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Ecotoxicological effect of agrochemicals on Calligrapha bicolorata Pallister

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SUMMARY

In this article, we will discuss the ecotoxicological effects of agrochemicals on *Calligrapha bicolorata* formerly known as *Zygogramma bicolorata*, a biocontrol agent for *Parthenium hysterophorus*. While agrochemicals enhance crop productivity, less than 1% reaches to targets, causing deleterious impacts on non-target species. It has been reported that exposure to herbicides and insecticides, including glyphosate, 2,4-D, neonicotinoids, and diamides reduce survival, delays development, and impairs reproduction in Z. *bicolorata*, compromising its weed-control efficacy. Long-term use of pesticide have deleterious on environments, threatens ecological balance and may further increases chemical dependence. The findings highlight the need for integrated weed management strategies that ensure selective agrochemical use and timing to protect beneficial arthropods while maintaining sustainable weed control.

INTRODUCTION

Calligrapha (formerly known as *Zygogramm*a) *bicolorata* Pallister (Coleoptera: Chrysomelidae) is a leaf-feeding beetle native to North America, particularly Mexico and the southern United States, where it naturally occurs on *Parthenium hysterophorus* and related species. Because of its high host specificity and strong defoliating ability, it was selected as a classical biological control agent against *P. hysterophorus*, one of the most problematic invasive weeds in India (Dhileepan, 2001). Following extensive host-range testing under quarantine conditions, the beetle was introduced into India in 1984 from Mexico through the Commonwealth Institute of Biological Control in collaboration with ICAR. Initial cultures were established at the Directorate of Biological Control, Bengaluru, and field releases began during 1985–1986 in southern India (Jayanth, 1987). The beetle established successfully and spread across diverse agro-climatic regions through natural dispersal and intentional redistribution (Jayanth & Bali, 1994). Both larvae and adults feed voraciously on leaves, tender stems, and inflorescences of *Parthenium*. Heavy infestations can cause 60–90% defoliation of plants and reduce flowering and seed production by 70–95%, significantly lowering the soil seed bank over successive seasons (Jayanth & Bali, 1994; Dhileepan, 2001). In several parts of central and southern India, seasonal population outbreaks of the beetle have resulted in large-scale natural suppression of *Parthenium* stands (Dhileepan, 2001).

The beetle completes multiple generations annually depending on temperature and host availability. Eggs are laid in clusters on the underside of leaves, larvae pass through four instars and pupate in the soil. Development is optimal at 25–30 °C, and population build-up generally coincides with the monsoon season when *Parthenium* growth is luxuriant (Jayanth & Bali, 1994). During adverse conditions, adults enter diapause in soil or plant debris, enabling survival across dry or cold periods and facilitating re-establishment in subsequent seasons. Because of its strict host specificity, adaptability, and strong defoliation capacity, *C. bicolorata* is regarded as one of the most successful classical weed biological control agents released in India. However, its performance can fluctuate due to climatic factors, host phenology, and exposure to agrochemicals, highlighting the need for compatibility with integrated weed management strategies (Dhileepan, 2001).

Studies indicate that less than 1% of pesticides applied in fields effectively reach their intended targets, while the vast majority disperses into surrounding soil, water, and air. This off-target contamination poses significant risks to human health and exerts lethal and sublethal effects on non-target species within agroecosystems, contributing to global biodiversity loss (Elhamalawy et al., 2024; Wan et al., 2025), although the use of agrochemicals in modern agriculture has significantly improved crop productivity but beneficial insects, including key natural enemies used in biological control programs, are frequently exposed to insecticides and herbicides, which may also disrupt ecological processes (Samanta et al., 2023., Gruss et al., 2025). In agroecosystems where *Parthenium* is prevalent, *C. bicolorata* is frequently exposed to agrochemicals, including herbicides and insecticides. Such compounds may induce both lethal and sublethal effects, altering survival, development, fecundity, and feeding activity, thereby diminishing the beetle's biological control performance (Singh et al., 2024). Therefore, understanding the ecotoxicological effects of agrochemicals on *C. bicolorata* is essential for developing compatible and environmentally sustainable weed-management strategies.

Impact of herbicides & insecticides on biology of the beetle

Several studies have demonstrated the there is array of harmful effects of herbicides and pesticides reported on *C. bicolorata* (Hasan & Ansari, 2016, Hasan & Ansari, 2017, Hasan *et al*., 2020, Aryan *et al*., 2023, Singh *et al*., 2024). Ecotoxic effects of commonly used herbicides are i.e. glyphosate, atrazine, metribuzin, alachlor, 2,4-D, pendimethalin and insecticides. i.e. neonicotinoids & diamides were evaluated on the biological and demographic parameters of the beetle in laboratory. Herbicidal treatment of glyphosate considerably affected larval development of *Z. bicolorata*. (Aryan *et al*., 2023) whereas indirect exposure experiments showed that glyphosate induced the highest mortality in 3rd instar larvae and delayed developmental transitions, including pre-pupation and pupation stages. Additionally, it significantly impacted sex ratio, fecundity, egg viability, and other fitness parameters. Hasan & Ansari, 2016 reported that in direct toxicity trials of 2,4-D & alachlor caused the highest mortality and delayed development in 3rd instar larvae. In a comparative study it was found that glyphosate exhibited mild toxicity, while 2,4-D was highly toxic to *Z. bicolorata*. The 2,4-D-treated group showed significantly reduced daily fecundity, net reproductive rate, intrinsic rate of increase, and finite rate of increase. Singh *et al*., 2024 documented that pendimethalin adversely affected several life parameters of *Z. bicolorata*, including 20.98% decrease in fecundity, 18.36% reduction in egg viability, and a decline in both female and male lifespans by approximately 11.18% and 13.80%, respectively. Pendimethalin further impaired the gut antioxidant defense system of *Z. bicolorata*, inducing oxidative stress that may compromise gut integrity and interfere with normal physiological functions. At the molecular scale, evidence of DNA damage in the midgut tissues of the beetle has also been reported.

From the experiments found that imidacloprid induced the highest mortality among treated adult beetles, whereas mortality was lowest under flubendiamide exposure, followed by cyantraniliprole and chlorantraniliprole (Hasan *et al*., 2020). Based on toxicity coefficient values, all tested insecticides were categorized as harmful, while diamide compounds were classified as moderately harmful for *C. bicolorata* according to IOBC standards. Hasan and Ansari (2017) evaluated both acute and sublethal impacts of six widely used insecticides on the biological traits and life table parameters of *Z. bicolorata*. Monocrotophos and imidacloprid caused the highest mortality in third-instar larvae and significantly prolonged the development of subsequent immature stages. Although none of the evaluated insecticides could be considered safe, malathion exhibited comparatively lower toxicity among the treatments.

Long-term ecological consequences

The indiscriminate application of agrochemicals poses significant long-term ecological risks to C. *bicolorata* and to the agroecosystems in which it serves as a biological control agent. Prolonged exposure to insecticides and herbicides may lead to a gradual decline in beetle populations through reduced survival, compromised reproductive capacity, and disrupted developmental processes across successive generations. Such declines undermine the beetle's effectiveness on *Parthenium hysterophorus*, facilitating the weed's resurgence and enhanced spread in chemically managed landscapes. Over time, the loss or reduction of *C bicolorata* can disturb ecological balance by breaking the natural weed–herbivore relationship that keeps parthenium populations in check. This may increase reliance on chemical weed control, creating a cycle of higher agrochemical inputs and further harm to non-target organisms. Therefore, the long-term ecological impact of agrochemicals extends beyond immediate toxicity, threatening the sustainability of biological weed management programs as well soil health, pollination.

Compatibility issues in integrated weed management

Integrated weed management (IWM) seeks to achieve sustainable weed suppression while minimizing adverse environmental impacts by integrating chemical, biological, and cultural control strategies. However, compatibility challenges arise when agrochemicals are applied in fields where biological control agents, such as *Zygogramma bicolorata*, a key regulator of *Parthenium hysterophorus* populations, are present (Jayanth & Bali, 1993). Non-selective herbicides and pesticides, or applications made at inappropriate times, may inadvertently harm this beneficial beetle, thereby reducing the effectiveness of biological control within integrated management systems.Improving compatibility between chemical and biological control requires the careful selection of selective or low-risk agrochemicals, optimization of application timing, and avoidance of chemical treatments during periods of peak beetle activity. When chemical interventions are strategically coordinated with biological control efforts, IWM can provide long-term and effective weed suppression while conserving beneficial arthropods. Therefore, understanding and managing these interactions is essential to ensure that integrated weed management remains both effective and ecologically sustainable.

CONCLUSION

Although the extensive application of agrochemicals has substantially enhanced agricultural productivity, it has also led to considerable off-target contamination with adverse consequences for ecosystems and biodiversity. In this context, the introduced biological control agent of *Parthenium hysterophorus*, the leaf-feeding beetle *Zygogramma bicolorata*, is particularly vulnerable to both lethal and sublethal impacts of widely used herbicides (e.g., glyphosate and 2,4-D) and insecticides, including neonicotinoids and diamides. Exposure to these compounds disrupts key life-history traits such as development, fecundity, and survival, thereby compromising the beetle's effectiveness in suppressing the invasive weed. Over the long term, such negative interactions threaten the viability of sustainable weed management programs that depend on this natural enemy. Consequently, the successful implementation of Integrated Weed Management (IWM) requires the judicious selection and precise timing of agrochemical applications to protect beneficial arthropods like *Z. bicolorata* while maintaining effective weed control.

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