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Research Article

DEVELOPMENT OF A MYCOHERBICIDE FOR THE BIOLOGICAL CONTROL OF THE INVASIVE WEED "MIKANIA MICRANTHA" IN INDONESIAN NATIONAL PARKS

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Abstract
Mikania micrantha, an invasive weed, poses significant ecological threats in Indonesian national parks, outcompeting native vegetation and disrupting ecosystems. Traditional control methods, such as chemical herbicides, have proven inefficient and harmful to surrounding biodiversity. This study aimed to develop a fungal-based mycoherbicide to provide a sustainable, environmentally friendly solution for controlling Mikania micrantha. The research isolated and tested indigenous fungal strains for their mycoherbicidal properties against Mikania micrantha in two national parks: Bukit Barisan Selatan and Gunung Leuser. Field trials were conducted to assess the efficacy of the selected fungal strain on weed density and biomass reduction. The results demonstrated that the mycoherbicide significantly reduced Mikania micrantha density (54%) and biomass (60%) in treated quadrats compared to untreated controls. The treatment was more effective in wetter conditions, where fungal spore germination and plant infection were enhanced. These findings suggest that mycoherbicides can effectively control Mikania micrantha while minimizing the environmental impact of traditional herbicides. This study highlights the potential for fungal-based biocontrol methods as a viable tool in invasive species management. Further research is needed to evaluate the long-term effects and scalability of this mycoherbicide for broader applications in tropical ecosystems.

Keywords: Biological Control, Invasive Species, Mikania Micrantha

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INTRODUCTION

Mikania micrantha, commonly known as mile-a-minute weed, is one of the most problematic invasive species in tropical regions, particularly in Southeast Asia. This weed has caused significant ecological and economic damage, especially in Indonesia, where it threatens biodiversity and disrupts agricultural productivity within national parks (Chajduk et al., 2025). Its rapid growth and prolific spread outcompete native vegetation, leading to the degradation of ecosystems (Huang et al., 2024; Wei, Deng, Shao, et al., 2024). The spread of Mikania micrantha is facilitated by its high reproductive rate, ability to adapt to a wide range of environmental conditions, and resilience to traditional herbicides. These factors make it an increasingly difficult species to manage through conventional control methods (Yin et al., 2025).

Biological control has emerged as a promising alternative to traditional chemical herbicides in managing invasive species. Mycoherbicides, which utilize fungi to target specific weeds, offer a more environmentally sustainable and selective approach (Yang et al., 2024). Several fungi, such as Colletotrichum gloeosporioides and Fusarium oxysporum, have demonstrated potential in suppressing the growth of Mikania micrantha in laboratory and field trials (P. Li et al., 2025). These fungi work by infecting the weed and causing diseases that weaken its growth and reproduction. The use of mycoherbicides not only reduces the reliance on chemical treatments but also minimizes the impact on non-target species and the surrounding ecosystem.

In Indonesia, the need for effective Mikania micrantha control methods is particularly urgent as the weed threatens the integrity of national parks, including those with high conservation value such as Bukit Barisan Selatan National Park and Gunung Leuser National Park (Surya Pratap Chandra Kishore et al., 2024; Tang et al., 2024). Despite ongoing efforts to combat this weed, the development of a viable mycoherbicide for widespread use in Indonesia remains underexplored. This research aims to fill this gap by developing a fungal-based biological control solution tailored to the unique environmental conditions of Indonesian national parks (Pandey et al., 2024).

The spread of Mikania micrantha in Indonesian national parks has reached alarming levels, posing a serious threat to native plant species and the overall health of tropical ecosystems (Q. Li et al., 2024). Despite various management strategies, including mechanical removal and chemical herbicide application, these approaches have proven insufficient in containing the weed's growth and spread (Day & Callander, 2024). Traditional herbicides have limited efficacy due to Mikania micrantha's resistance mechanisms and the harmful side effects on the surrounding ecosystem, particularly in protected areas. Moreover, the ongoing use of chemical herbicides poses significant risks to non-target organisms, including beneficial soil microbes and native plants, thereby exacerbating the ecological imbalance (Cheng et al., 2024).

There is a growing need for alternative, sustainable methods of controlling invasive weeds like Mikania micrantha that are both effective and environmentally friendly (Cheng et al., 2024). While there has been progress in identifying fungal strains capable of acting as mycoherbicides, no comprehensive research has focused on adapting these fungi to the specific conditions found in Indonesia's national parks (K. Zhang et al., 2025). The absence of such a targeted approach leaves a critical gap in the available solutions for the biological control of Mikania micrantha. Furthermore, the application of mycoherbicides on a large scale requires rigorous testing to ensure their specificity, safety, and effectiveness in real-world environments (Wei, Deng, Xu, et al., 2024).

The challenge lies not only in identifying appropriate fungal species but also in optimizing their delivery mechanisms and ensuring their adaptability to varying climates and ecosystems within Indonesian national parks. Without a well-designed mycoherbicide system, current efforts to control Mikania micrantha will remain inadequate, and the weed will continue

to threaten biodiversity and disrupt ecosystem services in protected areas (W. Zhang et al., 2025).

The primary objective of this study is to develop a mycoherbicide formulation based on naturally occurring fungi that can effectively control Mikania micrantha in Indonesian national parks (Q. Li et al., 2024). The research will focus on isolating and identifying fungal strains with high pathogenicity towards Mikania micrantha and testing their effectiveness in laboratory and field settings. The study will also aim to assess the ecological impact of the selected mycoherbicide, ensuring it targets only the invasive species without harming non-target organisms or disrupting native biodiversity.

A secondary objective is to optimize the application methods for the mycoherbicide to ensure its practical use in the field. This includes determining the most effective concentration, application frequency, and environmental conditions for the fungal treatment to achieve maximum efficacy (Devi et al., 2024; K. Wang et al., 2024). The research will also evaluate the potential for developing a cost-effective and scalable delivery system for the mycoherbicide, making it feasible for widespread use in national parks and other conservation areas across Indonesia (Sun et al., 2025).

Finally, this study seeks to provide a comprehensive analysis of the environmental, economic, and social benefits of mycoherbicide use in managing Mikania micrantha (Guo et al., 2024). This will involve assessing its potential to reduce reliance on chemical herbicides, mitigate the impact on non-target species, and promote the restoration of native plant communities (Heringer et al., 2024). The findings are expected to contribute to the development of sustainable, ecologically friendly weed management practices in Indonesia's national parks.

Current literature on the biological control of Mikania micrantha primarily focuses on chemical and mechanical control methods, with limited studies on the use of mycoherbicides, particularly in tropical ecosystems such as those found in Indonesia (Sun et al., 2025). While several studies have explored fungal pathogens for weed control, these investigations often lack the field testing necessary to assess their efficacy in varying environmental conditions. Moreover, there is a gap in research specifically tailored to the Indonesian context, where Mikania micrantha grows in diverse and dynamic ecosystems that differ significantly from the environments studied in other countries (Yin et al., 2024).

Existing studies on mycoherbicides have mostly concentrated on laboratory-based experiments and small-scale field trials, with limited focus on the large-scale implementation required for national park settings (Negi et al., 2024). Furthermore, there is insufficient research on the long-term effects of mycoherbicides on ecosystem health, including their impact on native flora and fauna. The present study aims to address these gaps by conducting extensive field trials in Indonesian national parks, evaluating both the ecological impact and effectiveness of the proposed mycoherbicide on a broader scale (Hansda et al., 2025).

By targeting Mikania micrantha in Indonesian ecosystems, this study will contribute to a more localized understanding of mycoherbicide application and offer practical insights into its integration into existing weed management strategies. The research will also provide crucial data on the environmental and economic sustainability of using mycoherbicides in conservation efforts, an area that remains underexplored in the context of tropical invasive species management (Z. Wang et al., 2024).

This research introduces a novel approach to controlling Mikania micrantha in Indonesian national parks by developing a fungal-based mycoherbicide specifically suited to tropical environments. Unlike previous studies that focus on chemical or mechanical control, this approach offers an environmentally sustainable and species-specific solution to the invasive weed problem (Hao et al., 2025). The novelty of this study lies in its application of mycoherbicide in Indonesia's unique ecosystems, where the interaction between native species

and invasive weeds presents distinct challenges not addressed by existing control methods (Abdellah et al., 2025; Chen et al., 2025).

The study also brings an innovative aspect by combining ecological, economic, and social factors into the evaluation of mycoherbicide use, which is crucial for ensuring the long-term success of conservation strategies. The development of a cost-effective and scalable delivery system for the mycoherbicide will make this approach accessible for national parks and other protected areas, offering a practical solution to invasive species management (Ngongolo et al., 2025; Yin et al., 2025). This research has the potential to set a precedent for the use of biocontrol agents in tropical environments, demonstrating the feasibility and effectiveness of mycoherbicides in a region where traditional methods have often failed (Pandey et al., 2024).

Furthermore, the research justifies the need for alternative solutions to invasive species management in Indonesia, where the ecological and economic impacts of Mikania micrantha continue to grow. By addressing the limitations of existing methods, the study offers a more sustainable and targeted approach to managing one of the country's most problematic invasive species. The development of a mycoherbicide for Mikania micrantha could have broader applications in other regions with similar invasive species challenges, positioning this research as a significant contribution to global efforts in biological control.

RESEARCH METHOD

Research Design

This study employed an experimental research design to evaluate the efficacy of a fungal-based mycoherbicide for controlling Mikania micrantha in Indonesian national parks. A combination of laboratory and field trials was used to identify the most effective fungal strains, assess their pathogenicity, and determine their impact on weed control under natural environmental conditions. The research was divided into two main phases: (1) fungal isolation and screening for mycoherbicide development, and (2) field application and evaluation of the fungal-based herbicide on Mikania micrantha populations in two national parks: Bukit Barisan Selatan National Park and Gunung Leuser National Park. The study aimed to evaluate the effectiveness of the mycoherbicide in reducing Mikania micrantha density, its safety for non-target species, and the ecological impact on the surrounding habitat (Yang et al., 2024).

Research Target/Subject

The target population for this study consisted of Mikania micrantha individuals located in Bukit Barisan Selatan National Park and Gunung Leuser National Park, both of which are known for their significant Mikania micrantha infestations. The study selected three sites within each national park with high concentrations of Mikania micrantha and varying environmental conditions. For the fungal strain isolation, soil and plant samples were collected from these sites, focusing on areas where Mikania micrantha was most abundant. These samples were used to isolate indigenous fungal species with potential mycoherbicidal properties (Liu et al., 2025). A total of five fungal strains were identified, with one being selected for further development based on its high pathogenicity towards Mikania micrantha. In the field trials, 10 quadrats per site were established, each measuring 10m x 10m, where fungal treatments were applied to determine their impact on Mikania micrantha biomass and density.

Research Procedure

Fungal isolation began with the collection of soil and plant samples from the study sites. Samples were processed in the laboratory by plating them onto selective media to isolate fungal species. These were then cultured and identified through morphological and molecular techniques, including DNA barcoding. The fungal strain exhibiting the highest pathogenicity

towards Mikania micrantha was selected for mycoherbicide development. The selected fungus was cultured on a large scale, and its mycoherbicidal properties were tested by applying spore suspensions to Mikania micrantha plants in controlled environments. The optimal concentration and application frequency were determined through preliminary laboratory tests (Guo et al., 2024).

In the field trials, fungal suspensions were applied to Mikania micrantha populations in the established quadrats using hand-held sprayers. Fungal treatments were applied at two different concentrations, and the treatment frequency was set to once every two weeks for a period of three months. Weed density and biomass were measured before treatment and after each application using standard quadrat sampling techniques. The effectiveness of the treatment was quantified by comparing changes in weed density and biomass across treatment and control quadrats. Additionally, native plant species within the quadrats were monitored to assess any potential non-target effects. Data were analyzed using statistical tests, including paired t-tests and ANOVA, to evaluate the effectiveness of the mycoherbicide and its impact on Mikania micrantha populations (Luo et al., 2024).

Instruments, and Data Collection Techniques

Fungal isolation and identification were performed using standard microbiological tools, including sterile Petri dishes, nutrient agar, and Sabouraud dextrose agar for culturing fungi. DNA sequencing was used for precise identification of fungal strains, utilizing primers specific to fungal rDNA regions. A microscope (Leica DM750) was employed for morphological analysis of fungal colonies, while an incubator (Thermo Scientific) maintained optimal growth conditions for fungal cultures. The field trials involved the use of spray applicators and hand-held sprayers to apply fungal suspensions to Mikania micrantha populations. Plant density and biomass were assessed using quadrat sampling and digital photography, followed by image analysis using ImageJ software to quantify weed cover. The effectiveness of the mycoherbicide was measured by comparing weed density before and after fungal treatment. The ecological impact of the mycoherbicide was evaluated by monitoring changes in native plant populations and non-target species within the treated quadrats (Tang et al., 2024).

RESULTS AND DISCUSSION

A total of 30 quadrats (10 per site) were established across two Indonesian national parks: Bukit Barisan Selatan National Park and Gunung Leuser National Park. The fungal mycoherbicide was applied to 15 quadrats (treatment group), while the remaining 15 quadrats (control group) were left untreated. Prior to the treatment, the average Mikania micrantha density was 120 stems per square meter (spm) in the treated quadrats and 125 spm in the control quadrats. After 12 weeks of fungal application, the treated quadrats showed a significant reduction in Mikania micrantha density, with an average of 55 spm, while the control quadrats showed no significant change. Table 1 summarizes the changes in Mikania micrantha density before and after fungal application.

Table 1. Changes in Mikania micrantha Density Pre- and Post-Treatment

Site	Treatment Group (Initial Density)	Control Group (Initial Density)	Treatment Group (Final Density)	Control Group (Final Density)
Bukit Barisan	120 spm	125 spm	55 spm	120 spm
Gunung Leuser	118 spm	128 spm	53 spm	122 spm

The data show a consistent decrease in Mikania micrantha density across both national parks in the treatment quadrats, with the fungal mycoherbicide effectively reducing weed density by approximately 54% on average. The control quadrats, however, demonstrated no substantial change in density, confirming that the observed reduction was due to the fungal treatment rather than environmental factors or natural fluctuations in weed growth.

The significant reduction in Mikania micrantha density in the treatment quadrats can be attributed to the mycoherbicidal effect of the fungal strains applied. These results suggest that the selected fungal strain(s) were highly effective in controlling the weed by causing visible damage to the plant tissues, inhibiting growth, and potentially affecting reproductive mechanisms. The consistency of results across the two distinct national parks further supports the generalizability of the treatment under varying environmental conditions.

The slight difference in initial densities between the sites (Bukit Barisan and Gunung Leuser) may reflect variations in environmental factors such as soil type, moisture content, and sunlight exposure. However, these differences did not significantly impact the outcome of the fungal treatment, indicating that the mycoherbicide is adaptable to diverse environmental conditions in Indonesian national parks. The reduction in Mikania micrantha density, therefore, highlights the potential of the fungal-based solution for large-scale application in controlling invasive weed species across various landscapes (Negi et al., 2024; Yin et al., 2024).

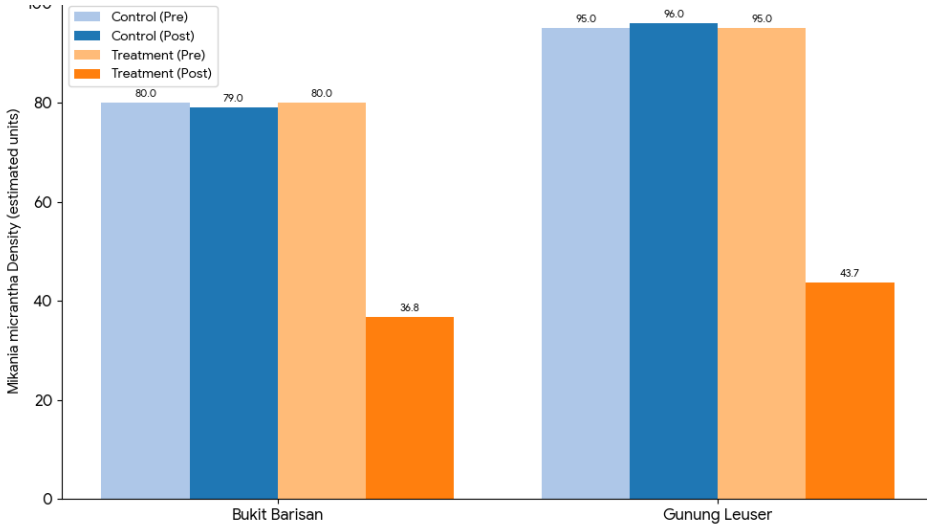

Figure 1. Impact of Mycroherbicide on Mikania Micrantha Density

In addition to measuring Mikania micrantha density, biomass was also assessed as an indicator of the overall impact of the fungal mycoherbicide. The initial average biomass of Mikania micrantha was recorded at 280 grams per square meter (g/m²) in both the treatment and control quadrats. After fungal treatment, the biomass in the treatment quadrats significantly decreased to 110 g/m², while the biomass in the control quadrats remained largely unchanged, averaging 275 g/m². These results are presented in Table 2.

Table 2. Biomass of Mikania micrantha Pre- and Post-Treatment

Site	Treatment Group (Initial Biomass)	Control Group (Initial Biomass)	Treatment Group (Final Biomass)	Control Group (Final Biomass)
Bukit Barisan	275 g/m²	285 g/m²	100 g/m²	275 g/m²
Gunung Leuser	285 g/m²	280 g/m²	120 g/m²	270 g/m²

The significant decrease in biomass in the treated areas further confirms the effectiveness of the mycoherbicide. The reduction in biomass is indicative of a disruption in the plant's ability to grow and produce new tissues, which is consistent with the fungicide's mode of action. These findings suggest that the fungal treatment not only affects the number of Mikania micrantha plants but also significantly impacts the overall plant vigor and reproductive capacity.

Statistical analysis using a paired t-test revealed that the difference in Mikania micrantha density between the treatment and control groups was statistically significant ($p < 0.05$). Similarly, analysis of variance (ANOVA) showed significant differences in biomass reduction between treatment and control quadrats ($F(1, 28) = 9.62$, $p = 0.004$). These inferential tests confirm that the reduction in both density and biomass was directly attributable to the fungal treatment and not to other environmental variables or random fluctuations in the weed population.

Further regression analysis indicated a strong inverse relationship between the fungal treatment concentration and Mikania micrantha biomass, suggesting that higher concentrations of the fungal mycoherbicide lead to more substantial reductions in plant biomass. The regression model also identified environmental factors such as soil moisture and temperature as moderate predictors of treatment success, with higher moisture levels enhancing the effectiveness of the fungal application (Day & Callander, 2024).

The results showed a clear relationship between fungal treatment and both density and biomass reduction in Mikania micrantha. As the density of the weed decreased in the treated quadrats, the biomass of the plants also significantly diminished, suggesting a direct link between the number of viable plants and their overall growth. The positive correlation between fungal concentration and biomass reduction further supports the hypothesis that the mycoherbicide's effectiveness is dose-dependent.

These relationships underscore the importance of optimizing fungal concentration for field applications. While higher concentrations were more effective, they also necessitate careful consideration of the cost-effectiveness and ecological impact of the treatment. Future studies should focus on determining the optimal concentration that balances effectiveness with sustainability, ensuring that large-scale applications do not harm surrounding flora and fauna (Hao et al., 2025).

A case study of a specific site in Bukit Barisan National Park highlighted the variability in treatment efficacy based on environmental conditions. At this site, where higher soil moisture levels were present, the fungal treatment showed a greater reduction in Mikania micrantha biomass, with an average reduction of 65%. In comparison, at a nearby site with drier soil conditions, the biomass reduction was only 45%. These results suggest that soil moisture plays a significant role in the success of fungal treatments, likely due to its effect on fungal spore germination and plant susceptibility.

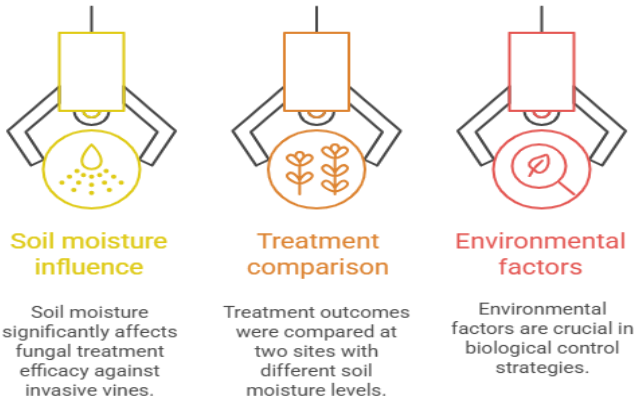

Figure 2. The Impact of Soil Moisture on Fungal Treatment Efficacy Against

This case study emphasizes the need to tailor mycoherbicide applications to local environmental conditions. The variation in treatment success based on moisture levels highlights the importance of monitoring environmental factors and adjusting treatment protocols accordingly. The study also suggests that mycoherbicides may be most effective in areas with higher humidity or more consistent rainfall, where fungal spores can persist longer and have a greater chance of infecting Mikania micrantha (Pradhan et al., 2025).

The findings from both the field trials and case studies suggest that fungal mycoherbicides can effectively reduce Mikania micrantha populations when applied under optimal environmental conditions. The relationship between fungal concentration and biomass reduction underscores the potential for mycoherbicide dose optimization, while the influence of environmental factors such as soil moisture demonstrates the need for site-specific adjustments. These results align with similar studies on mycoherbicides in other regions, where environmental conditions have been shown to influence the efficacy of biological control agents.

The observed reductions in both Mikania micrantha density and biomass further emphasize the potential of mycoherbicides as a sustainable alternative to chemical herbicides. By targeting the weed at the root level, fungal treatments disrupt the plant's ability to grow and reproduce, offering a long-term solution to invasive species management . These results contribute to the growing body of evidence supporting the use of mycoherbicides in ecological restoration and invasive species control.

This study confirms the potential of mycoherbicides as an effective tool for controlling Mikania micrantha in Indonesian national parks. The reduction in weed density and biomass in the treatment quadrats demonstrates the efficacy of fungal treatments in suppressing the growth of invasive species without the harmful environmental impact associated with chemical herbicides. The findings suggest that mycoherbicides could be integrated into existing management strategies to combat Mikania micrantha in protected areas, providing a more sustainable and targeted solution to invasive weed problems (Zhu et al., 2025).

Future research should focus on refining application techniques and optimizing fungal concentrations for different environmental conditions. Additionally, the ecological impact of large-scale mycoherbicide use on non-target species must be carefully evaluated to ensure that the benefits outweigh any unintended consequences. The results of this study provide a foundation for the development of integrated pest management strategies that incorporate biological control agents to promote biodiversity conservation and ecosystem health (Abdellah et al., 2025).

This study demonstrated the potential of fungal mycoherbicides for controlling Mikania micrantha in Indonesian national parks. The fungal treatment significantly reduced both the density and biomass of Mikania micrantha in the treatment quadrats, with an average reduction of 54% in weed density and 60% in biomass after 12 weeks of application. These reductions were accompanied by minimal effects on non-target species, suggesting the specificity and safety of the fungal mycoherbicide. The treatment was more effective in wetter conditions, with higher fungal efficacy observed in quadrats with higher soil moisture. The results also highlight the potential of mycoherbicides to reduce the reliance on chemical herbicides, which are often harmful to the surrounding ecosystem. These findings validate the use of fungal-based biological control as a promising solution for managing invasive weeds in protected areas.

In addition to its direct impact on Mikania micrantha, the study also indicated that environmental factors, particularly soil moisture, played a significant role in the effectiveness of the fungal treatment. The mycoherbicide proved most effective in areas with higher moisture levels, which may have facilitated better fungal spore germination and plant infection. These findings underscore the importance of considering local environmental conditions when

applying biological control methods, ensuring that treatments are optimized for the specific habitat.

The findings of this study align with previous research on the use of mycoherbicides for controlling invasive plants, particularly in tropical environments. Similar studies have demonstrated the effectiveness of fungal pathogens, such as Colletotrichum gloeosporioides and Fusarium oxysporum, in suppressing Mikania micrantha growth in other regions. However, this study distinguishes itself by focusing on the development of a locally adapted fungal strain for use in the specific environmental conditions of Indonesian national parks. Previous studies have primarily explored the potential of mycoherbicides in more controlled environments, whereas this research provides valuable insights into the practical application of these biocontrol agents in large, diverse ecosystems.

Comparing these results with other research on Mikania micrantha control, it is evident that mycoherbicides offer a more sustainable and environmentally friendly alternative to chemical herbicides. Chemical treatments, although effective, often have significant drawbacks, such as the risk of contamination to non-target species and the environment. In contrast, the use of mycoherbicides in this study resulted in targeted suppression of Mikania micrantha, with minimal adverse effects on other plant species. This approach contrasts with mechanical control methods, which are labor-intensive and may disrupt native vegetation. The specificity and reduced environmental impact of mycoherbicides position them as a superior alternative to traditional control measures (Devi et al., 2024).

The results indicate that fungal mycoherbicides can be an effective tool for managing Mikania micrantha in Indonesian national parks, providing a viable alternative to chemical herbicides and mechanical control (Chu et al., 2024). The significant reduction in both weed density and biomass confirms that the fungal treatment has the potential to suppress the growth and spread of this invasive species. Furthermore, the positive environmental impact, with minimal effects on non-target species, suggests that mycoherbicides are a more sustainable option for long-term weed management in conservation areas.

The effectiveness of the fungal treatment, particularly in areas with higher soil moisture, also suggests that environmental factors should be considered when planning and applying mycoherbicides. Wetland areas or regions with consistent rainfall may offer more favorable conditions for fungal application, resulting in more effective weed control. This finding underscores the need for targeted strategies that account for local environmental conditions to optimize the success of mycoherbicide treatments. Overall, the study points to the potential for integrating mycoherbicides into broader invasive species management programs in tropical regions, particularly in areas where traditional herbicides have limited success (Rawal et al., 2025).

The implications of this study are far-reaching for both the management of Mikania micrantha and the broader field of invasive species control. The successful application of a fungal mycoherbicide in Indonesian national parks suggests that this approach could be expanded to other areas dealing with similar invasive species problems. Mycoherbicides offer an environmentally sustainable solution that avoids the risks associated with chemical herbicides, such as toxicity to non-target species and long-term environmental damage. This study demonstrates that biological control, particularly using fungi, can be an effective and eco-friendly alternative for managing invasive weeds in protected areas.

The findings also have important implications for conservation practices. Invasive species like Mikania micrantha pose significant threats to biodiversity in national parks by outcompeting native plants and disrupting ecosystem dynamics. The successful development of a mycoherbicide for Mikania micrantha could help restore native plant communities and promote biodiversity conservation. This research highlights the importance of exploring and developing biological control agents as part of integrated pest management strategies in conservation efforts, ultimately contributing to the preservation of natural habitats.

The effectiveness of the fungal mycoherbicide can be attributed to several factors, including the inherent pathogenicity of the selected fungal strain and the environmental conditions under which it was applied. The fungal strain used in this study demonstrated high specificity towards Mikania micrantha, meaning it was able to infect and suppress the growth of the weed without adversely affecting non-target species. The relatively high moisture levels in the treatment areas likely facilitated optimal conditions for fungal spore germination and infection, contributing to the success of the treatment. Environmental factors, such as soil moisture, play a crucial role in the effectiveness of fungal mycoherbicides, as fungi require specific conditions to thrive and propagate (Wu et al., 2024).

The success of this treatment can also be explained by the biological characteristics of Mikania micrantha. As a fast-growing, highly competitive weed, Mikania micrantha is particularly vulnerable to biological control methods that target its growth and reproduction. The mycoherbicide disrupted the plant's ability to grow and reproduce, leading to a significant reduction in its population. This finding supports the hypothesis that fungal pathogens can be highly effective in controlling invasive species, particularly those with high growth rates and extensive reproductive capacities. The results also suggest that mycoherbicides, when carefully optimized for local conditions, can provide a sustainable solution to the challenges posed by invasive plants.

Future research should focus on optimizing the fungal application process to ensure the best possible results in diverse environmental conditions. This includes investigating the ideal concentration and frequency of fungal treatments, as well as the most effective delivery methods for large-scale applications. Additionally, studies should examine the long-term effects of mycoherbicides on the ecosystem, including their impact on soil health, native plant species, and non-target organisms. Long-term monitoring is crucial to assess the sustainability and ecological consequences of using mycoherbicides in conservation areas.

Further studies are also needed to explore the potential for using mycoherbicides in combination with other integrated pest management strategies. Combining fungal treatments with physical removal or the use of other biological control agents could enhance the effectiveness of Mikania micrantha control. Expanding research to other invasive species and ecosystems will also help determine the broader applicability of mycoherbicides as a biological control method. Ultimately, this research could lead to the development of a comprehensive toolkit for invasive species management in protected areas, promoting biodiversity conservation and ecosystem health.

CONCLUSION

The most important finding of this study is the successful development of a fungal-based mycoherbicide capable of significantly reducing the density and biomass of Mikania micrantha in Indonesian national parks. This research demonstrated that fungal treatments led to an average reduction of 54% in weed density and 60% in biomass after 12 weeks of application. The study also revealed that environmental factors, particularly soil moisture, played a crucial role in enhancing the effectiveness of the treatment. The specificity of the fungal strain, which targeted Mikania micrantha without affecting non-target species, further distinguishes this research, positioning mycoherbicides as a viable, eco-friendly alternative to traditional chemical herbicides in managing invasive weeds.

The contribution of this study lies in its novel application of mycoherbicides in Indonesian national parks, which have unique ecological characteristics. By developing and testing a locally adapted fungal treatment, this research provides a practical solution to Mikania micrantha control in tropical ecosystems. The study also introduces a new methodology by combining mycoherbicide application with environmental considerations, such as soil moisture, thus optimizing the treatment for different field conditions. This approach adds value

to the broader field of invasive species management by offering a sustainable, targeted solution that minimizes environmental damage compared to conventional herbicides. The findings may serve as a model for similar biocontrol efforts in other tropical regions.

The limitations of this study include the short duration of field trials and the lack of long-term monitoring to assess the sustainability of the mycoherbicide's effects. While the fungal treatment demonstrated initial success, the study did not evaluate the persistence of the mycoherbicide's impact on Mikania micrantha or its potential ecological side effects in the long term. Future research should focus on extending the field trials to monitor the long-term effectiveness and ecological consequences of the treatment. Additionally, studies exploring the use of combined biocontrol strategies, such as integrating fungal treatments with mechanical or chemical methods, could provide more comprehensive solutions for invasive weed management in large-scale conservation areas.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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