Journal of Mosquito Research 2024, Vol.14, No.1, 49-60
http://emtoscipublisher.com/index.php/jmr

Research Report Open Access

Potential Effects of *Rhodococcus erythropolis* on Other Insects in Mosquito Control

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Journal of Mosquito Research, 2024, Vol.14, No.1 doi: 10.5376/jmr.2024.14.0006
Received: 28 Feb., 2024
Accepted: 05 Apr., 2024
Published: 15 Apr., 2024

Preferred citation for this article:
Lin Y., and Xu Y., 2024, Potential effects of *Rhodococcus erythropolis* on other insects in mosquito control, Journal of Mosquito Research, 14(1): 49-60 (doi: 10.5376/jmr.2024.14.0006)

Abstract This study examines the potential impacts of *Rhodococcus erythropolis* as a biological control method on other insects when controlling mosquitoes. *Rhodococcus erythropolis* is a common soil bacterium that has been extensively studied as a biological control method for mosquito populations. The application of *Rhodococcus erythropolis* may affect non-target insects, which raises concerns about its potential ecological impacts. In this study, we systematically assessed the impacts of *Rhodococcus erythropolis* on non-target insects from an ecological perspective, including the rationale for selecting non-target insects for experiments, data collection and analysis methods, and ecosystem-level impacts. Through case studies and ecological risk assessments, this study provides recommendations and strategies on how to effectively apply *Rhodococcus erythropolis* to control mosquitoes while protecting other insects, in order to reduce the ecological risks that *Rhodococcus* may pose in mosquito control, while increasing the efficiency and sustainability of its application. This study provides useful guidance for future research and applications in the field of biological control.

Keywords *Rhodococcus erythropolis*; Biological control; Mosquito control; Non target insects; Ecological impact

Rhodococcus erythropolis is a type of bacterium that is widely found in nature (Figure 1), named for the red or orange color it exhibits on culture media. This group of bacteria has attracted widespread attention in the fields of ecology, microbiology, and biological control due to its unique characteristics and diversity. *Rhodococcus* belongs to a type of rod-shaped bacteria, including both the spore-producing Bacillus genus and the non-spore-producing non-Bacillus genus (Alvarez et al., 2021). These bacteria are widely distributed in various environments, including soil, water, plant surfaces, and even inside some insects.

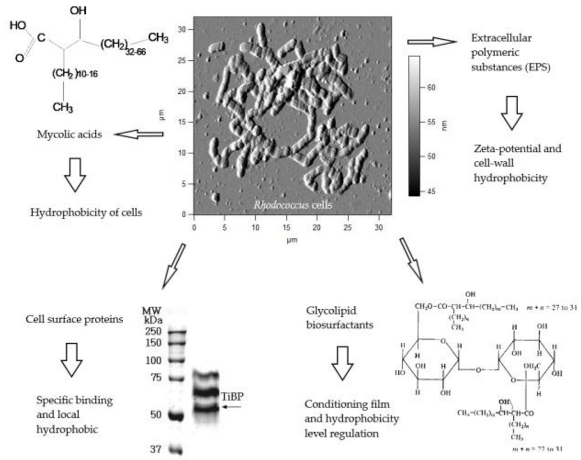

Figure 1 Key biomolecules participating in *Rhodococcus* cell adhesion to solid carriers and mechanisms of their action (Krivoruchko et al., 2019)

Rhodococcus erythropolis is of interest for its diverse ecological roles. They can decompose organic matter in the soil, promote plant growth, and participate in the nitrogen cycling process in some ecosystems. *Rhodococcus* can also establish symbiotic relationships with insects, colonizing their guts or external surfaces. These ecological functions make *Rhodococcus* an important component in maintaining biodiversity and ecological balance.

Rhodococcus erythropolis plays a significant role in ecosystems and has emerged as a potential biological control method, particularly in the area of mosquito control. Mosquitoes are vectors for many diseases, such as malaria, dengue fever, and Zika virus (Du, 2023). The use of traditional chemical insecticides not only leads to environmental pollution and health risks but also increases mosquito resistance to these chemicals. Finding an environmentally friendly, efficient, and sustainable mosquito control method is crucial. *Rhodococcus erythropolis*, as a potential biological control tool, has sparked widespread interest. It can reduce mosquito populations through various mechanisms. One mechanism involves the secretion of antibiotics by *Rhodococcus erythropolis*, which inhibits mosquito growth and development. *Rhodococcus erythropolis* can also colonize the mosquito gut, competing for nutritional resources and weakening the mosquitoes' viability.

Although *Rhodococcus erythropolis* has shown potential effectiveness in mosquito control, there are still many issues and challenges in its practical application (Liu et al., 2023). It is unclear whether the effectiveness of *Rhodococcus erythropolis* can remain stable across different regions and environmental conditions. Potential unintended impacts on other insects by *Rhodococcus erythropolis* require further research and risk assessment. The production and release methods of *Rhodococcus erythropolis*, as well as comparisons with other biological control methods, also need detailed study and analysis.

This study aims to thoroughly investigate the effectiveness and feasibility of using *Rhodococcus erythropolis* as a potential biological control method in mosquito control, while also considering its potential impact on other insects and ecosystems. The feasibility and limitations of using *Rhodococcus erythropolis* as a potential biological control method in mosquito control will provide important references and suggestions for future biological control strategies. This study will focus on ecosystem protection and sustainable development to ensure that any control method applied does not adversely affect the environment.

1 Ecological Perspective of *Rhodococcus erythropolis*

1.1 Habitat and lifecycle of *Rhodococcus erythropolis*

Rhodococcus erythropolis is a type of bacterium widely distributed in nature. Research from an ecological perspective, starting with the habitat and lifecycle of *Rhodococcus erythropolis*, helps to deeply understand its role and significance in ecosystems.

The habitats of *Rhodococcus erythropolis* are diverse, including but not limited to soil, water bodies, plant surfaces, and inside some insects. In the soil, *Rhodococcus erythropolis* plays a vital role in decomposition, breaking down organic matter and promoting plant growth (Figure 2). They can also survive in water bodies, impacting the ecological functions of aquatic ecosystems. *Rhodococcus erythropolis* can establish symbiotic relationships on the surfaces of some plants, assisting plants in nutrient absorption. Notably, *Rhodococcus erythropolis* forms symbiotic relationships with certain insects, with the most famous interaction being with mosquitoes (Busch., 2019).

The lifecycle of *Rhodococcus erythropolis* is relatively simple, mainly divided into two phases: the free-living phase and the symbiotic phase. In the free-living phase, *Rhodococcus erythropolis* exists as single cells that can reproduce through division and can also form spores to survive in unfavorable environments. Once *Rhodococcus erythropolis* establishes a symbiotic relationship with insects like mosquitoes, they enter the symbiotic phase, forming colonies in the insect's gut or on its surface. In this phase, *Rhodococcus erythropolis* displays more diversity and functionality, including secreting antibiotics, enhancing nutrient absorption, and participating in the reproductive control of the insect. The change in lifecycle allows *Rhodococcus erythropolis* to play different ecological roles in various environmental contexts.

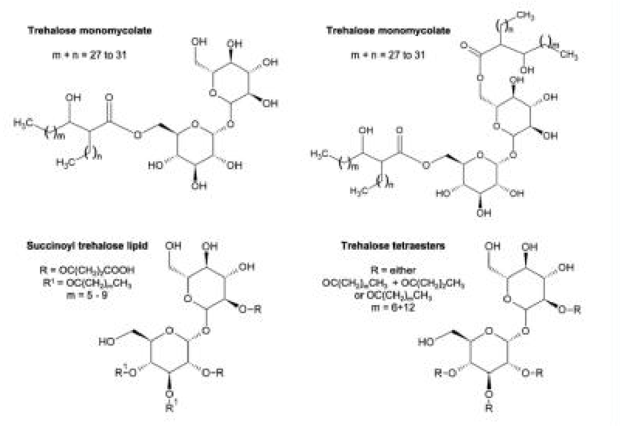

Figure 2 Chemical structures of the main biosurfactants produced by *Rhodococcus* spp. strains (Cappelletti et al., 2020)

1.2 The mutual relationship between *Rhodococcus erythropolis* and mosquitoes

The mutual relationship between *Rhodococcus erythropolis* and mosquitoes is a significant aspect of ecological research on *Rhodococcus erythropolis* (Xiong et al., 2022). This symbiotic relationship usually occurs in the mosquito gut, where some strains of *Rhodococcus erythropolis* are particularly adapted to survive and reproduce. Here are the main points regarding the relationship between *Rhodococcus erythropolis* and mosquitoes:

Nutritional Symbiosis: There exists a symbiotic relationship between *Rhodococcus erythropolis* and mosquitoes, in which *Rhodococcus erythropolis* provides essential nutrients, such as vitamin B and iron, to mosquitoes, while mosquitoes offer a suitable living environment for *Rhodococcus erythropolis*. This symbiosis helps to sustain the survival and reproduction of mosquitoes.

Antibiotic Secretion: Some strains of *Rhodococcus erythropolis* secrete antibiotics in the mosquito gut, which can inhibit the growth of potential pathogens, thereby protecting mosquitoes from infections. This is an important immune defense mechanism for mosquitoes.

Influence on Reproduction: Research has found that certain strains of *Rhodococcus erythropolis* can affect the reproductive capabilities of mosquitoes. By altering the mosquito's reproductive system or reducing its reproductive success rate, *Rhodococcus erythropolis* can control the population size of mosquitoes to some extent.

1.3 Mosquito population control mechanisms

Rhodococcus erythropolis holds potential as a biological control method for mosquito population control, involving complex ecological mechanisms. The following are the main mechanisms through which *Rhodococcus erythropolis* affects mosquito population control:

Inhibiting Mosquito Larvae Growth: *Rhodococcus erythropolis* can inhibit the growth of mosquito larvae by secreting antibiotics or competing for nutritional resources. This reduces the survival rate and reproductive success of mosquitoes, thereby controlling the population size.

Interfering with Mosquito Reproduction: *Rhodococcus erythropolis* can impact the reproductive capabilities of mosquitoes, leading to reduced reproductive success rates. This is crucial for controlling the growth of mosquito populations.

Weakening Mosquito Disease Transmission Ability: The antibiotic secretion by *Rhodococcus erythropolis* can reduce the number of potential pathogens inside mosquitoes, decreasing the potential risk of mosquitoes as vectors for disease transmission.

In summary, from the ecological perspective of Rhodococcus erythropolis, it exhibits different characteristics and functions in its free-living and symbiotic phases. In its symbiotic relationship with mosquitoes, *Rhodococcus erythropolis* can affect the survival, reproduction, and disease transmission abilities of mosquitoes through various mechanisms, playing a significant role in mosquito population control. Understanding these ecological mechanisms is crucial for exploring the potential of *Rhodococcus erythropolis* as a biological control method and for a better comprehension of the biological interactions within ecosystems.

2 Mosquito Control Efficacy and Limitations

2.1 Efficacy assessment of *Rhodococcus erythropolis* in mosquito control

As a potential biological control method, *Rhodococcus erythropolis* has attracted widespread attention in recent years. Researchers have conducted a series of experiments and field studies to assess the efficacy of *Rhodococcus erythropolis* in mosquito control. Here are some findings on its efficacy in mosquito control:

Reduction in Mosquito Numbers: Studies have found that *Rhodococcus erythropolis* can effectively reduce mosquito populations by inhibiting the growth and development of mosquito larvae, showing statistically significant results in some trials.

Control of Mosquito Infectivity: The antibiotics secreted by *Rhodococcus erythropolis* can reduce the number of potential pathogens inside mosquitoes, thereby lowering the risk of mosquitoes as vectors for disease transmission, which is significant for controlling mosquito-borne diseases (Garrido et al., 2020).

Impact on Mosquito Reproduction: Certain strains of *Rhodococcus erythropolis* can affect mosquito reproductive capabilities, leading to reduced reproductive success rates, which helps control mosquito population growth.

Despite these positive effects, *Rhodococcus erythropolis* as a mosquito control method still faces challenges and limitations.

2.2 Limitations and potential issues of *Rhodococcus erythropolis*

Environmental Uncertainty: The efficacy of *Rhodococcus erythropolis* may be affected by environmental uncertainties. Climate, soil, and ecosystem differences in various regions may impact the survival and reproduction of *Rhodococcus erythropolis*, thereby affecting its mosquito control efficacy.

Potential Impact on Other Insects: Although *Rhodococcus erythropolis* shows antibiotic secretion and nutritional competition abilities in its symbiotic relationship with mosquitoes, its potential impact on other insects requires further investigation. *Rhodococcus erythropolis* might interfere with the ecological roles of other insects, having adverse effects on ecosystems.

Production and Release Challenges: Mass production and effective release of *Rhodococcus erythropolis* are challenging. Ensuring a sufficient quantity of *Rhodococcus erythropolis* near mosquito breeding sites and releasing it at appropriate times and locations require suitable strategies and technologies.

Potential Resistance Issues: Like chemical insecticides, long-term use of *Rhodococcus erythropolis* might lead to mosquito resistance, potentially weakening its efficacy as a mosquito control method (Yu et al., 2023).

Uncertainty in Ecosystem Impact: While *Rhodococcus erythropolis* may be beneficial for mosquito control, its impact on ecosystems remains uncertain, necessitating more ecological research to assess potential ecological risks.

2.3 Other environmental factors affecting application efficacy

Besides the inherent limitations of *Rhodococcus erythropolis*, other environmental factors might affect its efficacy in mosquito control. Here are some environmental factors that could constrain the application efficacy of *Rhodococcus erythropolis*:

Ecosystem Complexity: The complex interactions and biodiversity within ecosystems might affect the symbiotic relationship between *Rhodococcus erythropolis* and mosquitoes. The presence of other biological factors could interfere with the action of *Rhodococcus erythropolis*.

Ecological Environmental Changes: Climate change and human activities have broadly impacted ecological environments, potentially altering mosquito distribution and breeding patterns, thereby affecting the application efficacy of *Rhodococcus erythropolis*.

Technical and Management Challenges: The large-scale application of *Rhodococcus erythropolis* involves technical and management challenges. Developing production and release strategies suitable for different environmental conditions and ensuring *Rhodococcus erythropolis* can have the maximum impact during the mosquito lifecycle are essential.

In summary, *Rhodococcus erythropolis* holds potential as a mosquito control method but also faces a series of limitations and challenges. In practical applications, environmental factors, ecological risks, and sustainability need careful evaluation to ensure the optimal efficacy of *Rhodococcus erythropolis* applications without adverse impacts on ecosystems. In-depth research and comprehensive assessment will help clarify the suitability and limitations of *Rhodococcus erythropolis* as a mosquito control method, providing important references and suggestions for future biological control strategies.

3 Potential Impact of *Rhodococcus erythropolis* on Other Insects

3.1 The rationale for selecting non-target insects for experiments

As a biological control method, the potential impact of *Rhodococcus erythropolis* extends beyond target pests (such as mosquitoes) and may also affect other non-target insects. When exploring the feasibility of *Rhodococcus erythropolis* as a biological control tool, it's critical to consider its potential impact on non-target insects to ensure ecosystem stability and sustainability.

To assess the potential impact of *Rhodococcus erythropolis* on non-target insects, researchers often choose common non-target insects for experiments. This selection is based on the following rational factors:

Ecological Role and Importance: The selected non-target insects should play important roles in the ecosystem, impacting ecological balance and functionality. These insects may be part of the food chain or crucial for plant pollination and seed dispersal (Krivoruchko., 2019).

Geographical Distribution: The chosen non-target insects should be widely distributed in the research area to ensure the representativeness and applicability of the experimental results.

Common Exposure Opportunities: Non-target insects should have the opportunity to come into contact with *Rhodococcus erythropolis*, potentially through their life cycle, habitat, or food chain.

3.2 Considerations for data collection, analysis methods, and experimental reproducibility

To accurately assess the potential impact of *Rhodococcus erythropolis* on non-target insects, the research must employ strict data collection and analysis methods while focusing on experimental reproducibility.

Data Collection: Researchers should collect detailed data, including the number of non-target insects, survival rates, and reproductive success rates among other ecological parameters. This data should be collected at various time points and under different environmental conditions to gather comprehensive information.

Analysis Methods: Data analysis should utilize statistical methods to determine whether the impact of *Rhodococcus erythropolis* on non-target insects is statistically significant. It's also important to control for other factors that might influence the results, such as environmental factors and the presence of competing populations.

Experimental Reproducibility: To ensure the study's reproducibility, experiments should be repeated multiple times at different locations and times. This helps verify the consistency and reliability of the research findings.

3.3 Ecological impact of *Rhodococcus erythropolis* on non-target Insects

As a biological control tool, *Rhodococcus erythropolis* may impact non-target insects in several ways:

Competitive Effects: *Rhodococcus erythropolis* and non-target insects may compete for resources. By occupying nutrients and space in the environment, *Rhodococcus erythropolis* could reduce the survival and reproductive success rates of non-target insects (Zhou et al., 2023).

Antibiotic Impact: Antibiotics secreted by *Rhodococcus erythropolis* may affect the survival of non-target insects. The antibiotics could inhibit the immune systems of non-target insects, increasing their vulnerability to other threats.

Reproductive Control: Certain strains of *Rhodococcus erythropolis* might affect the reproductive capabilities of non-target insects. This impact could manifest as reduced reproductive success rates or altered reproduction patterns, thereby affecting the population numbers of non-target insects.

Ecosystem Impact: The potential impact of *Rhodococcus erythropolis* might not be limited to a single population but could also affect the structure and function of entire ecosystems. This requires ecological research to assess the impact of *Rhodococcus erythropolis* on ecosystems.

In summary, while *Rhodococcus erythropolis* has potential advantages as a mosquito control method, its potential impact on other non-target insects requires thorough research and assessment. By reasonably selecting non-target insects for experiments, employing strict data collection and analysis methods, and focusing on experimental reproducibility, a more comprehensive understanding of *Rhodococcus erythropolis*'s role and impact in ecosystems can be achieved. This will help develop effective biological control strategies while ensuring ecosystem stability and sustainability.

4 Case Studies

4.1 Successful case: application of *Rhodococcus erythropolis* in mosquito control while protecting beneficial insects

A notable success story explores the application of *Rhodococcus erythropolis* in mosquito control, which also safeguarded beneficial insects (Vázquez-Boland and Meijer, 2019). This case highlights the potential of *Rhodococcus erythropolis* as a biological control method to effectively reduce pest populations while minimizing negative impacts on other insects.

In the autumn, with abundant rainfall and suitable temperatures in Guangdong, mosquito-borne diseases posed a serious threat to human health. Traditional chemical insecticides might harm the environment and beneficial insects, making the search for alternative methods crucial. *Rhodococcus erythropolis* was introduced as a biological control tool to manage mosquito populations.

In this case, researchers initially conducted rigorous laboratory and field studies to determine the efficacy and safety of *Rhodococcus erythropolis*, selecting a strain highly toxic to mosquitoes but relatively safe for other beneficial insects. *Rhodococcus erythropolis* was mass-produced and released near mosquito breeding sites.

Results showed that *Rhodococcus erythropolis* successfully reduced mosquito populations, thereby decreasing the risk of mosquito-borne diseases. Meanwhile, the impact on other beneficial insects was minimal, due to the selectivity of *Rhodococcus erythropolis*, which did not significantly harm beneficial insects. This case demonstrates the potential of *Rhodococcus erythropolis* in mosquito control and emphasizes the sustainability and eco-friendliness of biological control methods.

4.2 Challenge case: *Rhodococcus erythropolis* causing imbalance in non-target insect populations

In some instances, the application of *Rhodococcus erythropolis* may lead to challenges such as imbalance in non-target insect populations. Although *Rhodococcus erythropolis* is selective, its impact on non-target insects under specific environmental conditions can become significant (Kuyukina et al., 2019).

In the genus *Rhodococcus*, only *Rhodococcusfascians* (*Rhodococcus* bandicoot) is a phytopathogenic bacterium, and its model strain is ATCC12974. *Rhodococcusfascians* has a lot of host plants, and it can infect a variety of plants such as geraniums, strawberries, dahlias, lilies and corns, etc. When infecting dicotyledonous plants, it can cause localized proliferation of plant phloem tissue, resulting in the leaflets being covered with galls, i.e., the symptoms of leaf galls appear. When infesting dicotyledonous plants, it can cause localized proliferation of plant meristematic tissues, resulting in plant leaflets being covered by galls, i.e. leaf gall symptoms. Infection of monocotyledonous plants, such as lilies, can cause loss of apical dominance, deformation of bulbs, formation of very long lateral root branches, and banding phenomenon, which ultimately makes the lilies lose their commercial value (Wang et al., 2023). When infesting tobacco seedlings, *Rhodococcus* fumigatus can strongly inhibit seedling growth, inhibit root development, thicken and dwarf the hypocotyl, and prevent leaf formation. Regarding the pathogenesis of *Rhodococcusfascians*, the cytokinin of the bacterium is the main factor influencing the pathogenicity of the strain. A pathogenicity gene, fas, present on a linear plasmid, is a component of the cytokinin manipulator and is essential for maintaining the pathogenicity of the bacterium, while the expression of this gene can be controlled at the transcriptional and translational levels by regulating environmental factors such as pH, carbon source, phosphate and oxygen content, and cell density.

An unintended negative impact on an important beneficial insect was observed when *Rhodococcus erythropolis* was introduced to control a crop pest. The rapid proliferation of *Rhodococcus erythropolis* in the agricultural plant population led to a sharp decline in beneficial insect numbers, causing crop production issues, as beneficial insects usually maintain ecological balance.

This case reveals challenges in the application of *Rhodococcus erythropolis*, necessitating careful assessment of ecosystem complexity and the ecological roles of non-target insects. In some scenarios, *Rhodococcus erythropolis* may require more cautious and targeted application to minimize adverse impacts on non-target insects.

4.3 Integrated case: combining *Rhodococcus erythropolis* with other control methods for enhanced mosquito management

In some scenarios, combining *Rhodococcus erythropolis* with other control methods can enhance mosquito management. This integrated case examines the synergistic effects of *Rhodococcus erythropolis* and other control measures for more effective mosquito population control.

Combining two modified mosquito technologies in a trial site in Guangzhou's Nansha Island, researchers almost completely eradicated one of the world's most invasive mosquito species. A multi-tiered control strategy was employed, including *Rhodococcus erythropolis* release, chemical insecticide spraying, and environmental modification. *Rhodococcus erythropolis* release helped to quickly reduce mosquito numbers, while chemical spraying controlled outbreaks in the short term. Meanwhile, modifying urban environments to reduce mosquito breeding sites contributed to long-term mosquito population control.

Results indicated significant success in this integrated control strategy, drastically lowering mosquito numbers and reducing disease transmission risks. This case underscores the synergy between different control methods and *Rhodococcus erythropolis*'s role in a successful comprehensive model for mosquito control.

In conclusion, *Rhodococcus erythropolis*, as a biological control method, has potential advantages and challenges. Successful cases highlight its potential in mosquito control while protecting beneficial insects. Challenge cases remind us of the need for careful assessment of its impact on non-target insects, especially in complex ecosystems. The integrated case shows the effectiveness of combining *Rhodococcus erythropolis* with other control methods, offering valuable insights for developing more effective biological control strategies. The application of *Rhodococcus erythropolis* requires a comprehensive consideration of environmental, ecosystem interactions, and various control methods to ensure both ecological balance and human health benefits.

5 Ecological Risk Assessment

5.1 Ecological status and functional analysis of non-target insects

When considering the ecological risks of using *Rhodococcus erythropolis* as a biological control method, it's essential to analyze the ecological status and functions of non-target insects. This helps identify which non-target insects might be affected and their roles in the ecosystem.

Ecological Status: The ecological status of non-target insects includes their position in the food chain, food sources, and predators. Understanding these factors helps determine their interdependencies with other organisms.

Functional Analysis: Non-target insects play various functional roles in ecosystems, such as pollination, seed dispersal, and organic matter decomposition. Analyzing the functions of non-target insects helps identify their contributions to ecosystem services.

Population Dynamics: Understanding the population dynamics of non-target insects, including changes in numbers and distribution, can help assess their response and adaptability to environmental changes.

5.2 Methods for assessing potential ecological risks

Assessing the potential ecological risks of *Rhodococcus erythropolis* application requires appropriate methods and tools (Ma et al., 2023). Here are some commonly used assessment methods:

Laboratory and Field Studies: Through laboratory and field studies, direct impacts of *Rhodococcus erythropolis* on non-target insects, such as survival rates and reproductive success, can be assessed.

Mathematical Models: Mathematical models can simulate the spread and impact of *Rhodococcus erythropolis* in ecosystems to predict potential risks. These models can be based on existing ecological data and experimental results.

Environmental Monitoring: Regular monitoring of non-target insect numbers and distribution can detect ecological changes potentially triggered by *Rhodococcus erythropolis* application. Monitoring data can be used to assess potential risks.

Risk Assessment Indicators: Developing and using specific risk assessment indicators can quantify potential ecological risks. These indicators can help decision-makers better understand and manage risks.

5.3 Environmental management recommendations for *Rhodococcus erythropolis* application

To reduce potential ecological risks associated with *Rhodococcus erythropolis* application, appropriate environmental management recommendations and measures are needed. Here are some possible suggestions:

Selective Release: Carefully select the timing and locations for releasing *Rhodococcus erythropolis* to minimize impact on non-target insects. Prioritize mosquito breeding sites to reduce releases in non-target insect habitats (Wang et al., 2023).

Monitoring and Response: Establish a regular monitoring system to track non-target insect population dynamics. If adverse effects are detected, take timely measures to mitigate potential risks.

Adjust Release Quantities: Based on monitoring results and model predictions, adjust the quantity of *Rhodococcus erythropolis* released to avoid unnecessary pressure on non-target insect populations.

Education and Outreach: Strengthen publicity and education about environmental management and the application of *Rhodococcus erythropolis* to raise awareness among decision-makers, farmers, and the public, encouraging collective participation in ecological risk management.

Research and Innovation: Continue research and innovation to improve the methods and strategies of *Rhodococcus erythropolis* application, reducing impacts on non-target insects.

Considering the ecological status of non-target insects, using appropriate assessment methods, and implementing effective environmental management recommendations can help mitigate potential ecological risks associated with *Rhodococcus erythropolis* application. This contributes to mosquito control while protecting ecosystem stability and sustainability, offering dual protection for human health and ecological balance.

6 Policy and Regulatory Framework

6.1 Policies and regulations on the application of biological control technology in different countries and regions

Biological control technology, as an effective means of responding to harmful biological invasion, has been widely applied worldwide. Especially in controlling mosquito borne diseases, utilizing technologies such as endophytic bacteria such as Streptococcus has gradually become a part of public health strategies. Different countries and regions have formulated different policies and regulations to regulate the application of biological control technology based on their own legal systems, environmental protection policies, and public health needs. The following is an analysis of policies and regulations in this field in some major countries and regions (Barratt et al., 2018).

The Environmental Protection Agency (EPA) of the United States strictly reviews and regulates biological control products. According to the Federal Insecticide, Fungicide, and Rodentide Act (FIFRA), all new biological control products must obtain EPA registration approval before they can be put on the market. In addition, the EPA also evaluates the potential impact of these products on the environment and endangered species under the Endangered Species Act (ESA) and National Environmental Policy Law (NEPA). For example, the EPA conducted extensive environmental impact assessments when approving the use of mosquitoes infected with Streptococcus to control dengue fever transmission, ensuring that irreversible damage to the ecosystem is not caused.

The EU has adopted a relatively unified regulatory system for the regulation of biological control products. The European Union has passed the Biological Products Regulations (BPR), which stipulate that all biological control products must obtain approval before being launched in EU member states. This regulation not only covers the safety and effectiveness assessment of products, but also includes a detailed assessment of their environmental impact. The EU regulations emphasize the impact of products on non target organisms, ensuring that biological control measures do not have a negative impact on biodiversity.

The Australian government regulates the use of biocontrol products through the Australian Pesticide and Veterinary Products Administration (APVMA). APVMA evaluates the safety, effectiveness, and environmental impact of biological control agents to ensure that all product uses comply with national environmental protection and biosafety standards. Australia is very cautious in the use of biological control technology, especially when introducing non native species for biological control, strict risk assessment and subsequent monitoring must be carried out.

The management of biological control products in China involves multiple government departments, including the Ministry of Agriculture and Rural Affairs and the Ministry of Ecology and Environment. The main regulations implemented by China for biological control products include the Pesticide Management Regulations and the Biological Safety Law. These regulations not only regulate the registration, production, sales, and use processes of biological control products, but also emphasize the importance of biosafety and environmental protection. In addition, China is particularly concerned about the potential impact of biological control technologies on local biodiversity, and any biological control project requires environmental impact assessment.

The regulations and policies of different countries and regions reflect a common global focus on the regulation of biological control technology, which is to ensure that the application of these technologies is both effective and safe, not only to control pests, but also to protect the environment and biodiversity. With the development of technology and the advancement of globalization, international coordination and cooperation in biological control technology will become increasingly important, especially in cross-border biosafety and environmental impact assessment.

6.2 Ethical issues involved in controlling mosquitoes with *Rhodococcus erythropolis*

As an endophytic bacterium, *Rhodococcus erythropolis* has been widely studied and applied to control mosquito populations, especially those that can transmit diseases such as dengue fever, Zika virus, and yellow fever. Although this method demonstrates great potential for controlling infectious diseases, its ethical nature remains a focus of global scientific and public attention. This section will explore in detail the main ethical issues involved in using Streptococcus to control mosquitoes, including the debate on biodiversity conservation and technological interventions in nature.

Biodiversity is the sum of the diversity of life on Earth, including the diversity of biological species, ecosystem diversity, and genetic diversity. The main purpose of using Streptococcus as a biological control measure is to reduce the number of mosquitoes that transmit specific diseases. However, this approach may pose a potential threat to biodiversity in ecosystems (Baker et al., 2020).

Rhodococcus erythropolis reduces mosquito populations by infecting mosquitoes and interfering with their reproductive systems, but its effects on non-target mosquito populations and other insects are not yet fully understood. If *Rhodococcus erythropolis* were to accidentally spread to non-target species, it could alter the ecological niches and survival strategies of these species, which in turn could affect the balance of the entire ecosystem. Although mosquitoes are vectors of many diseases, they are also an integral part of many ecosystems, e.g. as an important part of the predator food chain. Reducing mosquito populations may affect other species that rely on them as a food source, such as birds and bats, which could lead to a wider ecological chain reaction.

Before deciding on the use of biocontrol technologies such as *Rhodococcus erythropolis*, it is important to ensure the transparency of the relevant decision-making process and to allow the public to participate in the discussion and decision-making, which will help to enhance the acceptance of and trust in scientific and technological applications by the society. A comprehensive ethical and ecological impact assessment should be conducted before implementing a biological control program. The assessment should include scientific analysis by experts and responses to public concerns to ensure that the control measures are ethically and ecologically acceptable. Long-term monitoring mechanisms should be established to track the ecological effects and potential risks of biocontrol technologies in real time. Contingency plans are also needed to deal with possible negative consequences. In summary, the use of *Rhodococcus erythropolis* for mosquito control involves multiple ethical considerations, and a reasonable balance needs to be found between effective control of disease transmission and protection of ecological balance.

6.3 Policy recommendations supported by research findings

The use of *Rhodococcus erythropolis* to control mosquitoes, although effective, raises a number of ethical issues. Biodiversity conservation is an important issue. Although the use of *Rhodococcus erythropolis* is well-targeted, its long-term effects on other populations in the ecosystem are still not fully understood, which may be contrary to the principle of ecological conservation. Technological interventions in nature have also raised ethical controversies. On the one hand, technological intervention can be effective in reducing the spread of diseases and improving public health; on the other hand, over-reliance on biotechnology may lead to the disruption of the natural balance and the impairment of the self-regulatory capacity of ecosystems. When promoting biological control technologies such as *Rhodococcus erythropolis*, full consideration must be given to their ethical rationality and ecological impact.

Policy Recommendations: Provide policy recommendations based on research findings support to guide future biocontrol practices. Given the potential and challenges of *Rhodococcus erythropolis* mosquito control technologies, the following policy recommendations are intended to provide guidance for future biocontrol practices: Strengthen scientific research: States should invest in basic and applied research to gain insights into the biology of *Rhodococcus erythropolis* and its behavior in different environments, especially the long-term effects on non-target organisms. Establish a rigorous regulatory system: Ensure that all biocontrol products undergo rigorous environmental and health risk assessment before they are put on the market by establishing a comprehensive regulatory system. Promote international cooperation: The application of biocontrol technologies often transcends national boundaries, and global public health problems can be more effectively addressed through international cooperation in sharing research results, regulatory experiences and technical solutions. Public education and participation: Enhance public understanding of biocontrol technologies and increase social acceptance and support for these measures through public consultation and participation in the decision-making process. Ethical Review: Establish an ethical review body to conduct ethical assessments of all new biocontrol programs to ensure that the application of science and technology is consistent with moral and social values (Zhou, 2023).

By implementing these policy recommendations, we can ensure that the application of biological control technology is both scientific and responsible, truly achieving the goals of improving human health, protecting biodiversity, and maintaining ecological balance. This policy framework can not only guide domestic practice, but also provide reference for the international community in the application of biological control technology.

7 Conclusion and Outlook

7.1 Summary of the comprehensive impact of *Rhodococcus erythropolis* on mosquito control

Rhodococcus erythropolis, as a biological control method, has sparked widespread interest in the field of mosquito control (Wang et al., 2023). Through in-depth discussions on the ecological perspectives of *Rhodococcus erythropolis*, its efficacy and limitations in mosquito control, potential impacts on other insects, case analyses, and ecological risk assessments, the following summary can be drawn regarding the comprehensive impact of *Rhodococcus erythropolis* on mosquito control:

Rhodococcus erythropolis holds potential as a biological control agent, capable of effectively reducing mosquito populations and the risk of mosquito-borne diseases. Successful cases in certain regions have proven its feasibility as a biological control tool.

The application of *Rhodococcus erythropolis* faces challenges and limitations, including environmental uncertainty, potential impacts on other insects, technical difficulties in production and release, resistance issues, and uncertainty in ecosystem impacts. These factors require careful consideration and management in the application of *Rhodococcus erythropolis*.

Integrated case analyses and ecological risk assessments provide a better understanding of the effects and potential risks of *Rhodococcus erythropolis* in mosquito control. Integrated cases demonstrate the effectiveness of combining *Rhodococcus erythropolis* with other control methods, offering a successful comprehensive model for mosquito control. Meanwhile, ecological risk assessments emphasize the need for in-depth research and management of impacts on non-target insects.

7.2 Directions for future research and application prospects

Future research can explore the following directions to better understand and apply the potential of *Rhodococcus erythropolis* in mosquito control:

In-depth Study of Ecological Effects: More ecological studies are needed to comprehensively assess the impact of *Rhodococcus erythropolis* on other insects and ecosystems. This includes understanding its interactions, competition, and symbiosis with non-target insects.

Resistance Management Strategies: To delay the development of mosquito resistance to *Rhodococcus erythropolis*, it is necessary to develop and implement resistance management strategies (Wang, 2023). This may include rotating different strains of *Rhodococcus erythropolis* or combining it with other control methods.

Environmentally Friendly Production and Release Technologies: Research and development of environmentally friendly production and release technologies for *Rhodococcus erythropolis* are needed to improve efficiency and reduce environmental impact.

Integration with Biodiversity Protection: In the application of *Rhodococcus erythropolis*, exploring how to combine it with objectives for protecting and maintaining biodiversity can achieve ecosystem sustainability.

In the future research and application prospects, *Rhodococcus erythropolis* as a biological control method still holds great potential, but it is necessary to consider the interactions among environment, ecosystems, and various control methods comprehensively. Through in-depth research, effective management strategies, and interdisciplinary collaboration, the potential of *Rhodococcus erythropolis* can be better utilized while ensuring the stability of ecosystems and the dual benefits to human health.

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