frontiers in Agronomy

TYPE Original Research
PUBLISHED 27 April 2026
DOI 10.3389/fagro.2026.1805940

Evaluation of UV-C light for control of *Tetranychus urticae* and *Eotetranychus lewisi* (Acari: Tetranychidae) on strawberry

Colin T. Koubek* and Mohammad Amir Aghaee

Strawberry Center, California Polytechnic State University, San Luis Obispo, CA, United States

OPEN ACCESS

EDITED BY
Oscar Liburd,
University of Florida, United States

REVIEWED BY
Masaya Tanaka,
Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries, Japan
Haifeng Jin,
Hainan University, China

*CORRESPONDENCE
Colin T. Koubek
ckoubek@calpoly.edu

RECEIVED 06 February 2026
REVISED 24 March 2026
ACCEPTED 13 April 2026
PUBLISHED 27 April 2026

CITATION
Koubek CT and Aghaee MA (2026) Evaluation of UV-C light for control of *Tetranychus urticae* and *Eotetranychus lewisi* (Acari: Tetranychidae) on strawberry. *Front. Agron.* 8:1805940. doi: 10.3389/fagro.2026.1805940

Twospotted spider mite, *Tetranychus urticae* Koch, is a major arthropod pest of strawberry production in California, while Lewis mite, *Eotetranychus lewisi* McGregor, has emerged as an occasional but increasingly problematic pest in recent decades. Management of both species relies heavily on miticides and biological control, but resistance to miticides in *T. urticae* and limited biological control options for *E. lewisi* highlight the need for alternative management tools. Ultraviolet-C (UV-C) light is currently used in commercial strawberry production to manage powdery mildew, yet its efficacy against mite pests under California field conditions is not clear. This study evaluated the ovicidal and lethal effects of UV-C exposure on *T. urticae* and *E. lewisi* through laboratory and open-field evaluations, along with dose–response bioassays. Laboratory ovicide assays demonstrated near complete suppression of egg hatch for both species following UV-C exposure at 600, 1200, and 1800 J/m^2. Field assays conducted across multiple seasons showed consistent and substantial reductions in egg hatch for *T. urticae* and *E. lewisi*, though efficacy varied among trials. Dose–response analyses indicated that larvae were more susceptible than adults, but lethal dose estimates for adults of both species exceeded 9,000 J/m^2, a UV-C dose currently not advisable under field conditions. Reported LD_{50} values confirmed that UV-C is unlikely to provide meaningful direct control of motile life stages at commercially viable exposure levels. To our knowledge, this study is the first to report ovicidal activity and lethal dose estimates for *E. lewisi* in response to UV-C light. These findings indicate that UV-C applications primarily function as an ovicidal tool for mite pests in strawberry production systems and may complement existing integrated pest management programs by targeting early developmental stages.

KEYWORDS
integrated pest management (IPM), Lewis mite, non-chemical control, sustainable pest management, ultraviolet-C (UV-C)

1 Introduction

Twospotted spider mite, *Tetranychus urticae* Koch, is a major pest of strawberries that can reduce yield by 10–25% (Rosa Giménez-Ferrer et al., 1994; Walsh et al., 2002; Lahiri et al., 2022). Lewis mite, *Eotetranychus lewisi* McGregor, has classically been a pest of greenhouse poinsettias (Doucette, 1962), but in the last two decades has become an occasional pest of strawberries in California (Howell and Daugovish, 2013, 2016). In California's coastal production regions, *T. urticae* remains the primary mite pest affecting strawberries (Holmes, 2024; Oatman, 1971; Strand, 2008). Feeding damage by *E. lewisi* closely resembles that of *T. urticae*, resulting in a bronzing of the leaves and reduced plant vigor (Howell and Daugovish, 2013). Both mite species infest the abaxial leaf surface and feed on cell contents, thereby disrupting physiological processes such as photosynthesis (Doucette, 1962; Jakubowska et al., 2022). Management of *T. urticae* and *E. lewisi* primarily relies on miticide applications and the release of predatory mites (Lahiri et al., 2022; Holmes, 2024).

Despite the availability of chemical tools for *T. urticae*, resistance has been documented to multiple active ingredients such as bifenazate, abamectin, and fenpyroximate (Jensen, 2023; Kwon et al., 2010). Management of *E. lewisi* is mainly a problem in organic production, as growers report that miticides provide effective control. Biological control also plays an important role in mite management in California strawberries. The predatory mite *Phytoseilus persimilis* Athias-Henriot is commonly used for controlling *T. urticae* (Howell and Daugovish, 2013; Holmes, 2024). However, *Phytoseiulus persimilis* does not prey on *E. lewisi*; therefore, a diversity of predatory mite species is required when both pests are present (Howell and Daugovish, 2013). These limitations, along with miticide resistance, have increased interest in non-chemical pest management tools that can complement existing integrated pest management (IPM) programs. One emerging approach is the use of ultraviolet-C (UV-C) light.

UV-C light is being used commercially in California strawberries for the management of powdery mildew, with field applied doses ranging from 600–1800 J/m^2. The mechanism of action by which UV-C kills an organism is through cyclobutane–pyrimidine dimers and pyrimidine (6–4) pyrimidone photoproducts that damage DNA (Holford et al., 2024). Control of powdery mildew with UV-C in open-field strawberries has been successful in Florida (Onofre et al., 2021) and California (Mello et al., 2022). UV-C has also been shown to be effective against Botrytis gray mold in the laboratory (Jin et al., 2017; Forges et al., 2018), but limited field efficacy research on the disease exists in California. Management of *T. urticae* using UV-C is reported to be effective in greenhouse strawberries (Short et al., 2018). UV-B has been shown to have ovicidal effects on *T. urticae* (Murata and Osakabe, 2014, 2017), with a reported LD_{50} of 580 J/m^2 on *T. urticae* eggs (Murata and Osakabe, 2013). UV-C has demonstrated a higher lethality and suppression of oviposition in non-diapausing *T. urticae* adults than UV-B (Suzuki et al., 2009). Montemayor et al., 2023a reported UV-C had ovicidal effects against *T. urticae* and reduced *T. urticae* infestation on strawberry trifoliates of the cultivar 'Florida Brilliance' in the field compared to the non-treated control in the 2020-2021 season. A season long UV-C field trial for *T. urticae* in California was unable to detect differences due to variable population numbers across all plots (Rojas, 2023). Reported LD_{50} values for *T. urticae* adults vary (Gala et al., 2021; Montemayor et al., 2023b), but all reported values confirm that field viable doses (600–1800 J/m^2) are unable to contribute meaningful mortality to adults.

Mite eggs are a critical life stage for population growth, and ovicidal tools like UV-C could provide a valuable component to existing IPM programs. There is limited research on *E. lewisi* and no literature has been published on UV-C for the management of *E. lewisi*. Understanding the lethality of UV-C on different life stages of both mites provides context for how UV-C should be perceived as a mite management tool within strawberry production. The objectives of this study were to evaluate the ovicidal activity of UV-C at field relevant doses against *E. lewisi* and *T. urticae* in laboratory and field conditions and to characterize the susceptibility of motile stages by estimating lethal dose parameters for *E. lewisi* adults and *T. urticae* larvae and adults.

2 Materials and methods

2.1 Colony rearing

Bean plants are commonly used for mass rearing *T. urticae* in laboratory settings; therefore, green beans were used to maintain the colony (Bustos et al., 2016; Hayder et al., 2026; Praslička and Huszár, 2004). Green bean seeds (*Phaseolus vulgaris* cv. Bush Lima, 'Fordhook No. 242'; Burpee Seeds, Warminster, PA, USA) were sown in square plastic pots (11 cm × 11 cm base, 15 cm height) filled with a substrate mix from the Cal Poly Horticultural Unit (35° 18'34"N 120°39'41"W). Plants were grown under LED lights in a controlled environment and were watered twice weekly. Three-week-old bean plants were placed into 60 × 60 × 60 cm rearing cages (BugDorm-2120F, MegaView Science, Taiwan, China) containing infested bean plants to establish colonies of *T. urticae*. The initial *T. urticae* colony originated from infested strawberry foliage in Field 25 at the Cal Poly Strawberry Center (35°18'19"N 120°40'36"W) collected in July 2024. The initial *E. lewisi* colony originated from a commercial strawberry field in Arroyo Grande, CA (35°10'21"N 120° 31'34"W) collected in March 2025. Colonies were maintained at room temperature and humidity with a 14:10 (L:D) photoperiod. Fresh bean plants were introduced into cages as older plants senesced.

2.2 Preparation of egg bioassay units

Egg bioassays were conducted using sterile 100 × 15 mm polystyrene Petri dishes (Fisher Scientific, Waltham, MA, USA). Each dish was lined with moistened cotton (30.5 cm cotton roll; Intrinsics Naturally, Arden, NC, USA) to maintain humidity. A 6.4 cm diameter circular window was cut into the lid and fitted with 150 μm polyethylene monofilament mesh using hot glue to allow airflow. Strawberry trifoliates of the cultivar 'Monterey' were collected from Field 35b at the Cal Poly Strawberry Center (35°18'20"N, 120° 40'22"W). Leaf discs (2.2 cm diameter) were excised using a cork borer (Humboldt Mfg. Co., Elgin, IL, USA) and placed abaxial side up on cotton. Two female adult mites were transferred to each disc and allowed to oviposit for 24 h in a growth chamber (Model I36VL, Percival Scientific, Perry, IA, USA) set to 25 ± 3 °C, 60 ± 3% RH, and a 14:10 (L:D) photoperiod. Adults were then removed, and eggs were counted under a dissecting microscope. Only leaf discs containing between 5 and 20 eggs were retained for experiments to standardize egg density and minimize variability among discs given that an identical number of eggs per disc could not be consistently obtained. This method was used for both *T. urticae* and *E. lewisi*.

2.3 Laboratory UV-C exposure

Laboratory assays were conducted in a 81 × 61 cm reflective tent (YieldLab, St. Louis, MO, USA) equipped with two GermAwayUV Xtreme Heavy Duty Mountable UV-C lamps (Philips TUV PL-L 55W, 254 nm). Lamps were mounted 30 cm above the exposure surface using a custom PVC frame. To calibrate spatial variation in irradiance, UV-C intensity was measured at 10 positions using an ILT2400 radiometer (International Light Technologies, Peabody, MA, USA). Stability was defined as a constant reading to the hundredth decimal place. Lamps were pre-warmed for 10 min based on stabilization data (plateau at 9 min 22 s). The mean wattage across the base of the tent was 43.4 W/m^2.

2.4 Laboratory egg bioassays

Eggs of *T. urticae* and *E. lewisi* were exposed to 0, 600, 1200, and 1800 J/m^2 in the laboratory UV-C tent described above. Treatments were randomly assigned to each leaf disc and had ten replicates. Photoreactivation is a mechanism where DNA damage caused by far UV (200–300 nm) is repaired by a photolyase after exposure to UV-A (315–400 nm) or visible blue light (400–450 nm) that can occur in all life stages of arthropods (Holford et al., 2024; Murata and Osakabe, 2014; Sancar, 2003). To prevent photoreactivation, leaf discs were stored for twelve hours in a light-proof container after UV-C exposure. Petri dishes containing *T. urticae* and *E. lewisi* eggs were then placed in a growth chamber set to 25 ± 3 °C and 60 ± 3% RH. All experimental units were arranged in a completely randomized design within their respective chambers. Egg hatch was assessed eight days post-treatment.

2.5 Dose–response bioassays of female adults and larvae

Dose–response bioassays were conducted to evaluate the lethal effects of UV-C exposure on adult and larval *T. urticae* and adult *E. lewisi*. The Petri dish setup with moistened cotton and the UV-C laboratory application tent were the same as described above. Mites were sourced from the laboratory colony at the Strawberry Center. For adult assays, five arbitrarily aged adult female mites were placed on each bean leaf disc. UV-C doses evaluated were 0, 6000, 12000, 18000, and 24000 J/m^2. For adult female *E. lewisi*, the dose 3000 J/m^2 was also included. Each dose had twenty replicates for *T. urticae* and ten replicates for *E. lewisi*. For larval assays, five larvae were placed on each bean leaf disc. Larval assays were attempted multiple times for *E. lewisi*, but control mortality was too high. The same setup was used with the following doses: 0, 500, 1000, 5000, 10000, and 20000 J/m^2, with each dose containing five replicates. Since lethal doses for larvae were expected to be lower, smaller doses were applied.

After exposure, Petri dishes were placed in a light-proof box for twelve hours to prevent photoreactivation, then transferred to the same growth chamber used in previous assays (Model I36VL, Percival Scientific) maintained at 25 ± 3 °C, 60 ± 3% RH, and a 14:10 (L:D) photoperiod. Mortality was assessed 48 hours post-treatment for both life stages. Experimental units were arranged in a completely randomized design within the growth chamber.

2.6 Field ovicidal evaluation

The experimental area within fields where assays were conducted was 1.6 hectares. The first field assay for *T. urticae* was conducted in November 2024 at a commercial summer-planted strawberry production site in Nipomo, California (34°59'41"N, 120°29'39"W). The field consisted of white plastic covered beds planted with a proprietary cultivar transplanted in June 2024, with four rows per bed, 31 cm between rows, and 39 cm between plants within each row. The second field assay for *T. urticae* and first field assay for *E. lewisi* was conducted at an adjacent site in April 2025 on fall-planted strawberries. This field consisted of brown plastic covered beds with a proprietary cultivar transplanted in October 2024, with the same cultivation spacing as above. The second *E. lewisi* field assay occurred in July 2025 at a fall-planted strawberry ranch in Nipomo, California (35°00'02"N, 120°33'16"W). This field consisted of silver plastic covered beds planted with a proprietary cultivar transplanted in October 2024, with the same cultivation spacing as above.

In November 2024, UV-C treatments were applied using the EDEN autonomous robotic platform (TRIC Robotics, San Luis Obispo, CA, USA). Three targeted UV-C dose levels were evaluated: low (600 J/m^2), medium (1200 J/m^2), and high (1800 J/m^2), along with an untreated control. Actual exposure levels were quantified by placing an ILT2400 optical radiometer in the middle of the strawberry bed facing upward. In November 2024, values of 650, 1310, and 1595 J/m^2 were recorded for the low, medium, and high treatments, respectively. In April and July 2025, UV-C treatments were applied using the LUNA autonomous robotic platform (TRIC Robotics, San Luis Obispo, CA, USA). Both the EDEN and LUNA robots use germicidal UV-C lamps operating at 254 nm, and the irradiance-based dosing is consistent between platforms. The target doses were the same, but actual doses recorded by the radiometer were 441, 798, and 1104 J/m^2 in April 2025, and 564, 1015, and 1493 J/m^2 in July 2025 for the low, medium, and high treatments, respectively. All applications were conducted within two hours after sunset to prevent photoreactivation.

Each leaf disc was randomly assigned to one of four treatments: low, medium, or high UV-C dose, or an untreated control. Each treatment contained 10 replicates, except for in the Nov 2024 field assay, where each treatment contained 15 replicates. Leaf discs were pinned to the abaxial surface of mid-tier strawberry leaves using No. 00 black enameled pins (BioQuip Products, Rancho Dominguez, CA, USA), with the egg surface oriented downward. This method was used by Montemayor et al., 2023a to evaluate ovicidal effects in a field environment. Orienting the leaves on the abaxial surface aimed to evaluate whether the UV-C robotic platform could achieve sufficient coverage on the underside of the leaf surface. Control discs were also pinned to account for any handling related mortality.

Following UV-C application, leaf discs were returned to Petri dishes and placed in a 48-quart light-proof insulated cooler (Coleman Company, Wichita, KS, USA) for transport and to prevent photoreactivation. Twelve hours after application, dishes were transferred to a growth chamber (Model I36VL, Percival Scientific) set to 25 ± 3 °C, 60 ± 3% RH, and a 14:10 (L:D) photoperiod and arranged in a completely randomized design. Cotton was remoistened as needed using distilled water. Egg hatch was assessed eight days after UV-C application. Percent egg hatch was calculated for each replicate.

2.7 Data analysis

For field and laboratory ovicidal assays, data did not meet the assumptions of normality despite attempts at transformation. Therefore, a non-parametric Kruskal–Wallis test was used to evaluate treatment effects, followed by Dunn's test with Holm correction for pairwise comparisons. The egg hatch percentage was used as the response variable in these analyses conducted in R version 4.3.2 (R Core Team, 2023).

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 *T. urticae* mortality, separate generalized linear models (GLM) with a binomial error distribution and logit link function were fitted for larval and adult stages. Probit analyses were also conducted, but the GLM showed a better model fit for the data. The models were constructed using the glm() function in R, with the number of dead and alive individuals as the response variable and UV-C dose as the continuous predictor.

To estimate lethal dose values, LD_{50} and LD_{90} values were calculated from the fitted models using the dose.p() function in the MASS package. Goodness-of-fit for each model was assessed using Pearson chi-square test. All dose response figures were produced using ggplot2, and fitted curves were overlaid on observed mortality proportions by dose.

3 Results

3.1 Twospotted spider mite

Exposure to UV-C radiation significantly affected *T. urticae* egg hatch under laboratory conditions (Kruskal–Wallis χ^2 = 25.11, *df* = 3, $P < 0.001$; Figure 1A). Egg hatch in the control group was significantly higher than in all UV-C treatment groups ($P < 0.05$), while no significant differences were detected among the 600, 1200, and 1800 J/m² treatments. Mean ± SEM egg hatch in the control group was 72.21 ± 6.91%, whereas hatch was substantially reduced in all UV-C exposure groups: 3.48 ± 2.33% at 600 J/m², 1.9 ± 1.27% at 1200 J/m², and 0.63 ± 0.63% at 1800 J/m².

In the 2024 field assay, UV-C exposure significantly reduced egg hatch of *T. urticae* (Kruskal–Wallis χ^2 = 39.31, *df* = 3, $P < 0.001$; Figure 1B). Egg hatch in the untreated control was significantly higher than in all UV-C treatment groups ($P < 0.001$), while no significant differences were detected among the 650, 1310, and 1595 J/m² treatments. Egg hatch in the control was 65.56 ± 4.88% compared with 11.48 ± 3.10%, 5.44 ± 1.07%, and 2.04 ± 0.77% at 650, 1310, and 1595 J/m², respectively, corresponding to 82–97% reductions in egg hatch relative to the control.

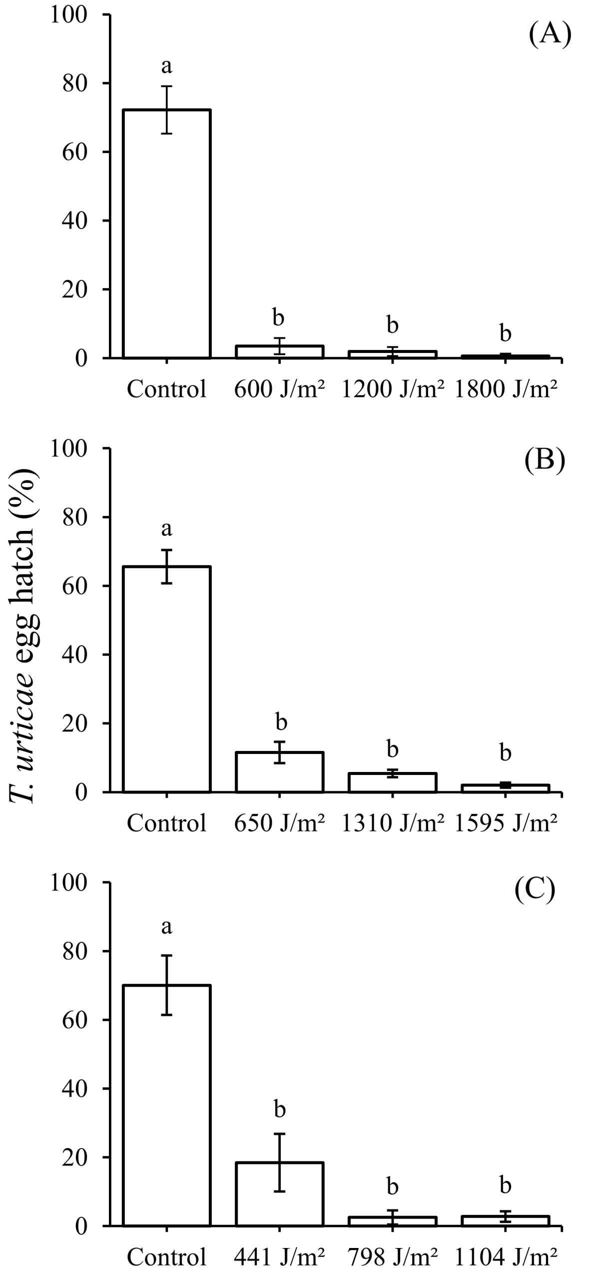

FIGURE 1
Percent egg hatch (%) of *T. urticae* after UV-C exposure in **(A)** laboratory, **(B)** November 2024 field, and **(C)** April 2025 field assays. Bars show mean ± SEM percent hatch for each treatment (n = 10 for A and C; n = 15 for **(B)**. Each assay was analyzed separately using a Kruskal-Wallis test. Treatments not sharing a letter differ significantly according to Dunn's test with Holm correction.

In the 2025 field assay, UV-C treatments significantly reduced egg relative to the control (Kruskal-Wallis χ^2 = 29.26, *df* = 3, $P < 0.001$; Figure 1C). Egg hatch did not differ among UV-C doses, but all treatments resulted in significantly lower hatch than the untreated control. Egg hatch was 70.08 ± 8.66% in the control group and was reduced to 18.47 ± 8.42%, 2.56 ± 2.05%, and 2.78 ± 1.53% at 441, 798, and 1104 J/m², respectively, representing 74–96% reductions in egg hatch.

Lethal dose estimates for *T. urticae* adult females derived from the fitted model indicated an LD_{50} of 9,912 J/m^2 and an LD_{90} of 16,683 J/m^2 (Table 1; Figure 2A). For *T. urticae* larvae, lethal dose estimates indicated an LD_{50} of 5,248 J/m^2 and an LD_{90} of 9,380 J/m^2 (Table 1; Figure 2B).

3.2 Lewis mite

In laboratory ovicidal assays, egg hatch of *E. lewisi* differed significantly among treatments (Kruskal–Wallis χ^2 = 35.66, *df* = 3, $P < 0.001$; Figure 3A). All UV-C treatments significantly reduced egg hatch relative to the untreated control ($P < 0.001$), while no differences were detected between UV-C treatments ($P > 0.50$).

In the first field assay, egg hatch of *E. lewisi* differed significantly among treatments (Kruskal–Wallis χ^2 = 24.03, *df* = 3, $P < 0.001$; Figure 3B). All UV-C treatments significantly reduced egg hatch relative to the untreated control ($P = 0.0166$), and no differences were detected among UV-C doses ($P = 0.12$). Egg hatch was 91.87 ± 2.58% in the control, compared with 42.52 ± 11.21%, 15.29 ± 7.72%, and 12.35 ± 7.06% at 441, 798, and 1104 J/m^2, respectively, corresponding to 54–87% reductions in egg hatch relative to the control.

In the second field assay, egg hatch again differed significantly among treatments (Kruskal–Wallis χ^2 = 21.03, *df* = 3, $P < 0.001$; Figure 3C). UV-C applications at 1015 and 1493 J/m^2 significantly reduced egg hatch compared with the untreated control ($P = 0.002$), whereas the 564 J/m^2 did not differ from the control ($P = 0.11$). Egg hatch did not differ between the 1015 and 1493 J/m^2 treatments ($P = 0.18$), although egg hatch at 1493 J/m^2 was significantly lower than at 564 J/m^2 ($P = 0.026$). Egg hatch was 90.90 ± 5.86% in the control, 62.04 ± 13.81%, 26.02 ± 7.14%, and 11.74 ± 5.91% at 564, 1015, and 1493 J/m^2, respectively, representing 32–87% reductions in egg hatch.

TABLE 1 Lethal dose observed at 48 h after UV-C application.

Species	Life stage	LD_{50} (J/m^2)	95% CI	LD_{90} (J/m^2)	95% CI	χ^2	df
Tetranychus urticae	Larva	5,248	4,104–6,392	9,380	7,298–11,463	1.23	4
Tetranychus urticae	Adult	9,912	9,058-10,765	16,683	15,297–18,068	7.72	3
Eotetranychus lewisi	Adult	11,014	9,841–12,187	18,159	16,152–20,167	3.58	4

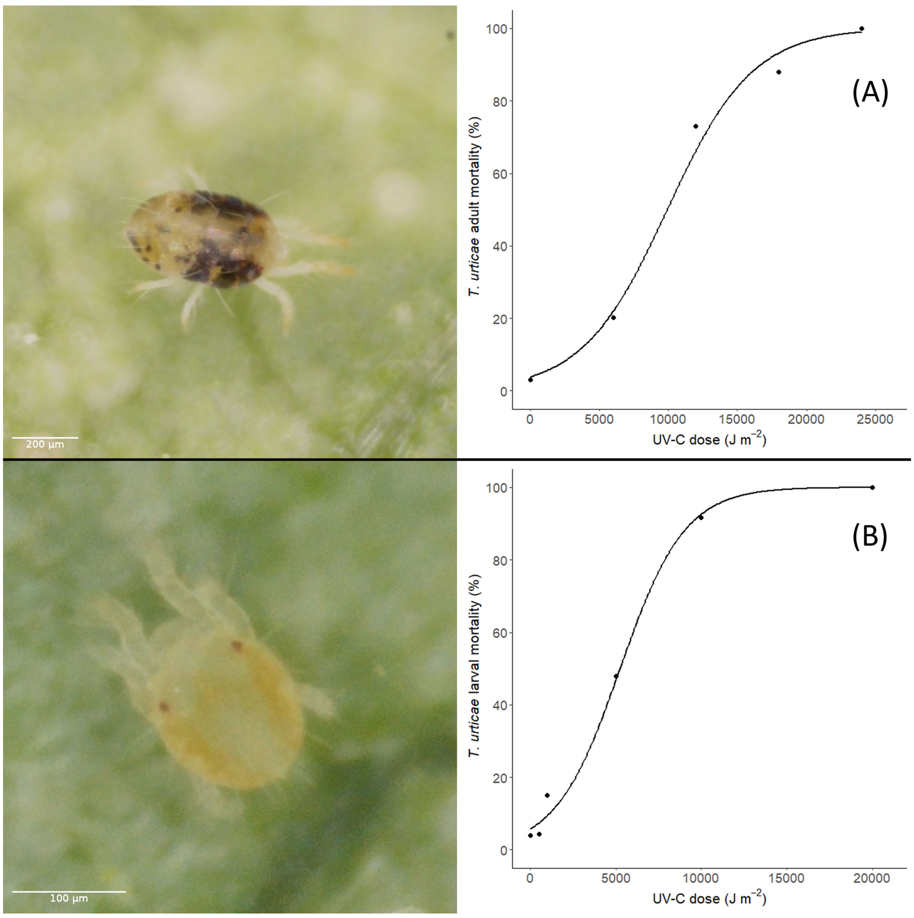

FIGURE 2
(A) *T. urticae* adult mortality (%) 48 h after UV-C application and, **(B)** Percent dead (%) *T. urticae* larvae 48 h after UV-C application.

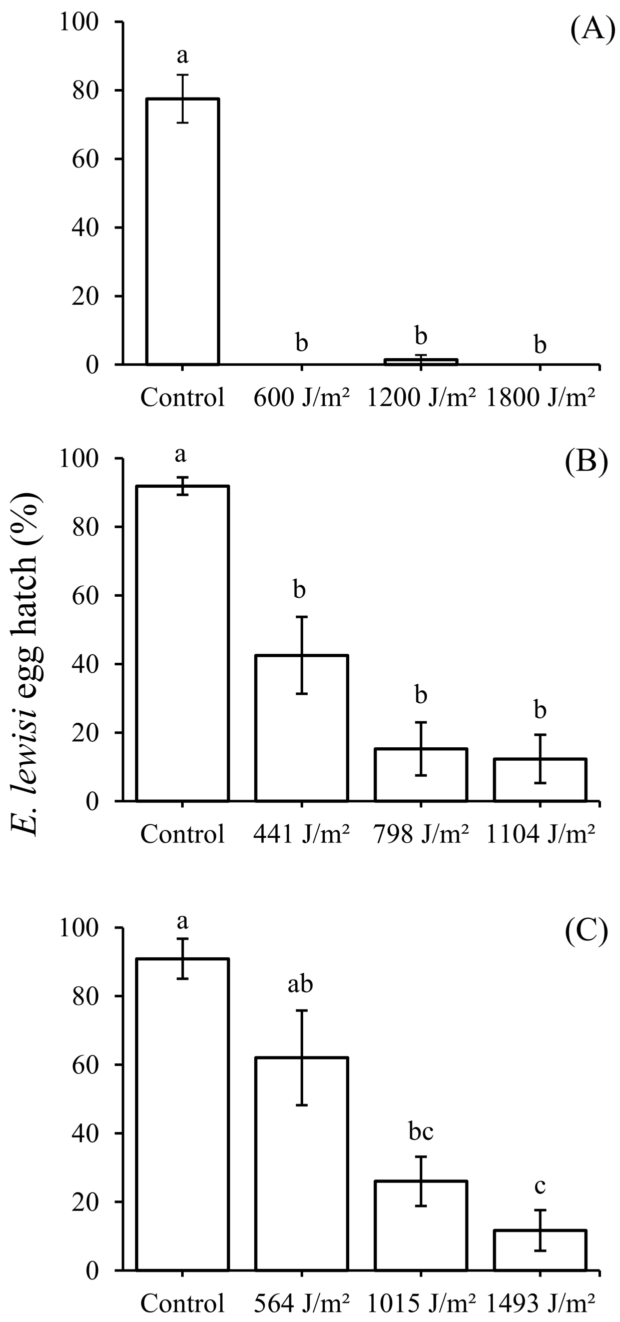

FIGURE 3
Percent egg hatch (%) of *E. lewisi* after UV-C exposure in **(A)** laboratory, **(B)** April 2025 field, and **(C)** July 2025 field assays. Bars show mean ± SEM percent hatch for each treatment (n = 10). Each assay was analyzed separately using a Kruskal-Wallis test. Treatments not sharing a letter differ significantly according to Dunn's test with Holm correction.

Lethal dose estimates for *E. lewisi* adult females derived from the fitted model indicated an LD_{50} of 11,014 J/m^2 and an LD_{90} of 18,159 J/m^2 (Table 1; Figure 4).

4 Discussion

This study demonstrates that UV-C applications are highly effective against the egg stage of both *T. urticae* and *E. lewisi*, while providing minimal control of post-embryonic life stages at field applied doses. These findings indicate that the primary value of UV-C in strawberry mite management lies in its ovicidal activity rather than direct suppression of larvae and adults. The susceptibility of mite eggs to UV-C exposure observed in this study is likely driven by biological and physical differences among life stages.

UV-C radiation is known to cause direct DNA damage through the formation of cyclobutene-pyrimidine dimers and pyrimidine-pyrimidone (6-4) photoproducts, leading to impaired cell division (Thoma, 1999; Todo, 1999; Holford et al., 2024). Adults generally exhibit greater tolerance to UV-induced damage than eggs, a trend that has been documented in several insect and mite species (Holford et al., 2024). Developing embryos are likely vulnerable to such damage due to rapid cell division and limited capacity for DNA repair during early developmental stages (Yoshioka et al., 2018). In contrast, larvae and adults may possess protective traits such as pigmentation, thicker cuticles, and behavioral avoidance mechanisms that may reduce UV exposure in motile stages (Suzuki et al., 2009). These biological differences could explain the varying susceptibility between life stages.

The greater variability in efficacy observed in field assays was likely due to mite eggs being located on the abaxial leaf surface, where UV-C exposure is influenced by canopy architecture and incomplete coverage of the abaxial leaf surface by the UV-C delivery platform. Both the LUNA and EDEN robot platforms utilize reflective skirt panels positioned around the strawberry bed to redirect UV-C light upward toward the abaxial leaf surface. However, UV penetration remains constrained by canopy structure. Tanaka et al., 2024 reported that UV-B coverage of the abaxial leaf surface decreases as canopy density increases. In the present study, canopy structure differed among field assays. In November and July, plants were smaller, as opposed to a denser, more upright canopy observed in April. However, the smaller plants in November and July positioned the abaxial surfaces of mid-tier leaflets closer to the plastic mulch, while the plants in April were more upright. This difference in canopy structure may explain why lower UV-C doses in the April assay produced ovicidal effects similar to those observed at higher doses in the November assay for *T. urticae* and the July assay for *E. lewisi*. Despite this variability, the ovicidal response observed is consistent with previous reports of UV-C susceptibility in spider mites.

Previous studies have demonstrated strong ovicidal activity of UV-C against *T. urticae* under field conditions (Montemayor et al., 2023a). In this study, the LD_{50} for *T. urticae* female adults 48 h after UV-C exposure was 9,912 J/m^2, compared with 7,450 J/m^2 reported by Montemayor et al. (2023b). Although both values are of similar magnitude, differences between studies may reflect biological variation among test populations. Carotenoids in *T. urticae* may be synthesized by carotenoid biosynthesis genes or acquired through host plant feeding (Bryon et al., 2017; Parmagnani et al., 2023). Although both studies reared *T. urticae* on green beans, differences in colony history may have influenced susceptibility. The colony used in the present study was recently established from a field population, whereas Montemayor et al., 2023b used a colony maintained in laboratory culture since 2019. Mites derived from field populations

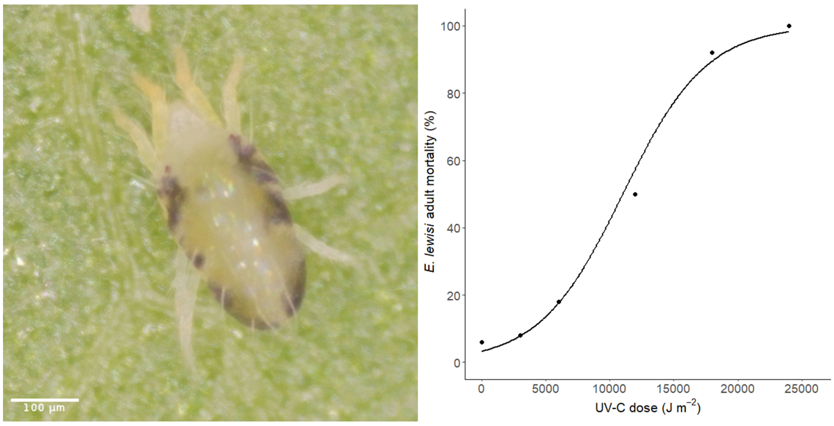

FIGURE 4
E. lewisi adult mortality (%) 48 h after UV-C application.

may retain traits that influence UV tolerance. Variation in pigmentation among *T. urticae* populations may also influence susceptibility to UV radiation. For example, diapausing adult females change from yellow-green to orange-red, which influences their response to UV exposure (Suzuki et al., 2009). Pigmentation differences may therefore affect UV-C susceptibility and contribute to variability in dose-response estimates across studies. While UV-C responses have been documented in *T. urticae*, comparable information for other tetranychid mites remains limited.

UV-C efficacy against *E. lewisi*, has not been previously reported; therefore, this study provides the first evidence of both ovicidal activity and adult dose-response relationships for this species. Ovicidal effects on *E. lewisi* were weaker at lower doses compared with *T. urticae*, but similar levels of egg mortality were observed at higher doses. The higher LD_{50} for *E. lewisi* adults suggests that motile stages of this species may be more tolerant to UV-C exposure. These results highlight differences in susceptibility between species and reinforce the importance of considering life stage and species when evaluating UV-C within an IPM context.

In California strawberry production, management of *T. urticae* relies on a combination of selective miticides and biological control. The predatory mite *Phytoseiulus persimilis* is the main biological control agent used for managing *T. urticae* in both conventional and organic systems. Several commonly used miticides provide ovicidal activity, however, resistance to multiple modes of action has been documented in field populations (Bi et al., 2016; İnak et al., 2022a, 2022; Jensen, 2023). In conventional production, incorporating UV-C with miticides may help broaden selection pressures by targeting the egg stage. In organic systems, it is essential that UV-C is compatible with biological control. Previous work has shown UV-C exposure at 200 and 350 J/m^2 reduced *P. persimilis* egg hatch by 90.4% and 92.8%, respectively, although it did not impact predation by *P. persimilis* on *T. urticae* eggs (Montemayor et al., 2023b). Other studies have demonstrated that UV-B used alongside *Neoseiulus californicus* McGregor and *P. persimilis* provided better control of *T. urticae* in greenhouse strawberries than either strategy by itself (Tanaka et al., 2024). These findings suggest UV-C may be most effective when used strategically. For example, UV-C could be used in the early growing season to suppress population growth of both mites before releasing predatory mites once the canopy becomes dense. More research needs to be done on how to time releases of predatory mites when used in conjunction with UV-C to optimize the strengths of both management tools.

In the case of *E. lewisi*, growers and pest control advisors report that conventional miticides work well and resistance has not been reported. However, management in organic systems remains challenging. The predatory mites *N. californicus*, *Amblyseiulus andersoni* Chant, and *Neoseiulus fallacis* Garman can be used to control *E. lewisi* since *P. persimilis* does not feed on it (Howell and Daugovish, 2013, 2016), but the ovicidal effects of UV-C on these predatory mites remains largely unknown. Discovering which biological agents are least affected by UV-C will allow for better integration of the technology within pest management systems.

In summary, this study demonstrates that UV-C provides consistent ovicidal activity against both *T. urticae* and *E. lewisi* in strawberry production systems, while offering limited direct control of motile life stages at field applied doses. Laboratory assays confirmed egg susceptibility, and field evaluations showed substantial suppression of egg hatch across multiple seasons and application platforms. Dose–response analyses indicate that lethal doses for larvae and adults exceed commercially achievable exposure levels. This reinforces that UV-C should not be viewed as a standalone replacement for miticides or biological control, but rather a complementary tool to target the egg stage and slow population growth. Continued research of application timing, canopy penetration, delivery technology, and sublethal effects may further enhance field efficacy and consistency. These findings support that UV-C is a life stage specific management strategy for mite pests in California strawberry production systems and provides a foundation for future research and implementation.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CK: Writing – review & editing, Formal analysis, Writing – original draft, Data curation, Investigation, Methodology. MA: Writing – review & editing, Supervision, Conceptualization, Resources, Funding acquisition, Visualization, Project administration.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This research was supported by the California Strawberry Commission.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

References

Bi, J. L., Niu, Z. M., Yu, L., and Toscano, N. C. (2016). Resistance status of the carmine spider mite, *Tetranychus cinnabarinus* and the twospotted spider mite, *Tetranychus urticae* to selected acaricides on strawberries. *Insect Sci.* 23, 88–93. doi: 10.1111/1744-7917.12190

Bryon, A., Kurlovs, A. H., Dermauw, W., Greenhalgh, R., Riga, M., Grbić, M., et al. (2017). Disruption of a horizontally transferred phytoene desaturase abolishes carotenoid accumulation and diapause in *Tetranychus urticae*. *Proc. Natl. Acad. Sci. U.S.A.* 114, E5871–E5880. doi: 10.1073/pnas.1706865114

Bustos, A., Rodríguez, D., Cure, J. R., and Cantor, F. (2016). A simulation model of the mass rearing of *Tetranychus urticae* Koch (Acari: Tetranychidae) on beans. *Neotrop. Entomol.* 45, 291–299. doi: 10.1007/s13744-016-0366-1

Doucette, C. F. (1962). The Lewis mite, *Eotetranychus lewisi*, on greenhouse poinsettia. *J. Econ. Entomol.* 55, 139–140. doi: 10.1093/jee/55.1.139

Forges, M., Vàsquez, H., Charles, F., Sari, D. C., Urban, L., Lizzi, Y., et al. (2018). Impact of UV-C radiation on the sensitivity of three strawberry plant cultivars (Fragaria x ananassa) against *Botrytis cinerea*. *Sci. Hortic.* 240, 603–613. doi: 10.1016/j.scienta.2018.06.063

Gala, J. L., Rebane, O., Ambroise, J., Babichenko, S., Nyabi, O., and Hance, T. (2021). Acaricidal efficacy of ultraviolet-C irradiation of *Tetranychus urticae* adults and eggs using a pulsed krypton fluoride excimer laser. *Parasites Vectors* 14, 578. doi: 10.1186/s13071-021-05085-7

Hayder, T., Meem, M. M., Tonni, F. A., Nikson, A. K., Gotoh, T., and Ullah, M. S. (2026). Effect of group rearing on the life table parameters of the two-spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae). *Acarologia* 66, 118–133. doi: 10.24349/uhbs-wb0j

Holford, P., Parajuli, S., Beattie, G. A. C., and Cen, Y. (2024). Arthropods and ultraviolet radiation: Survival, growth and development. *Ecol. Entomol.* 49, 451–462. doi: 10.1111/een.13318

Holmes, G. J. (2024). The California strawberry industry: Current trends and future prospects. *Int. J. Fruit Sci.* 24, 115–129. doi: 10.1080/15538362.2024.2342900

Howell, A. D., and Daugovish, O. (2013). Biological control of *Eotetranychus lewisi* and *Tetranychus urticae* (Acari: Tetranychidae) on strawberry by four phytoseiids (Acari: Phytoseiidae). *J. Econ. Entomol.* 106, 80–85. doi: 10.1603/EC12304

Howell, A. D., and Daugovish, O. (2016). Biocontrol of spider mites in California strawberry production. *Int. J. Fruit Sci.* 16, 169–177. doi: 10.1080/15538362.2016.1195316

İnak, E., Alpkent, Y. N., Çobanoğlu, S., Toprak, U., and Van Leeuwen, T. (2022a). Incidence of spiromesifen resistance and resistance mechanisms in *Tetranychus urticae* populations collected from strawberry production areas in Turkey. *Crop Prot.* 160, 106049. doi: 10.1016/j.cropro.2022.106049

İnak, E., Alpkent, Y. N., Saalwaechter, C., Albayrak, T., İnak, A., Dermauw, W., et al. (2022b). Long-term survey and characterization of cyflumetofen resistance in *Tetranychus urticae* populations from Turkey. *Pestic. Biochem. Physiol.* 188, 105235. doi: 10.1016/j.pestbp.2022.105235

Jakubowska, M., Dobosz, R., Zawada, D., and Kowalska, J. (2022). A review of crop protection methods against the twospotted spider mite—*Tetranychus urticae* Koch (Acari: Tetranychidae)—with special reference to alternative methods. *Agriculture* 12, 898. doi: 10.3390/agriculture12070898

Jensen, K. W. (2023). *Documenting Tetranychus urticae and Lygus hesperus resistance status in California strawberries* (San Luis Obispo, CA: California Polytechnic State University). master's thesis.

Jin, P., Wang, H., Zhang, Y., Huang, Y., Wang, L., and Zheng, Y. (2017). UV-C enhances resistance against gray mold decay caused by *Botrytis cinerea* in strawberry fruit. *Sci. Hortic.* 225, 106–111. doi: 10.1016/j.scienta.2017.06.062

Kwon, D. H., Seong, G. M., Kang, T. J., and Lee, S. H. (2010). Multiple resistance mechanisms to abamectin in the two-spotted spider mite. *J. Asia-Pac. Entomol.* 13, 229–232. doi: 10.1016/j.aspen.2010.02.002

Lahiri, S., Smith, H. A., Gireesh, M., Kaur, G., and Montemayor, J. D. (2022). Arthropod pest management in strawberry. *Insects* 13, 475. doi: 10.3390/insects13050475

Mello, P. P., Onofre, R. B., Rea, M., Bierman, A., Gadoury, D. M., Ivors, K., 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. doi: 10.1094/PHP-01-22-0002-RS

Montemayor, J. D., Smith, H. A., Peres, N. A., and Lahiri, S. (2023a). Potential of UV-C for management of two-spotted spider mites and thrips in Florida strawberry. *Pest Manage. Sci.* 79, 891–898. doi: 10.1002/ps.7263

Montemayor, J. D., Smith, H. A., Peres, N. A., Rossitto De Marchi, B., and Lahiri, S. (2023b). Is UV-C light compatible with biological control of twospotted spider mite? *Biol. Control* 183, 105269. doi: 10.1016/j.biocontrol.2023.105269

Murata, Y., and Osakabe, M. (2013). The Bunsen–Roscoe reciprocity law in ultraviolet-B-induced mortality of the two-spotted spider mite *Tetranychus urticae*. *J. Insect Physiol.* 59, 241–247. doi: 10.1016/j.jinsphys.2012.11.008

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

Murata, Y., and 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. doi: 10.1007/s10493-016-0100-z

Oatman, E. R. (1971). Mite species on strawberry in Southern California. *J. Econ. Entomol.* 64, 1313–1314. doi: 10.1093/jee/64.5.1313

Onofre, R. B., Gadoury, D. M., Stensvand, A., Bierman, A., Rea, M., and Peres, N. A. (2021). Use of ultraviolet light to suppress powdery mildew in strawberry fruit production fields. *Plant Dis.* 105, 2402–2409. doi: 10.1094/PDIS-04-20-0781-RE

Parmagnani, A. S., Mannino, G., Brillada, C., Novero, M., Dall'Osto, L., Maffei, M. E., et al. (2023). Biology of two-spotted spider mite (*Tetranychus urticae*): Ultrastructure, photosynthesis, guanine transcriptomics, carotenoids and chlorophylls metabolism, and decoyinine as a potential acaricide. *Int. J. Mol. Sci.* 24, 1715. doi: 10.3390/ijms24021715

Praslička, J., and Huszár, J. (2004). Influence of temperature and host plants on the development and fecundity of the spider mite *Tetranychus urticae* (Acarina: Tetranychidae). *Plant Prot. Sci.* 40, 141–144. doi: 10.17221/465-PPS

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

Rojas, J. L. A. (2023). *Evaluating the field efficacy of UV-C on two California strawberry arthropod pests* (San Luis Obispo (CA: California Polytechnic State University at San Luis Obispo). master's thesis.

Rosa Giménez-Ferrer, M., Erb, A. W., Bishop, B. L., and Scheerens, J. C. (1994). Host-pest relationships between the twospotted spider mite (Acari: Tetranychidae) and strawberry cultivars with differing levels of resistance. *J. Econ. Entomol.* 87, 168–175. doi: 10.1093/jee/87.1.168

Sancar, A. (2003). Structure and function of DNA photolyase and cryptochrome blue-light photoreceptors. *Chem. Rev.* 103, 2203–2237. doi: 10.1021%2Fcr0204348

Short, B., Janisiewicz, W., Takeda, F., and Leskey, T. C. (2018). UV-C irradiation as a management tool for *Tetranychus urticae* on strawberries. *Pest Manage. Sci.* 74, 2419–2423. doi: 10.1002/ps.5045

Strand, L. L. (2008). *Integrated pest management for strawberries* (UCANR Publications).

Suzuki, T., Watanabe, M., and Takeda, M. (2009). UV tolerance in the two-spotted spider mite, *Tetranychus urticae*. *J. Insect Physiol.* 55, 649–654. doi: 10.1016/j.jinsphys.2009.04.005

Tanaka, M., Yase, J., Kanto, T., and Osakabe, M. (2024). Combined nighttime ultraviolet B irradiation and phytoseiid mite application provide optimal control of the spider mite *Tetranychus urticae* on greenhouse strawberry plants. *Pest Manage. Sci.* 80, 698–707. doi: 10.1002/ps.7798

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. doi: 10.1093/emboj/18.23.6585

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

Walsh, D. B., Zalom, F. G., Shaw, D. V., and Larson, K. D. (2002). Yield reduction caused by twospotted spider mite feeding in an advanced-cycle strawberry breeding population. *J. Am. Soc Hortic. Sci.* 127 (2), 230–237. doi: 10.21273/JASHS.127.2.230

Yoshioka, Y., Gotoh, T., and Suzuki, T. (2018). UV-B susceptibility and photoreactivation in embryonic development of the two-spotted spider mite, *Tetranychus urticae*. *Exp. Appl. Acarol.* 75, 155–166. doi: 10.1007/s10493-018-0263-x