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RNAi Pesticides: Revolutionizing Sustainable Agriculture

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Abstract

As agriculture's reliance on traditional chemical pesticides continues to become unsustainable, Ribonucleic Acid Interference technology has emerged to popularity as a promising alternative. This paper underscores the importance of RNAi technology to pest control, as double stranded RNA molecules selectively silence genes that are crucial for survival for pests, while reducing harm for chemical runoff and impact on beneficial key stone species such as honeybees. Additionally, the paper emphasizes the high degradability in soil and water, and hence the mitigation of long-term contamination risks. However, the use of this technology simultaneously raises concerns, as it may negatively impact human health and nontarget organisms through unintended gene modification via spray applications. Through the analysis of RNAi technology's benefits, risks, and future implications, especially for marginalized communities, this essay builds an argument to address the long-established problems in human agriculture. It posits that RNAi technology can provide a pivotal step towards a sustainable agricultural future, and that this can be achieved with continuous innovation and rigorous regulation across both marginalized and industrial farming systems.

The Case for RNAi

The rise of chemical pesticides started in the 20th century with the surge in synthetic pesticides, notably DDT, developed in 1940 to cure diseases such as typhus and malaria *(*DDT - A Brief History and Status*).* After the realization that it was useful for livestock production, it quickly became a highly valued commodity with widespread use across the world. Over the following decades, pesticide usage became an integral part of agriculture and public health.

According to recent statistics, the use of pesticides for agricultural purposes increased steadily from 1990 to 2022, reaching about 3.69 million metric tons in 2022 (Global Pesticide Consumption 1990–2022). In a similar finding, Alavanja states that the United States alone uses over 1 billion pounds, contributing to about a fifth of global pesticide consumption. These pesticides are used for different purposes, such as protecting food and products from unwanted insects, maintaining the lawn and garden, and public health programs. Specifically in the agricultural sector, Alavanja posits that pesticides have long been an essential tool for modern agriculture, enhancing protection methods for plants from pests and a variety of different invasive species. They are crucial in the preservation of the health and productivity of agricultural systems, as they prevent any crop losses due to harmful organisms.

However, despite their benefits, a shift from the traditional method of pesticides is needed, as they not only prevent and kill harmful organisms but organisms that are also beneficial to our societies. For instance, organisms such as pollinators are heavily affected by the toxic chemical substances that they are exposed to through pesticides.

Thus, in response to these challenges, a new technology has emerged and captured the attention of scientists and farmers. This technology – RNAi – has emerged as a tool that can be used to inhibit the expression of specific genes. According to Rathod, the new RNA interference technology has shown vast potential for the field of genetic research and agriculture, proving to be a transformative technology with many estimated positive effects. Research indicates that the use of RNAi pesticides aims to tackle the main problem of the lack of pollination and pollinators in our current environments.

Pollinators, particularly honeybees, are essential keystone species that account for up to 80% of the world's flowering plants and one-third of global food production (Randall). However, Armstrong reports that there is a 51% and 48% decrease in the honey bee population in the United States during 2021-2022 and 2022-2023, respectively (Armstrong). This alarming decrease in the honey bee population explicitly conveys the worldwide crisis in pollinator numbers, underscoring the urgent need for sustainable pest control. Thus, this paper aims to examine the use of RNAi Pesticides as a method of pest control, focusing on its benefits, implications, risks, and future directions.

What Are RNAi Pesticides?

The new RNAi, also known as Ribonucleic acid interference, pesticide technology works by precisely targeting and turning off specific genes that are imperative for pest growth, reproduction, and survival (Li et al.). Turning off these specific genes selectively kills pest insects without having a direct impact on non-target species. At a cellular level, RNAi pesticides stop the process of information extraction from an organism's DNA, which happens in order to achieve protein synthesis.

Specifically, small pieces of double-stranded DNA (dsRNA) shut down protein translation by blocking the functions of mRNA. A dsRNA that matches the mRNA sequence enters the cell and interacts with the specific proteins, leading to the destruction of the target mRNA (Alyokhin). Consequently, no genetic information reaches the ribosome, forestalling protein synthesis. This process is important because proteins are vital components of living organisms, forming tissues and organs and activating biochemical processes necessary for survival (Sirinathsinghji). Hence, lacking these certain proteins will kill the organisms. Ultimately, RNA interference can disable nucleotide sequences that are only found in pests and parasites, not in beneficial insects such as honeybees, and thus can preserve honeybees through the detection and elimination of these parasites.

Benefits for Pollinators and the Environment

Research indicates that the use of RNAi pesticides has been associated with several environmental benefits. One of such is its ability to preserve honeybee colonies. Honeybees are vital species that predominantly affect their ecosystems, largely based on their existence. As RNAi pesticides preserve honeybees more efficiently, these honeybees will help maintain ecosystems that are largely dependent on them and the pollinations that they do (Keshamma). As mentioned above, according to the Sentient Climate, approximately 75 percent of flowering plants require the transfer of pollen by insects, specifically honeybees (Mishler). In these terrestrial ecosystems, honeybees are especially essential, pollinating the seeds and fruits that feed a wide variety of animals, from songbirds to grizzly bears. Therefore, the preservation would lead to an increased survival rate of these species and an overall increase in ecosystem resilience, making it harder for terrestrial ecosystems to deplete (Hatfield).

Furthermore, not only do RNAi pesticides preserve biodiversity, but they are also widely known to have high biodegradability rates. The Public Library of Science has stated that dsRNA, the type of acid used in these specific pesticides, exhibits very short half-lives, degrading by more than 90% within 35 hours of exposure, regardless of the soil type (Dubelman). This is due to the inherent chemical instability of RNAs. RNAs have 2-hydroxyl groups on the pentose ring, which makes them more susceptible to hydrolysis and, thus, easier to degrade through separation (Embl-Ebi). Since agriculture requires a lot of water and soil, dsRNA will likely be exposed to large quantities of water, which will break them down and lead to increased degradation efficiency without external care. However, the easily degradable nature of RNAi pesticides will minimize contamination in water and soils that will otherwise lead to the disruption of agricultural systems, reducing the accumulation of harmful chemical residues and further supporting healthy ecosystems. This will decrease the risk to humans and non-target organisms from long-term exposure.

Lastly, in addition to the two main environmental advantages that RNAi pesticides provide, they also possess the potential for improved crop quality. By specifically targeting harmful pests without affecting non-target organisms, RNAi pesticides can ensure healthier plants that are grown in more suitable conditions (Kaur).

Advantages Over Traditional Pesticides

In addition to its environmental and pollinator benefits, RNAi technology also proves to be a solution for social justice. This is mainly because it serves as an alternative to traditional pesticides. Traditional pesticides are known to be disadvantageous to marginalized communities, specifically colored farmers who don’t receive much support externally.

Firstly, one significant advantage of RNAi technology is the potential reduction of health risks associated with pesticide residues that are exposed to farmers.
Conventional pesticides often result in high bioaccumulation, with harmful chemical substances being exposed to farmers and nearby communities (Ray). In addition to this, the use of pesticides leads to the contamination of water sources, leading to harmful chemical substances being released into the environment, especially into rivers, lakes, and ground waters. This runoff will cause water contamination due to the low biodegradability values of such traditional pesticides, as said in Frontiers in Microbiology. For instance, Pathak asserts that pesticides like DDT and lindane, which are examples of Organochlorine Pesticides (OCPs), are widely used across the world for agricultural protection and usually linger for a long time in natural systems. However, these OCPs’ exposures have been linked to cancer, birth deformities, neurological damage, and immune system disease. These negative environmental effects of standard pesticides are further aggravated due to their disproportionate effects on poorer societies where individuals lack the healthcare to cope with resource contamination.

Additionally, RNAi pesticides have been observed to minimize the chemical exposure and pollution usually associated with the use of Traditional Pesticides. According to Environmental Analysis Health and Toxicology, traditional pesticides showed lasting effects on the air and water bodies as they drifted towards bodies of water where they were frequently bioaccumulated. The bioaccumulation would then make the living environment for fish toxic, making it harder for fish to survive. Whilst doing so, the accumulated toxic substances will also be consumed by the fish, leading to higher risks for rural fishers (Ray). This circular process thereby affects low-income marginalized individuals and groups that generally depend on aquaculture and fishing for their food sources. However, by using RNAi pesticides instead of the traditional type of pesticides, we can minimize chemical exposure and pollution, helping low-income communities that don’t have much access to healthcare systems.

Furthermore, another key benefit associated with the use of RNAi pesticides is the highly biodegradable nature of the technology. As RNAi pesticides wash off with water and soil rather than accumulating in the environment, they provide an essential solution to reducing long-term environmental contamination. This means that the cycle of harmful chemical substance buildups is broken, significantly lowering the risk of harmful chemical substance exposure to marginalized individuals.

Also, Griffith estimates that in the United States, approximately eight times more money was spent on pesticides in counties with populations of more than 40 percent persons of color than in counties with less than 6 percent. This disproportionate effect on a specific race highlights the lack of social justice in our society, necessitating the use of RNAi pesticides to decrease the severity of negative health effects.

Lastly, research indicates that colored farmers who use these traditional pesticides typically find it difficult to afford them on their own because pesticides are generally expensive. However, RNAi technology is beneficial to marginalized farmers as it is affordable and accessible, alleviating the financial burden. Although not implemented currently, communities plan to create a more cost-effective RNAi pesticide through a yeast-based production platform (Morrison). If this is done, it will be a game changer for poor farmers and agricultural managers, making every process much more efficient.

Risks and Future Directions

Despite the aforementioned benefits of RNAi pesticides, it is important to note that they possess some disadvantages that may limit their use. For instance, RNAi pesticides can lead to higher risks for non-target species and, therefore, lead to an environmental disadvantage. If honeybees share genes with target pests, unintended gene silencing in pollinators may occur. For example, one meta-analysis by FOTE found 101 potential bindings of interfering RNAs to the honeybee genome sequences. This would rather lead to harm to the honeybee colonies, undermining the original intended protective effect of these pesticides (Sirinathsinghji).

Additionally, RNAi pesticides may be disadvantageous in terms of public health since they can be inhaled by humans. Most RNAi-based pesticides are applied similarly to traditional pesticides through spray applications. According to frontiers in plant science, spray applications have a high chance of chemicals not hitting target pests and, therefore, drifting off towards humans, from which they are inhaled (Rodrigues). This may be detrimental to the human respiratory system, exacerbating problems such as chronic obstructive pulmonary disease and asthma (Harris).

What makes this concern much larger is that RNAi pesticides are applied in open-air experimentations. Unlike enclosed environments that prevent chemical dispersal and extended exposure, open-air environments make controlling nearly impossible, escalating the risk to humans and non-target organisms (Heinemann).

Furthermore, RNAi pesticides may also have unintended effects on crops and other bees, altering their genetic composition in a way that raises safety concerns. For instance, a study by Bayer/Monsanto found that a genetically modified RNAi corn that was initially designed to kill rootworms also killed non-target beetles that included the same type of genetic information as those rootworms (Sirinathsinghji). This lack of specificity in the technology raises concerns about how we will ensure the safety of these widespread pesticides.

Finally, RNAi technology also has stability issues due to its inherently high biodegradability. Despite the advantages of the high biodegradability of RNAi pesticides, they also have some disadvantages. For instance, as pesticides are degradable through simple water and soil supplements, they have limits to their efficiencies, leading to inevitably high frequencies in applications.

Final Thoughts on RNAi Pesticides

RNAi pesticides represent a major advancement in combating the negative impacts of conventional pesticides. By precisely targeting pests and rapidly breaking down in the environment, they offer a cleaner, more sustainable alternative for agriculture. RNAi pesticides, in contrast to chemical pesticides, do not remain in soil and water, thereby decreasing contamination and protecting important species such as honeybees, which are vital for pollination and biodiversity conservation.

However, RNAi pesticides do come with difficulties. Concerns regarding the potential effects on non-target species, the dangers to human health from application techniques, and the uncontrollable nature in outdoor settings emphasize the necessity for meticulous improvement. Scientists and regulators need to collaborate to enhance gene-targeting precision and create safer, more controlled methods for utilizing this technology in practical settings. Despite these obstacles, it is difficult to overlook the benefits of RNAi pesticides.

They provide a way to decrease dependence on toxic chemicals while supporting healthier ecosystems and fairer agricultural methods. Conventional pesticides have created a lasting impact on pollution, decreased biodiversity, and caused more harm to marginalized communities. On the other hand, RNAi technology could potentially undo certain aspects of the harm. With persistent innovation and ethical application, RNAi pesticides have the potential to be a fundamental component of contemporary farming, ensuring a balance between productivity, environmental protection, and societal accountability.

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