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Compatibility of Cordyceps javanica with Pesticides and Its Impact on the Biological Control of Aleurodicus cocois

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Compatibility of *Cordyceps javanica* with Pesticides and Its Impact on the Biological Control of *Aleurodicus cocois*

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Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Authors' contributions PVMS: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **LMS:** Conceptualization, Formal analysis, Methodology, Supervision, Writing – original draft. **SMMR:** Funding acquisition, Investigation, Methodology, Supervision, Writing – original draft. **MCRG:** Data curation, Investigation, Methodology. **EDQ:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review &

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Abstract: The compatibility of the *Cordyceps javanica*-based biopesticide with insecticides and fungicides used in cashew cultivation was evaluated through *in vitro* and *in vivo* assays. *In vitro* tests assessed conidial germination, mycelial growth, conidia production, and colony-forming unit (CFU) formation. *In vivo* assays evaluated the mortality of *Aleurodicus cocois* nymphs after application of *C. javanica* mixed with fungicides under screenhouse conditions. The interaction between *C. javanica* and the insecticides was predominantly positive *in vitro*, with adverse effects restricted to CFU formation. In contrast, synthetic fungicides inhibited fungal development, except for *Melaleuca alternifolia* essential oil. This effect was confirmed *in vivo*, as only the synthetic fungicides impaired infection of *A. cocois* by *C. javanica*. Thus, the compatibility of *C. javanica* with the evaluated pesticides varied according to the active ingredients. The insecticides showed distinct interactions, whereas all synthetic fungicides were incompatible both *in vitro* and *in vivo*. In contrast, *M. alternifolia* essential oil yielded positive results and did not compromise infection of *A. cocois* by *C. javanica*.

Keywords: Integrated Pest Management (IPM), cashew whitefly, *Melaleuca alternifolia*, entomopathogenic fungus, agrochemical interactions, synergism.

1. Introduction

Cashew cultivation (*Anacardium occidentale*), which occupied 6.16 million hectares worldwide in 2023 (FAOSTAT, 2025), faces major phytosanitary challenges due to the whitefly *Aleurodicus cocois* Curtis, 1846, a pest that threatens plantations in Brazil and causes both direct and indirect damage (Goiana et al., 2020; Liu et al., 2012; Evans, 2022). Control of this pest relies on a limited number of registered active ingredients, including acetamiprid + etofenprox, acetamiprid + lambda-cyhalothrin, flupyradifurone, bifenthrin, and pyriproxyfen (AGROFIT, 2026). Moreover, cashew cultivation is affected by powdery mildew, a disease caused by a complex of fungi, including *Erysiphe quercicola* (Erysiphales: Erysiphaceae) (Cardoso et al., 2017). These pathogens attack all plant organs, affecting commercial production and potentially causing total losses in orchards (Martin et al., 1997; Viana et al., 2016; Fonseca et al., 2023). Management of this disease also relies on a limited number of registered active ingredients, most of which are synthetic fungicides (AGROFIT, 2026).

Continuous and intensive use of these products accelerates selection of resistant populations, reducing treatment efficacy (Melander, 1914; Kole et al., 2019). In addition, concerns have grown regarding their negative impacts on ecosystems, including soil and water contamination, reductions in beneficial organism populations, and risks to human health associated with pesticide residues in food (Sánchez-Bayo & Wyckhuys, 2019; Tang et al., 2021; Hlongo et al., 2023). In this context, the pursuit for effective and sustainable control alternatives that can be integrated into Integrated Pest and Disease Management (IPM/IDM) programs has become increasingly important (Dara, 2019; Eben-Roth et al., 2024).

The search for sustainable alternatives for agricultural pest control has driven the development of biopesticides based on entomopathogenic fungi (Keswani et al., 2016; A.

M. Santos, A., et al., 2018; Bamisile et al., 2021). Among these, *Cordyceps javanica* Kepler, B. Shrestha & Spatafora (Hypocreales: Cordycipitaceae) has emerged as a promising biological control agent against whiteflies (Wu et al., 2020; Wu et al., 2021; Zhao et al., 2022). In this context, the biopesticide Lalguard C99 (strain BRM27666), formulated with aerial conidia of this entomopathogenic fungus, was recently registered in Brazil and Paraguay (AGROFIT, 2026). This product demonstrated high virulence against eggs and all nymphal instars of *A. cocois*, which appears to be more susceptible than other whitefly species (Silva et al., 2026). However, to enable its integration into cashew IPM programs, it is essential to assess its compatibility with pesticides already used in the crop.

The combination of entomopathogenic fungi with conventional pesticides may improve resistance management and reduce environmental contamination (Al-Ani et al., 2021; Mao et al., 2024). However, the outcome of these interactions depends on the pesticide involved. Some insecticides may enhance fungal performance by damaging the insect cuticle and facilitating infection (Kumar et al., 2018). In contrast, many fungicides are toxic to entomopathogenic fungi, inhibiting conidial germination and reducing inoculum viability (Kouassi et al., 2003; Shah et al., 2009; Celar & Kos, 2016; Wang et al., 2021).

Therefore, this study investigated the *in vitro* compatibility of *C. javanica* (Lalguard C99) with insecticides and fungicides used in cashew cultivation. Subsequently, under *in vivo* conditions, we evaluated how these associations influence the efficacy of the biopesticide against *A. cocois* nymphs.

2. Materials and Methods

All experiments were conducted at Embrapa Agroindústria Tropical, Fortaleza, Ceará, Brazil (3°45'09"S, 38°34'32"W; 21 m asl).

2.1. Preparation of synthetic pesticides and the bioinsecticide for bioassays

Eight synthetic pesticides registered for use in cashew cultivation (AGROFIT, 2026) were selected for this study, including four insecticides and four fungicides (Table 1).

The *Cordyceps javanica* isolate BRM 27666, obtained from infected *Bemisia tabaci* nymphs collected from soybean fields in Porangatu, Goiás, Brazil, was used in this study. This isolate is maintained in the Invertebrate Fungal Collection at Embrapa Rice and Beans, Santo Antônio de Goiás, Brazil, and was previously identified as *C. javanica* by Lopes et al. (2023).

For all experiments, the commercial product Lalguard C99, a wettable powder (WP) formulation containing 1×10^{10} viable conidia g^{-1} of *C. javanica*, was provided by Lallemand Plant Care (Patos de Minas, MG, Brazil). Conidia were suspended in 10 mL of a sterile aqueous solution and vortexed for 1 min. Immediately before application, the suspension was vortexed again for 1 min. Conidial concentration was determined using a hemocytometer (Brightline Improved Neubauer, New Optik®, Brazil) under 400× magnification.

Conidial viability was assessed on potato dextrose agar (PDA) plates by evaluating 200 conidia per plate after incubation for 16 h at 26°C. All conidial batches exhibited germination rates above 99%. Only conidia with germ tubes longer than their own diameter were considered germinated (Boaventura et al., 2021).

2.2. *In vitro* compatibility between *Cordyceps javanica* and pesticides

The effects of pesticides (Table 1) on the germination, mycelial growth, and sporulation of *C. javanica* were evaluated through *in vitro* bioassays using the highest concentrations recommended for cashew cultivation (AGROFIT, 2026). The respective

pesticide concentrations were incorporated into 100-mL Erlenmeyer flasks containing 50 mL of a fungal suspension (5×10^7 conidia mL^{-1}) prepared in sterile distilled water.

The methodology was adapted from Silva et al. (2013) and T. T. M. D. Santos et al. (2018). Incubation was conducted at 26 ± 1°C, 70 ± 10% relative humidity, and a 12-h photoperiod. Treatments consisted of conidial suspensions prepared in sterile distilled water either alone (control) or combined with the respective pesticides. To simulate tank-mix conditions, the suspensions were homogenized in a vortex mixer for 2 min and then maintained under constant agitation in a rotary shaker (250 rpm) for 2 h at 25°C. Each treatment was evaluated in triplicate.

For the germination assay, 25-µL aliquots of each suspension were transferred to 60-mm Petri dishes containing 5 mL of PDA medium. Germination was assessed between 16 and 48 h after inoculation. To evaluate mycelial growth and conidia production, 10-µL aliquots of the respective suspensions were inoculated onto 90-mm Petri dishes containing 10 mL of PDA medium. Colony diameter was measured after 10 days of incubation using a digital caliper.

Conidia production was also evaluated after 10 days of incubation. The culture medium containing each colony was transferred to a 50-mL tube containing 10 mL of sterile distilled water supplemented with Tween 80 (0.01%, v/v) and homogenized in a vortex mixer for 3 min. After serial dilution, conidia were quantified using a Neubauer hemocytometer under 400× magnification. The final concentration was calculated and expressed as the number of conidia per unit colony area (cm^2).

For colony-forming unit (CFU) quantification, the pesticide concentrations were mixed with 30 mL of a fungal suspension (1×10^3 conidia mL^{-1}) in 50-mL Falcon tubes. After simulation of the field mixture, 50-µL aliquots were spread onto 90-mm Petri dishes

containing 10 mL of PDA medium. Colony counts were performed after 5 days of incubation.

2.3. Biological compatibility index

The interaction between *C. javanica* and the evaluated pesticides was classified using the Biological Index (BI) proposed by Alves et al. (2007). Prior to the calculation, the absolute means obtained for each biological parameter were corrected and expressed as percentages relative to the control treatment (sterile distilled water), which was considered 100%.

The BI was calculated using the following equation:

$$BI = \frac{(47 \times VG + 10 \times GER + 43CP)}{100}$$

Wherein: BI = Biological Index; MG = mycelial growth (%); GER = conidial germination (%); and CP = conidia production (%).

Based on the BI values obtained, the pesticides were classified into three toxicity categories for the fungus: toxic (BI < 42), moderately toxic (42 ≤ BI ≤ 60), and compatible (BI > 60).

2.4. Interaction between *Cordyceps javanica* and fungicides on *Aleurodicus cocois* nymphs

The effect of combining *C. javanica* (5×10^7 conidia mL^{-1}) with fungicides at their highest recommended concentrations (Table 1) was evaluated on the mortality of second-instar *Aleurodicus cocois* nymphs. Experimental units consisted of cashew seedlings (*Anacardium occidentale* clone CCP 76) bearing four to six leaves and grown in plastic pots (12.5 × 3.5 × 12.5 cm) filled with pine bark substrate (Allgarden Holambra®, SP, Brazil). The plants were maintained in a screened greenhouse (9 × 8 m) covered with 50-mesh screen. The experiment was arranged in a completely randomized design with five replicates per treatment (approximately 25 nymphs per replicate). Treatments consisted

of fungicide–fungus combinations, fungicides applied alone, and a control treatment (sterile distilled water), simulating field spray conditions.

The *A. cocois* colony was maintained on cashew plants of clone CCP 76 (Goiana et al., 2020) in a greenhouse (2 × 3 m) covered with 50-mesh screen under environmental conditions of 35 ± 10°C, 50 ± 30% relative humidity, and a 12-h photoperiod (Testo 174 H; Testo SE & Co. KGaA, Lenzkirch, Germany). For the bioassay, six-month-old seedlings were exposed to *A. cocois* adults for 48 h to allow oviposition. After adult removal, the plants were enclosed in voile-covered cages until the nymphs reached the second instar, approximately 20 days after infestation (DAI) (Goiana et al., 2017).

Applications were directed to the abaxial leaf surface using a microsprayer (Paasche® type H airbrush equipped with a 0.3-mm needle) connected to an air compressor. A spray volume of 250 µL per leaf was applied to ensure uniform coverage. After treatment, the plants remained in the screened greenhouse, and microclimatic conditions were monitored using a Testo 174 H datalogger (Testo SE & Co. KGaA, Lenzkirch, Germany).

To confirm the causal agent of mortality, leaves were collected 10 days after application (DAA) and placed in 90-mm Petri dishes with moist cotton wrapped around the petiole. The dishes were maintained in a BOD incubator at 26 ± 2°C, 70–80% relative humidity, and a 12-h photoperiod. After an incubation period of up to 10 days, nymphs exhibiting yellowing and mycelial growth were considered infected by *C. javanica.*

2.5. Statistical analysis

Data obtained from the *in vitro* assays (conidia production, mycelial growth, and colony-forming units (CFU) were subjected to analysis of variance (ANOVA) after verification of the assumptions of normality (Kolmogorov–Smirnov test) and homoscedasticity (Levene's test). Germination data were analyzed using generalized linear models (GLMs) because the residuals did not meet the assumption of normality.

In the *in vivo* experiment, the virulence of *C. javanica*, applied alone or in combination with fungicides, was assessed based on total mortality, confirmed mortality, and median lethal time (LT_{50}). Mortality data were fitted to the nonlinear Gompertz and Weibull models, which were compared using the chi-square test ($p < 0.05$). LT_{50} values for second-instar *A. cocois* nymphs were estimated by nonlinear regression using the *drc* package version 3.0-1 (Ritz et al., 2015). Differences among LT_{50} estimates were determined based on the overlap of 95% confidence intervals (95% CI). All statistical analyses were performed using R version 4.3.2 (R Core Team, 2023).

3. Results

During the greenhouse experiment, the mean temperature was 35.5°C (range: 27.9–47.3°C), and the mean relative humidity was 68.6% (range: 51.7–81.5%) (Figure 1).

3.1. *In vitro* compatibility between *Cordyceps javanica* and chemical insecticides

Association with flupyradifurone did not significantly affect the germination of *C. javanica* conidia (Figure 2A; Table 2). In contrast, acetamiprid + etofenprox and spinetoram significantly reduced conidial germination compared with the control treatment, whereas the combination with deltamethrin completely inhibited germination during the first 48 h of evaluation (Figure 2A; Table 2).

None of the insecticides affected the mycelial growth of *C. javanica* (Figure 2B). A similar pattern was observed for conidia production, which was significantly reduced only in the treatment containing deltamethrin (Figure 2C). In contrast, all insecticide treatments significantly reduced CFU formation compared with the control (Figure 2D).

3.2. *In vitro* compatibility between *Cordyceps javanica* and fungicides

The germination of *C. javanica* did not differ from that of the control treatment in the presence of *M. alternifolia* (Figure 3A; Table 2). In contrast, difenoconazole significantly

reduced conidial germination, whereas azoxystrobin + difenoconazole and sulfur completely inhibited the process (Figure 3B; Table 2). Mycelial growth was also affected by the fungicides. The treatments containing *M. alternifolia* and sulfur did not differ from the control, whereas difenoconazole and the mixture of azoxystrobin + difenoconazole significantly reduced colony diameter (Figure 3C).

All fungicides significantly reduced conidia production compared with the control, with the magnitude of the effect decreasing in the following order: azoxystrobin + difenoconazole > difenoconazole > sulfur > *M. alternifolia* (Figure 3C). A similar pattern was observed for CFU formation, which was significantly reduced by azoxystrobin + difenoconazole, difenoconazole, and sulfur (Figure 3D). In contrast, the treatment containing *M. alternifolia* did not differ significantly from the control.

3.3. Compatibility assessment

The compatibility of *C. javanica* with the evaluated pesticides was classified into three categories: compatible, moderately toxic, and toxic (Table 3). Based on the Biological Index (BI), the fungus was compatible with all insecticides evaluated, with BI values ranging from 78.7 for deltamethrin to 97.6 for flupyradifurone (Table 3).

In contrast, the response to fungicides varied according to the active ingredient. The biofungicide based on *M. alternifolia* essential oil and sulfur were classified as compatible, with BI values of 86.8 and 61.1, respectively (Table 3). Conversely, difenoconazole (BI = 41.9) and the commercial mixture of azoxystrobin + difenoconazole (BI = 2.6) were classified as toxic to the entomopathogenic fungus (Table 3).

3.4. Interaction between *Cordyceps javanica* and fungicides against *Aleurodicus cocois* nymphs

The association of *C. javanica* with synthetic fungicides significantly reduced its efficacy against *A. cocois*, except when combined with *M. alternifolia* (Figure 4A; Table

4). The LT_{50} of the fungus applied alone (6.5 days) was similar to that observed for the mixture with the biofungicide (6.3 days) (Table 5). Fungicides applied alone did not cause significant nymphal mortality; therefore, LT_{50} values were not estimated for these treatments (Table 4).

Mortality confirmed as resulting from *C. javanica* infection was observed in most mixtures, except for the combination with azoxystrobin + difenoconazole (Figure 4B; Table 4). Only the association with *M. alternifolia* produced confirmed mortality comparable to that obtained with the fungus applied alone. Notably, the LT_{50} for confirmed infection was significantly lower in the *C. javanica* + *M. alternifolia* treatment (11.9 days) than in the fungus-only treatment (15.2 days) (Table 5). No confirmed mortality or LT_{50} estimates were recorded for treatments containing fungicides applied alone (Figure 4B; Tables 4 and 5).

4. Discussion

The demand for sustainable approaches to cashew pest and disease management has increased interest in Integrated Pest Management (IPM) programs (Amani et al., 2023). The integration of entomopathogenic fungi and synthetic insecticides or fungicides represents a promising strategy; however, its success depends on the selectivity of the chemical products toward the biological control agent (Mao et al., 2024). Previous studies have shown that biological responses vary according to the pesticide and application rate (Celar & Kos, 2016; Sain et al., 2022; Saldanha et al., 2022; Ribeiro et al., 2023; Ray et al., 2024), highlighting the need for case-by-case evaluations. Although tank mixing is a common practice in Brazil, this study provides the first information on the compatibility of *Cordyceps javanica* with pesticides registered for use in cashew cultivation.

Our *in vitro* assays indicated biological compatibility between *C. javanica* and most of the insecticides evaluated. Conidial germination, a key process for successful fungal infection and biological control (Ribeiro et al., 2014; Ribeiro et al., 2023), exceeded 95% in most treatments. Deltamethrin was the only insecticide to completely inhibit conidial germination during the initial evaluation period. Nevertheless, when compatibility was assessed using the Biological Index (BI) proposed by Alves et al. (2007), all insecticides were classified as compatible (BI > 60), with values ranging from 78.7 for deltamethrin to 97.6 for flupyradifurone. In the case of deltamethrin, this apparent discrepancy is explained by the weighting system of the BI, which assigns greater importance to vegetative growth and conidia production than to germination. However, from a biological perspective, even the insecticides classified as compatible significantly reduced CFU formation. This pattern suggests that insecticides may exert selective effects on specific stages of fungal development (Sain et al., 2019; Akbari et al., 2024).

The high toxicity of deltamethrin is consistent with the fungitoxic effects of pyrethroids previously reported for *Beauveria bassiana* (Hypocreales: Cordycipitaceae) (Forlani et al., 2014; Litwin et al., 2021; Mendarte-Alquisira et al., 2024). Under field conditions, such incompatibility may reduce the environmental persistence of biopesticides and limit the establishment of secondary infections within the agroecosystem (Schumacher & Poehling, 2012).

In contrast, synthetic fungicides markedly inhibited the development of *C. javanica*, likely due to their modes of action on mitochondrial respiration and ergosterol biosynthesis (Song & Nes, 2007; Patyal et al., 2013; Garcia-Riaño et al., 2022). This toxicity was confirmed by the Biological Index, which classified the azoxystrobin + difenoconazole mixture (BI = 2.6) and difenoconazole applied alone (BI = 41.9) as toxic to the entomopathogenic fungus. Sulfur, in turn, reached the compatibility threshold (BI

293 = 61.1) due to its limited effect on mycelial growth; however, like the other fungicides, it
294 severely impaired conidial germination and CFU formation. These findings are consistent
295 with previous reports describing the susceptibility of *C. javanica* isolates to fungicides
296 such as captan and iprodione (Er & Gökçe, 2004).

297 Because fungal growth was observed, albeit at low levels, in most treatments, the
298 effects of the fungicides can be considered predominantly fungistatic rather than
299 fungicidal (Shah et al., 2009). Nevertheless, these results should be interpreted with
300 caution because the assays were conducted using the maximum recommended field rates,
301 representing a stringent exposure scenario in which fungicide concentrations remain
302 constant. Under field conditions, pesticide residues decline rapidly over time (Griffin,
303 1996). Indeed, several studies have shown that reduced pesticide rates may favor fungal
304 development, highlighting promising opportunities for integrated management programs
305 (Khun et al., 2021; Pessini et al., 2022; Erdoğan & Sağlan, 2023; Samal et al., 2024).

306 Unlike the synthetic fungicides, *M. alternifolia* essential oil showed high
307 compatibility with *C. javanica* (BI = 86.8), maintaining conidial germination, colony
308 growth, sporulation, and CFU formation at levels comparable to the control treatment.
309 This monoterpene-rich biofungicide (Rocha Neto et al., 2019; Costa Gonçalves et al.,
310 2023) is registered for the control of anthracnose and powdery mildew in cashew
311 cultivation (AGROFIT, 2026). The compatibility demonstrated here represents a novel
312 finding and suggests a promising alternative for the simultaneous management of insect
313 pests and diseases. Such an approach may reduce dependence on conventional synthetic
314 pesticides and mitigate the environmental and resistance-related challenges associated
315 with their use (Hu et al., 2015; Vilaplana et al., 2018; Chechi et al., 2019).

316 *In vitro* and *in vivo* assays should be combined when validating pesticide
317 compatibility because discrepancies between laboratory and biological responses may

occur (Wari et al., 2020; Mejía & Espinel, 2022). In the present study, the results obtained with fungicides were consistent between the two approaches, as only the treatment containing *M. alternifolia* maintained the potential of *C. javanica* to control *A. cocois*. In contrast, the azoxystrobin + difenoconazole mixture completely inhibited fungal activity. Since difenoconazole applied alone caused a comparatively low impact, it can be inferred that azoxystrobin was the main inhibitory component in the commercial mixture, a finding consistent with the high toxicity of this active ingredient reported by D'Alessandro et al. (2010).

The results demonstrate that the compatibility of *C. javanica* with pesticides varies according to the active ingredients. Most insecticides proved compatible with the fungus, in contrast to the deleterious effect of deltamethrin and the severe incompatibility caused by most synthetic fungicides (Avery et al., 2013). Given these antagonistic interactions, the adoption of sequential application windows combined with field studies on pesticide residue dissipation is recommended (Khun et al., 2021). This study establishes important selectivity parameters for cashew management, in which the novel association between *C. javanica* and *M. alternifolia* oil emerges as a feasible tool for a combined control of insects and pathogens, favoring environmental sustainability and cost optimization in agroecosystems.

Clinical trial number: not applicable.

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Declaration of competing interest

The authors declare that they have no known conflicts of interest, financial or otherwise, associated with this publication.

TABLES

Table 1. Characteristics of the pesticides evaluated and their highest recommended rates for control of the main insect pests and diseases of cashew.

Chemical group	Active ingredient (ai)	Formulation[1]	Concentration (ai)	Highest recommended rate	Target
Insecticide					
Neonicotinoid + Pyrethroid	Acetamiprid + Etofenprox	OD	167 g/L + 300 g/L	50 mL/ha	*Aleurodicus cocois*
Pyrethroid	Deltamethrin	EC	25 g/L	200 mL/ha	*Anthistarcha binocularis*; *Selenothrips rubrocinctus*
Spinosyn	Spinetoram	WG	250 g/kg	120 g/ha	*A. binocularis; Anacampsis phytomiella; Cicinnus callipius; S. rubrocintus*
Butenolide	Flupyradifurone	SL	200 g/L	1 L/ha	*Aphis gossypii; A. cocois*
Fungicide					
Strobilurin + Triazole	Azoxystrobin+ Difenoconazole	SC	200 + 125 g/L	1000 mL/ha	*Colletotrichum gloeosporioides*
Triazole	Difenoconazole	EC	250 g/L	12 mL/ha	*C. gloeosporioides; Oidium anacardii*
Sulfur	Sulfur	WG	800 g/kg	600 g/ha	*O. anacardii; Erysiphe polygoni*
Essential oil	*Melaleuca alternifolia*	EC	222.5 g/L	1.5 L/ha	*C. gloeosporioides*; *O. anacardii*

[1] Oil Dispersion (OD); Water-Dispersible Granules (WG); Soluble Liquid (SL); Suspension Concentrate (SC); Emulsifiable Concentrate (EC).

Table 2 Germination of *Cordyceps javanica* conidia at 5×10^7 conidia mL^{-1} applied alone or in combination with pesticides and analyzed using a generalized linear model (GLM) with a binomial distribution. Model parameter estimates and their respective p-values are presented. Differences were considered significant at $p \leq 0.05$.

	Conidia germination			
Active Ingredient /Insecticide	Estimate	Standard error	T value	*p* value
C. javanica (*Cj*)	-0.0017	0.0033	-0.511	0.6230
Cj + Acetamiprid + Etofenprox	-0.0135	0.0046	-2.909	0.0196
Cj+ Deltamethrin	-	-	-	-
Cj+ Spinetoram	-0.0202	0.0046	-4.375	0.0024
Cj+ Flupyradifurone	-0.0017	0.0046	-0.362	0.7267
Active Ingredient /Fungicide				
C. javanica (*Cj*)	-0.00167	0.0072	-0.233	0.8239
Cj+ Azoxystrobin + Difenoconazole	-	-	-	-
Cj+ Difenoconazole	-0.0709	0.0102	-6.926	0.0004
Cj+ Sulfur	-	-	-	-
Cj+ *Melaleuca alternifolia*	-0.02024	0.0102	-1.990	0.0938

360 **Table 3.** Evaluation of the compatibility of *Cordyceps javanica* with pesticides.

Treatment	Biological Index (BI)	Compatibility classification
Control	100	-
Insecticide		
Acetamiprid + Etofenprox	95.8	Compatible
Deltamethrin	78.7	Compatible
Spinetoram	93	Compatible
Flupyradifurone	97.6	Compatible
Fungicide		
Azoxystrobin + Difenoconazole	2.6	Toxic
Difenoconazole	41.9	Toxic
Sulfur	61.1	Compatible
M. alternifolia	86.8	Compatible

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Table 4 *p*-values for comparisons of mortality curves of second-instar *Aleurodicus cocois* nymphs treated with *Cordyceps javanica* alone or in combination with fungicides at a concentration of 5×10^7 conidia mL^{-1} under screenhouse conditions. The *p*-values were estimated using a generalized linear model (GLM) with a binomial distribution. Mortality curves were considered significantly different at $p \leq 0.05$.

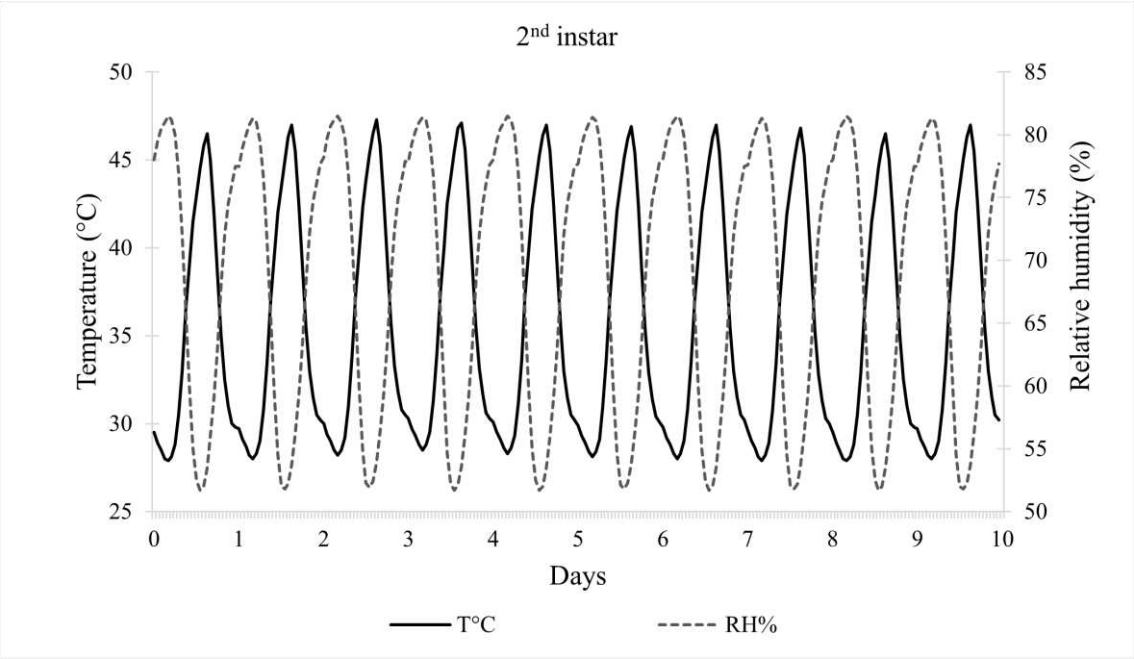
Second instar									
Nymphal mortality									
Treatment	Control	*C. javanica* (*Cj*)	*M. alternifolia*	*Cj* + *M. alternifolia*	Sulfur	*Cj* + Sulfur	Difenoconazole	*Cj* + Difenoconazole	Azoxystrobin + Difenoconazole
C. javanica Cj	<0.0001	-	-	-	-	-	-	-	-
Melaleuca alternifolia	1.0000	<0.0001	-	-	-	-	-	-	-
Cj + *M. alternifolia*	<0.0001	0.7773	<0.0001	-	-	-	-	-	-
Sulfur	0.5323	<0.0001	0.5120	<0.0001	-	-	-	-	-
Cj+ Sulfur	0.0466	<0.0001	0.0429	<0.0001	0.1703	-	-	-	-
Difenoconazole	0.8415	<0.0001	0.8875	<0.0001	0.4166	0.0293	-	-	-
Cj + Difenoconazole	0.6468	<0.0001	0.6242	<0.0001	0.8415	0.1245	0.5169	-	-
Azoxystrobin + Difenoconazole	0.8875	<0.0001	0.9203	<0.0001	0.4543	0.0343	1.0000	0.5598	-
Cj+ Azoxystrobin + Difenoconazole	0.8875	<0.0001	0.9203	<0.0001	0.4503	0.0341	1.0000	0.5598	1.0000
Mortality confirmation									
Treatment	Control	*C. javanica* (*Cj*)	*M. alternifolia*	*Cj* + *M. alternifolia*	Sulfur	*Cj* + Sulfur	Difenoconazole	*Cj* + Difenoconazole	Azoxystrobin + Difenoconazole
C. javanica Cj	<0.0001	-	-	-	-	-	-	-	-
M. alternifolia	1.0000	<0.0001	-	-	-	-	-	-	-
Cj + *M. alternifolia*	<0.0001	0.2713	<0.0001	-	-	-	-	-	-
Sulfur	1.0000	<0.0001	1.0000	<0.0001	-	-	-	-	-
Cj+ Sulfur	0.2815	0.0001	0.2815	<0.0001	0.2815	-	-	-	-
Difenoconazole	1.0000	<0.0001	1.0000	<0.0001	1.0000	0.2815	-	-	-
Cj + Difenoconazole	0.7184	<0.0001	0.7184	<0.0001	0.7184	0.4751	0.7184	-	-
Azoxystrobin + Difenoconazole	1.0000	<0.0001	1.0000	<0.0001	1.0000	0.2815	1.0000	0.7184	-
Cj+ Azoxystrobin + Difenoconazole	1.0000	<0.0001	1.0000	<0.0001	1.0000	0.2815	1.0000	0.7184	1.0000

Table 5 Estimates of nonlinear model parameters and median lethal time (LT_{50}) for second-instar *Aleurodicus cocois* nymphs treated with *Cordyceps javanica* alone or in combination with fungicides at a concentration of 5×10^7 conidia mL^{-1} under screenhouse conditions.

Treatment	Model	Model parameter [1]				TL_{50} (Cl95%)
		B	C	d	e	
		Mortality				
Control	Gompertz	-744.4	706.7	19.16	-5.31×10^{19}	-
Cordyceps javanica (*Cj*)		-572.3	43.35	782.9	5185.00	6.5 (3.6 - 9.3)
Melaleuca alternifolia		594.2	571.5	15.57	4.21×10^{19}	-
Cj + *M. alternifolia*		-355.6	-6.4	805.1	4184.0	6.3 (2.7 - 9.9)
Sulfur		-2101.0	-0.02	81.84	3910.0	-
Cj + Sulfur		-609.5	-0.4	232.8	3732.0	-
Difenoconazole		-	-	-	-	-
Cj + Difenoconazole		-322.6	-530.6	75.11	-3517.0	-
Azoxystrobin + Difenoconazole		212.2	238.3	6.45	2.43×10^{20}	-
Cj + Azoxystrobin + Difenoconazole		205.3	230.8	6.24	4.05×10^{19}	-
		Confirmation				
Control	Weibull	-	- [c]	-	-	-
C. javanica (*Cj*)		-2.09		0.89	11.63	15.2 (13.7 - 16.6)
M. alternifolia		-	-	-	-	-
Cj + *M. alternifolia*		-1.85		0.76	7.48	11.9 (10.6 - 13.2)
Sulfur		-	-	-	-	-
Cj + Sulfur		-0.72		0.13	1.32	-
Difenoconazole		-	-	-	-	-
Cj + Difenoconazole		1.45		0.05	7.71	-
Azoxystrobin + Difenoconazole		-	-	-	-	-
Cj + Azoxystrobin + Difenoconazole		-	-	-	-	-

[1] Model parameters: B = slope factor of the parameter "e"; C = lower limit of the response curve; d = upper limit of the response curve; e = inflection point of the curve.

371 # FIGURES



372

373 **Figure 1.** Temperature (°C) and relative humidity (%) recorded in the screenhouse at 1-h intervals during
374 experiments with second-instar *Aleurodicus cocois* nymphs.

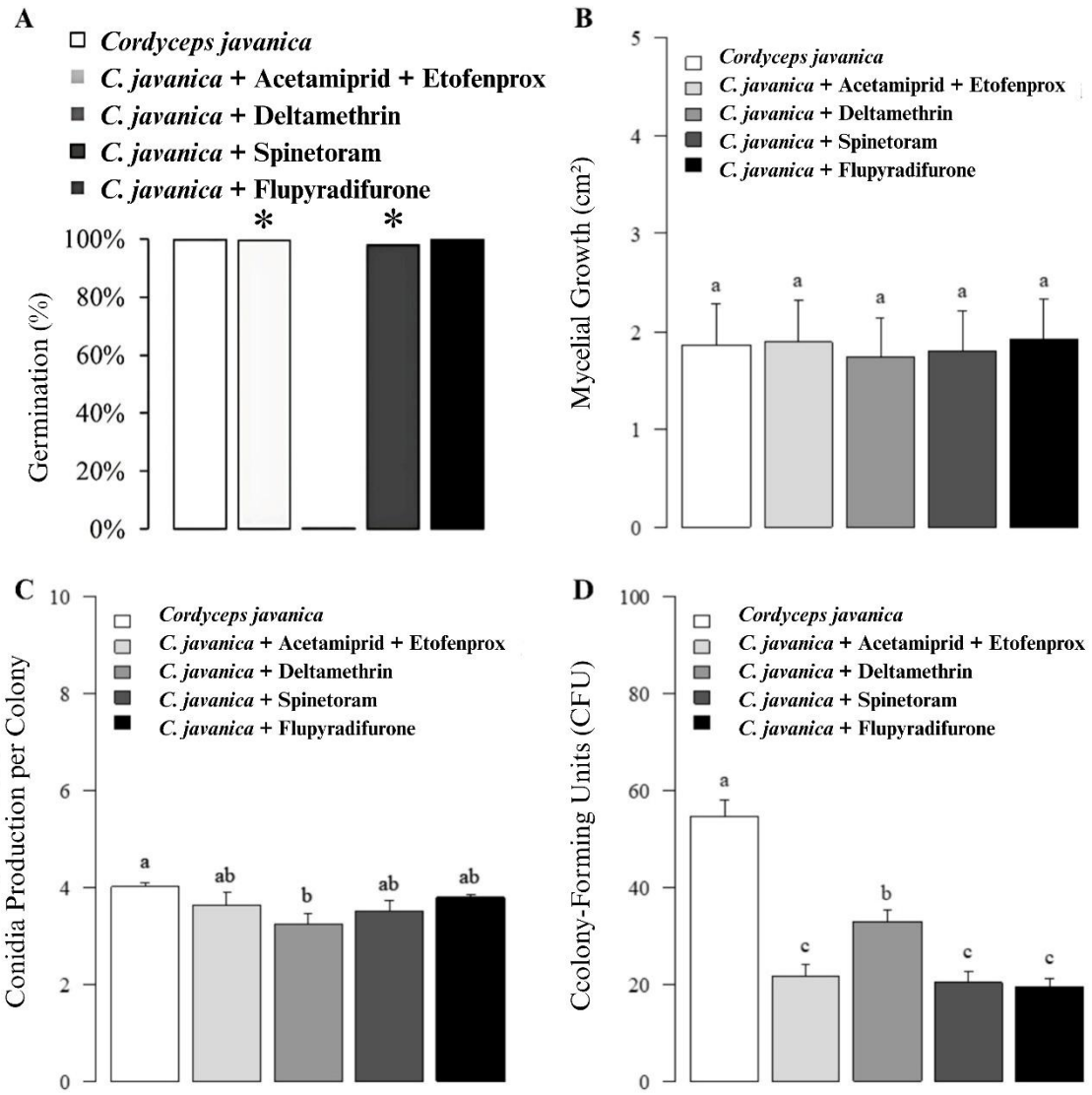


Figure 2. (A) *In vitro* germination of *Cordyceps javanica* conidia at a concentration of 5×10^7 conidia mL^{-1} in combination with insecticides after 16 h. Germination percentages were analyzed using a generalized linear model (GLM) with a binomial distribution. Differences were considered significant at $p \leq 0.05$ (*). (B) Mycelial growth (cm^2); (C) conidia production per colony; and (D) *in vitro* colony-forming units (CFU) of *C. javanica* at a concentration of 5×10^7 conidia mL^{-1} in combination with insecticides after 10 days (B and C) and 5 days (D). Means (A, B, C, and D) were analyzed by ANOVA and compared using Fisher's LSD test following verification of homoscedasticity.

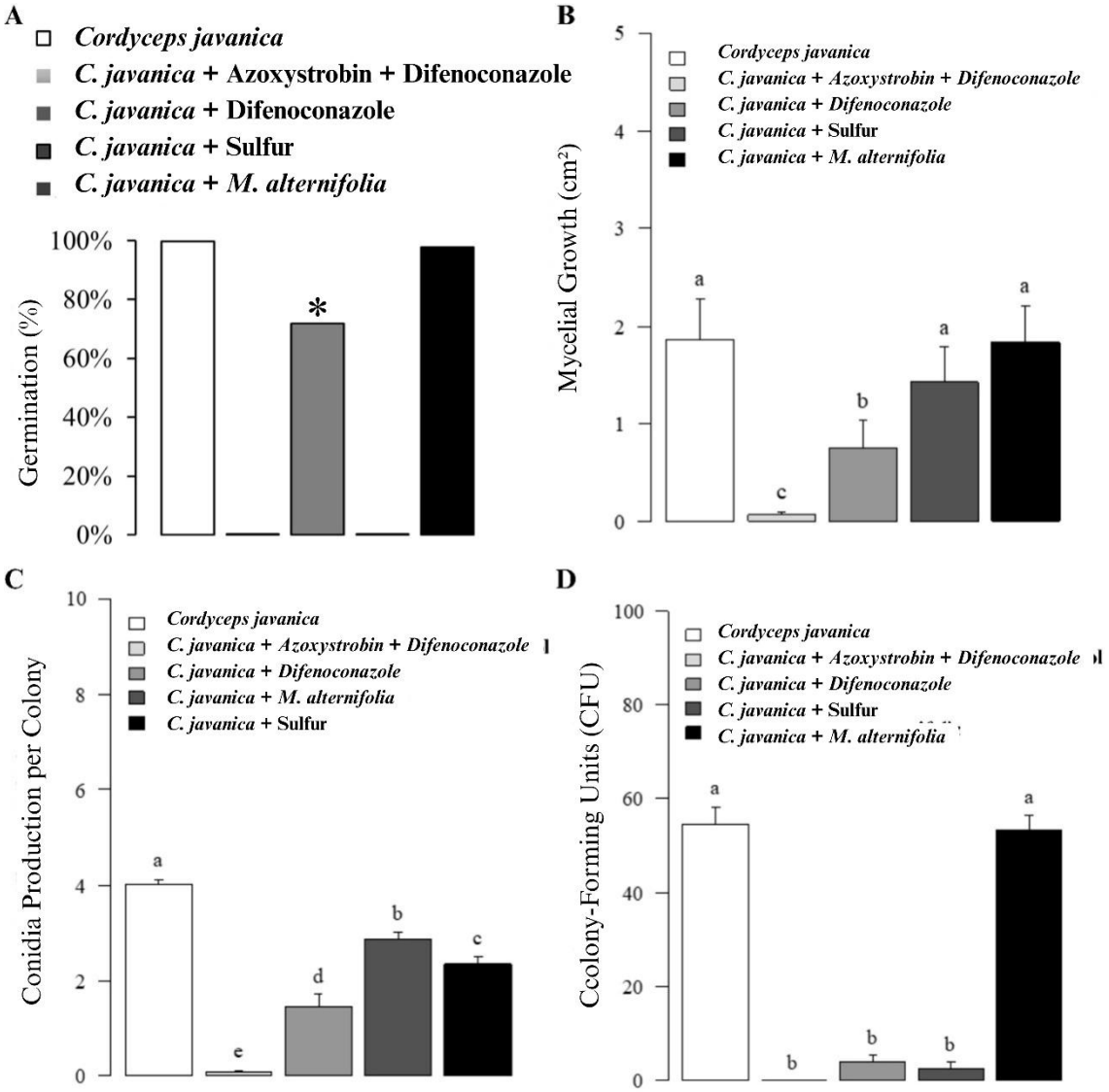


Figure 3. (A) *In vitro* germination of *Cordyceps javanica* conidia at a concentration of 5×10^7 conidia mL^{-1} in combination with fungicides after 16 h. Germination percentages were analyzed using a generalized linear model (GLM) with a binomial distribution. Differences were considered significant at $p \leq 0.05$ (*). (B) Mycelial growth (cm^2); (C) conidia production per colony; and (D) *in vitro* colony-forming units (CFU) of *C. javanica* at a concentration of 5×10^7 conidia mL^{-1} in combination with fungicides after 10 days (B and C) and 5 days (D). Means (A, B, C, and D) were analyzed by ANOVA and compared using Fisher's LSD test following verification of homoscedasticity.

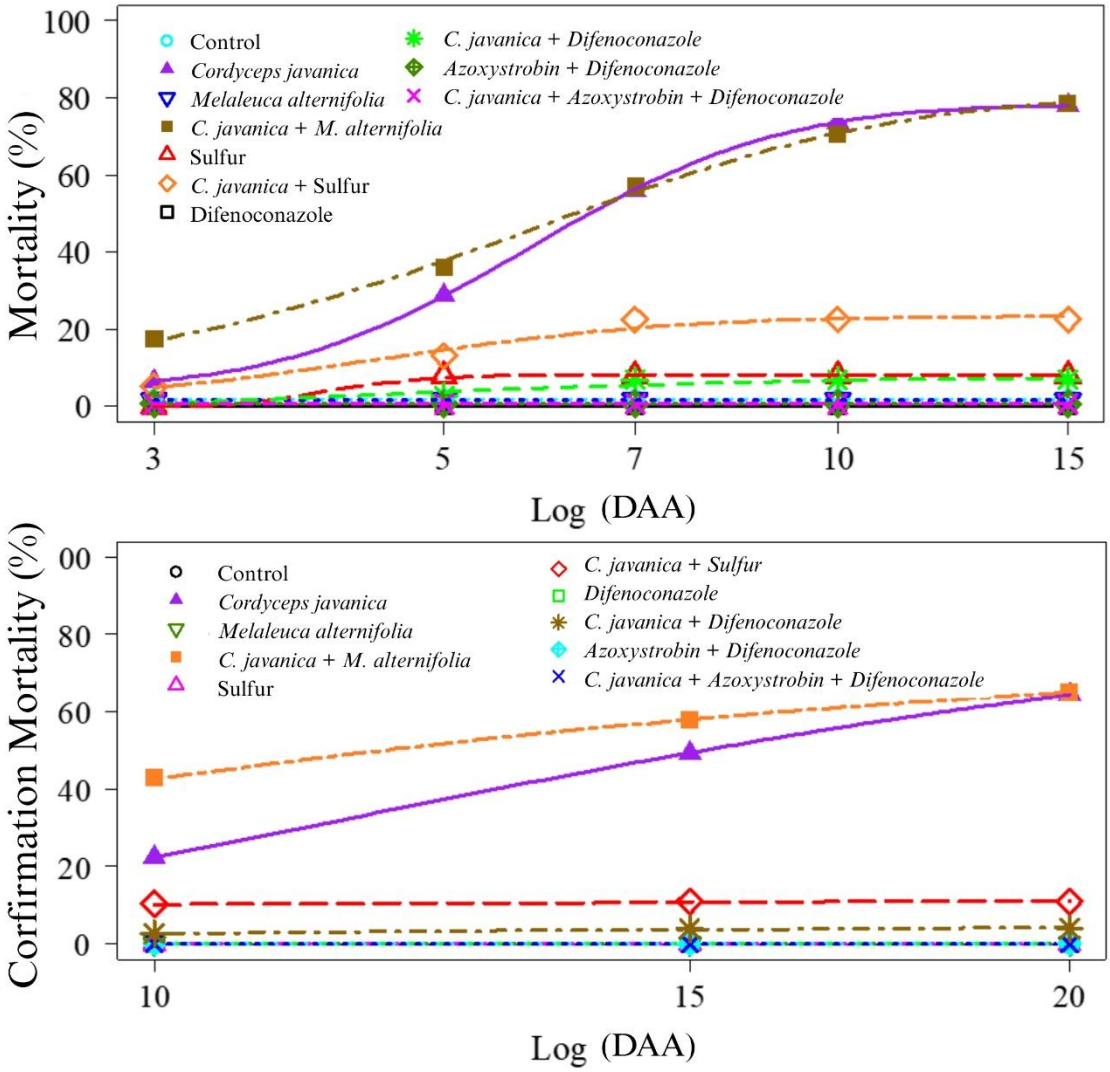


Figure 4. Total mortality (A) and confirmed mortality caused by *Cordyceps javanica* infection (B) in second-instar *Aleurodicus cocois* nymphs treated with *C. javanica* at a concentration of 5×10^7 conidia mL^{-1} under screenhouse conditions. Mortality curves were fitted using the nonlinear Gompertz (A) and Weibull (B) models.

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