (35°61′N, 51°40′E, 1068 m above sea level), using a completely randomized block design. The site consisted of 10-year-old *E. japonicus* var. *Aureus* shrubs, which were uniformly managed in terms of irrigation and fertilization. The shrubs were annually pruned, with heights of 90–100 cm and widths of 70–80 cm.
The oil applications were performed using a 200-L trolley sprayer equipped with a single-nozzle lance. A volume of 50 L of spray solution was used for each concentration. A low concentration (0.5%) was prepared and applied first, and the sprayer was thoroughly cleaned between treatments. A water-only treatment served as the control.
Because male and female *U. euonymi* are predominantly found on leaves and twigs, respectively, sampling included both plant parts to account for the entire population. This species overwinters as mated adult females (Ozyurt & Ulgenturk, 2007). From each experimental unit (2.5 m² plot), four shrubs were randomly selected, and from each shrub, one terminal 15-cm twig was excised from each of the four cardinal directions (north, south, east, west), resulting in a total of 16 twigs per plot. Each twig was placed individually in a labeled, ventilated plastic bag for transport to the laboratory. The number of live insects was counted on a 2-cm section of the branch surface and on the underside of two leaves per sample. Samples were examined in the laboratory using a stereomicroscope. The scale cover of each insect was removed; live individuals were identified by the presence of a fresh body beneath the shield, while a dry, dark-brown body identified dead individuals.
Live *U. euonymi* were counted one day before and 30 days after spraying. The experiment included four replications per treatment, with each replication covering 2.5 m² (approximately 3.5 m in length) of shrub foliage. Insecticide efficacy was calculated using the Henderson-Tilton formula (1955):

$$\text{Insecticide efficacy\%} = \left(1 - \frac{T_a}{C_a} \times \frac{C_b}{T_b}\right) 100$$

Where T_a and T_b represent the number of live insects on treated plants after and before spraying and C_a and C_b represent the number of live insects on control plants after and before spraying, respectively.

Field efficacy of insecticides

A second experiment evaluated the efficacy of seven treatments against *U. euonymi*: chlorpyrifos (EC 40.8%), imidacloprid (SC 35%), pyriproxyfen (EC 10%), chlorpyrifos + emulsifiable oil, imidacloprid + emulsifiable oil, pyriproxyfen + emulsifiable oil, and emulsifiable oil alone. Concentrations were 2, 0.4, 0.75, 2 + 4, 0.4 + 4, 0.75 + 4, and 4 mL/L, respectively. Specifications of the insecticides used are provided in Table 1. The experiment was conducted in July 2022 at Zeytoun Park, also in District 20 of Tehran (35°60′N, 51°42′E, 1061 m above sea level), using a randomized complete block design on *E. japonicus* shrubs. The experiment included four biological replications per treatment, with each replication consisting of a 2.5 m² plot of shrub foliage. All other conditions and procedures were identical to the first experiment, except that live *U. euonymi* were counted one day before and 3, 7, 14, and 21 days after spraying.

Table 1. Specifications of the insecticides used against *Unaspis euonymi* under urban green space conditions.

Common name	Formulation	Application rate (mL/L)	IRAC[1] group	Chemical class	Brand name (origin)
Emulsifiable oil	L 80%	4	UNM[2]	Mineral oils	Iramon (Iran)
Imidacloprid	SC 35%	0.4	4A	Neonicotinoids	Partonar (Iran)
Pyriproxyfen	EC 10%	0.75	7C	Insect Growth Regulator (IGR)	Hailir (China)
Chlorpyrifos	EC 40.8%	2	1B	Organophosphates	Agroxir (Iran)

Biological control program

Predator rearing

A colony of *C. bipustulatus* was established from individuals collected from the urban green space of District 20 of Tehran (35°60′N, 51°41′E, 1065 m above sea level) on common ivy (*Hedera helix* L.), where they were feeding on the scale insect *Aspidiotus nerii* Bouché (Hemiptera: Diaspididae).

The predator colony was maintained on a primary diet of nymphs and adults of *U. euonymi* reared on Japanese euonymus leaves. The colony was maintained in ventilated plastic containers (27 × 30 × 10 cm) under controlled environmental conditions (25 ± 1°C, 65 ± 5% RH, and a 16:8 h L:D photoperiod). Containers were inspected daily, and prey was replenished every two days. When predator eggs were observed, adults were transferred to new containers. A piece of moist cotton wool in a 1-cm-diameter plastic dish provided a water source (Atrchian et al., 2016). This rearing procedure was continued for approximately five generations to obtain a sufficient number of predators for field release.

Predator release and efficacy assessment

This experiment was conducted during June and July 2023 on infested *E. japonicus* shrubs in Inanj Park, District 20 of Tehran (35°63′N, 51°45′E, 1105 m above sea level). The park contained 6-year-old *E. japonicus* var. *Aureus* shrubs, which were uniformly irrigated, and no pesticides or fertilizers had been applied in the preceding six months. The shrubs were annually pruned, with heights of 85–100 cm and widths of 65–80 cm.

Infested shrubs (2 m² plots) were completely enclosed with a fine mesh fabric net fitted with a 50-cm zipper to facilitate sampling. Fifteen 3-day-old adult *C. bipustulatus*, collected from the laboratory colony, were released into each enclosed area. Predators were transported from the laboratory to the field in ventilated plastic containers (8 × 6 × 5 cm) using an aspirator, with 15 adults per container. A control treatment (no predators released) was also established and covered with mesh netting.

The number of *U. euonymi* was recorded one day before and 7 and 21 days after predator release. From each plant, a terminal 10-cm twig with all its leaves was excised and placed in a ventilated plastic bag for transport to the laboratory. Bags were labeled with the replicate information. The total number of live insects on the twig and all its leaves was counted. From each replicate, four branches were randomly selected from the four cardinal directions and examined in the laboratory using a stereomicroscope. The Henderson-Tilton formula (1955) was used to calculate the percentage reduction in the pest population. The experiment included four replications, with each replication consisting of one enclosed 2 m² plot of shrub foliage, completely covered with fine mesh netting.

Statistical analysis

Data normality was verified using the Kolmogorov-Smirnov test prior to analysis of variance (ANOVA). An arcsine transformation was used to transform percent values for analysis. For the emulsifiable oil and insecticide experiments, treatments showing significant differences in ANOVA were compared using Tukey's honestly significant difference (HSD) test at a 5% significance level. For the predator release experiment, a t-test was used to compare efficacy between the two time points (7 and 21 days after release), following confirmation of variance homogeneity with Levene's test. All analyses were performed using IBM SPSS Statistics, Version 22.0 (IBM Corp., Armonk, NY, USA).

Results

Efficacy of winter emulsifiable oil

Significant differences were observed in the efficacy of different winter emulsifiable oil concentrations against *U. euonymi* (Table 2). The 2% concentration resulted in the highest mean efficiency, while the 0.5% concentration resulted in the lowest.

Table 2. Mean percentage efficiency (± SE) of various winter emulsifiable oil concentrations (0.5, 1, 1.5, and 2%) on *Unaspis euonymi* population at 30 days after spraying.

Concentration	Mean efficiency%±SE
0.5%	20.36 ± 3.11 a*
1%	28.70 ± 4.38 ab
1.5%	32.58 ± 4.26 ab
2%	41.76 ± 4.12 b
F	4.962
df	3, 12
P	< 0.019

*Means followed by different letters within the column are significantly different (*P < 0.05*, Tukey's test)

Efficacy of insecticides

The efficacy of various insecticides against *U. euonymi* at different intervals after application is summarized in Table 3. Three days after application (DAA), efficacy ranged from 22.39% for emulsifiable oil alone to 59.26% for the combination of chlorpyrifos and emulsifiable oil. By 7 DAA, the highest efficacy was observed for pyriproxyfen combined with emulsifiable oil (61.33%), while emulsifiable oil alone remained the least effective treatment (23.19%). This trend persisted at 21 DAA, with emulsifiable oil maintaining the lowest efficacy (19.87%) and pyriproxyfen + emulsifiable oil retaining the highest (54.29%).

Table 3. Mean percentage efficiency (± SE) of various insecticide treatments on *Unaspis euonymi* population at different days (3, 7, 14, and 21) after spraying.

Treatment	Days after treatment			
	3	7	14	21
	Mean%±SE	Mean%±SE	Mean%±SE	Mean%±SE
Chlorpyrifos	44.71 ± 4.69 abc*	37.12 ± 6.17 ab	39.70 ± 6.59 b	30.13 ± 3.90 abc
Imidacloprid	33.28 ± 6.38 bc	40.04 ± 5.13 ab	38.47 ± 3.95 b	27.44 ± 4.75 bc
Pyriproxyfen	31.21 ± 5.62 bc	50.10 ± 4.03 a	61.50 ± 3.01 a	49.78 ± 4.23 ab
Chlorpyrifos + Emulsifiable oil	59.26 ± 7.37 a	54.95 ± 8.98 a	46.68 ± 4.06 ab	40.24 ± 10.86 abc
Imidacloprid + Emulsifiable oil	45.65 ± 3.84 ab	48.61 ± 6.40 ab	46.23 ± 6.56 ab	31.49 ± 4.60 abc
Pyriproxyfen + Emulsifiable oil	42.68 ± 3.49 abc	61.33 ± 3.76 a	65.81 ± 4.56 a	54.29 ± 2.74 a
Emulsifiable oil	22.39 ± 1.63 c	23.19 ± 1.52 b	28.79 ± 2.56 b	19.87 ± 2.89 c
F	5.662	5.164	7.686	5.153
df	6, 27	6, 27	6, 27	6, 27
P	< 0.001	< 0.002	< 0.0002	< 0.02

*Means followed by different letters within each column are significantly different (*P < 0.05*, Tukey's test)

Efficacy of *Chilocorus bipustulatus*

The mean efficacy of *C. bipustulatus* releases against *U. euonymi* was 33.33% at 7 days after release (DAR) and increased significantly to 74.76% by 21 DAR (t = -3.820, df = 6, P < 0.01; Fig. 1). This increase in predator efficacy corresponded with a significant reduction in the pest population. While the density of *U. euonymi* (number per leaf or twig) increased steadily in the control treatment over the 21-day period, it showed a clear decline in the predator-release treatment at both 7 and 21 DAR (Fig. 2).

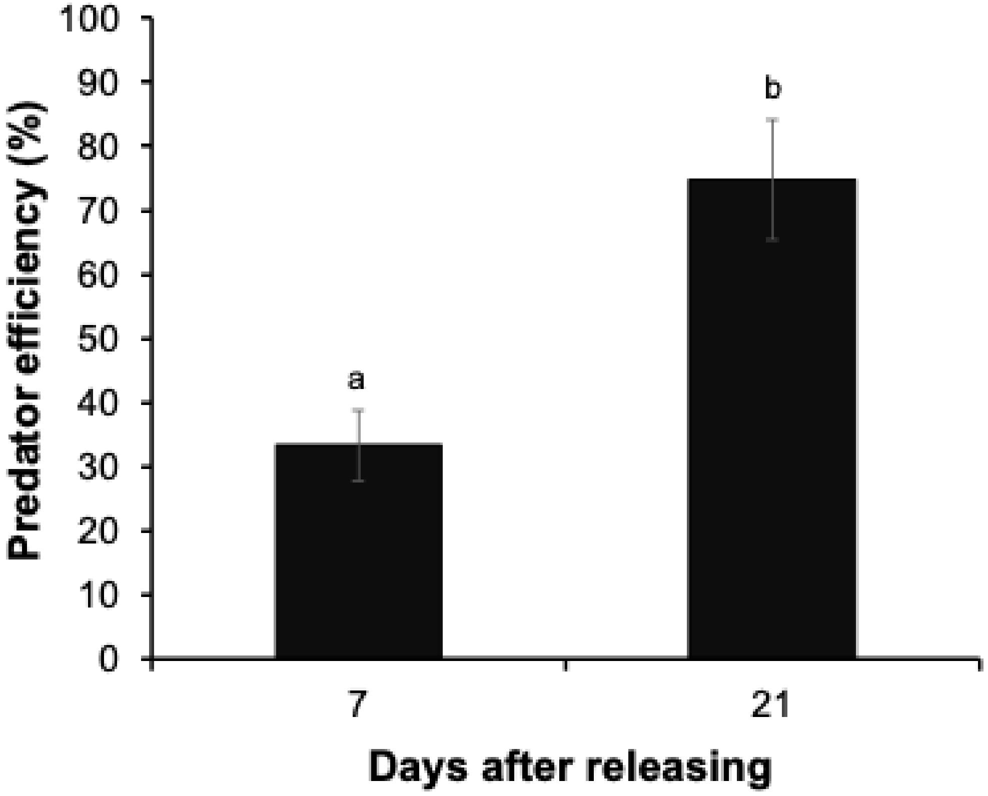

Fig. 1. Efficacy of *Chilocorus bipustulatus* releases against *Unaspis euonymi* at 7 and 21 days after release (DAR). Bars within the figure capped with the same letter are not significantly different (t-test, $P > 0.05$).

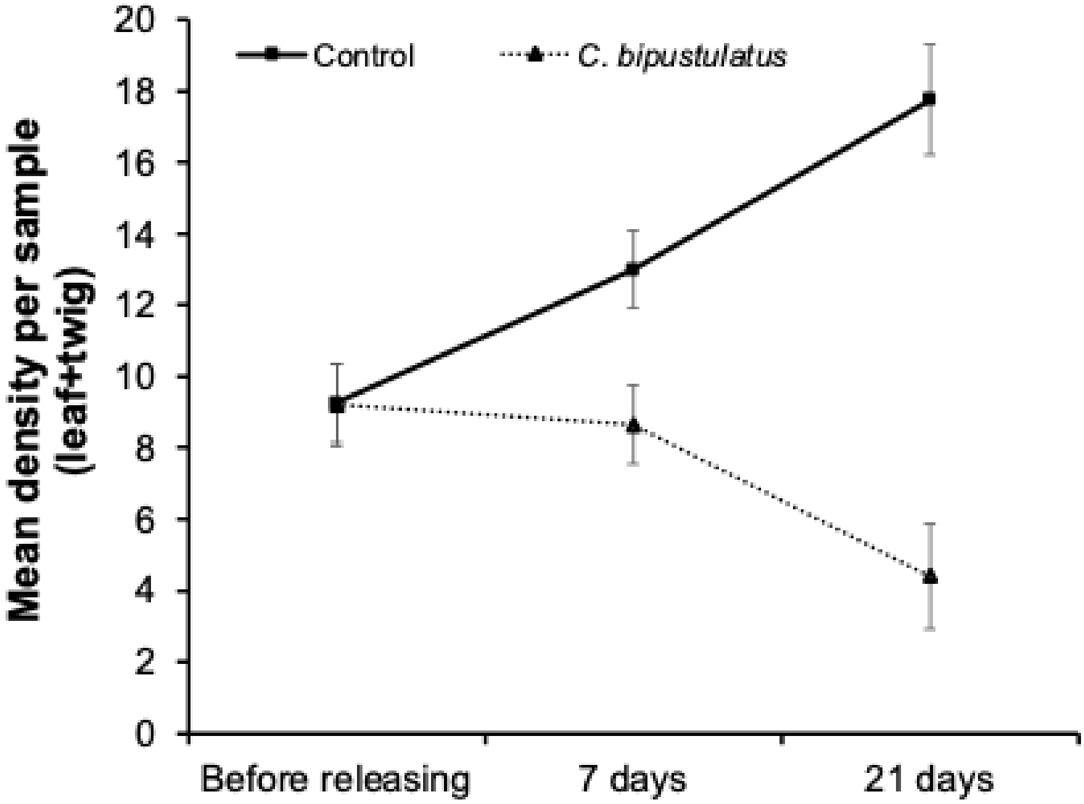

Fig. 2. Population density (mean ± SE) of *Unaspis euonymi* per sample (pooled leaf and twig) in control and predator-release treatments. Samples were taken one day before and at 7 and 21 days after the release of *Chilocorus bipustulatus*.

Discussion

This study provides evidence for the potential integration chemical and biological control methods to manage *U. euonymi* effectively in urban green spaces. The sequential evaluation of a winter emulsifiable oil, growing-season insecticides, and augmentative releases of *C. bipustulatus* provides a practical, season-long management framework.

The efficacy of winter emulsifiable oil was concentration-dependent, with the 2% concentration achieving significantly higher control (41.76%) than the 0.5% concentration (20.36%). This aligns with the established mode of action of oils, which physically suffocate pests by penetrating their protective covers (Sadof & Sclar, 2000; Jafari et al., 2025; Rezaie et al., 2025). This concentration-dependent efficacy is a well-established principle for dormant oil applications, which are most effective against sessile, overwintering insect stages (Nouri, 2007; Khaghaninia, 2009). The overwintering stage of *U. euonymi* consists of mated adult females with robust, waxy scales (Ozyurt & Ulgenturk, 2007), which necessitates higher application rates for effective penetration. The modest overall efficacy, even at the highest concentration, underscores a key limitation of dormant oil applications against this pest: the challenge of achieving complete spray coverage on the intricate architecture of *Euonymus* shrubs, where scales, especially on twigs, can be effectively shielded (Sadof & Sclar, 2000; Gholamzadeh-Chitgar et al., 2018). Therefore, while a high-concentration dormant oil application serves as a valuable first step to suppress overwintering populations with minimal non-target impact, it should not be relied upon as a standalone control measure.

The insecticide trials revealed critical insights for selecting chemical tools during the growing season. The consistent superiority of treatments combining insecticides with emulsifiable oil, particularly pyriproxyfen + oil, highlights an enhanced efficacy, likely due to improved penetration and physical action, as previously suggested for other combinations (e.g., Gholamzadeh-Chitgar et al., 2018; Rezaei et al., 2025). Pyriproxyfen, an insect growth regulator (IRAC Group 7C), disrupts juvenile development and is known for its efficacy against scale insects (Rebek & Sadof, 2003). Its combination with oil may enhance performance by facilitating penetration of the insecticide through the waxy cover or by providing physical control of early instars, as suggested by previous studies (Sadof & Sclar, 2000; Gholamzadeh-Chitgar et al., 2018). However, the specific mechanisms underlying this enhanced efficacy were not investigated in the present study. Such enhanced performance, if confirmed, could represent a valuable strategy for reducing insecticide rates while maintaining efficacy (Deguine et al., 2021; Rezaei et al., 2025). Conversely, the poor and declining performance of imidacloprid, both alone and in combination with oil, confirms previous findings of its inadequacy against *U. euonymi* (Sadof & Sclar, 2000; Rebek & Sadof, 2003). This failure may be attributed to the pest's protected nature and potentially limited vascular translocation of the systemic insecticide to the feeding sites of the settled scales. It is important to note that chlorpyrifos, another insecticide evaluated here, has been banned in Iran since 2024 due to human and environmental health concerns (PPO, 2024). Chlorpyrifos is an acetylcholinesterase inhibitor that causes neurotoxicity by preventing the breakdown of the neurotransmitter acetylcholine in the synaptic cleft. However, intensive and repeated use of this insecticide diminishes its efficacy and drives the development of resistance (Ejaz et al., 2017). Therefore, despite its observed efficacy, its use cannot be recommended. The results strongly suggest that such neonicotinoid and organophosphorus insecticides should be avoided in control programs for *U. euonymi*, while the integration of insect growth regulators like pyriproxyfen with emulsifiable oil offers a much more effective and sustainable chemical strategy.

The most promising results emerged from the biological control component. The significant increase in the efficacy of *C. bipustulatus* from 33.33% at 7 DAR to 74.76% at 21 DAR demonstrates its capacity for population establishment and sustained suppression. The initial lower efficacy may be attributed to an acclimatization period and the predator's functional response, while the subsequent increase in efficacy could reflect successful predation and possibly reproduction, as reported in other studies (e.g., Tazerouni et al., 2019). However, direct evidence of predator reproduction was not collected in the present study. This pattern of increasing impact is consistent with expectations for effective biological control agents (Van Driesche, 2022), although confirmation of long-term establishment would require further monitoring beyond the 21-day period. The voracity of *C. bipustulatus* has been documented against other scale insects (Santos et al., 2009; El Aalaoui et al., 2019), and our findings confirm its high potential for managing *U. euonymi*. The contrasting population trends, a steady increase in the control against a significant decline in the release treatment, provide clear evidence of the predator's suppressive ability. The successful use of *C. bipustulatus* underscores the importance of conserving and augmenting native natural enemies, a strategy that is both sustainable and resilient.

Conclusions

The findings of this study provide a scientific basis for developing a multi-tactic approach to managing *U. euonymi*. Based on our results, a dormant-season application of 2% emulsifiable oil can reduce overwintering populations, while the combination of pyriproxyfen and oil shows promise as a chemical option during the growing season if intervention is required. Additionally, augmentative releases of *C. bipustulatus* demonstrated substantial pest suppression and represent a promising biological control component. However, further research is needed to evaluate the long-term efficacy of this predator, optimize its release rates and timing, and assess its compatibility with other control tactics under field conditions.

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Ethical Approval and Consent

This article does not contain any studies involving human participants or animals performed by any of the authors.

CRediT author statement

M. Rezaei: Conceptualization, Methodology, Formal analysis, Investigation, Draft preparation, Final review & editing, Project administration. **M. Atapour:** Methodology, Formal analysis, Draft preparation, Final review & editing**.**

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Data Availability

All datasets generated during this study are available from the corresponding author upon request.

Conflict of interest

The authors have no conflicts of interest to declare.

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