Testing the efficacy of conventional and organic insecticides against an outbreak bush-cricket colonizing vineyards

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Academic editor: Michel Lecoq | Received 11 December 2025 | Accepted 17 February 2026 | Published 6 April 2026

https://zoobank.org/EF0249A9-C8C6-497B-9BE2-C81D7BD73745

Citation: Ortis G, Cavaletto G, Santoiemma G, Giannone F, Mazzon L (2026) Testing the efficacy of conventional and organic insecticides against an outbreak bush-cricket colonizing vineyards. Journal of Orthoptera Research 35(1): 233–240. https://doi.org/10.3897/jor.35.182212

Abstract

The endemic species *Barbitistes vicetinus* (Orthoptera, Tettigoniidae) is a flightless bush-cricket that is recognized as a pest in certain hilly areas of northeastern Italy. Under favorable conditions, its population can increase to outbreak levels, causing severe damage to broadleaf trees and crops, particularly vineyards and olive groves. Current population management methods rely on insecticide sprays; however, environmentally compatible chemical control options are still to be evaluated. In this study, we compared the effects of six active ingredients, representative of both conventional and organic insecticides, through field and laboratory trials; we also assessed the impact of different dosages for selected compounds. Vine shoots were sleeved and nymph and adult bush-crickets were caged before the application. Among the active ingredients tested, spinosad and deltamethrin were effective in killing bush-crickets under all experimental conditions. Doses as low as one-fourth of the standard deltamethrin application rate resulted in adult mortality levels comparable to those observed with the full dose. Pyrethrins exhibited moderate insecticidal activity, with enhanced effectiveness at double the standard dose against both nymphs and adults. High adult mortality was observed seven days after treatment with the fungal entomopathogens *Metarhizium anisopliae* and *Metarhizium acridum*. These data provide valid support for updating the guidelines aimed at controlling *B. vicetinus* for growers, landscape managers, and homeowners and can help guide future authorization processes for the tested active ingredients.

Keywords

Barbitistes vicetinus, bush-cricket, chemical control, fungal entomopathogens, pest management, survival analysis

Introduction

Although most orthopteran species are not considered pests, some can reach outbreak densities under favorable conditions, necessitating control measures to prevent crop damage (Tanaka and Zhu 2005, Zhang et al. 2019, Çiplak 2021, Lee et al. 2023). While the most severe economic losses are typically caused by species of the suborder Caelifera, damage by Ensifera is less frequent and usually associated with local species during certain years (Minja et al. 1999, Srygley 2014, Labarre et al. 2020).

Among bush-crickets of the genus *Barbitistes* Charpentier, 1825 (Orthoptera: Tettigoniidae), occasional outbreaks have been reported only for *B. constrictus* Brunner von Wattenwyl, 1878 in conifer forests of Central and Eastern Europe, *B. ocskayi* Charpentier, 1850 in broadleaf forests of north-eastern Italy and, less intensely, for *B. serricauda* (Fabricius, 1794) (Laussmann 1994, Stergulc et al. 2005, Holusa et al. 2006). In the last decade, large outbreaks of *Barbitistes vicetinus* Galvagni & Fontana, 1993 occurred in some areas of the northeast of Italy. The bush-cricket *B. vicetinus* is an endemic forest species with a distribution restricted to small, isolated hilly areas such as the Euganean and Berici Hills (Galvagni and Fontana 1993, 1999, Martinez-Sañudo et al. 2021). Since the first outbreak in 2008, the affected areas have progressively expanded, causing significant damage to forests and nearby crops and being a nuisance to residents due to the tendency of bush-crickets to invade streets and gardens (Cavaletto et al. 2018). During outbreaks, *B. vicetinus* feeds on many plant species and, due to its high mobility, is capable of colonizing neighboring crops from adjacent natural habitats such as forests and hedgerows without demonstrating a propensity to leave them (Ortis et al. 2025a). Severe defoliation, reaching up to 80%, affected several forest tree species (e.g., *Ostrya carpinifolia* Scop., *Fraxinus ornus* L., and *Castanea sativa* Mill.), and much damage was reported in vineyards and olive groves, the most common crops in the surrounding areas (Cavaletto et al. 2019). The species is flightless and tends to ascend to the upper canopy, where it primarily consumes leaves, flowers, and fruits. Eggs are laid in the soil in early summer and, depending on temperature, may hatch either during the next spring or remain in the ground overwinter for several years (Ortis et al. 2022, 2023). Nymphs emerge in late March, reaching the more mobile adult stage from the end of May. These adults reproduce during June and early July, after which the population declines and dies off.

In Italy and the European Union, several active ingredients—including spinosad, acetamiprid, deltamethrin, natural pyrethrins, and selected entomopathogenic fungi—are officially authorized in plant protection products against insect pests and may also be used for the management of orthopteran outbreaks (Italian Ministry of Health database: https://www.fitosanitari.salute.gov.it). However, based on preliminary observations (Cavaletto et al. 2015), only pyrethroid-based insecticides (e.g., deltamethrin) or products containing natural pyrethrins have been suggested for the control of *B. vicetinus*, highlighting the need for a broader evaluation of alternative active ingredients.

In the present study, we assessed the efficacy of several active ingredients against *B. vicetinus*, with particular emphasis on compounds permitted in organic farming, namely pyrethrins, spinosad, and azadirachtin, as well as three fungal entomopathogens. In addition, two conventional insecticides, deltamethrin and thiamethoxam, were included for comparison. This focus reflects both the need to reduce the use of synthetic chemicals in vineyards and the fact that *B. vicetinus* outbreaks often occur in vineyards embedded within high-value natural habitats and protected areas. We tested the impact of these insecticides on *B. vicetinus* nymphs and adults at different doses and application timings, aiming to provide the first systematic evaluation of environmentally compatible chemical control options for this emerging pest.

Materials and methods

Evaluation of insecticide effectiveness on nymphs.—To evaluate insecticide effectiveness on nymphs, we carried out two semi-field experiments in one vineyard located in the Euganean Hills (45°17'13"N, 11°41'22"E) and one laboratory experiment. To compare the efficacy of organic active ingredients, we also tested two conventional active ingredients, deltamethrin and thiamethoxam, which are commonly used for pest control and are known to induce high insect mortality. In the first semi-field experiment, we tested five active ingredients following the doses reported on the labels (Table 1: a), and in the second semi-field experiment, we doubled the application rates of some active ingredients (pyrethrins and spinosad) and tested the fungal entomopathogen *Metarhizium anisopliae* (Metschn.) Sorokīn (Ascomycota, Hypocreales). In the first field experiment, we used Pyganic, which has a concentration of 13 g/L of pyrethrins and was applied at the recommended rate of 200 ml/hl (Table 1: a), and in the second field experiment, we used Asset, which has a concentration of 40 g/L of pyrethrins and was applied at both the normal recommended rate of 120 ml/hl and at twice the rate (240 ml/hl) (Table 1: b). In the first field experiment, we used Laser spinosad at the normal rate of 20 ml/hl (Table 1: a), and in the second field experiment, we applied both the normal 20 ml/hl and a doubled dose of 40 mL/hl (Table 1: b).

Table 1. Characteristics and application rates of the insecticides used in field and laboratory experiments conducted on (a, b, c) nymphs and (d, e) adults.

Active ingredient	Trade name	IRAC MoA group	Application rate
a) Nymphs (field)			
Azadirachtin	Neemik	Limonoids (UN)	300 ml/hl
Deltamethrin	Decis Jet	Pyrethroids (3A)	50 ml/hl
Pyrethrins	Pyganic	Pyrethrum extracts (3A)	200 ml/hl
Spinosad	Laser	Spinosoids (5)	20 ml/hl
Thiamethoxam	Actara 25WG	Neonicotinoids (4A)	20 g/hl
b) Nymphs (field)			
Metarhizium anisopliae	Met52	Fungal entomopathogens	200 g/hl
Pyrethrins	Asset	Pyrethrum extracts (3A)	120, 240 ml/hl
Spinosad	Laser	Spinosoids (5)	20, 40 ml/hl
c) Nymphs (laboratory)			
Metarhizium anisopliae	Met52	Fungal entomopathogens	200 g/hl
Metarhizium acridum	Green Muscle	Fungal entomopathogens	200 g/hl
Beauveria bassiana	Naturalis	Fungal entomopathogens	150 ml/hl
Pyrethrins	Asset	Pyrethrum extracts (3A)	120, 240 ml/hl
Spinosad	Laser	Spinosoids (5)	20, 40 ml/hl
d) Adults (field)			
Deltamethrin	Decis Jet	Pyrethroids (3A)	50, 25, 12.5, 6.2, 3.1, 1.5, 0.7 ml/hl
e) Adults (field)			
Metarhizium anisopliae	Met52	Fungal entomopathogens	200, 400 g/hl
Pyrethrins	Asset	Pyrethrum extracts (3A)	120, 240 ml/hl
Spinosad	Laser	Spinosoids (5)	20 ml/hl

The treatments (insecticides plus untreated control) were tested with four replicates each. A replicate consisted of one vine shoot (50 cm long) enclosed in a tulle sleeve cage with ten *B. vicetinus* nymphs (third to fourth nymphal instar) (Fig. 1). The four replicates of each treatment were spaced at least 10 m apart along a vineyard row. Insects were collected manually from wild plants growing along the site margins immediately prior to each experiment. Treatments were applied using a manual sprayer, ensuring consistent pressure (2 bar), a uniform distance from the vegetation (approximately 30 cm), and equal application time (3 seconds per longitudinal side of the shoot), thereby directly affecting the insects. Mortality was assessed by counting the number of dead insects in each shoot at 1, 3, and 7 days after each treatment.

In the laboratory experiment, we tested three fungal entomopathogens: *Metarhizium acridum* (Driver and Milner) J.F. Bisch., S.A. Rehner and Humber, *M. anisopliae*, *Beauveria bassiana* (Bals.-Criv.) Vuill, spinosad, and pyrethrins at standard doses (Table 1: c). The treatments (insecticides plus untreated control) were tested with four replicates each. Six individuals were placed in each net cage (50 × 20 × 20 cm) and provided with branches of *Rubus* sp. as food inside a greenhouse under natural photoperiod, with temperatures fluctuating between 19°C and 35°C and relative humidity ranging from 70% to 80%. Treatments were applied as described above, and mortality was assessed at 1, 3, and 6 days after each treatment.

Insecticide effect evaluation on adults.—The experiments were conducted using the same methodology described above. A specific experiment was conducted in which the reference dose of the most promising insecticide (deltamethrin) was progressively reduced by dividing it by 2, 4, 8, 16, 32, and 64. Mortality was assessed at

1 and 3 days after each application (Table 1: d). In a second experiment, the doses of selected active ingredients (pyrethrins and *M. anisopliae*) were doubled, and six *B. vicetinus* adults were introduced to each shoot prior to treatment. Mortality was assessed at 1, 3, and 7 days after each treatment (Table 1: e).

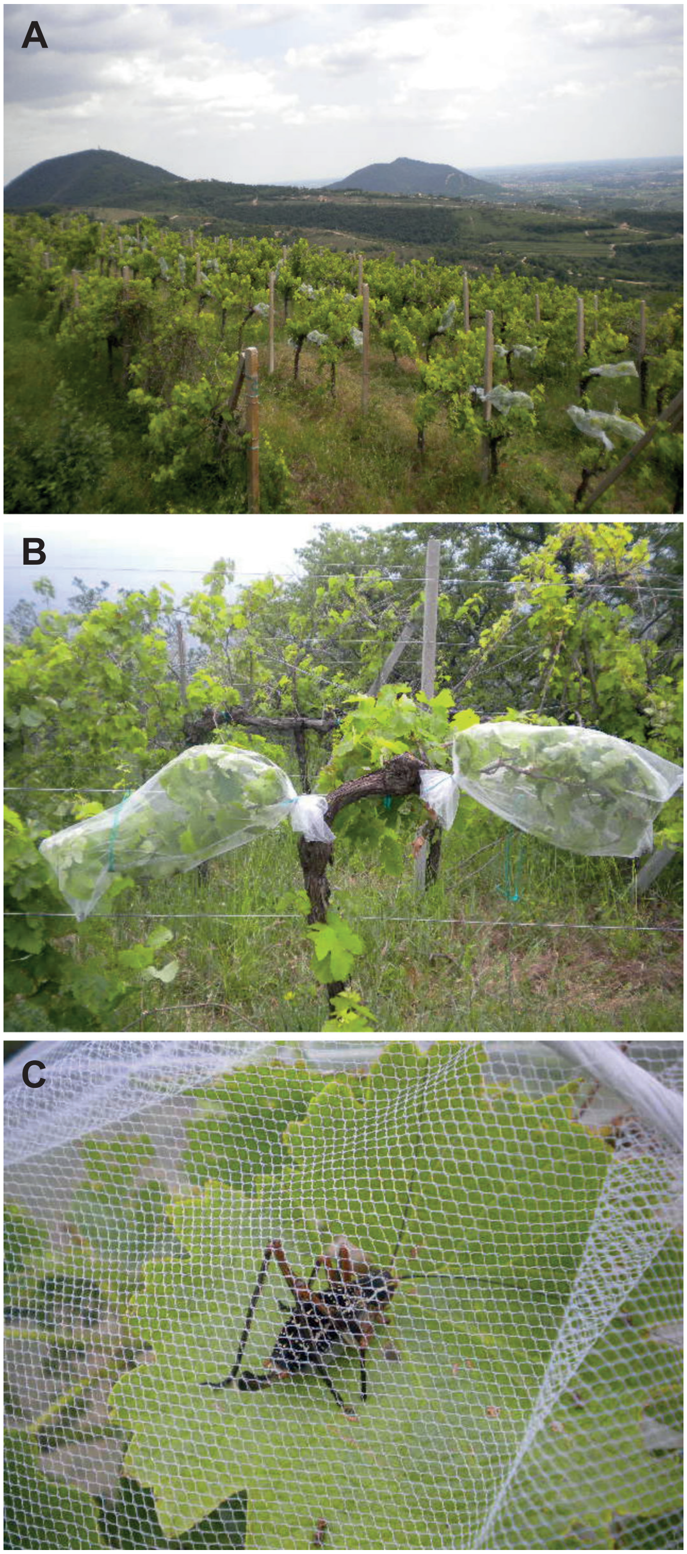

Figure 1. A. Vineyard used for semi-field experiments, **B.** example of a tulle sleeve cage installed on a vine, **C**. female *Barbitistes vicetinus* inside a tulle sleeve cage.

The mean daily temperature recorded during the field trials on nymphs was 11.2°C (18 April–25 April, Table 1: a) and 15.4°C (23 April–30 April, Table 1: b). The mean daily temperature recorded during the trials on adults was 24.5°C (15 June–18 June, Table 1: d) and 23.3°C in 2013 (11 June–18 June, Table 1: e). Rain events occurred during the field experiment on nymphs (mean rainfall 3.8 mm, Table 1: a) and (mean rainfall 2.4 mm, Table 1: b). Weather data were collected from the nearest meteorological station in Faedo – Cinto Euganeo (ARPAV, Veneto Regional Agency for Environmental Prevention and Protection).

Statistical analyses.—The effectiveness of the insecticide treatments was assessed using survival analysis. Survival curves were estimated using the Kaplan-Meier method (Klein and Moeschberger 2006). To account for potential intra-cluster dependence of insects within replicates, a marginal Cox proportional hazards model was applied (Martinussen and Scheike 2007). Five Cox models (one for each experiment on nymphs and adults) were built to compare insect survival between treatments. The dependent variable was the lifetime of each insect; the categorical explanatory variable was the treatment (including the control), and the cluster factor was the cage identity.

Cox models were developed using the 'survival' package (Therneau and Lumley 2020). Pairwise comparisons were performed with the 'emmeans' package (Lenth et al. 2020), and Kaplan-Meier survival curves were plotted using the 'survminer' package (Kassambara et al. 2020).

All analyses were performed using R 4.5.1 (R Core Team 2025).

Results

Insecticide effects on nymphs.—When applied under semi-field conditions, the active ingredients deltamethrin and spinosad showed high effectiveness against *B. vicetinus* nymphs, resulting in a mortality of nearly 100% of individuals within 1 day for deltamethrin and within 7 days for spinosad ($p < 0.05$) (Fig. 2). Compared to standard doses, doubled doses of spinosad and pyrethrins resulted in significantly higher mortality by the third day and near-total mortality by the seventh day (Fig. 3). There was no significant difference from the control for treatments with azadirachtin, pyrethrins at normal doses, thiamethoxam (Fig. 2), and *M. anisopliae* (Fig. 3).

Among the active ingredients tested in the laboratory experiment, the fungal entomopathogens, spinosad, and pyrethrins caused mortality in some individuals, resulting in a lower number of surviving insects compared with the untreated control. Conversely, *B. bassiana* caused little to no mortality, as almost all individuals survived (Fig. 4).

Insecticide effects on adults.—When applied against adults in semi-field conditions, deltamethrin at a normal dose and at a half and quarter dose caused nearly 100% mortality within 3 days (Fig. 5). Even very low doses of deltamethrin caused approximately 50% mortality (Fig. 5). Spinosad led to some mortality after 3 days and high mortality after 7 days (Fig. 6), while *M. anisopliae* led to high mortality within 7 days at both normal and doubled doses (Fig. 6). Pyrethrins were not significantly different from the untreated control (Fig. 6).

Discussion

The bush-cricket *B. vicetinus* is a locally established pest that poses a significant threat to both agricultural producers and homeowners. Management involves the use of insecticides, especially during major outbreak events, to reduce pressure on susceptible crops. However, the comparable efficacy observed for some organic insecticides in this study suggests that they may represent a more environmentally sustainable alternative to conventional products.

Among the tested compounds, the organic insecticide containing spinosad showed effectiveness comparable to that of the most effective conventional insecticide (deltamethrin), with similar effects on both nymphs and adults. These results are consistent with previous studies that evaluated these active ingredients against Caelifera under field conditions (Johnson et al. 1986, Amarasekare et al. 2004), showing that both insecticides may also exhibit high residual efficacy. Deltamethrin is a broad-spectrum insecticide commonly used to control various crop pests

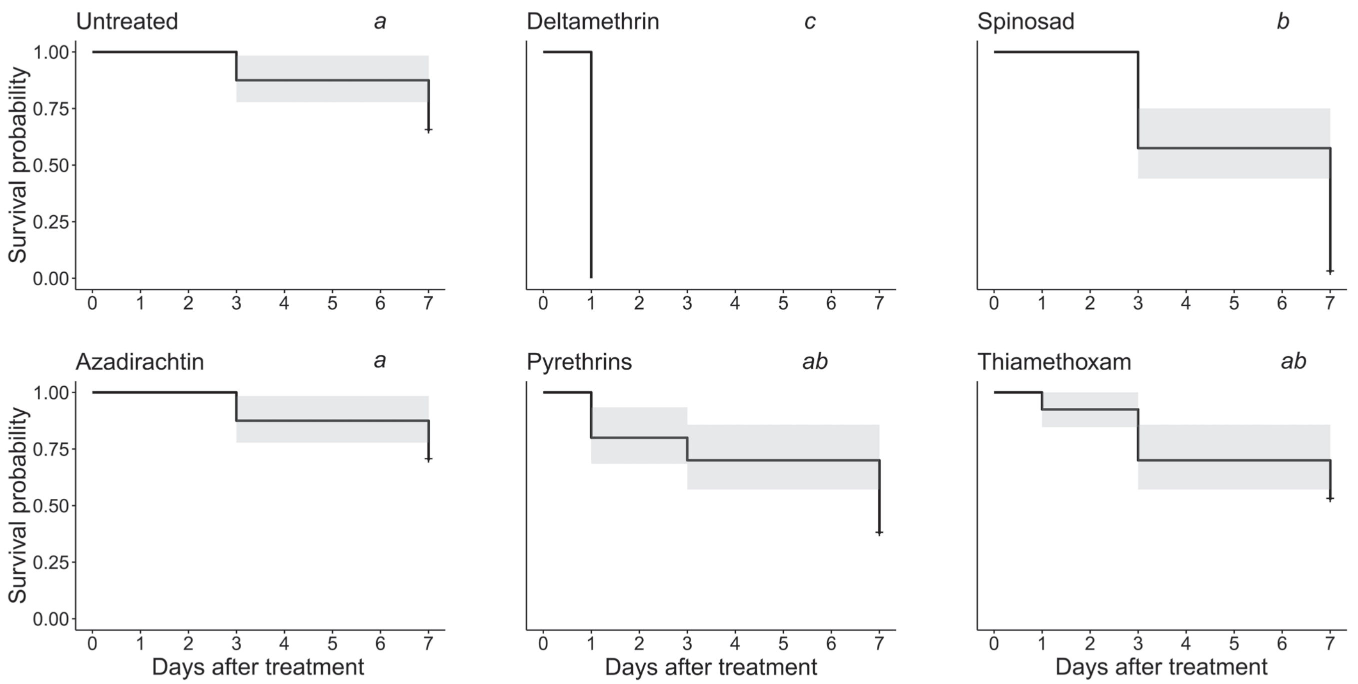

Figure 2. Kaplan-Meier survival curves showing the effects of treatments on *Barbitistes vicetinus* nymphs under semi-field conditions; 95% confidence intervals are reported. Censored data (i.e., surviving insects) are marked with a plus (+). Letters indicate significant differences ($p < 0.05$) in the pairwise comparisons between treatments.

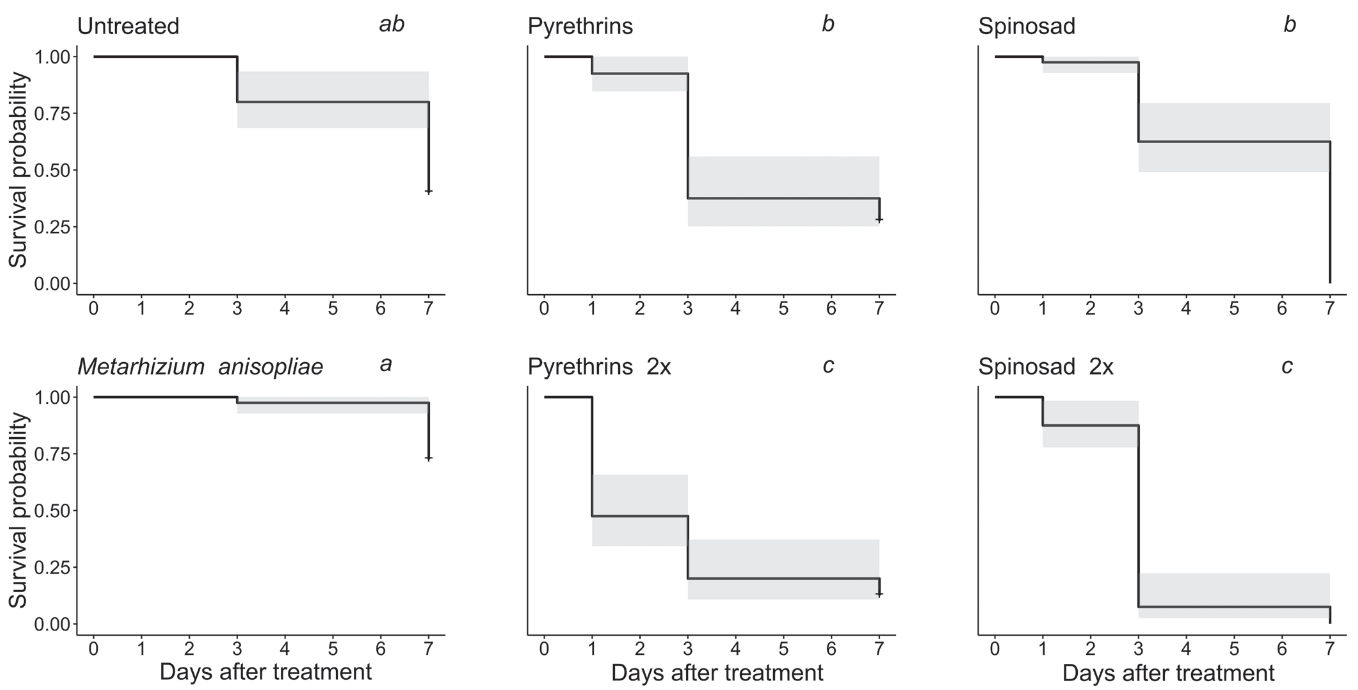

Figure 3. Kaplan-Meier survival curves showing the effects of treatments on *Barbitistes vicetinus* nymphs under semi-field conditions; 95% confidence intervals are reported. Censored data (i.e., surviving insects) are marked with a plus (+); 2× indicates the dose was doubled relative to the standard application rate. Letters indicate significant differences ($p < 0.05$) in the pairwise comparisons between treatments.

(Rehman et al. 2014); however, applying the minimal effective dose is recommended to protect non-target organisms and the environment. Our results demonstrated that deltamethrin doses as low as one-quarter of the reference concentration were sufficient to cause 100% mortality within three days, while even lower doses resulted in moderate mortality rates. The high efficacy of this insecticide suggests that reduced doses may be sufficient to control ensiferan species of similar size to *B. vicetinus*, potentially ensuring effective management of other pests while also lowering product purchase costs.

The organic active ingredient azadirachtin was ineffective, although previous studies have shown that it can affect insect molting and development while also exhibiting antifeedant activity against certain Acrididae species (Ghazawi et al. 2007, Sandoval-Mojica and Capinera 2011). Because its effects may manifest slowly, treatment-induced mortality might not be fully detectable within seven days and should therefore be evaluated over a longer observation period.

The organic insecticides containing pyrethrins exhibited moderate insecticidal activity, which increased at double the standard dose and was more pronounced against nymphs than adults. The lower effectiveness of natural pyrethrins compared to their synthetic analogues (i.e., pyrethroids) has been reported in other insect taxa and is partly attributed to the higher rate of environmental degradation and the greater metabolic breakdown of pyrethrins (Singh et al. 2022).

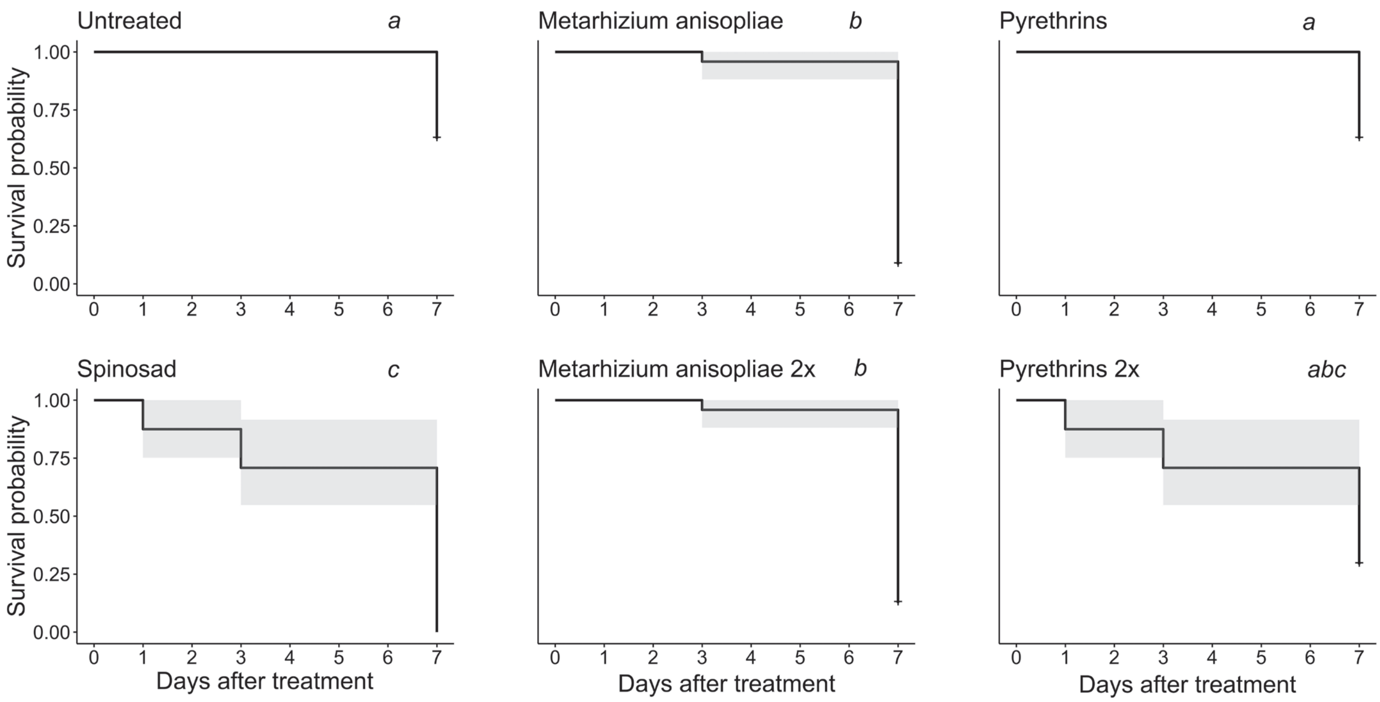

Figure 4. Kaplan-Meier survival curves showing the effects of treatments on *Barbitistes vicetinus* nymphs under laboratory conditions; 95% confidence intervals are reported. Censored data (i.e., surviving insects) are marked with a plus (+). Letters indicate significant differences ($p < 0.05$) in the pairwise comparisons between treatments.

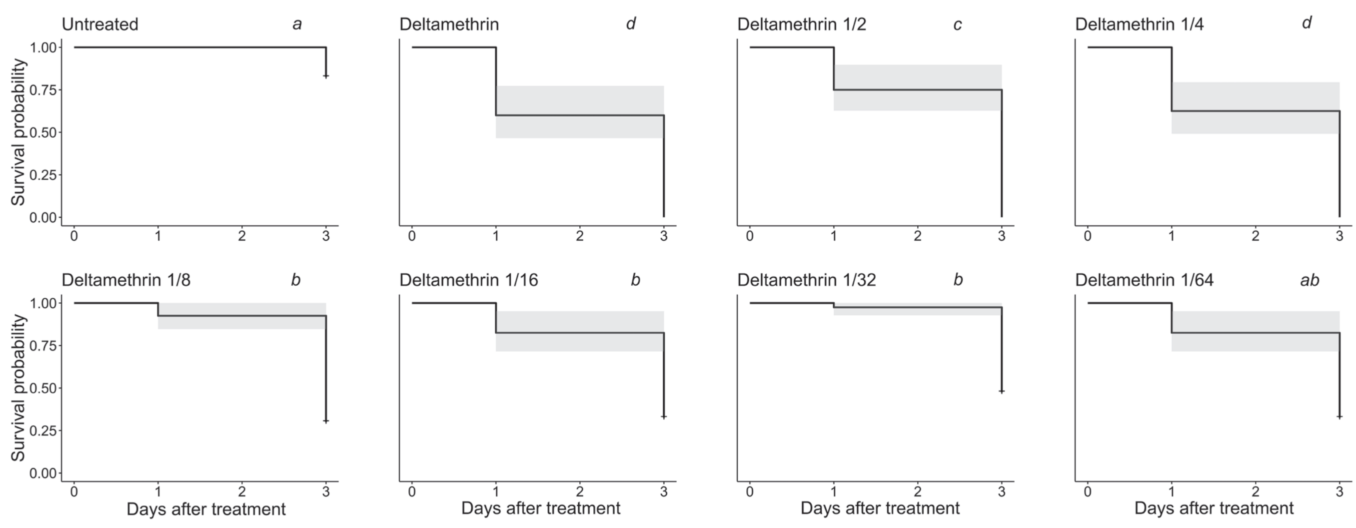

Figure 5. Kaplan-Meier survival curves showing the effects of reduced Deltamethrin doses on *Barbitistes vicetinus* adults under semi-field conditions; 95% confidence intervals are reported. Censored data (i.e., surviving insects) are marked with a plus (+). Letters indicate significant differences ($p < 0.05$) in the pairwise comparisons between treatments.

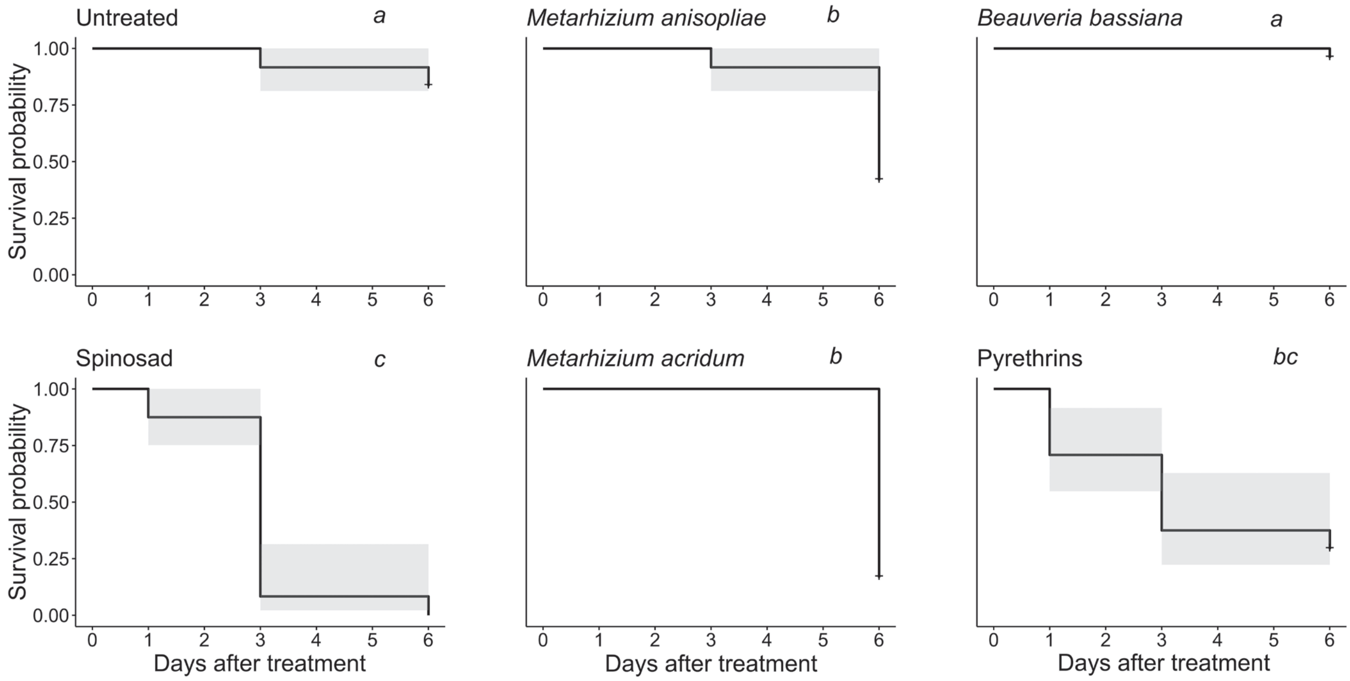

Figure 6. Kaplan-Meier survival curves showing the effects of treatments on *Barbitistes vicetinus* adults under semi-field conditions; 95% confidence intervals are reported. Censored data (i.e., surviving insects) are marked with a plus (+). 2× indicates the dose was doubled relative to the standard application rate. Letters indicate significant differences ($p < 0.05$) in the pairwise comparisons between treatments.

In the semi-field experiments, the entomopathogenic fungus *M. anisopliae* caused nearly complete mortality in *B. vicetinus* adults, although its insecticidal activity became evident only after a prolonged incubation period of seven days. The same mortality effect was not observed in nymphs. The laboratory experiment showed that both fungal entomophatogens *M. anisopliae* and *M. acridum* can kill insects after a prolonged incubation period, and while their performance varied with temperature (Arthurs and Thomas 2001, Liu et al. 2023), mortality in the field was more rapid when temperatures were high (Hunter et al. 2001). In contrast, assessing the efficacy of *B. bassiana* after only six days was likely insufficient to capture its full mortality potential.

In conclusion, this study evaluated the contact efficacy of a range of organic insecticides against the bush-cricket *B. vicetinus*, providing the first systematic assessment of environmentally compatible chemical control options for this pest. The active ingredients containing spinosad and pyrethrins were effective in killing bush-crickets; however, their low selectivity (de Castro et al. 2018, Hodosan et al. 2023) requires the need to integrate these chemical agents only where strictly necessary. The use of fungal entomopathogens may yield satisfactory results, although their effectiveness often requires precise timing and direct exposure of the pest. In addition, the input of some effective conventional insecticides (e.g., deltamethrin) may be reduced without compromising efficacy, given their comparable insecticidal activity. Insecticides with a prolonged residual effect should be considered in cases of reinfestation from adjacent habitats, particularly during the mating period when adult mobility is higher. Overall, this study highlights organic insecticides and reduced chemical inputs as sustainable strategies for managing *B. vicetinus* outbreaks and promotes organic management practices with potential benefits for agroecosystem functioning (Hole et al. 2005, Maretto et al. 2023).

From a management perspective, outbreaks of *B. vicetinus* should be addressed using an integrated strategy. Organic insecticides containing spinosad or pyrethrins may be used for rapid suppression of outbreak foci, with spinosad achieving mortality levels comparable to deltamethrin and pyrethrins showing increased efficacy at double dose, particularly against nymphs. These products should be applied only where necessary and combined with biological control agents. In this context, *M. anisopliae* represents a promising complementary tool, causing nearly complete mortality in adults under semi-field conditions after 7 days while potentially allowing conservation of natural enemies. Reduced doses of highly effective conventional insecticides (e.g., deltamethrin, effective down to one-quarter of the reference concentration, resulting in 100% mortality within three days) may be considered in severe infestation or reinfestation scenarios. Finally, the integration of chemical and biological control with habitat management and the conservation of natural enemies and parasitoids (Ortis et al. 2020, 2025b) may limit recolonization from adjacent areas and improve the long-term sustainability of *B. vicetinus* management.

Author contributions

Giacomo Ortis: writing – review and editing (lead); formal analysis (equal). Giacomo Cavaletto: investigation (lead); Writing – review and editing (equal); methodology (equal). Giacomo Santoiemma: formal analysis (lead); writing – review and editing (equal). Filippo Giannone: methodology (equal); Conceptualization (equal). Luca Mazzon: conceptualization (equal); funding acquisition (lead); supervision (lead); writing – review and editing (equal).

Data Availability Statement

The data that support the findings of this study are openly available in Dryad at: https://doi.org/10.5061/dryad.f1vhhmh8x.

Acknowledgments

We thank all farmers, students, and scientists involved in the study. This work was supported by the University of Padua under DOR project [DOR2184834/21].

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