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Impact of Emerging Pathogens in Crop Production

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ABSTRACT

Emerging pathogens are not a new concern in agriculture but have gained more attention due to their increasing frequency and severity. A well-known example is the potato late blight, which was brought on by the oomycete *Phytophthora infestans* and is infamous for causing the Irish Potato Famine in the 1840s. Cops have become more vulnerable to diseases due to fluctuations in the growing environments caused by climate change. Variation in precipitation patterns and increasing temperatures can foster the growth and spread of diseases. Furthermore, agricultural intensification, with its emphasis on monocropping and high-density planting, creates an ideal environment for the pathogens. Due to the lack of genetic diversity in monocultures, once a pathogen infects a crop, it can quickly decimate entire fields. Mechanism of disease spread and innovative approaches of management of emerging diseases are discussed. By prioritizing research, implementing sustainable practices, and fostering global cooperation, it is possible to mitigate the impact of these pathogens on global crop production and ensure food security for future generations.

Keywords: Pathogens; global crop production; Fusarium oxysporum; wheat blast.

1. INTRODUCTION

1.1 Background

In the contemporary era of agriculture, the rise of emerging disease presents a significant threat to global crop production. These diseases caused by fungi, bacteria, viruses, and nematodes, can lead to devastating crop losses, affecting both the yield and quality of agricultural produce. Historically, the agricultural sector has constantly battled with plant diseases; On the other hand, occurence and dissemination of new infections have been expedited by trade globalisation and climate change. The aforementioned phenomena present a significant obstacle to both food security and economic stability, especially in areas that strongly depend on agriculture.

Emerging pathogens in agriculture are not a new concern but have gained more attention due to their increasing frequency and severity. A well-known example is the potato late blight, which was brought on by the oomycete *Phytophthora infestans* and is infamous for causing the Irish Potato Famine in the 1840s. Similar concerns also exist today due to the emergence of new and more virulent strains of existing infections or their appearance in new locations. The reappearance of Panama disease in bananas due to *Fusarium oxysporum* f. sp. cubense TR4 and the wheat blast produced by the fungus *Magnaporthe oryzae*, illustrate persistent and dynamic nature of these threats [1].

1.2 Importance of Crop Production in Global Food Security

The crop production is the foundation of global food security and the source of nutrition for the world's population. Since plant-based meals provide more than 80% of human calories, it is imperative to constantly produce crops such as wheat, rice, maize, and soybeans [2].These staple crops are not only vital for direct human consumption but also serve as essential feed for livestock, linking crop production directly to meat and dairy production.

Strong crop production systems are crucial because of the growing world population, which is expected to reach 9.7 billion by 2050 and increase food consumption (United Nations, 2019). However, emerging diseases threaten to destabilize these systems, leading to potential food shortages and increased food prices. The impact is significantly greater in developing nations where agricultural practices may be less advanced and economic resilience weaker. The 2008 global food crisis, exacerbated by crop failures in major producing regions, illustrated the fragile nature of food security and the far-reaching consequences of disruptions in crop production.

In addition to food security, crop production is integral to economic stability and development. Agriculture employs a significant portion of the global workforce, particularly in developing nations where it can account for up to 60% of employment [3].Crop failures, therefore, have a cascading effect, leading to unemployment, reduced incomes, and increased poverty levels. Thus, protecting crop production from emerging diseases is crucial for food security but also economic and social stability.

1.3 Definition and Scope of Emerging Diseases

Emerging diseases are broadly defined as infectious agents that have recently increased in incidence or geographic range, or are newly recognized in a specific crop host [4]. These diseases may be new or re-emerging diseases that were once under control. The emergence of these diseases can be attributed to climate change, international trade, agricultural intensification, and changes in land use.

Crops have become more vulnerable to diseases due to the fluctuations in the growing environments caused by climate change. Variations in precipitation patterns and increasing temperatures can foster an environment conducive to the growth and spread of diseases. For instance, the geographic range of rust diseases in wheat has expanded due to changing climatic conditions, posing new challenges for disease management [5].

The globalization of agricultural trade means that crops and their associated pathogens can move quickly from one region to another. The introduction of *Xylella fastidiosa* to Europe, which devastated olive groves in Italy, is a stark reminder of how international trade can facilitate the spread of harmful pathogens [6].

Agricultural intensification, with its emphasis on monocropping and high-density planting, creates an ideal environment for the rapid spread of pathogens. Due to lack of genetic diversity in monocultures means that once a pathogen infects a crop, it can quickly decimate entire fields. This was observed in the outbreak of cassava mosaic disease in Africa, which spread rapidly through fields of genetically uniform cassava plants [7].

Changes in land use, such as deforestation and urbanization, also contribute to the emergence of new diseases. These activities disrupt natural ecosystems and can lead to the spillover of pathogens from wild plants to crops. The emergence of *Pseudomonas syringae* pv. actinidiae in kiwifruit orchards in New Zealand is one such example, where changes in land use and global trade played a role in the pathogen's spread [8].

Understanding the scope of emerging diseases requires a multidisciplinary approach, encompassing plant pathology, climate science, trade policies, and agricultural practices. Addressing the challenges posed by these pathogens involves integrated disease management strategies, including the development of resistant crop varieties, the implementation of strict biosecurity measures, and the adoption of sustainable farming practices.

2. OVERVIEW OF EMERGING PATHOGENS

Emerging diseases can be classified based on the taxonomic groups of the causative agents, such as bacterial, viral, fungal, or nematode pathogens. Another classification criterion involves their mode of transmission and spread. For example, some pathogens are soil-borne, while others are seed-borne or vector-borne, each having different implications for control strategies. Understanding the classification helps in devising appropriate management practices tailored to the specific pathogen type.

2.1 Mechanisms of Emergence

The emergence of new pathogens or new strains of existing pathogens can be driven by multiple mechanisms. These mechanisms include:

Genetic Changes: Pathogens can evolve through mutation, recombination, or horizontal gene transfer, leading to new strains with increased virulence or resistance to existing control measures [9]. Genetic diversity in pathogens can result in the emergence of strains capable of overcoming plant resistance genes, making previously resistant crop varieties susceptible.

Environmental Changes: Climate change, including shifts in temperature and precipitation patterns, can create favorable conditions for pathogen survival, reproduction, and spread. For instance, warmer temperatures can extend the growing season and geographic range of certain pathogens.

Agricultural Practices: Changes in agricultural practices, such as the intensification of farming, monoculture planting, and the overuse of chemical inputs, can lead to the emergence of pathogens.

Global Trade and Movement: The globalization of trade and the movement of plant materials across borders can introduce pathogens to new regions where they previously did not exist. This can result in outbreaks in areas where crops lack resistance to these newly introduced pathogens [10].

Table 1. Key emerging pathogens affecting global crop production

Crop	Pathogen	Disease	Impact
Wheat	*F. oxysporum f. sp. cubense*	Fusarium wilt	Threat to modern banana varieties, causing devastation.
Wheat	*Pyricularia oryzae pathotype Triticum*	Wheat blast	High yield losses, potential spread to new regions.
Banana	*Xanthomonas vasicola pv. musacearum*	BXW (Banana Xanthomonas Wilt)	Major threat to banana production worldwide.
Potato	*Phytophthora infestans*	Late blight	Devastating potato disease, responsible for historical famines.
Various	*Phakopsora pachyrhizi & Zymoseptoria tritici*	Soybean rust & Wheat blotch	Fungal diseases causing significant yield losses in major crops.

Changes in Host Susceptibility: The introduction of new crop varieties, which may be more susceptible to certain pathogens, can also play a role in the emergence of these diseases. Additionally, the breakdown of resistance genes in crops due to genetic changes in pathogens can make previously resistant crops vulnerable.

2.2 Examples of Recent Emerging diseases Affecting Crops

Wheat Blast (*M. oryzae Triticum*): Initially reported in Brazil in the mid-1980s, wheat blast is a fungal disease caused by a particular strain that has subsequently moved to Bangladesh and Zambia. Because it can quickly and severely reduce output under the right circumstances, this pathogen is a serious danger to the world's wheat supply [11].

Banana Fusarium Wilt (*F. oxysporum* f. sp. cubense TR4): The deadly Panama disease in bananas has spread from Southeast Asia to other banana-growing regions, threatening global banana production due to its persistence in the soil and the lack of effective control measures [12].

Cassava Brown Streak Disease (CBSD): Two viruses—the Ugandan cassava brown streak virus (UCBSV) and the cassava brown streak virus (CBSV)—cause CBSD. Due to the substantial tuber loss and impact on the region's food security, this disease has become a severe danger to East Africa's cassava output [13,14].

Pierce's sickness (*X. fastidiosa)*: Recently, the emergence of several diseases caused by this bacterial pathogen, different crops, such as citrus, grapes, and olive is observed. In grapes, *X. fastidiosa* is the source of illnesses including Pierce's sickness and Olive Quick Decline Syndrome. Concerns have been expressed over its possible effects on agricultural output and trade as a result of its spread throughout Europe, especially in Italy and Spain [15].

Tomato Brown Rugose Fruit Virus (ToBRFV): Since its discovery in Israel in 2014, ToBRFV has quickly spread to a number of nations, including the US, Mexico, and several European states. This virus affects tomatoes and peppers, causing severe fruit symptoms and reducing marketable yields. Its rapid spread and the lack of resistant varieties pose significant challenges to [16].

Table 2. Economic impact of emerging diseases on crop production

Causative agent	Economic Losses (in $ millions)	Affected Regions	Year
Phytophthora infestans	1,000	North America, Europe	2019
Fusarium oxysporum	500	Asia, Africa	2020
Xylella fastidiosa	1,200	Europe, South America	2021
Puccinia graminis	800	Worldwide	2022
Magnaporthe oryzae	950	Southeast Asia, Africa	2023
Ralstonia solanacearum	750	South America, Asia	2023

2.3 Economic Consequences

The costs associated with the emerging diseases include direct losses from reduced yields and quality, as well as indirect costs related to management and control measures.

2.3.1 Direct economic losses

The global annual loss due to plant diseases is estimated to be around 10-16% of the total crop production, translating to billions of dollars annually [17]. The impact is particularly severe in developing countries where agricultural practices may be less advanced, and resources for disease management are limited.

2.3.2 Indirect costs

Indirect costs include expenses for disease management, such as the development and application of pesticides, investment in breeding for disease-resistant crop varieties, and the implementation of quarantine measures. The cost of developing resistant varieties can be substantial, and these varieties may not always be fully effective due to the rapid evolution of pathogens.

2.4 Market and Trade Disruptions

Pathogen outbreaks can lead to trade restrictions and reduced market access for affected countries. For instance, the outbreak of Citrus Greening Disease (Huanglongbing) in Florida caused significant economic losses, not only due to decreased production but also because of export restrictions imposed by trading partners [18].

2.5 Effects on Yield and Quality

Emerging diseases affect crop yield and quality in multiple ways, leading to significant challenges for global food security.

2.6 Reduced Yield

Pathogens can cause a substantial reduction in crop yield by damaging plant tissues, disrupting physiological processes, and reducing photosynthetic efficiency. For example, the wheat rust fungus can lead to yield losses of up to 70% in susceptible wheat varieties [19].

2.7 Quality Deterioration

The quality of crops can be severely compromised by diseases. This includes changes in physical appearance, nutritional content, and storability. For instance, potato late blight reduces yield and tuber quality, leading to significant post-harvest losses [20].

2.8 Toxin Production

During some infections, pathogens produce toxins that contaminate food crops, posing health risks to humans and animals. A notable example is the aflatoxin produced by *Aspergillus flavus* in crops like maize and peanuts, which can lead to serious health issues and economic losses due to reduced marketability [21].

3. CASE STUDIES OF MAJOR CROP PATHOGEN

To illustrate the impact of emerging pathogens on global crop production, we examine specific examples of bacterial, viral, fungal pathogens, and nematodes.

3.1 Bacterial Pathogens

***Xylella fastidiosa*:**This bacterium affects a wide range of plants, including olive trees, grapevines, and citrus. The disease caused by *X. fastidiosa* has led to significant losses in southern Europe, particularly in Italy where it has devastated olive groves [22]. Management strategies include removing infected plants and controlling insect vectors, but these measures are costly and not always effective.

***Ralstonia solanacearum*:** This soil-borne pathogen causes bacterial wilt in many crops, including potatoes, tomatoes, and bananas. It is particularly problematic in tropical and subtropical regions. The disease can result in total crop loss, and the bacterium's ability to persist in the soil makes it challenging to manage [23].

3.2 Viral Pathogens

Tomato Brown Rugose Fruit Virus (ToBRFV): This newly emerged virus has caused severe damage to tomato crops in various countries. It leads to mottling and brown spots on fruits, significantly reducing their market value. The virus spreads rapidly through mechanical transmission and contaminated seeds, making it difficult to control [24].

Banana Bunchy Top Virus (BBTV): BBTV is a major threat to banana production worldwide. It causes stunted growth and "bunchy" appearance of leaves, leading to significant yield losses. The virus is transmitted by aphids, and control measures include using virus-free planting material and managing vector populations [25].

3.3 Fungal Pathogens

***Fusarium oxysporum*:** This fungus causes wilt illnesses in a variety of crops, such as tomatoes and bananas (also known as Panama disease or Fusarium wilt). There have been catastrophic losses in banana farms in Asia, Africa, and Latin America due to the Fusarium tropical race 4 (TR4) strain. Because the fungus lingers in the soil, it is quite challenging to remove.

***Magnaporthe oryzae*:** This fungus is one of the most harmful diseases affecting rice production worldwide and is the cause of rice blast disease. It results in severe yield losses by causing lesions on panicles, stems, and leaves. The disease can reduce rice production by up to 30%, with severe outbreaks causing even higher losses [26].

3.4 Nematodes

***Meloidogyne* spp. (Root-Knot Nematodes):** These nematodes infect the roots of many crops, causing galls that interfere with water and nutrient uptake. Crops like tomatoes, potatoes, and carrots are particularly vulnerable. Root-knot nematodes can cause yield losses of up to 50% in heavily infested fields [27].

***Heterodera* spp. (Cyst Nematodes):** These nematodes form cysts on the roots of host plants, disrupting their growth and development. Soybeans and sugar beets are major crops affected by cyst nematodes. Management strategies include crop rotation and resistant varieties, but these measures are not always effective [28].

4. DETECTION AND DIAGNOSIS

4.1 Traditional Methods

Traditional methods for detecting and diagnosing plant pathogens have been foundational in plant pathology for decades. These methods primarily include visual inspections [29], cultural techniques [30] and biochemical tests [31].

4.2 Advanced Molecular Techniques

Advanced molecular techniques such as Polymerase Chain Reaction [32], Next-Generation Sequencing [33], Loop-Mediated Isothermal Amplification [34].

4.3 Remote Sensing and Digital Tools

Large-scale early diagnosis and monitoring of plant diseases is now possible because to the integration of Remote sensing [35], Drones, or unmanned aerial vehicles, or UAVs [36], Digital Disease Diagnostic Tools including Mobile applications and digital platforms in agriculture [37].

The detection and diagnosis of emerging diseases in global crop production have evolved significantly, incorporating traditional, molecular, and digital methods. Each approach offers unique advantages and limitations, and an integrated strategy combining these methods is often the most effective in managing plant diseases. As technology continues to advance, the accuracy, speed, and accessibility of pathogen detection are expected to improve, providing better tools to safeguard global food security.

Emerging pathogens pose a significant threat to global crop production, necessitating effective management and control strategies. These strategies can be categorized into four main approaches: cultural practices, chemical controls, biological control methods, and integrated pest management (IPM). Each of these approaches plays a vital role in mitigating the impact of pathogens on crops.

4.4 Management of Emerging Diseases

Emerging pathogens diseases pose a significant threat to global crop production, necessitating effective management and control strategies. These strategies can be categorized into four main approaches: cultural practices, chemical controls, biological control methods, and integrated pest management (IPM).

4.5 Cultural Practices

Cultural practices are fundamental in managing crop diseases and involve modifying farming techniques to reduce the prevalence and impact of pathogens. These practices are often the first line of defense and include crop rotation, sanitation, and resistant varieties.

Table 3. Pathogen detection methods

Method	Pathogen Detected	Accuracy (%)	Time Required	Cost	Description
PCR (Polymerase Chain Reaction)	Various viruses, fungi	95	3-4 hours	High	A molecular technique used to amplify and detect DNA sequences.
ELISA (Enzyme-Linked Immunosorbent Assay)	Bacteria, viruses	90	2-3 hours	Medium	A plate-based assay technique for detecting and quantifying substances.
LAMP (Loop-mediated Isothermal Amplification)	Bacteria, viruses	92	1-2 hours	Medium	A single-tube method that amplifies DNA while maintaining a steady temperature.
qPCR (Quantitative PCR)	Various pathogens	98	2-3 hours	High	A PCR-based method to quantify DNA or RNA in a sample.
Immunofluorescence	Viruses, bacteria	85	1-2 hours	High	Uses antibodies labeled with a fluorescent dye to detect antigens.
Microarray Analysis	Multiple pathogens simultaneously	93	4-6 hours	Very High	A high-throughput method to study many genes at once for variations and expression levels.
Serological Tests	Bacteria, viruses	88	1-2 hours	Low	Detects antibodies or antigens in blood, often used for viral infections.
Next-Generation Sequencing (NGS)	All types of pathogens	99	24-48 hours	Very High	A high-throughput method to determine the sequence of nucleotides in DNA.
Biosensors	Specific bacteria, viruses	90	30 minutes - 1 hour	Medium	Uses a biological component to detect the presence of various pathogens.
Lateral Flow Assays	Viruses, bacteria	80	10-30 minutes	Low	Simple device intended to detect the presence of a target substance in a liquid sample.

4.6 Crop Rotation and Diversification

Crop rotation is the practice of successively planting various crop varieties on the same plot of land. By denying infections their preferred host, this technique upsets their life cycle. For example, rotating cereal crops with legumes can reduce the incidence of soil-borne pathogens like *Fusarium* spp., which cause root rot in cereals. Crop diversification, including intercropping, can also create a less favorable environment for pathogens and increase biodiversity, which can help in suppressing disease outbreaks.

4.7 Sanitation

Sanitation practices involve removing infected plant debris and maintaining clean fields to reduce the sources of inoculum. This includes the destruction of crop residues, which can harbor pathogens, and cleaning tools and machinery to prevent the spread of diseases. Proper disposal of infected plant material is crucial in managing diseases like late blight in potatoes caused by *P. infestans*.

4.8 Resistant Varieties

The use of disease-resistant crop varieties is a highly effective cultural practice. Breeding programs aim to develop varieties that are resistant to specific pathogens, thereby reducing the need for chemical controls. For instance, the development of rice varieties resistant to bacterial blight (*X.oryzae pv. oryzae)* has significantly reduced yield losses in affected regions [38].

4.9 Chemical Controls

Chemical controls involve the application of fungicides, bactericides, and nematicides to manage crop diseases. While effective, these controls must be used judiciously to prevent the development of resistance and minimize environmental impact.

Fungicides can be categorized into protectants, which prevent infection, and eradicants, which eliminate established infections. For example, azoxystrobin and other strobilurins are effective against a broad spectrum of fungal diseases and are commonly used in crops like wheat and grapes. However, the overuse of fungicides can lead to resistance, as seen with the development of resistant strains of powdery mildew (*Erysiphe necator*) in vineyards. Copper-based compounds are the most common bactericides. However, their overuse can result in phytotoxicity and environmental contamination. Newer bactericides, such as antibiotics like streptomycin, are used sparingly to prevent the development of resistant bacterial strains. Chemical nematicides, such as fumigants and non-fumigant nematicides, are effective but often have high toxicity and environmental concerns. Therefore, their use is increasingly being supplemented with other management strategies to reduce reliance on chemical nematicides.

4.10 Biological Control Methods

Biological control methods involve the use of natural enemies, biopesticides, and beneficial microorganisms to manage crop pathogens. These methods are environmentally friendly and can provide sustainable disease control.

4.11 Microorganisms

Beneficial microorganisms, such as mycorrhizal fungi and rhizobacteria, enhance plant health and resistance to pathogens. Arbuscular mycorrhizal fungi (AMF) improve nutrient uptake and can induce systemic resistance in plants against pathogens. Similarly, plant growth-promoting rhizobacteria (PGPR) like Pseudomonas fluorescens can suppress soil-borne diseases through mechanisms such as competition and antibiosis.

5. INNOVATIVE APPROACHES AND FUTURE PROSPECTS

5.1 Genetic Resistance and Breeding

5.1.1 Marker-Assisted Selection (MAS)

Marker-assisted selection (MAS) has revolutionized the breeding process by allowing for the identification and selection of desirable traits at the genetic level. This technique speeds up the breeding process and enhances the precision of developing resistant varieties. MAS has been successfully employed in rice breeding to develop varieties resistant to bacterial blight by identifying markers linked to resistance genes [39].

5.1.2 Genomic selection

Genomic selection, which uses genome-wide markers to predict the performance of breeding lines, is another promising approach. This method allows for the selection of superior genotypes early in the breeding cycle, thus reducing the time required to develop resistant varieties. In maize, genomic selection has accelerated the development of lines resistant to multiple pathogens, significantly boosting yields and resilience.

5.1.3 CRISPR and gene editing technologies

CRISPR-Cas9 has emerged as a groundbreaking tool in plant biotechnology, offering precise and efficient editing of plant genomes. This technology allows for the targeted modification of genes associated with disease resistance. For example, CRISPR-Cas9 has been used to knock out susceptibility genes in rice, thereby conferring resistance to bacterial blight. Looking ahead, the integration of CRISPR-Cas9 with other emerging technologies, such as synthetic biology and advanced bioinformatics, holds tremendous potential. These advancements could enable the creation of crops with enhanced resistance to new and evolving pathogens. Furthermore, as CRISPR technology becomes more refined and accessible, it is expected to play a pivotal role in ensuring food security in the face of climate change and pathogen pressure.

5.1.4 Microbiome management

The plant microbiome, consisting of bacteria, fungi, and other microorganisms, plays a crucial role in plant health and disease resistance. Inoculating plants with beneficial microbes that can outcompete or inhibit pathogens has shown promise in various crops. Bioinoculants, which are preparations containing beneficial microorganisms, are being increasingly utilized to boost plant health and resistance. In soybean, the use of rhizobial inoculants has improved resistance to soil-borne pathogens and enhanced nitrogen fixation, leading to better growth and yields.Advancements in microbiome engineering, such as the development of synthetic microbial potential in enhancing disease resistance in crops like wheat and maize.

5.1.5 Policy and regulatory frameworks

Effective policy and regulatory frameworks are essential to support the adoption and scaling of innovative approaches in crop protection. Policies that provide funding for agricultural research and offer incentives for private sector investment in biotechnologies are crucial [40].

The regulatory landscape for gene-edited crops varies widely across different countries. Clear guidelines and risk assessment frameworks are needed to address public concerns and ensure that gene-edited crops are developed and deployed responsibly.

5.1.6 Sustainable agricultural practices

Promoting sustainable agricultural practices through policy measures is vital for long-term crop health and productivity. Policies that encourage integrated pest management (IPM), crop rotation, and the use of biocontrol agents can help reduce reliance on chemical pesticides and mitigate the impact of pathogens. Collaborative efforts between policymakers, researchers, and farmers are essential to implement these practices effectively.

6. GLOBAL COLLABORATION AND RESEARCH INITIATIVES

6.1 International Organizations and Programs

The FAO establishes global standards for plant health through its many programmes, such as the International Plant Protection Convention (IPPC), and promotes collaboration among member nations to stop the introduction and spread of pests and diseases [41].

CGIAR (Consultative Group on International Agricultural Research) focusses on major crops and agricultural systems, addressing the challenges posed by emerging diseases through integrated pest management, crop improvement, and biosecurity measures [42].

The IITA (International Institute of Tropical Agriculture) conducts research on emerging plant diseases and develops innovative solutions to combat them. For example, their work on cassava diseases, such as cassava brown streak disease and cassava mosaic disease, has led to the development of disease-resistant varieties and improved management practices [43].

6.2 Collaborative Research Networks

The Global Plant Pathology Network is a collaborative platform to accelerate the development of effective strategies to manage plant diseases and protect global crop production [44]. Managed by CABI, the Plantwise Knowledge Bank is an online resource that provides diagnostic tools, treatment advice, and distribution maps for plant pests and diseases [45].

The ISPP (International Society for Plant Pathology) organizes international congresses, publishes research journals, and supports working groups focused on specific plant diseases and pathogens. [46].

6.3 Funding and Support Mechanisms

The Bill Melinda Gates Foundation provides funding for collaborative research projects and capacity-building programs, the foundation helps to strengthen global efforts to protect crop production from emerging threats [47].

The GEF (Global Environment Facility) partnering with international organizations and research institutions, the GEF helps to mobilize resources and knowledge to address the impact of plant diseases on global crop production [48].

Horizon Europe is the European Union's key funding program for partnerships between research institutions, industry, and other stakeholders, for the development and implementation of effective disease management strategies [49].

7. CONCLUSIONS

Emerging diseases pose a significant threat to global crop production, with the potential to cause severe economic and food security impacts. Pathogens such as fungi, bacteria, viruses, and nematodes have been identified as critical agents of crop diseases, and their emergence is often linked to changes in agricultural practices, climate change, and global trade. The rise in global travel and trade has facilitated the rapid spread of pathogens across borders, leading to outbreaks in regions previously unaffected. For example, the fungal pathogen *F. oxysporum* f. sp. *cubense*, responsible for Panama disease in bananas, has spread from Asia to the Americas, threatening banana production worldwide/

Key staple crops such as wheat, rice, maize, and potatoes are particularly vulnerable. Wheat rust, caused by *P. graminis* f. sp. *tritici*, has led to significant yield losses in Africa and the Middle East. Similarly, the rice blast fungus *M. oryzae* has had devastating effects on rice yields in Asia and Africa. Climate change exacerbates the problem by creating favorable conditions for pathogen proliferation and altering the geographic distribution of both crops and pathogens. Higher temperatures and increased humidity can enhance the growth and spread of fungal and bacterial pathogens. Crop losses due to emerging pathogens result in reduced food availability and higher prices, impacting both local economies and global markets. The economic burden of managing these diseases and the resulting yield losses can be substantial, affecting farmers' livelihoods and national economies. To effectively combat emerging diseases, it is essential to invest in research and develop integrated management strategies that are adaptive and resilient. Genetic engineering and CRISPR technology hold promise for developing pathogen-resistant crop varieties. Adapting agricultural practices to mitigate the impacts of climate change is crucial. This includes developing drought-resistant crop varieties, implementing water-efficient irrigation systems, and adopting agroforestry practices. Establishing a global surveillance system for crop pathogens can facilitate rapid response and containment. Collaborative efforts among countries and organizations to share data and resources can enhance preparedness and response strategies.

8. RECOMMENDATIONS FOR STAKEHOLDERS

Stakeholders, including policymakers, researchers, farmers, and industry players, must collaborate to address the challenges posed by emerging pathogens.

8.1 Policymakers

Develop and enforce regulations that prevent the spread of pathogens through trade and travel. This includes quarantine measures and the monitoring of imported plant materials.Funding and Support: Allocate funds for research and development of disease-resistant crops and sustainable agricultural practices. Support extension services to educate farmers on the latest management techniques [50].

8.2 Researchers

Encourage collaboration across disciplines, including plant pathology, climatology, and economics, to develop comprehensive solutions. Focus on understanding the mechanisms of pathogen emergence and spread. Facilitate the transfer of new technologies and practices to farmers, ensuring they are practical and cost-effective.

8.3 Farmers

Implement integrated pest management practices and adopt resistant crop varieties. Stay informed about emerging threats and participate in training programs. Community Engagement: Work collectively with local and national agricultural organizations to monitor and manage pathogen outbreaks. Share knowledge and resources within the farming community.

8.4 Industry Players

Sustainable Solutions: Invest in the development of sustainable agricultural products and technologies. Promote environmentally friendly pesticides and biocontrol agents. Engage in corporate social responsibility initiatives that support farmers and communities affected by crop diseases. Collaborate with governments and NGOs to improve agricultural resilience.

In conclusion, addressing the challenges posed by emerging diseases requires a multifaceted approach that includes scientific innovation, practical management strategies, and collaborative efforts across all stakeholders. By prioritizing research, implementing sustainable practices, and fostering global cooperation, it is possible to mitigate the impact of these diseases on global crop production and ensure food security for future generations.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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