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Ecological contribution of local *Beauveria bassiana* isolate to pest regulation and rice yield in tropical agroecosystems

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Abstract. *Uluputty MR, Leiwakabessy C, Goo N, Talahaturuson A, Umasangaji A. 2026. Ecological contribution of local* Beauveria bassiana *isolate to pest regulation and rice yield in tropical agroecosystems. Biodiversitas 27 (5): d270521. https://doi.org/10.13057/biodiv/d270521.* The brown planthopper (*Nilaparvata lugens*) is a major pest in rice agroecosystems, causing significant yield losses. This study evaluated the effectiveness of a local *Beauveria bassiana* isolate in controlling planthopper populations and its potential implications for agroecosystem management under field conditions. The experiment was conducted in an organically managed rice field in Ambon, Indonesia, using a randomized block design with five treatments and five replications. Observations included apparent mortality, population density, attack intensity, and rice yield. The results showed that the application of *B. bassiana* increased apparent mortality from 15.2% in the control to 73.8-78.5% in treated plots, reduced population density from 139.1 to 30.4-42.6 individuals per plot, and decreased attack intensity from 60.3% to 5.3-6.1%. Rice productivity also increased from 4.52 t ha^{-1} in the control to 5.84-6.12 t ha^{-1} following fungal application. However, mortality was assessed as apparent mortality based on population reduction, and no direct confirmation of fungal infection or environmental variables was conducted. These findings suggest that locally adapted entomopathogenic fungi can contribute to pest regulation, support microbial biodiversity, enhance sustainable rice production, and strengthen ecologically based integrated pest management strategies in tropical agroecosystems under diverse environmental conditions.

Keywords: *Beauveria bassiana*, brown planthopper, entomopathogenic fungi, pest regulation, rice agroecosystem

INTRODUCTION

Rice farming plays a strategic role in maintaining Indonesia's national food security and represents a key component of tropical agroecosystems, where ecological interactions between crops, pests, and natural enemies determine overall system stability. As a primary source of carbohydrates, rice is widely cultivated across diverse environments, from irrigated lowlands to rain-fed systems. Successful rice production depends not only on cultivation practices and water availability, but also on effective pest management, particularly against the brown planthopper (*Nilaparvata lugens* (Stål, 1854)), one of the most destructive pests in rice ecosystems. This pest causes direct damage through sap feeding, resulting in hopperburn symptoms, and acts as a vector of viral diseases, leading to significant yield losses (Timmanagouda and Maheswaran 2017; Iamba and Dono 2021). In Indonesia, the development of resistance to insecticides such as imidacloprid has been well documented, further exacerbating its impact and highlighting the need for more sustainable pest management strategies (Diptaningsari et al. 2019).

Brown planthopper infestations can result in severe economic losses due to both direct feeding damage and indirect effects through virus transmission, such as grassy stunt and ragged stunt diseases (Ghobadifar et al. 2014; Listihani et al. 2022). These combined effects may lead to partial or complete crop failure under severe infestation conditions. Therefore, controlling planthopper populations is essential for maintaining crop productivity and supporting agroecosystem functioning.

Conventional control strategies rely heavily on synthetic insecticides due to their rapid effectiveness. However, the long-term use of chemical inputs has led to several ecological and environmental concerns, including the development of pest resistance, disruption of natural enemy populations, and environmental contamination (Mu et al. 2016; Diptaningsari et al. 2019). Such practices are not aligned with the principles of sustainable agriculture, which emphasize ecological resilience, environmental health, and long-term productivity (Iamba and Dono 2021; Sun et al. 2024). In this context, biological control approaches offer a more environmentally compatible alternative.

The entomopathogenic fungus *Beauveria bassiana* (Bals.-Criv.) Vuill. has been widely recognized as an effective biological control agent against various insect pests, including planthoppers. This fungus infects its host through direct penetration of the insect cuticle, followed by internal proliferation and eventual host death. Its advantages include a broad host range, adaptability to tropical environments, and relative safety for non-target organisms (Gangaram et al. 2019). Furthermore, *B. bassiana* can be produced locally at relatively low cost, making it suitable for application at the farmer level (Ghobadifar et al. 2014). Numerous studies have demonstrated its effectiveness against major agricultural pests such as stem borers, armyworms, and planthoppers (Shah and Pell 2003; Faria and Wraight 2007).

Despite its proven potential, most previous studies have utilized commercial strains or isolates originating from different ecological regions, which may not perform optimally under specific local environmental conditions (Bamisile et al. 2021). Local isolates of *B. bassiana*, which have naturally adapted to particular agroecological conditions, are likely to exhibit higher ecological fitness and stability in field applications (Mascarin and Jaronski 2016). In addition, many studies have focused primarily on single parameters, such as mortality or infection rates, without integrating broader indicators such as population dynamics, plant damage, and crop yield (Aggarwal et al. 2016).

Several studies have primarily focused on the efficacy of *B. bassiana* under controlled or semi-field conditions, often emphasizing mortality rates and laboratory-based performance (Faria and Wraight 2007; Zimmermann 2007). However, limited studies have examined its field-level performance in relation to multiple response variables, including population dynamics, plant damage, and crop productivity under tropical agroecosystem conditions. Therefore, this study addresses this gap by evaluating the field-based effectiveness of a locally sourced *B. bassiana* isolate across multiple ecological and agronomic indicators.

The use of locally adapted entomopathogenic fungi is also relevant from a biodiversity perspective, as it reflects the utilization of indigenous microbial resources that are naturally integrated within agroecosystem processes. The utilization of such locally adapted strains may enhance ecological fitness and persistence under field conditions while reducing dependence on synthetic insecticides that can negatively affect non-target organisms and broader agroecosystem functioning. This study aimed to evaluate the effectiveness of a local isolate of *B. bassiana* in controlling *N. lugens* under field conditions, based on its effects on mortality rate, population density, attack intensity, and crop yield, as well as to assess its potential contribution to pest regulation within rice agroecosystems.

MATERIALS AND METHODS

Fungal isolate and preparation

The primary material used in this study was a local isolate of *B. bassiana* obtained from the Agrotechnology Laboratory, Faculty of Agriculture, Universitas Pattimura, Indonesia. The isolate was identified based on morphological characteristics, including colony morphology and conidial structure. The isolate was cultured on Potato Dextrose Agar (PDA) medium for 10 days at 25±2°C to obtain conidia. Spore suspensions were prepared using 0.02% Tween 80 solution and quantified using a hemocytometer. The suspensions were then diluted into five concentrations: 0 (control), 1×10^6, 1×10^7, 1×10^8, and 1×10^9 spores/mL. Conidial viability (germination rate) was not assessed prior to application, which may influence infection efficiency under field conditions. The isolate was identified based on morphological characteristics following standard taxonomic keys.

Study site and crop management

The study was conducted in a rice field ecosystem managed under organic conditions using local rice varieties, representing a typical lowland rice agroecosystem. The study was conducted from May to August 2023 during the main cropping season at the experimental field of Universitas Pattimura, located in Ambon, Maluku, Indonesia. The experiment was carried out under organically managed conditions in a typical tropical lowland rice agroecosystem. The rice variety used in this study was Ciherang, a widely cultivated high-yielding variety in Indonesia.

The planting system followed a 2:1 legowo row arrangement with a spacing of 25 × 12.5 cm to facilitate treatment application and observation. Efforts were made to maintain relatively uniform conditions across experimental plots. Environmental variables, such as temperature, humidity, and rainfall, were also not systematically monitored during the study period. However, the experiment was conducted under typical field conditions during the main cropping season, where these factors naturally fluctuate within ranges suitable for rice cultivation and pest development.

Experimental design and treatment application

This study used a non-factorial Randomized Block Design (RBD) consisting of five treatments and five replications. Each experimental unit consisted of a 2 × 2 m plot, randomly assigned to the treatments. Before treatment application, all plots were observed to ensure relatively uniform initial conditions of planthopper populations. This was conducted through direct field observations by randomly selecting a fixed number of rice hills per plot (e.g., 10-20 hills), followed by visual counting of planthopper individuals on each hill. The observations were performed in the morning to minimize insect movement and ensure consistency across plots.

Beauveria bassiana suspensions were applied 30 days after planting (DAP) using a manual sprayer in the morning, with efforts made to ensure uniform coverage across all plots. Each treatment was evenly sprayed onto the leaf surface. Conidial viability was not assessed prior to application; therefore, the applied concentrations represent nominal spore counts rather than confirmed viable propagule densities. Observations were conducted at five time points: day 3, 7, 14, 21, and 28 after application to evaluate the temporal dynamics of treatment effects. Blocking was applied to account for potential field heterogeneity; however, the specific factors underlying block formation were not quantitatively assessed and should be interpreted as a source of experimental variability.

Observation parameters

Four main parameters were observed in this study: (i) Planthopper mortality (%): Mortality was assessed as apparent mortality based on reductions in population counts between observation periods, rather than confirmed fungal infection through re-isolation or microscopic examination; (ii) Population density (individuals per plot): The number of live planthoppers was counted in 10 randomly selected clumps per plot as an indicator of population dynamics; (iii) Attack intensity was assessed based on the percentage of leaf damage using a visual scoring approach. The scoring scale followed the Standard Evaluation System (SES) for rice developed by the International Rice Research Institute, where damage levels were classified based on the proportion of affected leaf area (IRRI 2013). All visual assessments were conducted by the same observer to maintain scoring consistency across plots. However, no formal blinding procedure was applied, and the assessment relied on visual estimation, which may introduce observer-related subjectivity; (iv) Rice productivity (tons/ha): Yield was measured based on the dry grain weight per plot and converted to tons per hectare. Rice was harvested at 105 days after planting (DAP), corresponding to the physiological maturity stage of the Ciherang variety. Environmental variables, such as temperature, humidity, and rainfall were not systematically recorded during the experiment, although these factors may influence fungal performance under field conditions.

Data analysis

The obtained data were analyzed using Analysis of Variance to determine the effect of *B. bassiana* dosage on each parameter. Further multiple comparisons were performed using Tukey's Honestly Significant Difference (HSD) test at the 5% significance level ($\alpha = 0.05$). All statistical analyses were conducted using SPSS version 26.0.

RESULTS AND DISCUSSION

Mortality

Mortality in this study was assessed as apparent mortality based on reductions in population counts rather than confirmed fungal infection through re-isolation. Therefore, the reported values represent apparent mortality and do not confirm infection at the individual level. Statistical analysis showed that *B. bassiana* application had a significant effect on brown planthopper mortality ($p<0.001$) (Table 1). Further analysis using Tukey's HSD test indicated significant differences among treatments ($p<0.05$). Higher doses of *B. bassiana* were generally associated with increased apparent mortality compared to the control, although differences among higher dose treatments were not always statistically significant.

The application of *B. bassiana* at different concentrations significantly increased the mortality of *N. lugens* compared with the control. Mortality increased from approximately 23-26% at day 3 to more than 84% at day 28 across all treated plots, whereas the control consistently exhibited low and stable mortality (<5%). Although higher spore concentrations were associated with a faster initial increase in apparent mortality, final mortality levels at day 28 were relatively similar across treated doses (Table 1).

This pattern suggests that while dosage influences the rate of response, exposure duration plays a key role in determining overall effectiveness. The rapid increase in mortality during the first two weeks, followed by a plateau, is consistent with previous studies demonstrating the effectiveness of *B. bassiana* in infecting insect hosts (Chakrabarti and Kumar 2008). In line with Meyling et al. (2018), the present results indicate that the interaction between spore concentration and exposure time is an important factor in determining infection success. This may reflect the presence of a biological efficacy threshold, beyond which increasing the dose does not result in proportional gains in control performance.

From a biological perspective, the marked increase in mortality during the early observation period may reflect the active infection phase of *B. bassiana*, as described in previous studies. During this phase, fungal spores are reported to penetrate the insect integument, proliferate within the host body, and produce metabolites that contribute to host mortality (Zhang et al. 2019a; Baek et al. 2022). The absence of a comparable increase in mortality in the control plots supports the role of treatment in influencing pest dynamics, although environmental and natural mortality factors cannot be entirely excluded. From an applied perspective, the comparable effectiveness of medium and high doses suggests that lower spore concentrations may be sufficient when adequate exposure time is ensured. This finding has practical implications for the development of cost-efficient and environmentally friendly pest management strategies. Overall, these results support the potential role of locally isolated *B. bassiana* as a biological control agent within sustainable and ecologically based Integrated Pest Management (IPM) programs in tropical agroecosystems. Therefore, mortality in this study should be interpreted as apparent mortality based on population reduction rather than confirmed fungal-induced death.

Population density of brown planthoppers (individuals per plot or specific area)

Statistical analysis showed that *B. bassiana* application had a significant effect on brown planthopper population density ($p<0.001$). Different doses resulted in varying levels of population suppression, indicating the effectiveness of *B. bassiana* as a biological control agent under field conditions. The application of *B. bassiana* significantly reduced the population density of *N. lugens* compared with the control (Table 2). At 28 days after application, population density decreased from 139.1±8.4 individuals per plot in the control to 30.4±3.8 individuals at the highest dose (1×10^9 spores mL^{-1}). All treatment doses (1×10^6 - 1×10^9 spores mL^{-1}) showed substantial reductions in population density relative to the control.

Population trends over time indicated a consistent decline in treated plots, whereas the control population increased. For example, population density decreased from approximately 120 individuals per plot at day 3 to around 30 individuals at day 28 in treated plots, while the control increased from approximately 113 to 139 individuals. These findings suggest that *B. bassiana* contributed to the suppression of planthopper populations under field conditions.

The decline in population density during the early observation period, followed by convergence at later stages, is consistent with previous studies reporting the effectiveness of *B. bassiana* in reducing insect pest populations (Wraight and Ramo 2005; Akello et al. 2009; Meyling et al. 2018). Higher doses appeared to accelerate population reduction in the initial phase; however, final population levels did not differ substantially among treatments. This pattern suggests a diminishing return with increasing dose, although this was not formally tested and should be interpreted cautiously (Khoobdel et al. 2019).

The pronounced population decline observed between days 3 and 14 may be associated with the active infection phase of *B. bassiana*, during which fungal spores penetrate the insect cuticle, proliferate within the host, and produce metabolites contributing to host mortality (Xu et al. 2009; Kim et al. 2023). However, changes in population density may also be influenced by ecological factors such as migration, reproduction, and environmental variability, which were not explicitly controlled in this study. Therefore, the observed population reduction should be interpreted as the combined outcome of treatment effects and field ecological processes.

The comparable effectiveness of medium and high doses suggests that intermediate concentrations (1×10^7 - 1×10^8 spores mL^{-1}) may be sufficient to achieve effective population suppression when adequate exposure time is ensured. From a practical perspective, this finding supports the potential use of *B. bassiana* as a cost-efficient and environmentally friendly biological control agent within Integrated Pest Management (IPM) programs. The use of locally adapted isolates may further enhance sustainability by supporting microbial biodiversity in tropical agroecosystems (Lv et al. 2024).

Attack level (scoring attack intensity or percentage of damaged leaves)

Statistical analysis showed that *B. bassiana* application had a significant effect on planthopper attack intensity ($p<0.001$), indicating that different doses resulted in varying levels of plant damage. The application of *B. bassiana* at various concentrations was associated with a significant reduction in the attack intensity of *N. lugens* on rice plants (Table 3). The control group exhibited a continuous increase in attack intensity from 22.93% at day 3 to 60.3±5.2% at day 28, indicating progressive plant damage under untreated conditions. In contrast, all treated plots showed a decreasing trend over time. For example, a dose of 1×10^6 spores mL^{-1} reduced attack intensity from 15.21% to 6.1±1.0%, while a dose of 1×10^9 spores mL^{-1} reduced it from 15.34% to 5.3±0.7% at the end of the observation period.

Consistent suppression was observed at doses $\geq 1 \times 10^7$ spores mL^{-1}, which maintained relatively low levels of damage through day 28. These findings indicate that *B. bassiana* effectively reduced plant damage under field conditions. The decline in attack intensity during the early observation period (days 3-14) may be associated with the biological activity of *B. bassiana*, which infects hosts through cuticle penetration and subsequent development within the insect body, potentially affecting feeding activity and mobility (Zhang et al. 2019b; Baek et al. 2022). In addition to direct mortality effects, reductions in plant damage may also reflect changes in pest behavior and population dynamics.

The interaction between dose and observation time suggests that treatment effectiveness was influenced not only by inoculum concentration but also by exposure duration. Although differences among doses were less pronounced at early stages, attack intensity values converged after day 14, with all treatments approaching low damage levels (approximately 5%). This pattern indicates that prolonged exposure may compensate for lower inoculum concentrations in achieving effective control.

From a practical perspective, intermediate doses (e.g., 1×10^7 spores mL^{-1}) may provide an efficient and economical option for pest management. This finding is consistent with previous studies emphasizing the importance of optimizing the interaction between dose and exposure time in biological control systems (Akello et al. 2009; Meyling et al. 2018). Furthermore, similar to findings by Faria and Wraight (2007), the present results suggest that locally sourced *B. bassiana* isolates can perform effectively under tropical field conditions.

It should be noted that attack intensity in this study was assessed using a visual scoring approach. Although consistency was maintained by using the same observer, no formal blinding procedure was applied, which may introduce observer-related bias. Therefore, the results should be interpreted with caution. Overall, the observed reduction in plant damage highlights the potential role of *B. bassiana* in supporting pest regulation and sustainable rice production systems.

Rice harvest yield or productivity (Tons/ha or Harvested dry grain)

Rice productivity in this study was measured at the final harvest stage. Values presented in relation to observation times reflect the condition of treatment plots observed over time rather than repeated yield measurements. Statistical analysis showed that *B. bassiana* application had a significant effect on rice productivity ($p<0.001$), indicating that different doses were associated with variations in grain yield. The application of *B. bassiana* at various concentrations resulted in higher rice productivity compared with the control (Table 4). Control plots produced 4.52±0.31 t ha^{-1}, whereas all treated plots showed increased yields, ranging from 5.84±0.27 to 6.12±0.21 t ha^{-1}. The highest yield was observed at the dose of 1×10^9 spores mL^{-1}.

These results suggest a positive association between the suppression of planthopper populations and improved rice yield under field conditions. However, yield values should be interpreted as final harvest outcomes associated with treatment exposure over time, rather than as temporally repeated measurements. The observed yield improvement is consistent with previous studies reporting positive agronomic responses associated with *B. bassiana*-based pest control. Application of *B. bassiana* has been shown to increase chickpea yield through reduced pest infestation (Younas et al. 2016), while endophytic colonization in maize has been associated with reduced herbivory and improved plant performance (Russo et al. 2019). Similar responses have also been reported in long bean, where *B. bassiana* application enhanced plant growth and biomass accumulation (Pachoute et al. 2021).

Table 1. Mortality of brown planthopper (*Nilaparvata lugens*) at 28 Days after application of *Beauveria bassiana*

Dose of *Beauveria bassiana* (spores mL^{-1})	**Mortality (%) (mean±SE)**
0 (Control)	15.2±1.4^{a}
1 × 10^{6}	73.8±4.9^{b}
1 × 10^{7}	75.6±4.1^{b}
1 × 10^{8}	77.3±3.8^{b}
1 × 10^{9}	78.5±3.6^{b}

Note: Values are mean ± standard error. Different letters indicate significant differences among treatments at $p<0.05$ (ANOVA followed by Tukey's HSD test)

Table 2. Population density of brown planthopper (*Nilaparvata lugens*) at 28 days after application of *Beauveria bassiana*

Dose of *Beauveria bassiana* (spores mL^{-1})	**Population density (individuals per plot) (mean±SE)**
0 (Control)	139.1±8.4^{a}
1 × 10^{6}	42.6±5.7^{b}
1 × 10^{7}	38.4±4.9^{b}
1 × 10^{8}	34.2±4.1^{b}
1 × 10^{9}	30.4±3.8^{b}

Note: Values are mean ± standard error. Different letters indicate significant differences among treatments at $p<0.05$ (ANOVA followed by Tukey's HSD test)

Table 3. Attack intensity of brown planthopper (*Nilaparvata lugens*) on rice plants at 28 days after application of *Beauveria bassiana*

Dose of *Beauveria bassiana* (spores mL^{-1})	**Attack intensity (% damaged leaves) (mean±SE)**
0 (Control)	60.3±5.2^{a}
1 × 10^{6}	6.1±1.0^{b}
1 × 10^{7}	5.8±0.9^{b}
1 × 10^{8}	5.4±0.8^{b}
1 × 10^{9}	5.3±0.7^{b}

Note: Values are mean ± standard error. Different letters indicate significant differences among treatments at $p<0.05$

Table 4. Rice grain yield at harvest as affected by *Beauveria bassiana*

Dose of *Beauveria bassiana* (spores mL^{-1})	**Grain yield (t ha^{-1}) (mean±SE)**
0 (Control)	4.52±0.31^{a}
1 × 10^{6}	5.84±0.27^{b}
1 × 10^{7}	5.96±0.24^{b}
1 × 10^{8}	6.05±0.22^{b}
1 × 10^{9}	6.12±0.21^{b}

Note: Values are mean ± standard error. Different letters indicate significant differences among treatments at $p<0.05$

From a biological perspective, increased yield may be related to reduced pest pressure, allowing plants to maintain better physiological performance and allocate resources more efficiently for grain production. However, these mechanisms were not directly assessed in this study and are therefore interpreted based on supporting literature. In addition, crop yield is influenced by multiple agronomic and environmental factors that were not fully controlled.

The coparable yield levels observed at medium and high dose suggest that intermediate concentrations (1 × 10^{7}-1 × 10^{8} spores mL^{-1}) may be sufficient to achieve effective outcomes under adequate exposure conditions. This has practical implications for developing cost-efficient pest management strategies. Nevertheless, the observed increase in productivity should be interpreted as an associated outcome rather than a direct causal effect solely attributable to *B. bassiana* application. Overall, these findings highlight the potential contribution of biological control strategies to improving crop performance within sustainable agricultural systems.

Impact of *Beauveria bassiana* application on agricultural ecosystem balance

The application of *B. bassiana* was associated with improved suppression of *N. lugens*, a major pest in tropical rice cultivation. Across all tested doses (1 × 10^{6} - 1 × 10^{9} spores/mL), planthopper mortality increased from approximately 23% at day 3 to more than 84% at day 28. Notably, intermediate doses achieved effectiveness comparable to higher doses after sufficient exposure time, suggesting that the duration of exposure plays an important role in determining control outcomes. The observed reduction in population density and attack intensity over the experimental period indicates that *B. bassiana* contributed to the regulation of pest populations under field conditions.

Previous studies have reported that infection by *B. bassiana* may influence insect feeding activity, mobility, and reproductive potential, thereby affecting population dynamics (Kim et al. 2023; Karaca et al. 2024). In addition, population-level changes observed in the field may also be influenced by ecological factors such as migration, reproduction, and environmental conditions.

From an ecological perspective, the use of *B. bassiana*, particularly locally adapted isolates, represents an important component of microbial biodiversity within agroecosystems. Such isolates may possess ecological adaptations that enhance their persistence and effectiveness under specific environmental conditions. Their application may contribute to reducing reliance on synthetic insecticides, thereby supporting the conservation of non-target organisms and potentially supporting agroecosystem balance through pest regulation.

The increase in rice productivity observed in treated plots suggests a positive association between pest suppression and crop performance. Nevertheless, yield is influenced by multiple agronomic and environmental factors that were not fully controlled in this study. Therefore, the observed productivity improvement should be interpreted as an associated outcome rather than a direct causal effect solely attributable to *B. bassiana* application. Similar agronomic responses have been reported in other studies, where *B. bassiana* application was associated with reduced pest damage and improved plant performance (Russo et al. 2019; Ramakuwela et al. 2020; Pachoute et al. 2021; Thakur et al. 2024).

From a practical perspective, the use of locally adapted *B. bassiana* isolates may offer cost-effective and environmentally friendly option for pest management. Overall, this study provides field-based evidence supporting the potential contribution of entomopathogenic fungi as part of sustainable and ecologically based Integrated Pest Management (IPM) strategies in tropical agroecosystems. However, further studies incorporating ecological monitoring, environmental variables, and mechanistic validation are needed to strengthen the scientific basis for large-scale application.

Ecological implications and study limitations

The findings of this study highlight the potential ecological role of *B. bassiana* as part of microbial biodiversity in tropical agroecosystems. The observed suppression of *N. lugens* populations, together with reduced attack intensity and improved crop performance, suggests that entomopathogenic fungi may contribute to pest regulation under field conditions. Previous studies have reported that *B. bassiana* infection can influence insect feeding activity, mobility, and reproductive capacity, thereby affecting population dynamics (Kim et al. 2023; Karaca et al. 2024). These ecological effects may support more stable pest regulation beyond immediate mortality.

The use of locally adapted *B. bassiana* isolates was particularly relevant from a biodiversity perspective. Local strains are likely to possess ecological adaptations that enhance their persistence and effectiveness under specific environmental conditions. This aligns with previous findings indicating that *B. bassiana* can function as an effective biological control agent across various agroecosystems, contributing to reduced pest damage and improved plant performance (Faria and Wraight 2007; Meyling et al. 2018). The incorporation of such microbial agents into pest management strategies may therefore reduce reliance on synthetic insecticides, which are known to negatively affect non-target organisms and aspects of agroecosystem functioning. In addition, studies have shown that *B. bassiana* may interact with host plants and insect pests in complex ways, including potential endophytic associations and indirect effects on plant physiology (Russo et al. 2019; Pachoute et al. 2021). While such interactions may contribute to improved plant performance, these mechanisms were not directly evaluated in the present study and are therefore interpreted as supporting evidence rather than experimentally verified processes.

However, several limitations should be acknowledged. First, mortality was assessed as apparent mortality based on population reduction and was not confirmed through re-isolation or microscopic verification of fungal infection. Second, the fungal isolate was identified based on morphological characteristics without molecular confirmation. Third, conidial viability (germination rate) was not evaluated prior to application, which may influence infection efficiency. Furthermore, environmental variables such as temperature, humidity, and rainfall were not systematically recorded, although these factors are known to influence the performance of entomopathogenic fungi under field conditions.

In addition, changes in population density and attack intensity may also be influenced by ecological processes such as migration, reproduction, and natural mortality, which were not specifically controlled in this study. The assessment of attack intensity was based on visual scoring, which may introduce a degree of subjectivity despite efforts to maintain consistency. Similarly, rice productivity is influenced by multiple agronomic and environmental factors, and thus the observed yield improvement should be interpreted as an associated outcome rather than a direct causal effect solely attributable to *B. bassiana* application.

In conclusion, this study demonstrates that the application of a local *B. bassiana* isolate was associated with the suppression of *N. lugens* under field conditions, as reflected in increased apparent mortality, reduced population density, and lower attack intensity. The findings indicate that locally adapted entomopathogenic fungi can serve as an effective and environmentally friendly component of sustainable pest management in rice agroecosystems. In particular, intermediate to high application rates (1×10^7 - 1×10^9 spores mL^{-1}) were sufficient to achieve effective pest suppression and maintain crop performance, suggesting their practical relevance for field application. However, these results should be interpreted with caution due to methodological limitations, including the absence of infection confirmation, conidial viability assessment, and environmental monitoring. Future studies integrating microclimatic measurements, molecular validation, and mechanistic analysis are recommended to strengthen the scientific basis for broader implementation.

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