The role of fungal-based biopesticides in the fight against global warming

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Abstract*— *Agricultural practices, including chemical pesticides, are responsible for around 30% of the worldwide emissions that contribute to climate change. Insect pests and weeds will invade the crops more often due to a longer growing season and a warmer environment, which will probably result in more chemical pesticide use, which in turn causes harmful emissions that worsen climate change in coming decades. Unlike traditional methods, pesticides made from natural components such as plants, animals, etc. are considered less harmful to the environment and can safeguard the ecosystem from the negative impacts of global warming. Widely used entomopathogenic environment-friendly fungi such as Beauveria bassiana and Metarhizium anisopliae have the ability to penetrate directly into pest cuticles to cause death. The fungus continues to grow from inside out of the carcass and disperse conidial spores to cause new infections to continue the cycle. Thus, the whole process protects the crops from pathogens without adding harmful gases to the environment. The present paper discusses the need for the use of fungal biopesticides as an alternative to chemical biopesticides with a focus on the impact on global warming and human health.

Index Terms—*Fungal biopesticides, Global warming, Climate change, Food security.*

I. INTRODUCTION

The greenhouse effect occurs naturally. It contributes to warming the earth's surface and supplying the heat required for the survival of all living things. Our planet would be colder than it is now without greenhouse gases. However, human activities like the burning of fossil fuels, farming, and land clearing increase the amount of greenhouse gases in the atmosphere, which traps more heat resulting in global warming. Greenhouse gases emissions from forestry, agriculture, and fisheries have nearly doubled during the past 50 years as a result of increased agricultural production to fulfill the demands of an expanding population [4]. Overall food production is anticipated to expand by 70% between 2005 and 2050 to feed a population of 9.1 billion people with existing eating habits, leading in an additional 30% increase in world GHG emissions from agriculture [5]. The majority of this expansion in agricultural and related emissions will take place in Asian and African nations, where a sizable portion of the population depends on these industries and related ones for a living. The United Nations Framework Convention on Climate Change (UNFCCC) set an aim in the 2015 Paris Agreement to keep global warming to well below 2 °C over pre-industrial levels, with an aspirational objective of 1.5 °C. A significant decrease in global emissions is necessary to accomplish this aim.

India has a significant impact on lowering global emissions and shaping the future climate since it is the third-largest producer of greenhouse gases (GHGs) in the world, behind China and the United States. In India, the agricultural sector accounts for 18% of the country's total GHG emissions, primarily from the production of cattle, fertiliser usage, and crop waste burning [6]. Currently, India is going through a period of both tremendous economic expansion and population transformation. With this economic expansion and an anticipated population of 1.71 billion people in 2050, food demand is anticipated to double. As a result, future increases in agricultural emissions in India are anticipated.

By 2050, it is predicted that there will be additional 2 billion people on the planet, most of whom will live in Africa and Asia due to the exponential growth of the world's population [1]. This growth in population increases the demand for food, which necessitates additional inputs for crop production, and this has placed significant stress on agriculture and its related industries. The need for pesticides is rising as a result of the existing crop production system. In order to protect their crops from pests, farmers in underdeveloped countries often turn to the use of pesticides. Chemical pesticides significantly improved food security and global agriculture in a number of ways, but they also pose potential risks to natural health and environmental sustainability [2]. Despite a growing awareness of the dangers posed by chemical pesticides, the annual quantity of pesticide manufacturing and consumption throughout the globe has continued to climb. [3]

II. CHEMICAL PESTICIDES AND GLOBAL WARMING

A. *Pest resistance to the warmer climate*

Climate change poses a threat to food security in the twenty-first century because it may alter the geographic range and pesticide receptivity of harmful insects and other pests. Where these shifts will occur and how they may effect existing pest control efforts is unknown at this time. [10]. More breakouts and damage from unwanted pests and weeds result from natural system imbalances brought on by higher temperatures. Because there are more pests to control as a result, pesticide consumption increases. However, environmental factors such as the increase in temperature, which affect pesticide absorption, penetration, translocation, and detoxification, have a significant impact on pesticide efficacy [7].

In areas with historically minimal pest danger, numerous pests have increased their geographic range due to climate change. Pesticide use and pesticide resistance have both grown in these areas at the same time [11]. To fully understand the connection between range shifts and pesticide resistance, one must have a firm understanding on how climate change will impact the global distribution of pest species. Pests must be able to withstand cold stress in order to continue expansion, and reproduction when conditions are more favorable. Climate change has emerged as a key factor limiting the distribution and abundance of insect species. Nonetheless, many pest species undergo periodic migrations throughout the year. When the weather rises, they move from their warm overwintering areas into the rest of the country, but they disappear from the colder regions throughout the winter. Pest species can consequently be either permanently present (permanent) or only seasonally present (transient), depending on the local circumstances [10].

Pests are frequently exposed to the same pesticide in areas with permanent populations, resulting in a rise in pests that are resistant every year. Over time, this can result in local adaptation and the buildup of pesticide resistance. [10, 12]. Pests, particularly those that may be killed by pesticides, have limited exposure to the outside world during seasonal occupancy. If pests reproduce rapidly during a given season, a temporary increase in resistance may develop as a consequence of repeated exposure throughout that season. The potential of pests to develop resistance to insecticides used locally may be affected by climate change if the circumstances under which they might persist locally are exacerbated. (go from transitory to permanent) [10, 13].

B. Pesticide contribution to climate change

Almost 30 percent of global emissions that contribute to climate change are attributable to agricultural practices, including the use of pesticides, according to research from the Intergovernmental Panel on Climate Change. Pesticide sulfuryl fluoride, which is used to treat insects such as termites, bedbugs, and cockroaches, increases greenhouse gas (GHG) emissions. As a greenhouse gas, nitrous oxide is 300 times more potent than carbon dioxide, and its use in fumigants has been related to its release. [9]. In terms of environmental sulphur emissions, pesticides and fertilizers recently surpassed the fossil fuel industry. As a result, worries about health and the environment will grow dramatically, especially for those people and ecosystems who are more susceptible to the harmful consequences of chemical exposure. Advocates contend that if the production and use of pesticides are exacerbating the effects of the climate crisis, then pesticide policy and regulation must address and eradicate chemical usage. Alternatives for chemical pesticides such as biological or fungal pesticides should be explored. By reducing the use of hazardous, petroleum-based pesticides, improving soil health, and carbon sequestering, a shift from chemical-intensive agriculture to regenerative organic agriculture can greatly lessen the threat of climate catastrophe.

The toxicity of pesticides is also increased by warmer seas. When pesticides are present in streams in even trace concentrations, the effects on fish and other aquatic species deteriorate as water temperatures increase. Researchers have shown that even at low concentrations, pesticides can disrupt some fish species' normal sexual development and negatively impact their capacity to reproduce, grow, and swim [8].

The widespread consensus is that as the earth warms, pesticides' effects will worsen. Most pesticides have greater toxicity when used at higher temperatures than at the same dose [14]. Increased pesticide application rates at greater dosages in agriculture due to increasing pest species abundance, crop modifications, and maybe due to the utilization of larger agricultural areas [15], and increasing precipitation causes pesticide runoff in ponds in agricultural regions [15].

III. BIOPESTICIDE AS AN ALTERNATIVE

Biopesticides constitute naturally occurring compounds used to treat plants in forests, gardens, farms, and other agricultural settings with the purpose of warding off various pests. Biopesticides, or pest control based on living microorganisms such as bacteria, cyanobacteria, and microalgae, hold enormous potential for reducing crop loss without lowering the quality of the final product [16]. The US Environmental Protection Agency states that "biopesticides are produced from natural sources such as animals, plants, microbes, and certain minerals". These biocontrol agents generate genes or metabolites that may be used to prevent crop harm. [17]. Due to their eco-friendliness and host-specificity, the usage of biopesticides is significantly more favorable than that of their chemical equivalents [18].

A. Types

Biopesticides come in a variety of forms, and they are grouped together based on the methods used for extraction and the molecules or compounds that were employed in their creation [19]. Microbial pesticides come from microscopic creatures including bacteria, fungus, and viruses. Numerous biopesticides have been discovered and developed over the past 10 years thanks to intensive research on microbial biopesticides, which has also opened the road for their commercial viability [19]. Pseudomonas, Yersinia, Chromobacterium, and other bacterial species are among the major categories of entomopathogens, while fungi include species of Beauveria, Metarhizium, Verticillium, Lecanicillium, Hirsutella, Paecilomyces, etc [16].

B. Advantages of Biopesticides

Biopesticides are environmentally benign, precise in their target organisms, and not harmful to unintended creatures, they are therefore effective enough to replace synthetic pesticides in the control of pests [20]. Further, biopesticides work well in modest doses and disintegrate swiftly without leaving any troublesome residues. Biopesticides' biological makeup causes them to degrade quickly, limit environmental buildup, and stop the development of water and soil contamination. Also, biopesticides are sufficiently degraded by exposure to air, moisture, hot temperatures, and sunshine [18].

C. Limitations

Despite the benefits of utilizing them, biopesticides have not been as widely used as anticipated due to the expenses associated with researching, testing, and obtaining regulatory approval for novel biological agents, the cost of producing pesticides is also high. Another reason is shelf life, because biopesticides are sensitive to changes in temperature and humidity, they have a limited shelf life. Limited field effectiveness as a result of regional and environmental factors further limits the usage of biopesticides. Due to their limited effectiveness against a wide variety of pests and diseases, farmers have little interest in biopesticides. They need to use a wide range of biological treatments to control illnesses and bugs in the field. These treatments are difficult to use, expensive, and inconvenient, and not all pests or pathogens can be treated with them [16].

IV. FUNGAL BIOPESTICIDES

Due to their wide spectrum of host species, fungus-based biopesticides may be the most flexible biological control agents. These fungi are a diverse group that spans over 90 genera and 750 species [21]. Contrary to many bacterial and all viral biopesticides, fungal biopesticides have the advantage of not needing to be consumed in order to be effective. But because they are living things, they frequently require a certain set of conditions, such as moderate temperatures and wet soil, in order to thrive. Fungi are excellent for the management of sucking pests because of their unique capacity to destroy insects by piercing through the cuticle.

A. Beauvaria bassiana

One of the historically most significant and often utilized fungi in this genus is the white muscardine fungus Beauveria bassiana. There are at least 49 species in the genus Beauveria, of which 22 are thought to be pathogenic [22]. The entomopathogenic fungus Beauveria bassiana grows naturally in soils all over the globe and may infect many different kinds of insects. When the fungus's minuscule spores come into contact with the body of an insect host, they germinate, break through the cuticle, and proliferate inside, killing the insect in a couple of days [21]. A white mould forms on the corpse and begins to release new spores to continue the cycle.

B. Metarhizium anisopliae

Because of the green tint of their conidial cells, Metarhizium produces a sickness in insect hosts known as "green muscardine”. These fungus conidia, or mitotic (asexual) spores, germinate when they come into contact with an insect host's body and emerge as hyphae that pierce the cuticle. After a few days, the insect dies as a result of the fungus's internal growth, which is likely made possible by the development of insecticidal cyclic peptides [21]. If the ambient moisture level is high enough, a white mould will then appear on the corpse and become green as spores are released.

C. Method of functioning

The spores of the fungus initially land on the insect's cuticle, where they subsequently germinate and penetrate the cuticle by developing appressorium. Hyphae form in the hypodermis, continue to grow in the blood cells and body of the insect, and eventually kill it [23]. Asexual spores can spread on these deceased people by saprophytic growth, causing permanent sexual and asexual phases. The release of toxins by fungus is one of the most extensively researched topics in entomopathogenic mechanisms. For instance, in artificial conditions, toxins are secreted by Beauveria bassiana and Metarhizium anisopliae. Even before they spread, these compounds have the ability to kill insects and produce spores in the tissue of parasitic fungi. In most instances, the toxic impact rather than mycosis that results from the digestion of fungal propagules can result in mortality [24]. One of an insect's most crucial characteristics is the presence of the parasitic fungus that are saprophytic and resistant to environmental factors. They may be separated from the soil and organic wastes, as a result, increasing the likelihood that they will be used as biological agents [23].

V. EFFECT OF ENVIRONMENTAL FACTORS ON FUNGAL BIOPESTICIDES

Temperature and humidity have a major role in determining the virulence and efficacy of entomopathogenic fungus against post-harvest insects. For instance, it is commonly accepted that high relative humidity conditions enhance the growth of entomopathogenic fungi [25]. It is well acknowledged that high temperatures have a deleterious impact on conidial viability and germination. It becomes clear that optimal storage conditions must exist in order for entomopathogenic fungi to function effectively and avoid the degradation of stored grains. This is necessary for the management of insects in warehouses and storage facilities [26].

A. Temperature

The virulence and efficacy of entomopathogenic fungus in suppressing post-harvest insects may be significantly influenced by abiotic conditions such as temperature and relative humidity. Their effectiveness against storage insects is significantly influenced by temperature. High-temperature conditions often result in a reduction in conidial viability and germination. With the rise in temperature, M. anisopliae's potency against T. confusum larvae also increased [27]. Yet, greater temperatures may encourage better conidial adhesion, leading to a higher prevalence of fungal infection among insects. The causes of the increased effectiveness of M. anisopliae against storage insects are unclear [26].

B. Humidity

It was formerly believed that entomopathogenic fungi thrived only in damp conditions or that their insecticidal effectiveness suffered in dry ones. The decreased efficacy of B. bassiana at humidity levels lower than 90% demonstrates that humidity is the key factor of whether spores will germinate and infect [28]. High humidity seems to be beneficial for fungal development since fungi need consistently humid conditions in order to finish growing and producing spores. Long-term stored foods like grains and legumes may benefit from more evaluation of fungal strains that have been shown to efficiently suppress insects in dry settings [26].

C. Soil temperature and moisture

This fungal pathogen lives naturally in soil, and the physical and chemical characteristics of the soil have an impact on how infectious it is to insects. One of the most crucial parameters affecting how a host insect reacts to an entomopathogenic fungus infection is the temperature and moisture of the soil [29, 31]. Because of the growing interest in the use of insect pathogens in pest management programmes, it is vital to choose fungal infections that are resistant to the wide range of abiotic conditions that may be found within the ecosystem that is being investigated. During the period of two weeks on sandy loam and peat soils at a temperature of 28 °C, a strain of B. bassiana showed a colony count increase of 200% compared to the baseline count [30]. This was found when compared to the baseline count. When M. anisopliae was grown at a temperature of 25 degrees Celsius in sandy loam and clay soils, conidial survival and sporulation were shown to decline more rapidly in wet soils than in moderately dry soils [32].

VI. EFFECT OF CLIMATE CHANGE ON FUNGAL BIOPESTICIDES VIRULENCE

The climatic conditions that represent the upper limit of tolerance for different fungal species might vary, and the interactions that take place between entomopathogenic fungus, the insect it is trying to kill, and the surrounding environment can be rather intricate. It was formerly believed that weather had a role in the spread of fungus, the capacity to create conidia from decomposing matter, and the use of entomopathogenic fungi in the management of insect pests. [33, 34]. High humidity substantially stimulates the development of fungal conidia, high temperatures induce catastrophic losses in conidial viability, and rainfall actively contributes to the spread of entomopathogenic fungi from the soil environment to the crop surface [33]. Rainfall actively contributes to the epidemiology of this entomopathogenic fungus and easily spreads the soil-borne B. bassiana to the surface of whorl-stage corn in the absence of insects [35].

For germination, penetration, and infection to take place in the majority of fungi, the insect cuticle must have a minimum relative humidity (RH) of 95%. Even though high ambient RH levels may not always be necessary for infection to occur, the longevity of conidial survivability in the environment is a crucial element impacting the effectiveness of entomopathogenic fungi. Before infection, the conidia must have easy access to water to avoid desiccation and sustain vitality. [33, 36]. B. bassiana's germination and growth rates were dramatically slowed by an increase in CO2. Along with temperature and relative humidity, UV light is a significant environmental element that lowers the viability of B. bassiana and M. anisopliae and affects whether these entomopathogenic fungi may be used as biocontrol agents [37]. Different M. anisopliae isolates exhibit varying climatic susceptibilities, and their distribution is much more strongly correlated with how well they adapt to the local abiotic circumstances than with the presence or lack of sensitive hosts [38].

The ideal temperature for the germination and sporulation of some types of Metarhizium fungus is 25°C, whereas high and low temperatures have a negative impact. Moreover, the entomopathogenic fungi go dormant under conditions of high temperature and bright sunshine [33]. Temperature and relative humidity are among the abiotic elements that have a significant impact on entomopathogenic fungi infection, incubation, and survivability, especially in tropical and subtropical climates. A perfect balance of temperature and humidity is also essential for the spread of these epidemics [33]. The relocation of conidia to areas that offer shelter from extreme heat and UV radiation is also aided by the greater irrigation levels.

As a result, these possibilities might be investigated to lessen the negative impacts of climatic elements so that they can be successfully used in pest management in field circumstances.

VII. EFFECT OF CLIMATE CHANGE ON PESTS

Agricultural crops are impacted by climate change both directly and indirectly, as are the pests that affect them. The environment and other insect species are indirectly harmed, whereas the reproduction, development, survival, and dissemination of pests are directly impacted. [39]. Insects are poikilothermic animals, meaning that the temperature of their bodies is affected by the surrounding environment. Temperature is therefore likely the key environmental factor affecting insects in different stages of their life cycle [40]. New, diversified ecosystems created by climate change provide an opportunity for the spread of insecticides. Moreover, it may multiply and spread to other locations. The interplay between agricultural crops and insect pests may be profoundly altered by the combined effects of rising temperatures and the complex physiological effects of CO2. Farmers should be prepared for completely new, significant pest challenges in the future as a consequence of climate change. The international spread of agricultural pests is a worldwide concern because of the damage they can do to crops. [41].

Low temperatures are frequently more important than high temperatures in defining an insect pest's geographic range, and climate change will have a substantial influence on this. Because of climate change and growing global commerce, which enables individuals to disperse over the globe, many pest species are expanding their range. If the distribution of insect pests on farms changes, it may have a major effect on crop yields [41]. Pest species' current ranges are expected to expand poleward as a result of climate change. By 2055, it is anticipated that the ranges of insect pests would expand to higher elevations, with more generations occurring in central Europe [42]. Nevertheless, global warming was predicted to reduce the number of generations in southern Europe, which would have a detrimental effect on the insect pest population. This data demonstrates that climate change affects many animals in various ways. [43]. Because of extreme summer heat and winter cold, the B. oleae can only survive in the arid areas of Arizona and southern and central California. It is anticipated that as high summer temperatures grow increasingly unfavorable, climate change may further restrict its occurrence in many Californian locales. On the other hand, it is anticipated that the climate around the California coast would be more favorable for them to grow [41].

Being cold-blooded or poikilothermic, insects have a restricted ability to maintain homeostasis in response to changes in the surrounding temperature. In order to survive in environments that are thermally challenging, they have developed a range of survival techniques. Insects are often divided into two categories when it comes to overwintering strategies: freeze-tolerant and freeze-avoidant. Diapause is a physiological adaptation method used by the first group of insects, whereas behavioural avoidance or migration is a technique used by the second group of insects [44]. Increased overwintering population and hence a larger number of insects on plants during the warmer season of the year might result from increased overwintering survival. In turn, this would lead to a rise in insect population growth, early infestations, and subsequent crop loss from insect pests [45]. Several studies have shown that warmer temperatures aid anholocyclic aphid species in the United Kingdom in surviving the winter and may even postpone the onset of their departure by up to a month. A longer window of time for viral infection means that aphid populations might develop to dangerous levels over the following growing season, thanks to increased breakouts and earlier spring migrations caused by climate change. [41, 46].

CONCLUSION

In order to keep up with the rising demand for food, chemical pesticides are employed in agriculture on a global scale. Using chemical pesticides so often has undoubtedly protected crops. The use of pesticides on a large scale, nevertheless, has also sparked worries about their presence in our food supply and environment. In contrast to the need to boost agricultural productivity without placing an undue dependence on chemical pesticides, there are growing worries about the loss of biodiversity and global warming. Biopesticides are manufactured from naturally occurring compounds that work in an environmentally favorable and non-toxic way to manage pests. Biopesticides, therefore, present less of a risk to the environment, human health, and climate change. They may be used in organic farming, are often more selective in their killing of pests, have less or no lingering side effects, and are safer to employ than chemical pesticides. The general public has to be made aware of the necessity to convert to fungal-based biopesticides for their pest control needs since environmental safety is a global concern. The performance of biopesticides is anticipated to be predictable. When used appropriately, fungal-based biopesticides have the power to both protect the environment and make agriculture more sustainable.

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