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Evaluation of Biological Control Agents (Beauveria bassiana and Metarhizium anisopliae) Compared with the Chemical Insecticide Oxamyl for Management of the Fig Wax Scale Insect (Ceroplastes rusci) and Its Impact on Final Fruit Quality

Ruqaya S. Al-Abadi[1*] and Shaymaa H. Al-Obaidy[2]

1-Department of Plant Protection, College of Agricultural Engineering Sciences, University of Baghdad, Iraq
2-Biological Control Research Unit, College of Agricultural Engineering Sciences, University of Baghdad, Iraq

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*Corresponding Author E-Mail:
Roqia.saadoun1704b@coagri.uobaghdad.edu.iq

ABSTRACT

The fig wax scale insect, *Ceroplastes rusci* L., is a significant pest of fig trees, causing direct damage and indirect quality deterioration that affects fruit marketability and processing suitability. This laboratory study was conducted to evaluate the insecticidal efficacy of two entomopathogenic fungi, *Beauveria bassiana and Metarhizium anisopliae*, in comparison with the chemical insecticide Oxamyl 24% SL, against different nymphal instars and adult stages of *C. rusci*. The goal was to identify effective management strategies that minimize chemical residues and enhance the quality of the final fruit product. The results demonstrated that Oxamyl 24% SL was the most potent treatment, achieving the highest overall mean mortality rates across all stages, with peak efficacy observed against the second nymphal instar (57.58%) and the pre-oviposition adult stage (49.82%). Among the biological agents, *B. bassiana* exhibited significantly superior pathogenicity compared to *M. anisopliae* against all tested stages, with overall mean mortality rates ranging from 32.34% to 44.59%. The maximum efficacy of *B. bassiana* (74.12% mortality) was recorded against the first nymphal instar at 30 days post-exposure, highlighting its cumulative effect. Notably, nymphal stages were consistently more susceptible to all treatments than adult stages. The study concludes that *B. bassiana* represents a highly promising biological alternative for integration into Integrated Pest Management (IPM) programs. Its high cumulative mortality and ability to penetrate the insect's protective wax coating offer a sustainable strategy for suppressing *C. rusci* populations. Adopting such a biological control agent could significantly reduce reliance on chemical insecticides like Oxamyl, thereby lowering pesticide residues in harvested figs and contributing to the production of safer, higher-quality fruit for the fresh market and food processing industries.

1- INTRODUCTION

The fig wax scale insect, *Ceroplastes rusci* L., is considered one of the major economic pests of fig trees. Field and regional studies have shown that high infestation levels can cause direct reductions in tree vigor and productivity [1,2]. The importance of this pest is linked to its complex damage pattern: it extracts plant sap from vegetative tissues and excretes honeydew, which promotes sooty mold development, thereby negatively affecting photosynthetic efficiency, vegetative growth, and fruit quality [3]. Biological investigations further indicate that *C. rusci* possesses adaptive traits that enable prolonged establishment on host plants, with marked fluctuations in population abundance according to prevailing climatic conditions [4]. Seasonal abundance data also demonstrate that pest population dynamics vary across the year, making intervention timing a decisive factor for successful control and economic loss reduction [5,6].

Pest management is further complicated by the broad host range of *C. rusci* and its occurrence on multiple plant species, which increases its persistence and dispersal potential across different agroecosystems [7]. From taxonomic and morphological perspectives, specialized references show that scale insects possess structural traits—including waxy coverings—that reduce the efficacy of many treatments, particularly at advanced developmental stages [8,9]. Therefore, reliance on chemical control alone may not ensure adequate long-term sustainability, especially under integrated pest management (IPM) principles.

In this context, entomopathogenic fungi have emerged as promising agents in biological control programs, particularly ***Beauveria bassiana*** and ***Metarhizium anisopliae***, due to their pathogenicity against a wide range of insect pests [10]. Applied studies on ***C. rusci*** have supported the efficacy of certain fungal isolates in reducing pest density, albeit with variability depending on environmental conditions and targeted developmental stage [11]. Their efficacy is based on well-established infection mechanisms initiated by conidial adhesion and germination, followed by cuticle penetration via specialized enzymes, internal proliferation within the insect body, and eventual host death [12,13].

Concurrently, recent trends support integrating biological control with alternatives of lower environmental impact, including selected botanical pesticides. Field studies have reported encouraging outcomes when entomopathogenic fungi were combined with plant-based compounds against scale insects [14]. At the local level, studies in fig orchards of Babylon Province confirmed associations between pest activity and environmental factors, emphasizing the need for locally informed control programs [15].

Accordingly, this study was designed to evaluate the effects of ***B. bassiana***, ***M. anisopliae***, and Oxamyl 24% SL on different developmental stages of ***C. rusci***, aiming to identify the most effective treatment by stage and exposure time and to support practical recommendations for sustainable plant protection programs in fig orchards.

2-Materials and Methods

Plant material

Plant material infested with ***Ceroplastes rusci*** L. (twigs, leaves, and fruits) was collected from infested fig orchards in Babylon Province, Iraq. Samples were stored in polyethylene bags and transferred to the laboratory for artificial infestation procedures. Eighteen fig seedlings (cv.

Sultani), aged 1.5–2 years, were used; seedlings were grown in 30-cm-diameter pots containing loamy mixed soil.

Insect rearing and infestation

Insect eggs were carefully extracted from beneath the wax shields and from the abdominal cavity of field-collected adult females. Using a soft brush, eggs were distributed onto leaves and stems of healthy seedlings. Seedlings were monitored daily until egg hatch, crawler emergence, and settlement were confirmed; infestation success was verified microscopically.

Treatments

Infested seedlings were treated with two local entomopathogenic fungal isolates, ***Beauveria bassiana*** and ***Metarhizium anisopliae***. Fungal suspensions were prepared at 5 g L^{-1} (approximately 1 × 10^7 conidia mL^{-1}). Oxamyl 24% SL (Mobedco, Jordan) was applied at the recommended concentration (100 mL per 100 L water). Treatments were sprayed using a calibrated hand sprayer (2.5 mL per spray) from a 15-cm distance, at 10 sprays per seedling until complete wetting; control seedlings were sprayed with distilled water only.

Mortality assessment

Insect mortality was recorded at 3, 7, 14, 21, 28, and 30 days after treatment. **Corrected mortality was calculated using the Dawood *et al.* equation.** To confirm fungal pathogenicity, dead insects were surface-sterilized in 1% sodium hypochlorite for 1 min, rinsed, plated on PDA medium, and incubated at 25 ± 1°C for 7 days [16].

Statistical analysis

Data were analyzed using a Completely Randomized Design (CRD) with three replicates for the laboratory experiment. Mean separation was performed using LSD at P = 0.05 in GenStat ver. 12 [17].

3-Results and Discussion

1. Evaluation of the insecticidal efficacy against first-instar nymphs of *Ceroplastes rusci* L.

The results presented in Table (1) showed clear significant differences among treatments in controlling first-instar nymphs of the fig wax scale, ***Ceroplastes rusci***. Oxamyl 24 recorded the highest overall mean mortality (59.64%), outperforming the biological control treatments. Among the biocontrol agents, ***Beauveria bassiana*** was superior, with an overall mean mortality of 44.59%, compared with 38.93% for ***Metarhizium anisopliae***, indicating relatively higher efficacy of the ***B. bassiana*** isolate under laboratory conditions.

Time-course observations also revealed a progressive increase in mortality with longer exposure periods. The highest mortality for ***B. bassiana*** reached 74.12% on day 30, whereas ***M. anisopliae*** reached 71.90% on the same day. In contrast, Oxamyl 24 exhibited a faster initial response, achieving 54.89% mortality by day 7 and reaching a peak effect of 75.01% on day 28.

Table (1). Mortality (%) of first-instar nymphs of *Ceroplastes rusci* L. treated with Oxamyl 24%, *Beauveria bassiana*, and *Metarhizium anisopliae* at different post-exposure days

Treatments	3 Days	7 Days	14 Days	21 Days	28 Days	30 Days	Treatment Mean (%)
Oxamyl 24	14.11	54.89	67.00	69.71	75.01	12.77	59.64
Beauveria bassiana	0.12	15.17	35.89	66.65	75.59	74.12	44.59
Metarhizium anisopliae	0.31	21.15	33.78	51.00	55.44	71.90	38.93
LSD5%	11.29**						5.05**
Days Mean (%)	4.84	30.40	45.55	62.45	68.68	38.74	
LSD5%	5.65**						

2. Evaluation against second-instar nymphs of *Ceroplastes rusci* L.

The results presented in Table (2) revealed significant differences among treatments in their efficacy against second-instar nymphs of ***C. rusci***. Within the biological control treatments, ***B. bassiana*** showed superior performance, achieving an overall mean mortality of 42.75%, compared with 40.32% for ***M. anisopliae***. The highest mortality caused by ***B. bassiana*** reached 63.96% at day 30, whereas ***M. anisopliae*** reached 51.78% on the same day. The chemical insecticide Oxamyl 24% exhibited clear superiority over the biological treatments, with an overall mean mortality of 57.58%, along with an early response at day 7 (54.78%) that increased progressively to 72.89% by day 30.

Table (2). Mortality (%) of second-instar nymphs of *Ceroplastes rusci* L. treated with Oxamyl 24%, *Beauveria bassiana*, and *Metarhizium anisopliae*

Treatments	3 Days	7 Days	14 Days	21 Days	28 Days	30 Days	Treatment Mean (%)
Oxamyl 24%	12.45	54.78	65.78	67.69	71.89	72.89	57.58
Beauveria bassiana	1.00	32.00	45.09	56.54	57.90	63.96	42.75
Metarhizium anisopliae	0.00	21.90	30.67	43.00	47.07	51.78	40.32
LSD5%	9.97**						4.99**
Days Mean (%)	4.48	36.23	47.18	55.74	58.95	62.88	
LSD5%	7.48**						

3. Evaluation against third-instar nymphs of *Ceroplastes rusci* L.

Data in Table (3) indicate that the response of third-instar nymphs of ***C. rusci*** varied according to treatment type and assessment interval. Under biological control treatments, ***B. bassiana*** performed relatively better than ***M. anisopliae***, with overall mean mortalities of 38.03% and 34.07%, respectively. The effect of ***B. bassiana*** was cumulative over time, with mortality increasing progressively to reach 62.63% by day 30, whereas the highest mortality recorded for ***M. anisopliae*** was 50.56% on the same day. Oxamyl 24% showed overall mean efficacy of 39.56%, appearing early (10.45% at day 3), then rising rapidly to 50.98% at day 7, reaching a peak of 69.87% at day 21, and subsequently declining to 45.71% by day 30.

Table (3). Mortality (%) of third-instar nymphs of *Ceroplastes rusci* L. treated with Oxamyl 24%, *Beauveria bassiana*, and *Metarhizium anisopliae*

Treatments	3 Days	7 Days	14 Days	21 Days	28 Days	30 Days	Treatment Mean (%)
Oxamyl 24%	10.45	50.98	16.66	69.87	43.70	45.71	39.56
Beauveria bassiana	0.00	14.21	53.36	56.43	41.52	62.63	38.03
Metarhizium anisopliae	0.00	43.13	27.29	36.39	47.07	50.56	34.07
LSD5%	8.97**						4.99**
Days Mean (%)	3.48	36.11	32.44	54.23	44.10	52.97	
LSD5%	7.48**						

4. Evaluation against pre-oviposition adult females of *Ceroplastes rusci* L.

The results in Table (4) showed that the response of pre-ovipositional adult females of *C. rusci* varied according to treatment type. Oxamyl 24 exhibited higher efficacy than the biological treatments, recording an overall mean mortality of 49.82%. Among the biological control options, *B. bassiana* achieved a mean mortality of 34.78%, surpassing *M. anisopliae* (30.30%). Final mortality percentages at day 30 reached 75.12% for Oxamyl 24, 57.60% for *B. bassiana*, and 54.57% for *M. anisopliae*.

Table (4). Mortality (%) of pre-oviposition adult females of *Ceroplastes rusci* L. treated with Oxamyl 24%, *Beauveria bassiana*, and *Metarhizium anisopliae*

Treatments	3 Days	7 Days	14 Days	21 Days	28 Days	30 Days	Treatment Mean (%)
Oxamyl 24	14.15	23.34	52.57	69.60	64.11	75.12	49.82
Beauveria bassiana	0.00	14.17	25.89	54.47	56.52	57.60	34.78
Metarhizium anisopliae	0.00	13.15	21.23	38.39	54.45	54.57	30.30
LSD5%	7.07**						3.30**
Days Mean (%)	4.72	16.89	33.23	54.15	58.36	62.43	
LSD5%	4.11**						

5. Evaluation against ovipositing adult females of *Ceroplastes rusci* L.

The results presented in Table (5) showed that ovipositing adult females of ***C. rusci*** responded differently depending on treatment type. Oxamyl 24 recorded the highest overall mean mortality (48.66%), outperforming the biological control treatments. ***B. bassiana*** achieved a mean mortality of 32.34%, while ***M. anisopliae*** recorded 31.30%. Final mortality percentages at day 30 reached 71.12% for Oxamyl 24, 57.60% for ***B. bassiana***, and 59.56% for ***M. anisopliae***.

Table (5). Mortality (%) of ovipositing adult females of *Ceroplastes rusci* L. treated with Oxamyl 24%, *Beauveria bassiana*, and *Metarhizium anisopliae*

Treatments	3 Days	7 Days	14 Days	21 Days	28 Days	30 Days	Treatment Mean (%)
Oxamyl 24	14.50	32.45	51.57	59.69	62.63	71.12	48.66
Beauveria bassiana	0.00	12.17	22.24	45.47	56.56	57.60	32.34
Metarhizium anisopliae	0.00	13.15	25.23	35.39	54.45	59.56	31.30
LSD5%	7.07**						3.30**
Days Mean (%)	4.83	19.26	33.01	46.85	57.88	62.76	
LSD5%	4.11**						

4-General Discussion

The results presented in Tables (1–5) demonstrate significant variation in the efficacy of the tested treatments against different developmental stages of the fig wax scale, *Ceroplastes rusci*. The superior performance of *Beauveria bassiana* can be attributed to its strong ability to overcome the external waxy barrier of *C. rusci*, which is a principal factor underlying the difficulty of controlling scale insects. As fungal propagules successfully adhere to the insect surface, germinate, and penetrate the cuticle, the intensity of fungal infection increases, resulting in higher mortality levels. Accordingly, the progressive increase in mortality over time is a biologically expected outcome of entomopathogenic fungal action, as these agents require an adequate incubation period to complete successive infection stages (spore germination, hyphal development, and secretion of cuticle-degrading enzymes and fungal toxins). This interpretation is consistent with previous reports [18,19].

The superiority of Oxamyl is explained by its specific mode of action and its effective penetration through the wax covering, which provides a relatively faster response than biological control treatments. Moreover, the upward trend in efficacy across successive assessment intervals indicates a sustained cumulative effect, in agreement with earlier findings [20]. This result highlights the practical importance of systemic/semi-systemic insecticides in the management of sapsucking pests, where efficacy may increase over time as the active ingredient continues to reach insect feeding sites, consistent with the findings reported in [21]. The results of this study have direct implications for food safety and fruit quality. The high efficacy of *B. bassiana* against *C. rusci* suggests that this entomopathogenic fungus can be integrated into IPM programs to reduce reliance on chemical insecticides such as Oxamyl. Reducing chemical residues on fig fruits is particularly important because figs are often consumed fresh or with minimal processing, and pesticide residues pose potential health risks to consumers. Biological control with *B. bassiana* offers a sustainable approach that not only effectively suppresses pest populations but also ensures safer, higher-quality fruit for the fresh market and food processing industries [22,23].

Ethical Approval

This study did not involve human participants or animals. All experimental procedures were conducted in accordance with institutional and laboratory biosafety guidelines.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Data Availability

All data supporting the findings of this study are available within the manuscript.

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