

Efficacy of *Beauveria bassiana* as a biopesticide: A meta-analysis

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ABSTRACT

Objective: To perform a meta-analysis evaluating the efficacy of *Beauveria bassiana* as a biological control agent against agricultural pests.

Methodology: A bibliographic search was conducted using the Embase and PubMed databases, applying the terms *Beauveria bassiana*, entomopathogenic fungi, crop, plant, and mortality, connected by the operator “AND.” The search encompassed studies published from 2019 to 2024. The analysis focused primarily on reported mortality rates, crop species treated, conidial concentrations, and targeted pest species.

Results: The most frequently applied conidial concentration was 1×10^8 conidia/mL. Mortality rates ranging from 25% to 75% were the most commonly reported, particularly in trials targeting Hemipteran pests, where favorable outcomes were consistently observed.

Limitations: There was notable variability across studies in terms of fungal concentration, crop type, application technique, and reproducibility of laboratory results, which may affect the generalizability of findings.

Conclusions: The use of *Beauveria bassiana* is recommended for the control of Hemipteran pests, given the consistently high mortality rates reported. Additionally, its potential as a biocontrol agent for mites is proposed, although further evidence is required to support this application. Conidial concentrations of 1×10^7 and 1×10^8 conidia/mL are suggested, preferably utilizing locally adapted *Beauveria bassiana* strains.

Keyword: Biopesticide, entomopathogenic fungus, biological control, agriculture.

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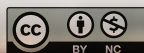
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INTRODUCTION

Agriculture remains one of the main sources of income in several countries, particularly those with favorable climates for diverse crop cultivation. According to data from the World Bank, agricultural crop revenues contribute up to 25% of the gross domestic product (GDP) in certain nations, while in countries with limited arable land or less suitable climatic conditions, this contribution drops to approximately 4% of GDP (World Bank, 2024). Compared to other productive sectors, agriculture faces



a wide range of challenges that can negatively impact crop growth, fruit development, and, ultimately, harvest yields. Key factors influencing agricultural productivity include climate change (*e.g.*, temperature fluctuations), soil quality, water availability (*e.g.*, droughts or floods), and inefficient irrigation practices often linked to poor human management (FAO, 2023).

These are compounded by nutrient availability, plant pathogens, and insect infestations—one of the leading causes of crop and economic losses worldwide. Insects alone are responsible for up to 40% of global crop losses, posing a major threat to the sustainability of the agricultural sector (FAO, 2020). Consequently, a significant portion of agricultural investment is directed toward pest control, with over \$30 billion spent annually on chemical pesticides. These substances, while effective, pose risks to human health, especially to farmers and consumers. In 2014, the World Health Organization (WHO) estimated approximately 100,000 deaths per year due to pesticide exposure, with an additional 200,000 cases of poisoning linked to improper use (OPS, UNEP, FAO, and MSP, 2014). More recently, these figures have increased, contributing to rising incidence rates of pesticide-related diseases across all age groups. Notably, in rural areas, children are particularly vulnerable, with evidence linking pesticide exposure to neurodevelopmental disorders and increased risk of cancers such as leukemia. In neonates, exposure has been associated with congenital malformations and behavioral abnormalities (Boedeker *et al.*, 2024; UNICEF, 2022). Studies conducted between 2002 and 2012 confirmed a significant association between pesticide exposure and neurological impairments in children, including cognitive, behavioral, and motor deficits.

These were manifested through reduced attention, memory, learning ability, concentration, and reflexes attributed to the neurotoxic effects of these chemicals (Muñoz-Quezada *et al.*, 2013). Beyond health implications, indiscriminate pesticide use, inadequate management, and inconsistent international regulations have had severe environmental consequences. These include contamination of soils and water bodies with pesticide residues. Silva *et al.* (2019) analyzed 317 soil samples from agricultural lands and detected pesticide residues in 83% of them; among these, 58% contained between two and over ten distinct chemical residues.

In light of these issues, numerous innovative alternatives for pest control have emerged. These include the use of bacteria, entomopathogenic nematodes (EPNs), sterile insect techniques, entomopathogenic fungi (EPFs), viruses, protozoa, natural predators such as insects, arachnids, and some vertebrates, parasitic organisms, and biochemicals like pheromones or growth regulators, all of which have shown promising results. Among these, entomopathogenic fungi have attracted considerable attention due to their ability to control various pest species. Although over 90 genera and more than 700 EPF species have been identified, only a few have been extensively studied. *Metarhizium anisopliae* stands out for its high virulence and commercial success. Similarly, *Beauveria bassiana* has garnered research interest due to its potential as an insect control agent across a range of crops. Therefore, the aim of this review is to summarize and discuss current knowledge on *B. bassiana* as a biological pest control tool.

MATERIALS AND METHODS

A comprehensive literature review was conducted using the PubMed and Embase search engines. The selection criteria included articles published between January 1, 2019, and November 1, 2024. The search employed the keywords *Beauveria bassiana*, entomopathogenic fungi, crop, plant, and mortality, connected using the operator “AND.” In Embase, the initial search using only *Beauveria bassiana* returned 2,472 articles. This number was progressively reduced by applying the following keyword combinations: *Beauveria bassiana* AND crop (210 articles), *Beauveria bassiana* AND crop AND plant (101 articles), *Beauveria bassiana* AND crop AND plant AND mortality (42 articles), and finally *Beauveria bassiana* AND crop AND plant AND mortality AND entomopathogenic fungi (28 articles). After applying the publication date filter (2019-2024), 20 articles remained.

An identical search strategy was applied in PubMed, resulting in 30 articles. Duplicate entries between both databases and inaccessible full texts were excluded. A thorough review of the remaining articles was then performed, selecting only those that included pest mortality data, the concentration of *Beauveria bassiana* used during application, and the number of exposure days. Articles lacking any of these criteria were discarded, yielding a final selection of 24 articles for analysis (Figure 1). Studies that included comparisons between *B. bassiana* and other entomopathogenic fungi or chemical agents were also considered; however, only data specifically related to *B. bassiana* were extracted and analyzed in this review.

To generate graphical data, average pest mortality rates reported in the articles were used. This approach was chosen because some studies presented varying mortality outcomes across repeated trials; therefore, mean values were calculated to ensure consistency in the data analysis.

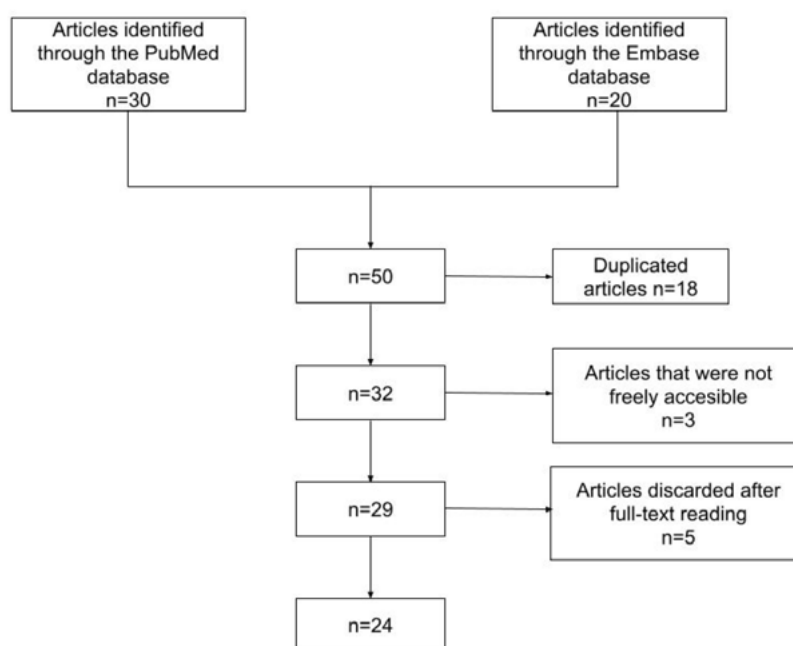


Figure 1. Flowchart for study identification.

RESULTS AND DISCUSSION

Through the review of 24 selected articles, various conidial concentrations of *Beauveria bassiana* used to assess pest mortality were analyzed. These concentrations ranged from $<1 \times 10^5$ to $>1 \times 10^{10}$ conidia/mL. A few studies reported extreme values, using concentrations as low as $<1 \times 10^2$ or as high as $>5 \times 10^{12}$ conidia/mL. However, these were excluded from the review as they served other purposes and did not report the required parameters (Figure 1). The reviewed studies demonstrated that *B. bassiana* can induce pest mortality at a range of concentrations (Figure 2). Nonetheless, the majority of the trials employed concentrations of 1×10^6 , 1×10^7 , 1×10^8 , and 1×10^9 conidia/mL, with 1×10^8 conidia/mL being the most frequently used. Notably, higher concentrations were typically associated with trials involving commercial formulations rather than locally sourced fungal isolates. This suggests that higher doses may be necessary to achieve effective results when using commercial strains, possibly due to their lower adaptability to local environmental conditions. In contrast, regionally adapted strains may exhibit better efficacy at lower concentrations, as they are more compatible with the local climate, soil, and target pests.

Regarding pest mortality data, considerable variability was observed in the relationship between reported mortality rates and the conidial concentrations used. This variability can be attributed to the type of pest targeted and the methodological differences among studies. Some experiments were conducted under laboratory conditions using seeds, culture media, plants, or directly on insects, while others were carried out in the field under diverse pest and crop scenarios.

Despite these differences, it was evident that concentrations of 1×10^6 and 1×10^8 conidia/mL were consistently associated with high mortality rates, whereas other concentrations tended to result in moderate or low mortality levels (Figure 3). Notably, in one study using a concentration $>1 \times 10^{10}$ conidia/mL, no significant increase in mortality was observed. This finding suggests that higher conidial concentrations do not necessarily correlate with

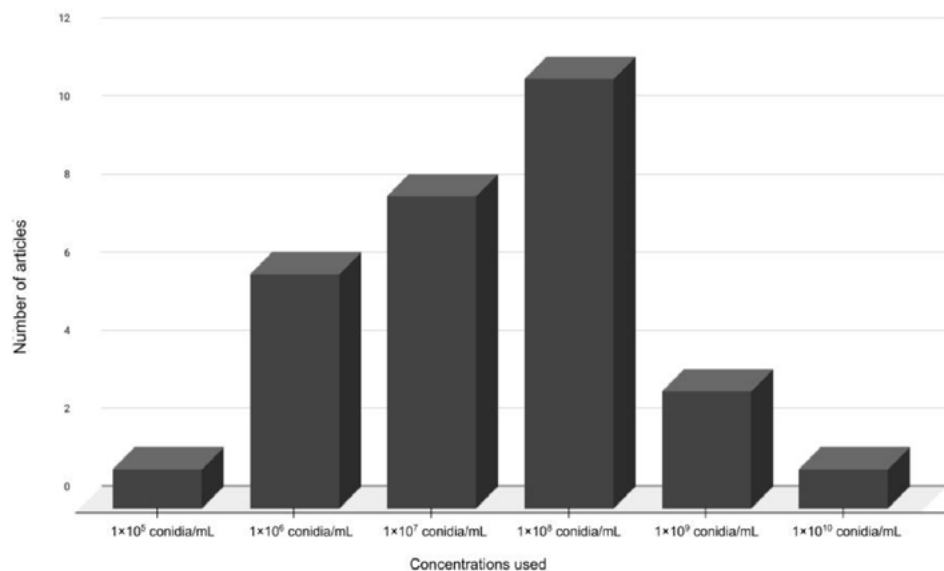


Figure 2. Comparison of *Beauveria bassiana* concentrations and pest mortality rates across studies.

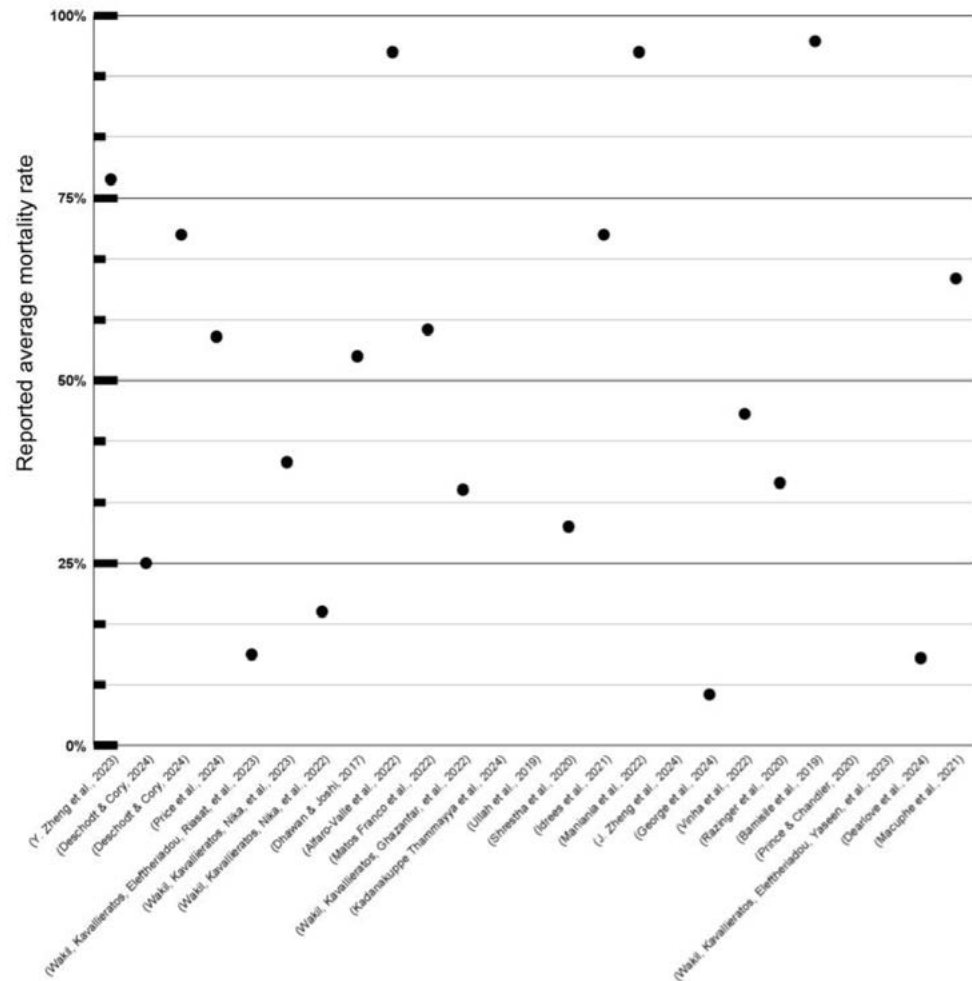


Figure 5. Average Mortality Percentage Reported in Each Analyzed Study.

Of the total articles reviewed, 23 focused on insecticidal activity and one reported acaricidal function (Figure 6). The latter achieved a 95% mortality rate against the papaya mite *Tetranychus merganser*, making *Beauveria bassiana* a promising option for mite control, as reported by Alfaro-Valle *et al.* (2022). The highest mortality rates were observed against a range of pest species, including *Phthorimaea absoluta* (Lepidoptera), *Tenebrio molitor* (Coleoptera), *Brevicoryne brassicae* (Hemiptera), *Diaphorina citri* Kuwayama (Hemiptera), *Lygus lineolaris* (Hemiptera), *Paracoccus marginatus* Williams & Granara de Willink (Hemiptera), *Phenacoccus solenopsis* Tinsley (Hemiptera), and the papaya mite *Tetranychus merganser*.

Based on the average mortality percentages reported across the reviewed studies, Coleopteran insects were the most frequently used organisms in experimental trials (Figure 7). However, mortality rates within this order varied considerably, ranging from 12.46% to 77.56%, making it difficult to establish a consistent expectation of *B. bassiana* efficacy against Coleoptera. In contrast, Hemipteran pests showed consistently high mortality rates. Eight out of nine studies reported mortality rates above 50%, with two

while its efficacy against Coleopterans and Lepidopterans appears to be more variable and less consistent. Consequently, the integration of *B. bassiana* with complementary pest management strategies is advised to enhance overall effectiveness.

Additionally, findings support the dual utility of *B. bassiana* as both an insecticide and acaricide, with one study reporting a 95% mortality rate against the mite *Tetranychus merganser*.

Finally, the optimal concentration for *B. bassiana* formulations, particularly when derived from local strains adapted to regional conditions, ranges between 1×10^7 and 1×10^8 conidia per milliliter.

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