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Efficacy and limitations of ultraviolet-C light for control of *Lygus hesperus* (Hemiptera: Miridae) eggs and nymphs in strawberry

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Lygus hesperus Knight (Hemiptera: Miridae) is a major pest of California strawberries, where feeding injury from nymphs and adults leads to fruit deformation and economic losses. Management relies heavily on insecticides, with supplemental mechanical removal using bug vacuums. Insecticide resistance and inconsistent vacuum efficacy have prompted interest in non-chemical alternatives. Ultraviolet-C light is currently used for powdery mildew management in California strawberries but has not been evaluated for efficacy against *L. hesperus*. This study assessed the ovicidal effects of ultraviolet-C on *L. hesperus* and determined LD_{50} and LD_{90} values for 1st, 3rd, and 5th instars. In laboratory assays, ultraviolet-C exposure at 350 J/m^2 significantly reduced egg hatch compared to the control, while higher doses (650 and 1,000 J/m^2) did not differ statistically. In the field-applied ultraviolet-C treatments, the 2024 results did not show significant hatch reductions, whereas the 2025 results showed a significant reduction in egg hatch at 1,015 J/m^2. Dose–response modeling showed high lethal thresholds, with LD_{50} values ranging from 19,527 to 25,591 J/m^2 across instars. Occasional molting disruption and wing deformities were observed after 5th instars molted into adults. These findings suggest that ultraviolet-C is not a viable stand-alone strategy for controlling *L. hesperus* nymphs but may offer a slight ovicidal effect. Further research is needed to evaluate sublethal effects and to explore integration with mechanical control methods, particularly in organic production systems where effective chemical strategies are limited.

Keywords: ovicidal activity, integrated pest management, nonchemical control

Introduction

California is the leading strawberry producer in the United States, generating over $3 billion in revenue in 2021 (Holmes 2024, Koster et al. 2024). The western tarnished plant bug, *Lygus hesperus* Knight (Hemiptera: Miridae) and *Lygus elisus* Van Duzee are significant arthropod pests of strawberries (Wells et al. 2020, Holmes 2024). When *Lygus* spp. nymphs and adults feed on embryos within developing achenes, the tissue beneath the feeding site ceases development, causing the berry to become distorted (Allen and Gaede 1963, Strand 2008). This phenomenon is commonly referred to as catfacing and causes significant economic loss by making the berries unsaleable for the fresh market (Strand 2008). Damage from *Lygus* spp. becomes problematic in peak production during the summer months in the Central Coast growing regions (Joseph and Bolda 2016). The tolerance for *Lygus* spp. damage is low, with the treatment threshold being one nymph or adult per 20 plants sampled (Strand 2008). To keep *Lygus* spp. populations below threshold, management in California strawberry production primarily relies on chemical insecticides and in some cases, mechanical removal using bug vacuums (Joseph and Bolda 2016, Wells et al. 2020).

Lygus hesperus has developed resistance to several classes of insecticides, leaving growers with fewer effective tools to manage this pest (Snodgrass and Scott 2000, Snodgrass et al. 2009, Koubek and Aghaee 2025). Of the registered insecticides for *Lygus* spp. in California strawberries, there are seven distinct insecticide resistance action committee (IRAC) classes. Common active ingredients registered for use on *Lygus* spp. in California strawberries are naled (IRAC 1B), malathion (IRAC 1B), bifenthrin (IRAC 3), fenpropathrin (IRAC 3), thiamethoxam (IRAC 4A), acetamiprid (IRAC 4A), flupyradifurone

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(IRAC 4D), novaluron (IRAC 15), indoxacarb (IRAC 22A), and flonicamid (IRAC 29). A section 18 emergency use exemption for using afidopyropen (IRAC 9D) on *Lygus* spp. has been made for 2024 and 2025 in several of California's strawberry-producing counties (CA DPR 2024). Resistance to organophosphates, pyrethroids, neonicotinoids, and benzoylureas has been documented (Snodgrass and Scott 2000, Snodgrass et al. 2009, Du et al. 2023, Jensen 2023). As resistance to most conventional insecticides undermines chemical control tactics, the use of mechanical methods such as the bug vacuum has become supplemental in *Lygus* spp. management (Holmes 2024).

Reported outcomes on the effectiveness of bug vacuums in managing *Lygus* spp. have been inconsistent (Vincent and Lachance 1993, Pickel et al. 1995, Rancourt et al. 2003). Vacuuming an alfalfa trap crop within strawberry fields reduced *Lygus* spp. abundance, but may lead to increased catfacing in rows adjacent to the trap crop (Swezey et al. 2007). Vacuums provided no reduction of *Lygus* spp. nymphs as a standalone treatment or when combined with insecticide applications (Joseph and Bolda 2018a). Innovations in bug vacuum design have improved performance, yielding a 2.2-fold increase in efficacy over traditional models (Wells et al. 2020). A recent study reported tractor mounted vacuums had a negative effect on natural enemies and no significant effect on *Lygus* spp. abundance or crop loss (Lu et al. 2024). The challenges associated with chemical resistance and variable efficacy of bug vacuums have prompted research into novel approaches, including ultraviolet-C (UV-C) light as a non-chemical control strategy.

The use of UV-C light is an emerging technology to control pathogens and arthropods in commercial strawberry fields in California. Ultraviolet (UV) radiation is categorized by UV-C (100 to 280 nm), UV-B (280 to 315 nm), and UV-A (315 to 400 nm) (Diffey 2002, Vázquez and Hanslmeier 2006, Tang et al. 2024). UV-C damages DNA by producing cyclobutene-pyrimidine dimers (CPD) and pyrimidine-pyrimidone (6 to 4) photoproducts (Chang et al. 1985, Thoma 1999, Todo 1999, Holford et al. 2024). Photoreactivation is a process driven by DNA photolyase that can repair UV-C damage within organisms if they are exposed to near-UV or blue light after UV-C application (Todo 1999, Murata and Osakabe 2017, Vechtomova et al. 2021). A 4-h lag time between UV-B irradiation and visible light irradiation prevented photoreactivation in *Tetranychus urticae* Koch (Acari: Tetranychidae) eggs, whereas larvae showed efficient reactivation after the 4-h lag (Murata and Osakabe 2014). Applications of UV-C must occur at night to prevent photoreactivation (Murata and Osakabe 2014).

Currently, a fleet of autonomous UV-C emitting robots is operating on approximately 1,000 acres of strawberries in Oxnard and Santa Maria, California, with field-applied doses typically ranging from 600 to 1,800 J/m^2. Mercury bulbs are used to emit UV-C, and applications begin after sunset. The technology is primarily used by strawberry growers for managing powdery mildew, especially in organic production systems. UV-C light is a highly effective tool for the management of powdery mildew (Onofre et al. 2021, Mello et al. 2022). Low doses have shown to be a valuable ovicidal tool for strawberry pests such as *T. urticae* (Montemayor et al. 2023), *Trialeurodes vaporariorium* Westwood (Hemiptera: Aleyrodidae) (Leskey et al. 2021), and *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae) (O'Hearn 2023). The impact of UV-C light on *Lygus* spp. has not been studied, leaving it unknown whether applications offer any benefit for managing this pest. The objectives of this study were to (1) evaluate if UV-C light has an ovicidal effect on *L. hesperus* eggs under laboratory and strawberry field conditions, and (2) determine the LD_{50} and LD_{90} values for 1st, 3rd, and 5th instar *L. hesperus* nymphs through laboratory assays.

Materials and Methods

Colony Rearing

The *L. hesperus* colony was initiated using individuals provided by the USDA Arid Land Agricultural Research Center in Maricopa, Arizona, and has been maintained at the Cal Poly Strawberry Center since 2023. Egg packs were created using 10.2 cm × 5.1 cm sheets of PM-992 Parafilm (Bemis Company, Inc., Neenah, WI, USA), heat-sealed along the edges. A solution of 10 g agar in 470 mL deionized water was heated to 82.2 °C and cooled slightly before adding 10 mL green food dye (DyeCraft Direct, Hillsborough, NJ, USA). The resulting agar-dye mixture was then poured into the Parafilm packets to create the egg packs. Adults and nymphs were reared separately to reduce predation. Adults were housed in 30 cm × 30 cm × 30 cm rearing cages (BugDorm, DP1000, Taichung, Taiwan), with egg packs placed on the mesh top as an oviposition substrate. Nymphs were maintained in 1.5-gallon tubs (Rubbermaid, Atlanta, GA, USA) with modified lids containing 800-µm mesh. Both stages were provisioned with a #25 4 oz. cardboard tray (Carnival King, Little Neck, NY, USA) filled with sunflower seeds, and organic green beans were provided three times weekly. Egg packs were collected weekly and transferred to new rearing containers. The colony was held in a growth chamber (Model I36VL, Percival Scientific, Perry, IA, USA) set to 20 ± 3 °C, 60 ± 3% RH, and a 14:10 (L:D) photoperiod.

Egg Pack Preparation

Experimental *L. hesperus* egg packs were created by filling 5.1 × 5.1 cm Parafilm packets with the agar-dye solution described previously. Packs were placed atop adult cages for 24 h to allow oviposition. Parafilm egg packs were used for ease of egg counting and because oviposition occurred more readily in them than in natural substrates. After this period, eggs were counted under a dissecting microscope. Egg packs containing 5 to 25 eggs were retained for experiments due to the inability to get an exact number of eggs. Each egg pack was numbered, and then treatment was randomly assigned to each pack for field and laboratory ovicide assays.

Laboratory UV-C Exposure

Laboratory assays were conducted in an 81.3 × 61.0 cm tent (YieldLab, St. Louis, MO, USA) equipped with two GermAwayUV Xtreme Heavy Duty Mountable UV-C lamps (Philips TUV PL-L 55 W, 254 nm). Lamps were mounted 30.5 cm above the exposure surface using a custom PVC frame. To calibrate spatial variation in irradiance, UV-C intensity was measured at 10 positions across the tent using an ILT2400 radiometer. The mean wattage across the base of the tent was 43.4 W/m^2. Stability was defined as a constant reading to the hundredth decimal place. Lamps were pre-warmed for 10 min based on stabilization data. Mean irradiance values were used to calculate exposure doses.

Egg substrates of *L. hesperus* were exposed to three UV-C doses (350, 650, and 1,000 J/m^2) and an untreated control ($n = 10$ per treatment). The 350 J/m^2 dose was included in the lab treatments to assess the field-applied UV-C dose used in Florida (Montemayor et al. 2023), but was not tested in field assays due to the inability of the robot platforms to apply under 600 J/m^2. Egg packs were placed facing upward inside the exposure tent to ensure direct irradiation. Treatments were randomly assigned to each egg pack, and samples were stored overnight in a light-proof wooden box to prevent photoreactivation. Egg packs were transferred into the ventilated plastic cups mentioned previously and maintained in a growth chamber at 20 ± 3 °C, 60 ± 3% RH, and a 14:10 (L: D) photoperiod. All experimental units were arranged in a completely randomized design. Egg hatch data were collected 15 days post-treatment.

Field Ovicidal Evaluation

The first field assay was conducted in November 2024 in a summer-planted commercial strawberry production field in Nipomo, California (34°59′41″N, 120°29′39″W). The second field assay took place in July 2025 in a fall-planted commercial strawberry production field in Nipomo, California (35°00′31″N, 120°29′10″W). UV-C treatments were applied using the EDEN autonomous robotic platform in the 2024 assay and the LUNA robotic platform in the 2025 assay (Fig. 1; TRIC Robotics, San Luis Obispo, CA, USA).

Strawberry beds were 162.6 cm center to center, with four rows of plants spaced 30.5 cm between rows and 39.4 cm between plants within a row. The treatment area for each dose was six beds, with each bed being 91 m long. Three target UV-C dose levels were evaluated: low (600 J/m^2), medium (1,200 J/m^2), and high (1,800 J/m^2), along with an untreated control. Each treatment and the control had 6 replicates in the first assay and 10 replicates in the second assay. Actual exposure levels were quantified using an ILT2400 optical radiometer (International Light Technologies, Peabody, MA, USA) placed atop the strawberry bed. The measured dose values were 650, 1,310, and 1,595 J/m^2 in the first assay and 564, 1,015, and 1,493 J/m^2 in the second assay for the low, medium, and high treatments, respectively. Egg packs were placed on top of the strawberry crowns in the middle two plant rows with the oviposition surface oriented upward to mimic the likely places where *L. hesperus* eggs are laid. The strawberry plants where the egg packs were placed within a bed were randomly selected. All applications were conducted after sunset to prevent photoreactivation.

Following exposure, egg packs were transported back to the laboratory in a lightproof wooden box and kept in the dark until morning to prevent photoreactivation. The next morning, egg packs were transferred into ventilated 946 mL deli cups (Choice, New York, NY, USA) with 20 pinholes in the lid covered by taped coffee filters to prevent escape but allow for airflow. Cups were placed in a growth chamber (Model I36VL, Percival Scientific) set to 20 ± 3 °C, 60 ± 3% RH, and a 14:10 (L:D) photoperiod. Experimental units were arranged in a completely randomized design within the growth chamber. Egg hatch was assessed 12 days after application by counting emerged nymphs.

Dose–Response

Dose–response assays were conducted using a 100 × 15 mm Petri dish. A 3.81 cm section of organic green bean was hot-glued to the bottom of each Petri dish to provide a food source and to prevent the bean from rolling onto the nymphs. Open ends of green beans were hot-glued closed to prevent nymphs from going within the green bean to avoid UV-C irradiation. The 1st, 3rd, and 5th instars were tested. Each dose contained 5 replicates consisting of four *L. hesperus* of the target instar placed within each dish. Prior to UV-C application, the polystyrene Petri dish lid was replaced with a 0.16 cm thick, 10.16 × 10.16 cm piece of quartz glass (McMaster-Carr, Santa Fe Springs, CA, USA) to prevent escape by the nymphs during exposure but allow improved UV-C transmission compared to the polystyrene lid. UV-C doses were recalibrated by placing the quartz glass over the ILT2400 radiometer across 10 points at the base of the tent and applying the same irradiance measurement methodology described in the section. The average wattage with quartz glass was 38.0 W/m^2. Dosages of 0, 5,000, 10,000, 15,000, 25,000, 50,000, and 80,000 J/m^2 were applied to first instars; 0, 100, 1,000, 10,000, 25,000, 50,000, and 75,000 J/m^2 to third instars;

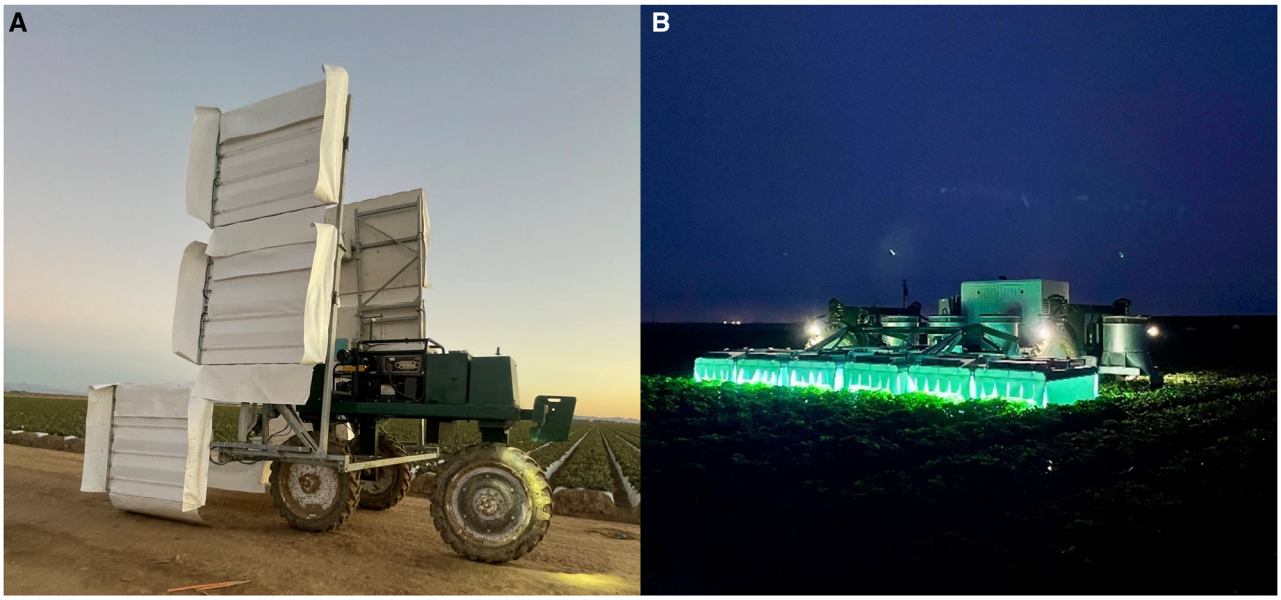

Fig. 1. (A) The EDEN platform used in the 2024 assay and (B) the LUNA platform used in the 2025 assay.

and 0, 1,000, 10,000, 30,000, 60,000, 90,000, and 120,000 J/m^2 to fifth instars. After application, the standard Petri dish lid was put back on, and dishes were stored in a light-proof container overnight. The following morning, dishes were placed in a growth chamber at 20 ± 3 °C and 60 ± 3% RH. All experimental units were arranged in a completely randomized design within the growth chamber. Moribund individuals were counted as dead. Mortality was assessed 48 h post-treatment.

Data Analysis

For *L. hesperus* field and laboratory ovicidal assays, treatment effects on percent egg hatch data were arcsine square root-transformed prior to analysis to meet assumptions of normality. A weighted least squares ANOVA was conducted, with the total number of eggs per replicate used as the weighting factor to account for variation in the number of eggs per egg pack across replicates. Mean separation was performed using Tukey's honestly significant difference (HSD) test ($\alpha = 0.05$). These analyses were conducted using JMP Pro version 18.0.02 (SAS Institute Inc., Cary, NC, USA).

All dose–response analyses were conducted using R version 4.3.2 (R Core Team 2023). To evaluate the effects of UV-C dose on *L. hesperus* mortality, a binomial logit generalized linear model was used for each instar. The models were constructed using the glm() function in R, with the number of dead and alive individuals as the response variables and UV-C dose as the continuous predictor.

The dose.p() function in the MASS package was used to calculate LD_{50} and LD_{90} values from the fitted models. Goodness-of-fit for each model was assessed using the Pearson χ^2 test. Dose–response figures were produced using ggplot2, and fitted curves were overlaid on observed mortality proportions by dose.

Results

Ovicidal Assays

The proportion of *L. hesperus* eggs that hatched differed significantly among UV-C exposure treatments in the laboratory ($F = 2.99$; df = 3, 36; $P = 0.044$) (Fig. 2). The 350 J/m^2 treatment resulted in a significantly lower hatch rate compared to the control ($P < 0.05$), while the 650 and 1,000 J/m^2 treatments did not differ significantly from the control or from each other. Mean ± standard error of the mean (SEM) percent egg hatch in the untreated control group was 56.9 ± 6.1%, while hatch rates were reduced to 31.4 ± 8.8% in the 350 J/m^2 treatment, 44.0 ± 9.3% in the 650 J/m^2 treatment, and 37.8 ± 4.5% in the 1,000 J/m^2 treatment.

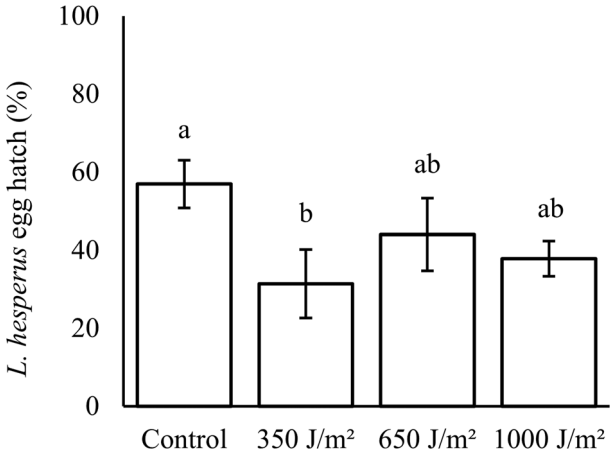

Fig. 2. Egg hatch percentage of *Lygus hesperus* following exposure to 350, 650, and 1,000 J/m^2 of UV-C light under laboratory conditions. Bars represent mean (± SEM) percent hatch for each treatment ($n = 10$ per treatment). Treatments not sharing the same letter are significantly different based on Tukey's HSD test following ANOVA on arcsine square root-transformed data ($P < 0.05$).

In the first field experiment, UV-C treatment had no statistically significant effect on *L. hesperus* egg hatch rates ($F = 1.64$; df = 3, 20; $P = 0.212$) (Fig. 3A). Mean ± SEM percent egg hatch in the control group was 57.8 ± 8.2%. Egg hatch rates in UV-C-treated groups were 49.5 ± 5.4% at 650 J/m^2, 39.2 ± 4.4% at 1,310 J/m^2, and 45.7 ± 7.5% at 1,595 J/m^2. Although hatch was numerically reduced in all UV-C treatments relative to the control, none of these differences were statistically significant.

In the second field experiment, UV-C treatment had a statistically significant effect on *L. hesperus* egg hatch ($F = 4.15$; df = 3, 36; $P = 0.013$) (Fig. 3B). The 1,015 J/m^2 treatment significantly reduced egg hatch compared to the control ($P < 0.05$), although none of the UV-C treatments statistically differed

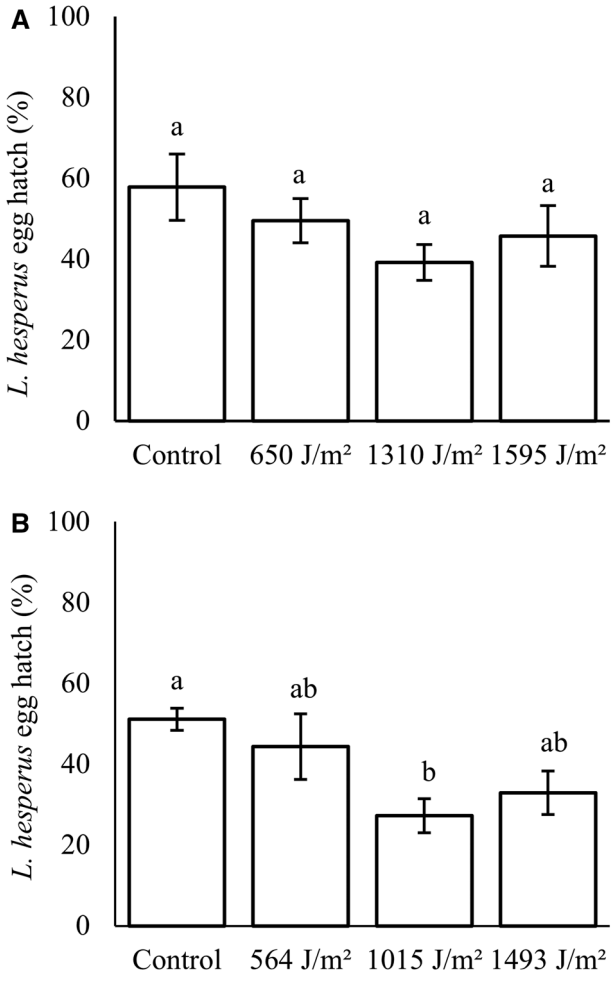

Fig. 3. (A) Egg hatch percentage of *Lygus hesperus* following UV-C exposure under field conditions in Nov 2024 and (B) Jul 2025. Bars represent mean (± SEM) percent hatch for each treatment group ($n = 6$ (A); $n = 10$ (B)). Assays were analyzed separately using a weighted least squares ANOVA on arcsine square root-transformed data ($P = 0.212$ (A); $P < 0.05$ (B)). Treatments not sharing the same letter are significantly different based on Tukey's HSD.

from each other. Mean ± SEM percent egg hatch in the control group was 51.2 ± 2.73%. Egg hatch rates in UV-C treated groups were 44.4 ± 8.11% at 564 J/m^2, 27.2 ± 4.20% at 1,015 J/m^2, and 32.9 ± 5.36% 1,493 J/m^2.

Dose–Response

First instar *L. hesperus* nymph indicated a lack of model fit (χ^2 = 18.532, df = 5, P = 0.002). Overdispersion was accounted for using a quasibinomial logit model. The estimated median lethal dose (LD_{50}) for 1st instars was 19,527 ± 3,815 J/m^2, and the 90% lethal dose (LD_{90}) was 30,947 ± 6,376 J/m^2 (Fig. 4A). Third instar *L. hesperus* displayed an acceptable model fit (χ^2 = 3.376, df = 5, P = 0.642). The LD_{50} for 3rd instars was 23,879 ± 2,804 J/m^2, and the LD_{90} was 43,388 ± 5,218 J/m^2 (Fig. 4B). Fifth instar *L. hesperus* nymphs exhibited the best model fit (χ^2 = 2.376, df = 5, P = 0.795). The LD_{50} for 5th instars was 25,591 ± 3,926 J/m^2 and the LD_{90} was 59,248 ± 7,911 J/m^2 (Fig. 4C).

Discussion

This study investigated UV-C light as a potential management strategy for *L. hesperus* in the California strawberry industry, focusing on ovicidal effects and dose–response thresholds for nymphal stages. Ovicidal effects of UV-C at low doses have been documented for *T. urticae* (Montemayor et al. 2023), *T. vaporariorium* (Leskey et al. 2021), and *B. tabaci* (O'Hearn 2023), among other pests. Laboratory assays showed a significant reduction in egg hatch at 350 J/m^2 compared to the control. The doses 650 and 1,000 J/m^2 did not separate from the control or 350 J/m^2. In the 2024 field assay, none of the UV-C doses significantly reduced egg hatch compared to the control, although they were numerically lower. In the 2025 field assay, the dose of 1,015 J/m^2 had a significantly reduced egg hatch percentage compared to the control. The lack of statistical difference in the 2024 field assay may be due to only having 6 replicates, as opposed to the 2025 assay, which had 10 replicates. In both laboratory and field assays, the ovicidal response did not appear to be dose dependent. The egg parasitoid *Anaphes iole* Girault (Hymenoptera: Mymaridae) prefers *L. hesperus* eggs depending on the depth in which they are oviposited into plant material (Conti et al. 1996), and this variation in ovipositional depth may influence the efficacy of UV-C as an ovicide for *L. hesperus*.

Eggs of *L. hesperus* are laid within plant tissues such that only the egg cap remains exposed above the surrounding substrate (Conti et al. 1997). Female *L. hesperus* oviposit the most in fruit and petioles on strawberry (Joseph and Bolda 2018b, Udayagiri and Welter 2000). Plants protect themselves from UV radiation with UV-absorbing compounds and protective structures (Urban et al. 2016). Given the limited penetration of UV-C through plant tissue (Vanhaelewyn et al. 2020), the internal positioning of the egg may provide a physical barrier that protects the embryo from exposure. Parafilm was used as an ovipositional substrate for egg packs, which has poor UV-C penetration similar to plants. The lack of a dose-dependent ovicidal relationship shown in the laboratory and field assays may be attributed to the depth in which eggs were oviposited within egg packs. Differences in ovipositional depth between parafilm and plant tissue may alter the extent to which UV-C acts as an ovicide on *L. hesperus* eggs. The concealed oviposition strategy of *L. hesperus* reduces egg exposure to UV-C light, thereby constraining its potential as an ovicidal tool.

Dose–response assays revealed that UV-C light had limited lethality against nymphal stages, with LD_{50} values ranging from 19,527 J/m^2 for 1st instars to over 23,000 J/m^2 for 3rd and 5th instars. The LD_{50} values for all instars are well above the doses achievable by current UV-C delivery systems in commercial fields (600 to 1,800 J/m^2). Future advancements in light technology could allow for the application of the high doses required to kill motile stages of *L. hesperus*, but phytotoxicity could become an issue at higher doses. Onofre et al. (2021) reported that applications of 170 J/m^2 twice per week did not produce phytotoxic symptoms on strawberry, but Van Delm et al. (2014) showed that application of 500 J/m^2 four times per week did cause strawberry burn. However, the latter study was conducted in a plastic greenhouse with tray plants, which may have increased their susceptibility to leaf burn. The fields where the bioassays took place in this study received 600 J/m^2 twice per week for months leading up to the bioassay, and no phytotoxicity symptoms were observed. After application of the maximum doses in field bioassays, 1,595 J/m^2 in Nov 2024 and 1,493 J/m^2 in Jul 2025, no phytotoxicity symptoms were observed upon revisiting plots. Application frequency, growing conditions, and cultivar may influence the inconsistency in reported phytotoxicity of UV-C on strawberries. Based on the high lethal dose requirements found in this study, current UV-C applications are not a viable strategy for managing nymphal stages of *L. hesperus*.

Sublethal effects on fecundity, fertility, developmental rates, molting, and wing deformities of *L. hesperus* exposed to UV-C light have not been investigated. Occasional molting interference and wing deformities were observed after 5th instars molted into adults in the dose–response experiment. UV-C has shown to cause wing deformities in *Tribolium castaneum* (Wu et al. 2025) and *Drosophila melanogaster* (Lotfy et al. 2024) at high dose applications. Development of wing deformities in *L. hesperus* has the potential to affect the field distribution of populations and the efficacy of bug vacuums, although field-applied doses are much lower than the doses in the aforementioned studies.

One limitation of this study is that ovicidal assays were conducted using eggs deposited in parafilm egg packs rather than within plant tissue. Although both plant tissue and parafilm both have minimal UV-C penetration, ovipositional depth is likely to vary based on plant structure. Future research should investigate sublethal effects of field-applied UV-C doses to determine if wing deformities or a reduced reproductive output occur in surviving adults. Although UV-C is unlikely to provide stand-alone control of *L. hesperus*, sublethal impacts and integration with mechanical control warrant further investigation as part of a diversified integrated pest management strategy.

Commercial field applied dosages in California are 600 J/m^2, which is well below the 19,527 J/m^2 LD_{50} of 1st instars. In comparison to current management strategies, such as insecticides and vacuuming, UV-C provides limited utility in managing *L. hesperus* nymphs due to the high doses required. However, UV-C may contribute to a slight ovicidal effect depending on the depth at which eggs are deposited within plant tissues. TRIC robotics, SAGA robotics, and other companies are developing robotics that integrate multiple mechanisms, such as incorporating a bug vacuum positioned behind the UV-C lamps. This strategy could affect the efficacy of the

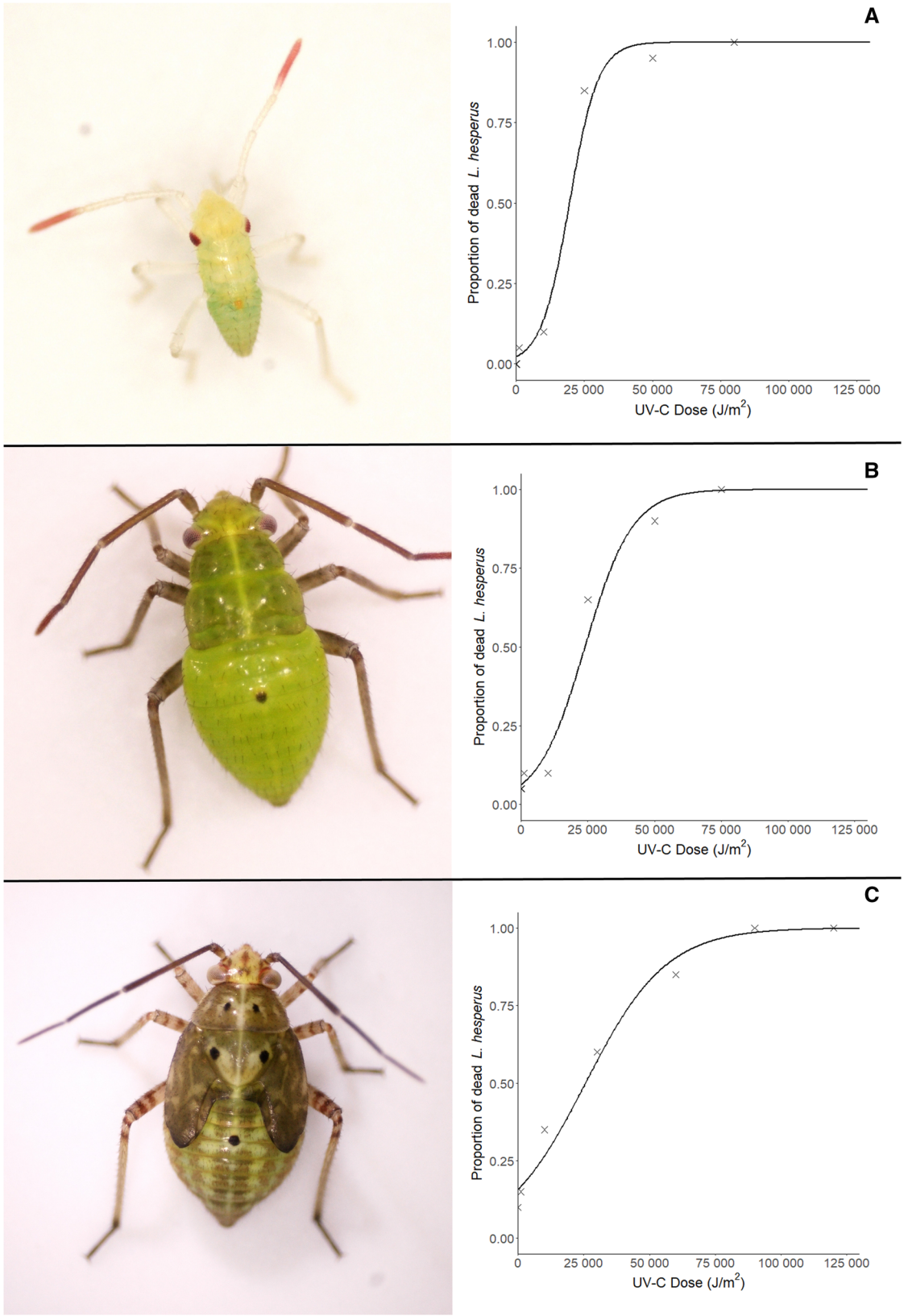

Fig. 4. Dose–response relationships for UV-C-induced mortality of *Lygus hesperus* nymphs. Mortality curves and observed proportions of dead individuals are shown for (A) 1st instars, (B) 3rd instars, and (C) 5th instars across a range of UV-C dosages (J/m²). Representative images of each instar are shown adjacent to corresponding dose–response plots.

bug vacuum depending on the behavioral response of *L. hesperus* to UV-C at night. The integration of mechanical removal of motile stages coupled with UV-C, providing slight ovicidal activity, could offer improved efficacy for managing *L. hesperus* in organic production. As interest in non-chemical pest management continues to grow, understanding both the limitations and opportunities of UV-C technology is essential for defining its role within integrated pest management programs.

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Author Contributions

Colin Koubek (Conceptualization [equal], Data curation [lead], Formal analysis [lead], Investigation [lead], Methodology [lead], Writing—original draft [lead]) and Mohammad Amir Aghaee (Conceptualization [equal], Data curation [supporting], Formal analysis [supporting], Funding acquisition [lead], Investigation [supporting], Methodology [supporting], Project administration [lead], Resources [lead], Visualization [lead], Writing—review & editing [equal])

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Conflicts of Interest

None declared.

References

Allen WW, Gaede SE. 1963. The relationship of lygus bugs and thrips to fruit deformity in strawberries. *J. Econ. Entomol.* 56:823–825. https://doi.org/10.1093/jee/56.6.823.

California Department of Pesticide Regulation (CA DPR). 2024. FIFRA Section 18 Crisis Emergency Exemption: for use of afidopyropen on field-grown strawberries to control Lygus outbreaks. https://ceqanet.lci.ca.gov/2024050902.

Chang JC, Ossoff SF, Lobe DC, et al. 1985. UV inactivation of pathogenic and indicator microorganisms. *Appl. Environ. Microbiol.* 49:1361–1365. https://doi.org/10.1128/aem.49.6.1361-1365.1985.

Conti E, Jones WA, Bin F, et al. 1996. Physical and chemical factors involved in host recognition behavior of *Anaphes iole* Girault, an egg parasitoid of *Lygus hesperus* Knight (Hymenoptera: Mymaridae; Heteroptera: Miridae). *Biol. Control* 7:10–16. https://dx.doi.org/10.1006/bcon.1996.0057.

Conti E, Jones WA, Bin F, et al. 1997. Oviposition behavior of *Anaphes iole*, an egg parasitoid of *Lygus hesperus* (Hymenoptera: Mymaridae; Heteroptera: Miridae). *Ann. Entomol. Soc. Am.* 90:91–101. https://doi.org/10.1093/aesa/90.1.91.

Diffey BL. 2002. Sources and measurement of ultraviolet radiation. *Methods* 28:4–13. https://doi.org/10.1016/S1046-2023(02)00204-9

Du Y, Zhu Y-C, Portilla M, et al. 2023. The mechanisms of metabolic resistance to pyrethroids and neonicotinoids fade away without selection pressure in the tarnished plant bug *Lygus lineolaris*. *Pest Manag. Sci.* 79:3893–3902. https://doi.org/10.1002/ps.7570.

Holford P, Parajuli S, Beattie GAC, et al. 2024. Arthropods and ultraviolet radiation: survival, growth and development. *Ecol. Entomol.* 49:451–462. https://doi.org/10.1111/een.13318.

Holmes GJ. 2024. The California strawberry industry: current trends and future prospects. *Int. J. Fruit Sci.* 24:115–129. https://doi.org/10.1080/15538362.2024.2342900.

Jensen KW. 2023. *Documenting Tetranychus urticae and Lygus hesperus resistance status in California strawberries*. California Polytechnic State University. https://www.proquest.com/docview/3110356191/abstract/E8E87ECD75AD4018PQ/1.

Joseph SV, Bolda M. 2018a. Evaluating the potential utility of an electrostatic sprayer and a tractor-mounted vacuum machine for *Lygus hesperus* (Hemiptera: Miridae) management in California's coastal strawberry. *Crop Prot.* 113:104–111. https://doi.org/10.1016/j.cropro.2018.08.005.

Joseph SV, Bolda M. 2018b. Influence of insecticides on oviposition behavior of western tarnished plant bug on strawberry. *Am. J. Entomol.* 2:36–41. https://doi.org/doi:%252010.11648/j.aje.20180204.11.

Joseph SV, Bolda M. 2016. Efficacy of insecticides against *Lygus hesperus* Knight (Hemiptera: Miridae) in the California's central coast strawberry. *Int. J. Fruit Sci.* 16:178–187. https://doi.org/10.1080/15538362.2016.1219293.

Koster JT, Ding S, Holmes GJ, et al. 2024. Effect of sequential crop termination and bed fumigation on *Verticillium dahliae* soil and plant density in strawberry. *Int. J. Fruit Sci.* 24:1–17. https://doi.org/10.1080/15538362.2023.2292132.

Koubek CT, Aghaee MA. 2025. Insecticide tolerance in field populations of western tarnished plant bug (*Lygus hesperus*) in strawberry, 2024. *Arthropod Manag. Tests* 50:tsaf085. https://doi.org/10.1093/amt/tsaf085.

Leskey TC, Short BD, Emery M, et al. 2021. Effect of UV-C irradiation on greenhouse whitefly, *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae). *Fla. Entomol.* 104:148–150. https://doi.org/10.1653/024.104.0215.

Lotfy M, Khattab A, Shata M, et al. 2024. Destructive effects of UVC radiation on *Drosophila melanogaster*: mortality, fertility, mutations, and molecular mechanisms. *PLoS One* 19:e0303115. https://doi.org/10.1371/journal.pone.0303115.

Lu A, Gonthier D, Sciligo A, et al. 2024. Arthropod arbiters: natural enemy communities mediate the effects of landscape and local-scale complexity on *Lygus*-induced crop loss in organic strawberries. *Front. Sustain. Food Syst.* 8:1336888. https://doi.org/10.3389/fsufs.2024.1336888.

Mello PP, Onofre RB, Rea M, et al. 2022. Design, construction, and evaluation of equipment for nighttime applications of UV-C for management of strawberry powdery mildew in Florida and California. *Plant Health Prog.* 23:321–327. https://doi.org/10.1094/PHP-01-22-0002-RS.

Montemayor JD, Smith HA, Peres NA, et al. 2023. Potential of UV-C for management of two-spotted spider mites and thrips in Florida strawberry. *Pest Manag. Sci.* 79:891–898. https://doi.org/10.1002/ps.7263.

Murata Y, Osakabe M. 2014. Factors affecting photoreactivation in UVB-irradiated herbivorous spider mite (*Tetranychus urticae*). *Exp. Appl. Acarol.* 63:253–265. https://doi.org/10.1007/s10493-014-9773-3.

Murata Y, Osakabe M. 2017. Photo-enzymatic repair of UVB-induced DNA damage in the two-spotted spider mite *Tetranychus urticae*. *Exp. Appl. Acarol.* 71:15–34. https://doi.org/10.1007/s10493-016-0100-z.

O'Hearn J. 2023. Effect of ultraviolet radiation (UVC) on *Bemisia tabaci* eggs. https://doi.org/10.21203/rs.3.rs-3224862/v1.

Onofre RB, Gadoury DM, Stensvand A, et al. 2021. Use of ultraviolet light to suppress powdery mildew in strawberry fruit production fields. *Plant Dis.* 105:2402–2409. https://doi.org/10.1094/PDIS-04-20-0781-RE.

Pickel C, Zalom F, Walsh D, et al. 1995. Vacuums provide limited *Lygus* control in strawberries. *Cal. Ag*. 49:19–22. https://doi.org/10.3733/ca.v049n02p19.

R Core Team. 2023. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. https://www.r-project.org/.

Rancourt B, Vincent C, De Oliveira D. 2003. Field evaluation of efficacy and persistence of an insect vacuum device against the tarnished plant bug (Hemiptera: Miridae) in a day-neutral strawberry field. *J. Econ. Entomol*. 96:401–406. https://doi.org/10.1093/jee/96.2.401.

Snodgrass GL, Gore J, Abel CA, et al. 2009. Acephate resistance in populations of the tarnished plant bug (Heteroptera: Miridae) from the Mississippi River Delta. *J. Econ. Entomol*. 102:699–707. https://doi.org/10.1603/029.102.0231.

Snodgrass GL, Scott WP. 2000. Seasonal changes in pyrethroid resistance in tarnished plant bug (Heteroptera: Miridae) populations during a three-year period in the delta area of Arkansas, Louisiana, and Mississippi. *J. Econ. Entomol*. 93:441–446. https://doi.org/10.1603/0022-0493-93.2.441.

Strand LL. 2008. *Integrated pest management for strawberries*. UCANR Publications.

Swezey SL, Nieto DJ, Bryer JA. 2007. Control of western tarnished plant bug *Lygus hesperus* Knight (Hemiptera: Miridae) in California organic strawberries using alfalfa trap crops and tractor-mounted vacuums. *Environ. Entomol*. 36:1457–1465. https://doi.org/10.1093/ee/36.6.1457.

Tang X, Yang T, Yu D, et al. 2024. Current insights and future perspectives of ultraviolet radiation (UV) exposure: friends and foes to the skin and beyond the skin. *Environ. Int*. 185:108535. https://doi.org/10.1016/j.envint.2024.108535.

Thoma F. 1999. Light and dark in chromatin repair: repair of UV-induced DNA lesions by photolyase and nucleotide excision repair. *EMBO J*. 18:6585–6598. https://doi.org/10.1093/emboj/18.23.6585.

Todo T. 1999. Functional diversity of the DNA photolyase/blue light receptor family. *Mutat. Res*. 434:89–97. https://doi.org/10.1016/S0921-8777(99)00013-0.

Udayagiri S, Welter SC. 2000. Escape of *Lygus hesperus* (Heteroptera: Miridae) eggs from parasitism by *Anaphes iole* (Hymenoptera: Mymaridae) in strawberries: plant structure effects. *Biol. Control* 17:234–242. https://doi.org/10.1006/bcon.1999.0802.

Urban L, Charles F, de Miranda MRA, et al. 2016. Understanding the physiological effects of UV-C light and exploiting its agronomic potential before and after harvest. *Plant Physiol. Biochem*. 105:1–11. https://doi.org/10.1016/j.plaphy.2016.04.004.

Van Delm T, Melis P, Stoffels K, et al. 2014. Control of powdery mildew by UV-c treatments in commercial strawberry production. *Acta Hortic*. 1049:679–684. https://doi.org/10.17660/ActaHortic.2014.1049.105.

Vanhaelewyn L, Van Der Straeten D, De Coninck B, et al. 2020. Ultraviolet radiation from a plant perspective: the plant–microorganism context. *Front. Plant Sci*. 11:597642. https://doi.org/10.3389/fpls.2020.597642.

Vázquez M, Hanslmeier A. 2006. Solar ultraviolet radiation and magnetism. In: *Ultraviolet radiation in the solar system*. Springer Netherlands. p. 35–68. https://doi.org/10.1007/1-4020-3730-9_2.

Vechtomova YL, Telegina TA, Buglak AA, et al. 2021. UV radiation in DNA damage and repair involving DNA-photolyases and cryptochromes. *Biomedicines* 9:1564. https://doi.org/10.3390/biomedicines9111564.

Vincent C, Lachance P. 1993. Evaluation of a tractor-propelled vacuum device for management of tarnished plant bug (Heteroptera: Miridae) populations in strawberry plantations. *Environ. Entomol*. 22:1103–1107. https://doi.org/10.1093/ee/22.5.1103.

Wells J, Fink C, Edsall M, et al. 2020. Prototype *Lygus* spp. vacuum provides improved pest management in California strawberries. *Int. J. Fruit Sci*. 20:1019–1028. https://doi.org/10.1080/15538362.2020.1820261.

Wu Y, Miao S, Sun H, et al. 2025. Impact of UV-C irradiation on the growth and antioxidant responses in *Tribolium castaneum*. *J. Stored Prod. Res*. 112:102636. https://doi.org/10.1016/j.jspr.2025.102636.