Punjab University Journal of Zoology

40(2): 157-168 (2025)
https://dx.doi.org/10.17582/journal.pujz/2025/40.2.157.168

OPEN ACCESS

Review Article

Mechanisms and Strategies for Combating Infectious Diseases in *Zea mays* L.: A Comprehensive Review

Muhammad Saeed[1], Sajid Hussain[1*], Naveed Iqbal Raja[1*], Noor Us Saba[2], Noshin Ilyas[1], Zia Ur Rehman Mashwani[1]

[1]*Department of Botany, PMAS Arid Agriculture University, Rawalpindi*
[2]*National Institute of Food Sciences and Technology, University of Agriculture, Faisalabad*

Article History
Received: May 31, 2025
Revised: July 05, 2025
Accepted: July 24, 2025
Published: October 01, 2025

Authors' Contributions
MS wrote the manuscript. SH and ZURM reviewed and edited the draft. NIR conceptualized and supervised the research. NUS reviewed the literature. NI and NUS did formal analysis. NI helped in data curation. ZURM visualised and validated the final draft.

Keywords
Infectious disease, *Zea mays L.*, Crop rotation, Phytomicrobiome, Disease resistant varieties, Nanotechnology

Abstract | Maize is one of the most essential grain staples. Infectious illnesses can significantly reduce yield. Effective microbial disease control in maize is critical to safeguarding this key staple grain for people and cattle. Tolerance to such transmissible microorganisms necessitates an integrated disease management strategy that incorporates environmentally friendly measures. This article discusses current improvements in disease control using phytomicrobiomes, crop rotation, disease-resistant cultivars, and nanotechnology. Synthetic biology-based modifications to phytomicrobiomes can help to attenuate infectious illnesses, but knowing how microbiota interact with pathogens is critical. The introduction of novel maize varieties that can endure biotic stress, along with crop rotation, increases microbiota diversity and lowers the danger of microbial assaults on maize crops. Nanotechnology is an emerging subject that provides novel possibilities for maize disease management. We also discuss how these novel technologies provide ecologically friendly avenues for managing maize diseases, ultimately contributing to sustainable agricultural productivity. A complete grasp of disease management brings up new opportunities for increasing agricultural output.

Novelty Statement | This study introduces an evaluation of cutting-edge technologies and strategies to combat against the infectious diseases in maize. Unlike the studies had been made previously, this work highlights to integrate the synthetic biology and microbiome management as innovative approaches to increase disease resistance in maize. The study presents novel insights into management techniques boosting microbiota diversity and minimize the microbial attacks specially focusing on the emerging field of nanotechnology in controlling the maize diseases, looking forward on sustainable agricultural practices and promoting ecofriendly practices against disease management.

To cite this article: Saeed, M., Hussain, S., Raja, N.I., Saba, N.U., Ilyas, N. and Mashwani, Z.U.R., 2025. Mechanisms and strategies for combating infectious diseases in *Zea mays* L.: A comprehensive review. *Punjab Univ. J. Zool.*, **40**(2): 157-168. https://dx.doi.org/10.17582/journal.pujz/2025/40.2.157.168

Introduction

Maize, scientifically known as *Zea mays* L., is a life-sustaining grain that is sometimes referred to as the "Queen of Cereals" (Ngairangbam *et al*., 2024). This C4 plant, from the Poaceae family, is a worldwide species with the highest production levels of any cereal. It is a rapidly developing crop that now accounts for the majority of world grain trading. Maize has attracted global interest due to its high utilization rate, with around 83% of production used in animal feed, carbohydrate, starch, and biofuel industries. Maize is used for the following purposes worldwide: Food (17%), feed (61%), and industrial uses (22%). Maize output

Corresponding authors: Naveed Iqbal Raja and Sajid Hussain
drnaveedraja@uaar.edu.pk, sajidhussaindgk121@gmail.com

in 170 countries totals roughly 1,147.7 million metric tons, with 193.7 million hectares under cultivation (Nisar *et al*., 2024). The top maize producers include the United States, China, Brazil, Mexico, India, Indonesia, France, and Argentina. Maize is Pakistan's third most important crop in terms of planted area. The Dietary Reference Index (DRI) for 100 grams of maize emphasizes its ability to provide needed calories, carbs, and protein, making it especially advantageous to women and children (Galani *et al*., 2022).

Maize is one of the most valued crops, ranking after rice and wheat in significance. It is an important source of nourishment for both people and animals, improves immunological function, and has the ability to treat major chronic illnesses, as shown in Figure 1. Maize grains include B complex vitamins, which are essential for good hair, skin, heart, and brain function. Maize decoction is also used to treat symptoms including vomiting, nausea, and bladder difficulties.

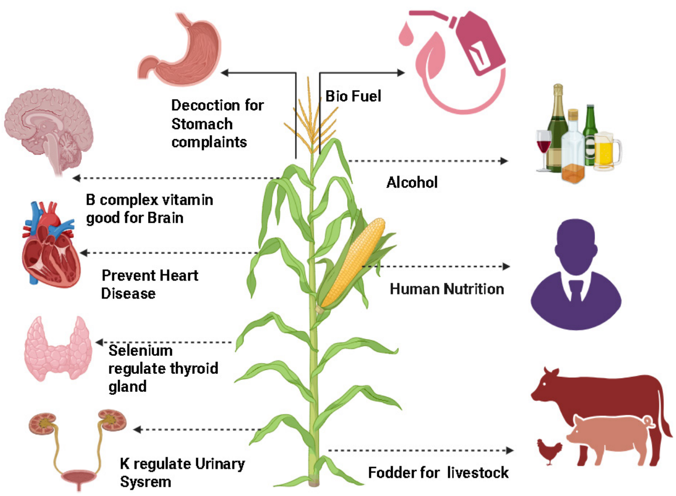

Figure 1: Elaborates the nutritional, medicinal, and industrial importance of Zea mays *L*.

Figure 1 depicts how linoleic acid in *Zea mays* oil helps regulate blood pressure, normalize blood cholesterol levels, and prevent heart disease. Furthermore, maize oil contains antioxidants that help control oxidative stress and protect cells and tissues from harm (Trinidad *et al*., 2021). Maize is also high in vitamins A, C, and K, as well as beta-carotene and selenium, which are required for thyroid function and immunological health (Baudron *et al*., 2024). Figure 1, elaborates the multiple benefits of maize, source of alcohol and essential source of human diet as well as used as fodder for livestock. Bio fuel has been made through proper process by the application of catalyst which are used in the production of fuel. In the field of pharmacology maize attained more to cure urinary system, heart diseases and stomach complaints.

Microbial assaults on maize occur from the start of ear development to postharvest, reducing the nutritional profile of the grain, triggering the formation of toxins that are hazardous to both people and animals, and posing a substantial danger to food security. Pest and diseases have been found to cause worldwide crop losses ranging from 19.5% to 41.1% (Savary *et al*., 2019). In Ontario and the United States, the economic impact of maize production loss has been estimated to be $55.90 per hectare. Several fungal species, including *Rhizoctonia*, *Fusarium*, and *Verticillium*, cause serious harm to maize crops in the field. In addition, fungal infections that harm stored grains include *Penicillium* spp., *Aspergillus* spp., and *Fusarium* spp. The maize streak disease strain induces chlorotic banding and inhibits maize plant development, resulting in yield losses of 6% to 10% (Emeraghi *et al*., 2021). Furthermore, both mottle virus and maize dwarf mosaic virus can cause deadly necrosis disease, with severe infestations causing in yield losses of up to 90%.

Lethal necrosis disease cost Kenya an estimated $45 million in 2012 (Biswalaa *et al*., 2022). Goss's wilt is a bacterial disease that affects all varieties of maize. Although these microbial diseases are difficult to control, proper management is critical for long-term maize productivity and food security (Soliman *et al*., 2018). Microbial disease control in maize is very difficult for farmers because pathogens can attack at many phases of corn growth, and there are no good monitoring tools to identify microbial infestations (Lindsey *et al*., 2020). Implementing efficient disease management measures is essential since maize is a significant staple cereal. Crop rotation is a traditional practice that can enhance resistance to microbial diseases, and it continues to be utilized today. However, many farmers primarily rely on chemical applications, such as fungicides, pesticides, and bactericides, to maximize yield (Dinesh *et al*., 2022). The continuous use of these chemicals can harm beneficial microbiota that promote plant growth and lead to the bioaccumulation of toxic substances in the grain. Additionally, pathogens may develop resistance to these chemical treatments over time (Wu *et al*., 2020).

Alternative approaches for managing microbial diseases in maize include the use of bio pesticides and the manipulation of phytomicrobiomes. The phytomicrobiome plays a crucial role in enhancing soil health, promoting plant growth and development, and combating microbial diseases. It achieves this by signaling to the roots, altering community structures, and directly secreting compounds that inhibit pathogens (Kumar and Murali, 2023). Biological control methods are reliable tools for managing microbial diseases effectively. Additionally, genetic engineering techniques have led to the development of disease-resistant varieties, which have obtained global attention. These disease-resistant varieties possess the potential to compete effectively with pathogens and promise high yield production. It is urgent to identify and implement accurate solutions to mitigate these diseases. Integrated disease management (IDM) is a comprehensive approach that incorporates various strategies for disease control, based on physical, biological,

Links Researchers

and chemical principles. This article explores key strategies for mitigating disease in maize.

Most vulnerable diseases of Maize

Fungal disease

Table 1: Different fungal diseases.

S.	Disease	Fungal strain	Mainly affected part	Refernces
1	Corn smut	*Ustilago maydis*	All parts	Aydogdu and Boyraz (2011)
2	Fusarium ear rot	*Fusarium verticillioides*	Ear	Deshapande *et al.* (2019)
3	Eyespot	*Aureobasidiunzeae*	Leaf	Kumar *et al.* (2024)
4	Northern corn leaf blight	*Exserohilum turcicum*	Leaves	Anderson *et al.* (2024)
5	Common corn rust	*Puccinia sorghi*	Leaves	Holan *et al.* (2024)
6	Anthracnose stalk rot	*Colletotrichum graminicola*	Stalk and leaves	Kleczewski *et al.* (2014)
7	Kernel rot	*Aspergillus flavus*	Ear	Mukanga *et al.* (2010)
8	Southern corn leaf blight	*Bipolaris maydis*	Leaves	Bruns *et al.* (2017)
9	Crazy top downy mildew	*Sclerophthora macrospora*	Stalk	Frederiksen and Renfro (1977)
10	Charcoal ear rot	*Macrophomina phaseolina*	Seedling, leaves and stem	Mueller *et al.* (2016)
11	Corn grey leaf spot	*Cercospora zeae-maydis*	Root,leaves and stem	Dhau *et al.* (2017)
12	Aspergillus ear	*Aspergillus flavus*	Ear	Mukanga *et al.* (2010)
13	Leaf blight	*A. alternata*	Leaves	Xu *et al.* (2022)
14	Wilt disease	*F. oxysporum*	Leaves	Compas *et al.* (2019)
15	Stalk rot	*Fusarium poae*	Ear	Borowik *et al.* (2024)
16	Stalk rot	*F. avenaceum*	Leaves	Harish *et al.* (2024)
17	Leaf spot	*Bipolaris sorokiniana*	Leaves	Gubišová *et al.* (2024)
18	Grey leaf spot	*Cercospora zeina*	Leaves	Marais *et al.* (2024)
19	Laef blight	*Bipolaris maydis*	Leaves	Meshram *et al.* (2024)
20	Seedling mortality	*Pythium ultimum Trow*	Seed	Sharma *et al.* (2024)
21	Ear rot	*Stenocarpella maydis (Berk.) Sutton,*	Ear and leaves	Dorigan *et al.* (2024)
22	Foot rot disease	*Gibberella fujikuroi (Sawada)*	Leaves and stem	Kuar *et al.* (2024)
23	Ear rot	*Fusarium moniliforme J.*	Ear and leaves	Telichko *et al.* (2024)
24	Late wilt disease	*Magnaporthiopsis maydis*	Leaves	Degan *et al.* (2020)

Bacterial disease

Table 2: Bacterial diseases of maize.

S. No	Vulnerable disease	Bacterial starin	Mainly affected part	References
1	Seedling soft rot	*Stenotrophomonas maltophilia*	Seedling stunt and leaves	Heidar *et al.* (2024)
2	Stalk rot	*Pseudomonas syringae pv. laps*	Crown and root rot	Prokić *et al.* (2024)
3	Stalk	*Enterobacter cloacae subsp. dissolvens*	Post emergence die back	Kumar *et al.* (2024)
4	Stalk rot of maize	*Erwinia chrysanthemi pv. zeae)*	Leaf spot	Jatoth *et al.* (2024)
5	White spot disease	*Pantoea ananatis*	Leaves and ear	Obasa *et al.* (2024)
6	Bacterial leaf streak	*Xanthomonas vasicola pv. Zeae*	Leaves	Ahmed *et al.* (2024)
7	Goss's wilt	*Clavibacter nebraskensis*	Leaves and stem	Soliman *et al.* (2018)
8	Bacterial leaf blight	*Clavibacter nebraskensis*	Leaf spot	Soliman *et al.* (2018)
9	Bacterial leaf spot	*Xanthomonas compestris pv.holcicola*	Leaves	Arias *et al.* (2020)
10	Bacterial stalk rot	*Enterobacter dissolvens*	Stalk nodes and leaf sheath	Hoffmann *et al.* (2024)
11	Bacterial strip	*Pseudomonas andropogens*	Bud ,stem and leaves	Mehl *et al.* (2023)
12	Top rot and stalk rot	*Erwinia carotovora subsp. carotovora*	Stem, bad and leaf sheath	Almasoud *et al.*,(2024)
13	Holcus spot	*Pseudomonas syringae*	Leaves	Heidari *et al.* (2024)
14	Purple leaf sheath	*Hemiparasitic bacteria*	Discoloration of leaves	Savov *et al.* (2024)
15	Corn stunt	*Spiroplasma kunkelii*	Ear and leaves	Haaset *et al.* (2024)
16	Stewart's disease	*Erwinia stewartii*	leaves	Mangel *et al.* (2024)
17	Leaf blight disease	*Pantoea stewartii*	Leaf sheath and ear	Farthing *et al.* (2024)
18	Bacterial streak disease	*X. campestris pv. holcicola*	Leaves and ear	Bathke *et al.* (2022)
19		*Xanthomonas vasicola pv. vasculorum*	Ear and leaf sheath	Plazas *et al.* (2018)
20	Leaf spot disease	*Pantoea ananatis*	Leaves sheath	Toaza *et al.* (2021)
21	Stalk rot	*Burkholderia gladioli*	Rooting of rot	Chiangkhaek *et al.* (2024)

Viral diseases

Table 3: Viral diseases of Maize.

S. No	Lethal disease	Virus	Mainly affected area	Refernces
1	Maize dwarf mosaic	Maize dwarf mosaic virus (MDMV)	Young leaves	Khanna *et al.* (2024)
2	Maize chlorotic mottle	Maize chlorotic mottle virus (MCMV)	Leaf sheath	Kiman *et al.* (2024)
3	Maize line	Maize line virus	Mid rib and leaves	Gentzel *et al.* (2024)
4	Cucumber mosaic	Cucumber mosaic virus (CMV)	Leaves and stem	Usanga *et al.* (2024)
5	Maize mosaic	Maize mosaic virus (MMV)	Midrib	Xavier *et al.* (2024)
6	Barley yellow dwarf	Barley yellow dwarf virus	Leaves	Khanna *et al.* (2024)
7	Johnsongrass mosaic	Johnsongrass mosaic virus	Ear and Leaves	Han *et al.* (2024)
8	Cereal chlorotic mottle	Cereal cholortic mottle virus	Leaf streak	Abraham *et al.* (2024)
9	Corn lethal necrosis	Maize cholorotic mottle virus	Yellowing of leaves	Gentze *et al.* (2024)
10	Maize streak	Maize streak virus (MSV)	Leaves and ear	Magdy *et al.* (2024)
11	Maize strip	Maize strip virus	Leaves	Abebe *et al.* (2024)
12	Maize white line mosaic	Maize white line mosaic virus	Leaves	Gentze *et al.* (2024)
13	Northern cereal mosaic	Northern cereal mosaic virus	Ear and leaves	Ohlson *et al.* (2024)
14	Rice stripe	Rice stripe virus	Leaf and midrib	Zhang *et al.* (2024)
15	Oat sterile dwarf	Oat sterile dwarf mosiac (OSDV)	Stem and leaves	Jones *et al.* (2024)
16	Oat pseudorosette	Oat pseudorosette virus	Leaf sheath	Kashyap*et al.* (2024)
17	Sugarcane mosaic of maize	Sugarcane mosaic virus (SCMV)	Leaves	Gao *et al.* (2024)

Principle to control infectious disease on maize

Phytomicrobiome

The phytomicrobiome can successfully manage maize diseases by directly secreting toxins that kill pathogens and indirectly stimulating the plant's immune response. These techniques can help to achieve sustainable maize yield production. The diverse microbiota demonstrate a variety of pest control methods. For example, several bacteria release poisons that are fatal to pests when consumed. *Rhizoctonia solani* causes sheath blight disease in maize, resulting in considerable yield losses. However, Pseudomonas strains, notably AS21 and A19, have been reported to reduce mycelial growth by 54.55% and 57.5% in vitro, as well as 65.60% and 66.57% in cell culture. These strains can cause resistance and slow down the growth of other fungal infections (Sahgal *et al.*, 2024). Furthermore, rhizosphere bacteria such as *Enterobacter asburiae* and *Bacillus siamensis* have been shown to limit the growth of fungi such as *Alternaria alternata* (26.20% inhibition) and *Fusarium equiseti* (20.63%) (Akanmu and Babalola, 2024). Fungi may bind to pathogens, infiltrate their tissues, and grow, releasing spores that then infect more cells and diseases. This cycle will continue until the crop is safeguarded. Figure 2 explain the intricate genes of the phytomicrobiome to regulate infectious diseases.

Trichoderma spp. are also helpful at controlling microbial illnesses because they create vital nutrients, lipids, minerals, and vitamins that help plants flourish. *Aspergillus terreus* and *Penicillium citrinum* produce organic acids, gibberellins, and siderophores in sunflowers, which effectively suppress the growth of pathogenic fungi like *Fusarium graminearum*, *Valsa sordida*, and *Sphaeropsis sapinea* (Ling *et al.*, 2024).

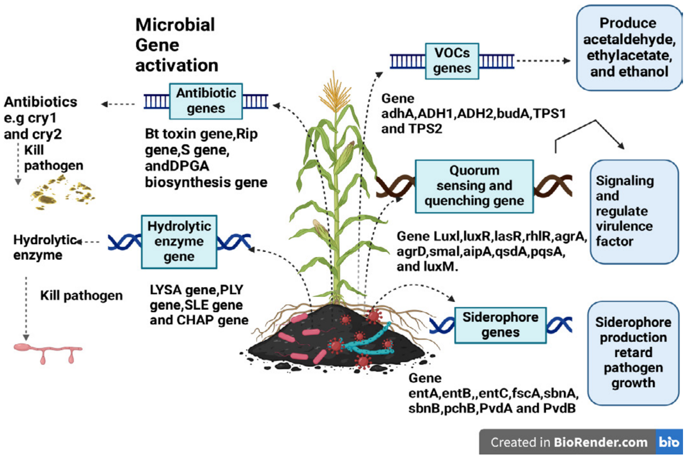

Figure 2: Intricate genes of the phytomicrobiome to regulate infectious diseases.

Viruses may infiltrate pathogens' bodies, hijack their metabolic machinery, reproduce, and induce cell lysis, ultimately killing the pathogen. Figure 2 illustrates how mycoviruses, such as DNA virus 1 (SsHADV-1) and (+) ssRNA, can suppress fungal infections. Mycoviruses have been shown to efficiently control diseases such as *Puccinia striiformis*, *Magnaporthe oryzae*, and *Sclerotinia sclerotiorum* (Contreras *et al.*, 2024). The phytomicrobiome also improves plant immunity by stimulating the generation of secondary metabolites and improving overall development (Gwa and Ekefan, 2024). The LYSA gene controls hydrolytic enzyme synthesis, which damages infectious agent cell membranes and degrades cellular organelle membranes (Grabowski *et al.*, 2021). The PLY gene creates lytic enzymes that change the structure of pathogens, reducing their potential to cause illness. These genes may be put into plants via genetic engineering to improve immunity to numerous diseases (Ma *et al*., 2024). SLE genes produce antibodies, inflammatory mediators, and immune cells, stimulating the immune system and inhibiting pathogen development. The CHAP gene is helpful in controlling bacterial illnesses because it encodes lysins that can target and destroy specific bacterial strains. While lysins are utilized outside of agriculture to prevent dangerous bacteria, their short shelf life remains a major problem (Samuel *et al*., 2024). Biotechnologists are attempting to extend the shelf life and potency of these chemicals. The ADH1 and ADH2 genes encode enzymes that detoxify hazardous compounds and are used in the synthesis of bio insecticides. These enzymes produce poisons that kill infections, demanding careful management to protect crops and beneficial bacteria (Wang *et al*., 2024). The TPS1 and TPS2 genes create volatile organic chemicals that resist infectious pathogens (Ribeiro *et al*., 2024). Pests face resource competition, and vector-borne illnesses can reduce yields significantly, frequently resulting in crop loss. However, using beneficial bacteria can help manage these fatal conditions. Emerging genetic engineering approaches seek to manipulate beneficial bacteria to improve pest control effectiveness. Figure 2 shows how synthetic biology might enhance disease management. This strategy includes inserting resistance genes into helpful microbes, allowing them to combat pests while still stimulating plant development (Saeed *et al*., 2024). Despite the benefits of biopesticides, local farmers are generally unaware of their use, and these products are not widely available on the market. Furthermore, the limited shelf life of bio-based insecticides creates issues. Researchers are continually attempting to increase the shelf life of these items. There is an urgent need to promote the use of biopesticides through awareness campaigns and assure their availability on the market. The phytomicrobiome is critical to sustained maize production and food security. Figure 2 demonstrates use of phytomicrobiome enhance immunity of maize to cope with different diseases. Microbial gene activation activates Bacillus thuringiensis toxin gene that produce antibiotics cry1 and cry2 to kill pathogen. Hydrolytic enzyme gene produces hydrolytic enzyme that directly kill disease causing microorganism. Volatile organic compound and siderophore retard pathogen growth.

Disease resistant varieties

Gene editing methods offer the potential to generate maize variants that are resistant to microbial diseases. Mega nucleases, TALENs (Transcription Activator-Like Effector Nucleases), ZFNs (Zinc Finger Nucleases), CRISPR/Cas9, CRISPR/Cas13, walk-like kinases (WAKLs), and cell wall-associated kinases (WAKs) are receptor-like kinases (RLKs) that can be used to develop resistance against fungal diseases, as illustrated in Figure 3. The ZmWAK gene was inserted into maize to reduce *Sporisorium reilianum* hyphal development, whereas ZmWAK-RLK1 improves immunity to corn leaf blight. WAK genes have an important role in microbial disease management, with ZmMM1 and ZmCCoAOMT2 shown to be beneficial against gray leaf spot disease in maize (Zhong *et al*., 2024).

Genetic breeding is an environmentally beneficial and sustainable method of maize production since it produces disease-resistant varieties that include both resistance and desirable features. The pedigree methodology may be used to develop pathogen-resistant cultivars, but the backcross method assures that these characteristics are successfully introduced. For example, the cotton rust gene has been transmitted from *Gossypium arboreum* and *Gossypium anomalum* to *Gossypium hirsutum*. Mutation breeding can also generate resistant lines by inducing mutations in seeds with alpha, beta, and X-rays. This approach activates genes that protect against certain diseases, such as *Brassica campestris*. However, mutant breeding is frequently less cost-effective and time-consuming than genome editing. The variety of bacterial pathogens makes bacterial illness treatment difficult. S genes are important in resolving this complexity since they target bacterial illnesses and can be introduced into plant species by genome editing (Zaidi *et al*., 2018). For example, *Xanthomonas oryzae* pv. *oryzae* causes bacterial blight in rice, resulting in yield losses ranging from 10% to 20%. TALE (Transcription Activator-Like Effector) proteins can signal S genes and increase their expression to help regulate such disorders. Fungal infections also cause large losses in maize production, which can be mitigated by incorporating R genes into maize types by genome editing (Chen *et al*., 2024). Powdery mildew is a serious fungal disease that affects postharvest maize. It can be controlled by adding R genes. The discovery of the milo gene has opened the door to generating disease-resistant crops, such as wheat allohexaploids, using CRISPR and TALEN editing, as seen in Figure 3. Furthermore, DNA viruses, including geminiviruses, include roughly 360 species that cause serious plant diseases. Artificial zinc finger proteins, in the absence of nucleases, can target viral replication origins and block replication proteins. ZFNs have been engineered to inhibit the replication genes of the tobacco curled shoot virus and the tomato yellow leaf curl China virus. Both CRISPR and ZFNs are potential techniques for controlling microbial illnesses in maize (Yin *et al*., 2024). MON810 maize varieties offer resistance against insect (Otim *et al*., 2022). DK777 and DK 90-98 maize varieties provide sufficient resistance against viral diseases i.e. MLND. Figure c explores the mechanism for developing resistance in maize against pathogens through inserting CRISPER case 9 technology. EMS, X ray, alpha and beta rays are used for inducing resistance through R, S, Avr and walk protein interaction in maize. S gene, walk gene, R gene and Avr gene can be proved a better tool for making maize resistance varieties against pathogen.

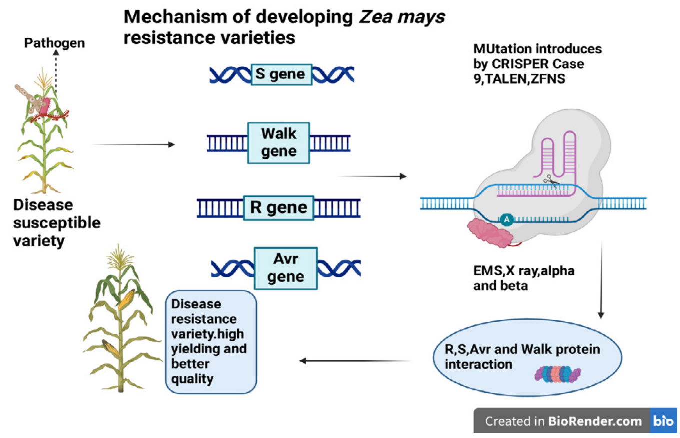

Figure 3: Explains the development of disease resistant varieties.

Crop rotation

Crop rotation is an effective technique for treating microbial illnesses because it changes the forms and functions of microbial communities in the rhizosphere. For example, rotating tobacco fields with maize can have a detrimental influence on the bacterium *Ralstonia solanacearum*, which causes tobacco bacterial wilt. Research has demonstrated that alternating tobacco with maize improves nutrient enrichment and boosts the variety of beneficial microorganisms. Tobacco –maize crop rotation enhances availability of potassium, nitrogen and phosphorus (Ma *et al.*, 2024). This rotation disturbs plant pathogens' life cycles and boosts microbial diversity, resulting in competition between pathogens and harmful bacteria, reducing pest survival rates.

Crop rotation increases microbial diversity significantly, since these microorganisms release gibberellins, secondary metabolites, and siderophores that can promote immunity in maize crops (Ma *et al.*, 2024). Maize-soybean rotation, for example, improves soil nutrients and increases microbial diversity, making it important for disease control. Soybean and maize intercropping predominately fix nitrogen in the soil and reduce pressure of pest attack (Xu *et al.* 2020). Similarly, wheat-maize rotation contributes to increased organic content in the soil, supports beneficial microbiota, and adds secondary metabolites to the field, which can help mitigate microbial diseases in maize, as illustrated in Figure 4. Wheat-maize crop rotation primarily improves organic content and availability of nutrients nitrogen, phosphorous and potassium amplified (Yang *et al.* 2024). Other crop rotations, such as *Zea mays* L. with *Brassica rapa*, maize with *Saccharum officinarum* L., maize with *Solanum tuberosum*, and maize with *Arachis hypogaea*, have also been shown to enhance microbial diversity in the rhizosphere and effectively manage microbial diseases in maize (Li *et al.*, 2021). Figure 4 focus on traditional method for managing harmful pathogens through replacing beneficial microbes by crop rotation strategy. *Solanum tuberosum* crop enhance potassium and phosphorus content in the soil and disrupt the pathogenic life cycle. *Archais hypogea, Glycine max, Nicotina taacum, Brassica rapa and Sccharum officinale* crops build up the community of beneficial microorganism.

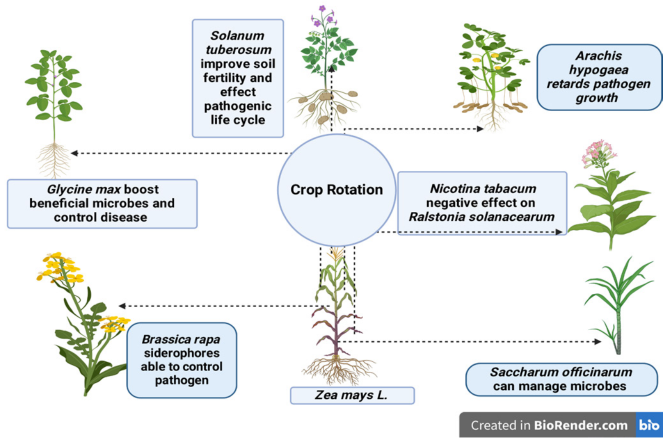

Figure 4: Elucidates maize crop rotation and its effect on infectious disease.

Nanotechnology

Nanotechnology is a contemporary method that manipulates particles on the nanoscale, which generally ranges from 1 to 100 nm. This technique has several uses in medical treatment, the food business, medicines, biological research, and environmental science. In agriculture, nanotechnology can be used to manage microbial infections and insect infestations, both of which pose considerable hazards to maize productivity. Fungal infections, in particular, can cause significant losses in maize output. Nanocomposites made from plants, bacteria, fungus, or chemicals are being researched to treat certain ailments. These nanocomposites adhere to fungal cell walls, forming holes that enable access, weakening the cell wall, penetrating the cell membrane, and eventually entering the cytoplasm. Once inside, they assault mitochondria, attach to respiratory enzymes, and prevent ATP synthesis, as shown in Figure 5. Furthermore, these nanoparticles can reach the nucleus via nuclear pores and damage DNA by forming bonds with sulfur and phosphorus, limiting mRNA production and blocking the active sites of respiratory enzymes. This chain reaction eventually kills the virus. Silver nanoparticles (AgNPs) derived from *Rhazya stricta* are antifungal against the pathogen *Alternaria alternata* (Al-Sahli *et al.*, 2024). Selenium nanoparticles also have antifungal properties, preventing mold and gray mold infections in strawberries. Silver and selenium nanocomposites in varying concentrations can be used to treat fungal infections such as *Fusarium moniliforme*, *Alternaria padwickii*, *Cephalosporium acremonium*, *Botrytis cinerea*, *Alternaria linicola*, and *Fusarium semitectum* (Hamouda *et al.*, 2024).

Metal oxide nanoparticles can produce free radicals within bacterial cells, causing the formation of reactive oxygen species and inhibiting ATP generation, ultimately resulting in bacterial cell demise, as shown in Figure E. Nickel oxide, zinc oxide, and silver oxide nanoparticles have been demonstrated to treat bacterial infections caused by *Pantoea ananatis*, *Dickeya zeae*, and *Xanthomonas vasicola* pv. *vasculorum* (Mamede *et al*., 2024). Magnesium oxide nanoparticles (MgONPs) can help plants survive both abiotic and biotic stressors. MgONPs have antibacterial characteristics that prevent pathogen colonization and proliferation by disrupting bacterial morphology and physiological activities. They can also improve plant resilience by modulating antioxidants, secondary metabolites, and hormones (Ali *et al*., 2024).

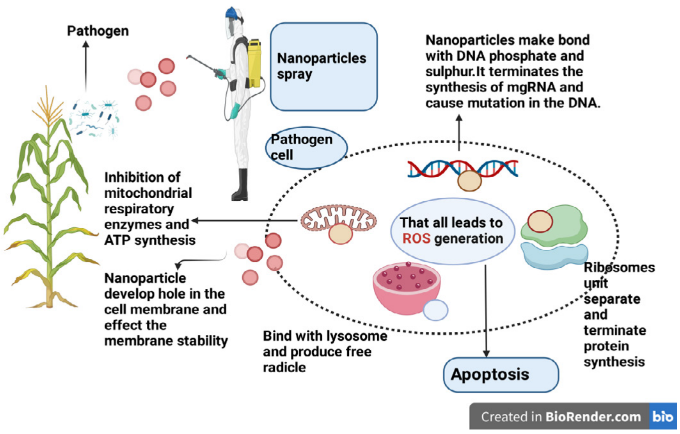

Figure 5: Pictorial overview of nanoparticles mechanism of action for killing pathogen.

Gold nanoparticles (AuNPs) have antiviral properties, notably against the maize chlorotic mottle virus (MCMV), which can result in severe maize production losses. Severe infections can result in crop destruction, particularly when MCMV co-infects with other viruses like the Johnson grass mosaic virus, maize dwarf mosaic virus (MDMV), sugarcane mosaic virus (SCMV), and wheat streak mosaic virus, causing severe necrosis and posing a threat to the global maize industry. Silver nanoparticles can effectively control MCMV by preventing the replication origin and suppressing protein synthesis (Zhong *et al*., 2024). Furthermore, silver nanoparticles have been proven to suppress the tobacco mosaic virus, consequently improving cereal crop output (Ahsan *et al*., 2023). The use of nanotechnology provides an environmentally benign and promising strategy to controlling microbiological infections in maize, contributing to sustainable agricultural output. Figure 5 elaborates the mechanism of nanotechnology to mitigate the pathogens and enhance the production of maize. Nanoparticles enter in the body of pathogen and affected the cellular organelles, inhibit mitochondria respiratory enzymes and ATP synthesis, react with lysosomes and produce free radicles that lead to oxidative stress and pathogen died.

Conclusions and Recommendations

The techniques described above will be used to successfully manage microbial infectious illnesses in maize. Introducing disease-resistant genes into maize and generating new varieties, as well as monitoring genomic sequences, can help identify genes that play important roles in resistance to both minor and serious illnesses. Using synthetic biology techniques, we will encourage the inclusion of R and WAK genes into maize. Furthermore, the phytomicrobiome should be changed to improve its capacity to combat diseases, and more study is needed to understand the complicated processes by which bacteria act as biocontrol agents. Given the immense diversity of microbiota, determining the precise mechanisms of action can be difficult; however, advances in proteomics and bioinformatics may give useful information. Sequencing the genomes of the most susceptible maize diseases is critical for developing effective management measures. In the future, the phytomicrobiome is predicted to be a strong tool for disease prevention and large-scale production. Crop rotation, albeit a classic strategy, is still a viable and cost-effective option for farmers in developing nations. This approach can improve soil fertility, enrich nutrients, reduce diseases, and boost production. Nanotechnology, as an emerging area, has great potential for combating infectious illnesses. Green-synthesized, fungal, or chemical-based nanoparticles can elicit immunity against biotic and abiotic stressors by stimulating the generation of secondary metabolites and controlling plant development, therefore improving disease resistance and increasing output. Managing infectious diseases in maize is a significant problem that requires joint research efforts from microbiologists, pathologists, geneticists, biotechnologists, horticulturists, and nanotechnologists. Such multidisciplinary dynamics will be critical for developing effective ways to reduce microbial infections in maize while increasing overall yield output.

Declarations

Acknowledgement

Author express the gratitude and recognize the contributions, guidance and support of all co-authors.

Funding

The authors declare that no external funding was received for this work.

IRB approval

Ethical approval does not apply.

Ethical approval

Ethical approval does not apply.

Declaration of generative AI and AI-assisted technologies in the writing process

No Generative AI and AI-assisted technologies wer used in the writing process.

Statement of conflict of interest

The authors have declared no conflict of interest.

References

Abebe, D., 2024. Affected, dispersal, impacts and evaluation of resistance reaction of maize streak virus. A mini review. *J. Fd. Nutr.*, **3**: 2836-2276.

Ahmed, K., Dubey, M.K. and Dubey, S., 2024. Guarding maize: Vigilance against pathogens early identification, detection, and prevention. In: *Microbial data intelligence and computational techniques for sustainable computing*. Singapore: Springer Nature Singapore. pp. 301-318. https://doi.org/10.1007/978-981-99-9621-6_19

Ahsan, T., Khalil, A., Javeed, A. and Basharat, E., 2023. Plant Virus Disease Management by Nanobiotechnology. In: *Nanophytopathology*. CRC Press. pp. 133-144. https://doi.org/10.1201/9781003344513-10

Akanmu, A.O. and Babalola, O.O., 2024. *Characterization and biocontrol potential of some rhizobacteria against fungal pathogens causing foliar diseases in maize*.

Ali, S., Ulhassan, Z., Shahbaz, H., Kaleem, Z., Yousaf, M.A., Ali, S. and Zhou, W., 2024. Magnesium oxide nanoparticles as novel sustainable approach in enhancing crop tolerance to abiotic and biotic stresses. *Environ. Sci. Nano.*, **11**(8): 3250-3267. https://doi.org/10.1039/D4EN00417E

Zhang, C., Guo, M., Dong, J., Liu, L., Zhou, X. and Wu, J., 2023. Visual and super-sensitive detection of Maize chlorotic mottle virus by dot-ELISA and Au Nanoparticle-based immunochromatographic test strip. *Viruses*, **15**: 1607. https://doi.org/10.3390/v15071607

Almasoudi, N.M., Al-Qurashi, A.D., Elsayed, M.I. and Abo-Elyousr, K.A., 2024. Native bacterial bioagents for management of potato soft rot disease caused by *Pectobacterium carotovorum* subsp. carotovorum. *Egypt. J. Biol. Pest Contr.*, **34**: 31. https://doi.org/10.1186/s41938-024-00794-4

Al-Sahli, S.A., Al-Otibi, F., Alharbi, R.I., Amina, M. and Al-Musayeib, N.M., 2024. Silver nanoparticles improve the fungicidal properties of *Rhazya stricta* decne aqueous extract against plant pathogens. *Sci. Rep.*, **14**: 1297. https://doi.org/10.1038/s41598-024-51855-5

Anderson, N.R., McCoy, A.G., Castellano, C., Chilvers, M.I., Alinger, E., Allen, T.W. and Wise, K.A., 2024. Sensitivity of the causal agent of northern leaf blight of corn, *Exserohilum turcicum*, to the demethylase-inhibiting fungicide flutriafol. *Pl. Hlth. Progr.*, pp. PHP-11.

Arias, S.L., Block, C.C., Mayfield, D.A., Santillana, G., Stulberg, M.J., Broders, K.D. and Munkvold, G.P., 2020. Occurrence in seeds and potential seed transmission of *Xanthomonas vasicola* pv. vasculorum in maize in the United States. *Phytopathology*, **110**: 1139-1146. https://doi.org/10.1094/PHYTO-08-19-0306-R

Ashwini, S., Prashanthi, S.K., Vidyashankar, D., Hegde, Y.R., Krishnaraju, P.U., Muttappagol, M. and Krishnanand, I., 2024. Insights into the virulence profiles and molecular diversity of *Xanthomonas oryzae* pv. oryzae isolates associated with bacterial blight of rice in major districts of Karnataka, India. *Physiol. Mol. Pl. Pathol.*, pp. 102338. https://doi.org/10.1016/j.pmpp.2024.102338

Bathke, K.J., Jochum, C.C. and Yuen, G.Y., 2022. Biological control of bacterial leaf streak of corn using systemic resistance-inducing Bacillus strains. *Crop Prot.*, **155**: 105932. https://doi.org/10.1016/j.cropro.2022.105932

Baudron, F., Cairns, J.E., Haefele, S.M., Hassall, K.L., Ndhlela, T., Nyagumbo, I. and Joy, E.J., 2024. Projecting the contribution of provitamin A maize biofortification and other nutrition interventions to the nutritional adequacy and cost of diets in rural Zimbabwe. *J. Nutr.*, **154**: 1815-1826. https://doi.org/10.1016/j.tjnut.2024.04.009

Biswal, A.K., Alakonya, A.E., Mottaleb, K.A., Hearne, S.J., Sonder, K., Molnar, T.L. and Prasanna, B.M., 2022. Maize lethal necrosis disease: Review of molecular and genetic resistance mechanisms, socio-economic impacts, and mitigation strategies in sub-Saharan Africa. *BMC Pl. Biol.*, **22**: 542. https://doi.org/10.1186/s12870-022-03932-y

Borowik, P., Stocki, M., Tkaczyk, M., Pluta, P., Oszako, T., Tarakowski, R. and Okorski, A., 2024. The differentiation of the infestation of wheat grain with *Fusarium poae* from three other *Fusarium* species by GC–MS and electronic nose measurements. *Agriculture*, **14**: 1028. https://doi.org/10.3390/agriculture14071028

Campos, M.D., Patanita, M., Campos, C., Materatski, P., Varanda, C.M., Brito, I. and Felix, M.D.R., 2019. Detection and quantification of *Fusarium* spp.(*F. oxysporum, F. verticillioides, F. graminearum*) and *Magnaporthiopsis maydis* in maize using real-time PCR targeting the ITS region. *Agronomy*, **9**: 45. https://doi.org/10.3390/agronomy9020045

Chen, R., Gajendiran, K. and Wulff, B.B., 2024. R we there yet? Advances in cloning resistance genes for engineering immunity in crop plants. *Curr. Opin. Pl. Biol.*, **77**: 102489. https://doi.org/10.1016/j.pbi.2023.102489

Chiangkhaek, O. and Akarapisan, A., 2024. Characterization and identification of *Burkholderia gladioli* causing stalk rot of sweet corn in Thailand. *J. Phytopathol.*, **172**: e13314. https://doi.org/10.1111/

jph.13314

Contreras-Soto, M.B. and Tovar-Pedraza, J.M., 2024. Viruses of plant-pathogenic fungi: A promising biocontrol strategy for *Sclerotinia sclerotiorum*. *Arch. Microbiol.*, **206**: 38. https://doi.org/10.1007/s00203-023-03774-8

Degani, O., 2021. A review: Late wilt of maize the pathogen, the disease, current status, and future perspective. *J. Fungi*, **7**: 989. https://doi.org/10.3390/jof7110989

Deshapande, A.S., Giraddi, S.G., Karibasappa, K.G. and Desai, S.D., 2019. Fungal disease detection in maize leaves using haar wavelet features. In: *Information and communication technology for intelligent systems: Proceedings of ICTIS 2018*. Springer Singapore. 1: 275-286. https://doi.org/10.1007/978-981-13-1742-2_27

Dinesh, R., Anand, C., John, K.R., George, M.R., Bharathi, S. and Kumar, J.S., 2022. An overview of chemicals and drugs in aquaculture disease management. *Indian J. Anim. Hlth.*, **62**: 1-20. https://doi.org/10.36062/ijah.2022.05222

Dorigan, A.F., Barros, A.V., Moreira, S.I., Ferreira, A.N. and Alves, E., 2024. Use of confocal laser scanning microscopy to locate *Stenocarpella maydis* in corn stalk (*Zea mays*). https://doi.org/10.21203/rs.3.rs-4566140/v1

Emeraghi, M., Achigan-Dako, E. G., Nwaoguala, C. N. and Oselebe, H., 2021. Maize streak virus research in Africa: an end or a crossroad. *Theoret. Appl. Genet.*, **134**(12): 3785-3803.

Farthing, W.M., 2024. *Role of the Leucine-responsive regulatory protein during growth of the bacterial corn pathogen Pantoea stewartii subspecies stewartii in the xylem environment*. Doctoral dissertation, Virginia Tech.

Galani, Y.J.H., Orfila, C. and Gong, Y.Y., 2022. A review of micronutrient deficiencies and analysis of maize contribution to nutrient requirements of women and children in Eastern and Southern Africa. *Crit. Rev. Fd. Sci. Nutr.*, **62**: 1568-1591. https://doi.org/10.1080/10408398.2020.1844636

Gao, Q., Zang, Y., Qiao, J.H., Zhang, Z.Y., Wang, Y., Han, C.G. and Wang, X.B., 2024. The plant rhabdovirus viroporin P9 facilitates insect-mediated virus transmission in barley. *Plant Cell*, koae162. https://doi.org/10.1093/plcell/koae162

Gao, X., Du, Z., Hao, K., Zhang, S., Li, J., Guo, J. and Wu, Y., 2024. ZmmiR398b negatively regulates maize resistance to sugarcane mosaic virus infection by targeting ZmCSD2/4/9. *Mol. Pl. Pathol.*, **25**: e13462. https://doi.org/10.1111/mpp.13462

Gentzel, I.N., Paul, P., Wang, G.L. and Ohlson, E.W., 2024. Effects of maize chlorotic mottle virus and potyvirus resistance on maize lethal necrosis disease. *Phytopathology®*, **114**: 484-495. https://doi.org/10.1094/PHYTO-05-23-0171-R

Grabowski, Ł., Łepek, K., Stasiłojć, M., Kosznik-Kwaśnicka, K., Zdrojewska, K., Maciąg-Dorszyńska, M. and Węgrzyn, A., 2021. Bacteriophage-encoded enzymes destroying bacterial cell membranes and walls, and their potential use as antimicrobial agents. *Microbiol. Res.*, **248**: 126746. https://doi.org/10.1016/j.micres.2021.126746

Gubišová, M., Hudcovicová, M., Hrdlicová, M., Ondreičková, K., Cilík, P., Klčová, L. and Gubiš, J., 2024. Superabsorbent seed coating and its impact on fungicide efficacy in a combined treatment of barley seeds. *Agriculture*, **14**: 707. https://doi.org/10.3390/agriculture14050707

Gwa, V.I. and Ekefan, E.J., 2024. Microbial secondary metabolites and their roles in biocontrol of phytopathogens. In: *Bioactive microbial metabolites*. Academic Press. pp. 1-30. https://doi.org/10.1016/B978-0-443-18568-7.00007-0

Haas, I.C.R., Canale, M.C., Lopes, J.R.S., Pascholati, S.F. and Bedendo, I.P., 2023. Biochemical modifications and corn stunt progression is dependent on maize susceptibility to *Spiroplasma kunkelii* infection. *Tropical Pl. Pathol.*, **48**: 556-563. https://doi.org/10.1007/s40858-023-00598-1

Hamouda, R.A., Abdel-Hamid, M.S., Hagagy, N. and Nofal, A.M., 2024. The potent effect of selenium nanoparticles: Insight into the antifungal activity and preservation of postharvest strawberries from gray mold diseases. *J. Sci. Fd. Agric.*, **104**(11): 6756-6768. https://doi.org/10.1002/jsfa.13502

Han, X., Yang, X., Chen, S., Wang, H., Liu, X., Wang, D. and Shi, Y., 2024. Barley yellow dwarf virus-GAV 17K protein disrupts thiamine biosynthesis to facilitate viral infection in plants. *Pl. J.*, **119**(1): 432-444. https://doi.org/10.1111/tpj.16772

Harish, J., Venkateshbabu, G., Prasannakumar, M.K., Devanna, P., Mahesh, H.B., Balasundara, D.C. and Jambhulkar, P.P., 2024. Stalk rot species diversity and molecular phylogeny associated with diseased maize in India. *World J. Microbiol. Biotechnol.*, **40**: 185. https://doi.org/10.1007/s11274-024-03991-3

Heidari, M. and Aeini, M., 2024. Stenotrophomonas maltophilia causing maize (*Zea mays* L.) seedling soft rot disease, an emerging threat to maize crop. *J. Phytopathol.*, **172**: e13299. https://doi.org/10.1111/jph.13299

Hoffmann, A., Zenelt, W. and Krawczyk, K., 2024. Wpływ metody inokulacji roślin kukurydzy patogenami bakteryjnymi na powstawanie i rozwój objawów chorobowych. *Progr. Pl. Prot.*, **64**.

Holan, K.L., White, C.H. and Whitham, S.A., 2024. Application of a U-net neural network to the puccinia sorghi–maize pathosystem. *Phytopathology®*, PHYTO-09. https://doi.org/10.1094/PHYTO-09-23-0313-KC

Jatoth, R., Kashyap, A.S., Babu, P.L., Singh, D., Gogoi, R., Manzar, N. and Padaria, J.C., 2024. Unravelling the aetiology of *Dickeya zeae* using polyphasic approaches for bacterial stalk rot in maize. *Pl. Pathol.*, **73**: 1007-1022. https://doi.org/10.1111/ppa.13858

Jones, M.W. and Ohlson, E.W., 2024. Susceptibility and yield response of commercial corn hybrids to maize dwarf mosaic disease. *Pl. Dis.*, **108**(6): 1786-1792. https://doi.org/10.1094/PDIS-01-24-0155-RE

Kashyap, P.L., Kumar, S., Kaul, N., Kapoor, P., Jasrotia, P. and Singh, G.P., 2024. Emerging and re-emerging viruses of wheat: Current status and future challenges. In: *Viral diseases of field and horticultural crops*. Academic Press. pp. 49-53. https://doi.org/10.1016/B978-0-323-90899-3.00093-8

Kaur, R., Chopra, Y. and Saini, D.K., 2024. Emerging biotechnological tools for rice bakanae/foot rot disease resistance. In: *Fungal diseases of rice and their management*. Apple Academic Press. pp. 311-347. https://doi.org/10.1201/9781003332169-16

Khanna, M., Kumari, P., Sharma, T., Angira, A., Choudhary, N., Kaushal, L. and Awasthi, L.P., 2024. Maize. In: *Viral diseases of field and horticultural crops*. Academic Press. pp. 87-92. https://doi.org/10.1016/B978-0-323-90899-3.00092-6

Kimani, E.N., Micheni, C.M., Muriki, L.G., Kiarie, S.M., Miano, D.W., Macharia, I. and Wangai, A., 2024. Influence of genotypes and crop growth stage at time of infection on seed transmission of *Maize chlorotic* mottle virus. *Arch. Phytopathol. Pl. Prot.*, **57**: 95-111. https://doi.org/10.1080/03235408.2024.2331040

Kumar, P. and Murali, V., 2023. A review on soil and phytomicrobiome for plant disease management. *Int. J. Environ. Clim. Change*, **13**: 2890-2904. https://doi.org/10.9734/ijecc/2023/v13i102955

Kumar, P., Sharma, R. and Kumar, K., 2024. A perspective on varied fungal virulence factors causing infection in host plants. *Mol. Biol. Rep.*, **51**: 392. https://doi.org/10.1007/s11033-024-09314-x

Li, G., Xu, Z., Wang, J., Mu, C., Zhou, Z., Li, M. and Weng, J., 2024. Gene pyramiding of ZmGLK36 and ZmGDIα-hel for rough dwarf disease resistance in maize. *Mol. Breed.*, **44**: 25. https://doi.org/10.1007/s11032-024-01466-9

Li, M., Guo, J., Ren, T., Luo, G., Shen, Q., Lu, J. and Ling, N., 2021. Crop rotation history constrains soil biodiversity and multifunctionality relationships. *Agric. Ecosyst. Environ.*, **319**: 107550.

Li, J., Huang, L., Zhang, J., Coulter, J.A., Li, L. and Gan, Y., 2019. Diversifying crop rotation improves system robustness. Agron. Sustain. Dev., **39**. https://doi.org/10.1007/s13593-019-0584-0

Lindsey, A., Philomena, J., Murugan, S. and Renitta, R.M., 2020. Microbial disease management in agriculture: Current status and future prospects. *Biocatal. Agric. Biotechnol.*, **23**: 101468. https://doi.org/10.1016/j.bcab.2019.101468

Ling, L., Feng, L., Li, Y., Yue, R., Wang, Y. and Zhou, Y., 2024. Endophytic fungi volatile organic compounds as crucial biocontrol agents used for controlling fruit and vegetable postharvest diseases. *J. Fungi*, **10**: 332. https://doi.org/10.3390/jof10050332

Ma, H.K., Wang, Z.J., Li, M.J., Rao, Q.L., Cai, J. and Gu, X.F., 2024. Deciphering the effects of crop rotation on tobacco bacterial wilt through general and specific disease suppression. *Eur. J. Pl. Pathol.*, **168**: 501-514. https://doi.org/10.1007/s10658-023-02779-9

Ma, J., Liu, D., Zhao, P., Dou, M., Yang, X., Liu, S. and Liu, Y., 2024. Intercropping of tobacco and maize at seedling stage promotes crop growth through manipulating rhizosphere microenvironment. *Front. Pl. Sci.*, **15**: 1470229. https://doi.org/10.3389/fpls.2024.1470229

Ma, R., Zhu, B., Xiong, J. and Chen, J., 2024. The pathogenic mechanism of *Enterocytozoon hepatopenaei* in *Litopenaeus vannamei*. *Microorganisms*, **12**: 1208. https://doi.org/10.3390/microorganisms12061208

Magdy, I.F.N., Barro, M., Bangratz, M., Sérémé, D., Filloux, D., Fernandez, E. and Poulicard, N., 2024. Old foe, New host: Epidemiology, genetic diversity, and pathogenic characterization of maize streak virus in rice fields from Burkina Faso. Special Focus Issue, 9.

Mamede, M.C., Silva, A.C.A. and Tebaldi, N.D., 2024. Dickeya zeae, Pantoea ananatis, and Xanthomonas vasicola pv. vasculorum: Control with the use of nanoparticles. *Ciência e Agrotecnol.*, **48**: e018423. https://doi.org/10.1590/1413-7054202448018423

Mangeli, F., Sistani, F., Lori, Z., Azadvar, M., Hosseinipour, A. and Shahriyari, N., 2024. First report of maize leaf blight disease caused by *Pantoea stewartii* subsp indologenes in Kerman Province, Iran. *Crop Prot.*, pp. 106836. https://doi.org/10.1016/j.cropro.2024.106836

Marais, I., Buitendag, C., Duong, T.A., Crampton, B.G., Theron, J., Kidanemariam, D. and Berger, D.K., 2024. Double-stranded RNA uptake for the control of the maize pathogen *Cercospora zeina*. *Pl. Pathol.*, **73**(6): 1480-1490. https://doi.org/10.1111/ppa.13909

Mehl, H.L., 2024. Sorghum. In: *Agrios plant pathology*. Academic Press. pp. 781-787. https://doi.org/10.1016/B978-0-12-822429-8.00036-4

Meshram, S., Gogoi, R., Bashyal, B.M., Mandal, P.K., Hossain, F. and Kumar, A., 2024. Investigation on comparative transcriptome profiling of resistant and susceptible non-CMS maize genotypes during *Bipolaris maydis* race O infection. *Heliyon*, **10**. https://doi.org/10.1016/j.heliyon.2024.e26538

Nisar, A., ul Haq, I., Habib, A. and Arshad, M., 2025. Diversity and identification of *Metarhizium anisopliae* isolates from maize ecosystems in Punjab, Pakistan. *Pak. J. Agri. Sci.*, **62**: https://doi.org/10.21162/PAKJAS/25

Ngairangbam, H., Kaur, A.P., Singh, G. and Menon, S., 2024. Effect of different spacing and nutrient management on growth and yield of maize: A review. *J. Adv. Biol. Biotechnol.*, **27**: 682-692. https://doi.org/10.9734/jabb/2024/v27i6928

Obasa, K., Coker, D. and Santiago-González, J.C., 2024. Late-season decline, a bacterial disease of corn caused by *Pantoea ananatis*, identified in sorghum. *Pl. Hlth. Prog.*, **25**(4): 348-352. https://doi.org/10.1094/PHP-04-24-0038-SC

Ohlson, E.W., Khatri, N. and Wilson, J.R., 2024. Experimental host and vector ranges of the emerging maize yellow mosaic polerovirus. *Pl. Dis.*, **108**: 1246-1251. https://doi.org/10.1094/PDIS-06-23-1124-RE

Otim, M.H., Alibu, S., Asea, G., Abalo, G., Sserumaga, J.P., Adumo, S. and Oikeh, S.O., 2022. Performance of Bt maize event MON810 in controlling maize stem borers *Chilo partellus* and *Busseola fusca* in Uganda. Crop Prot., **156**: 105945. https://doi.org/10.1016/j.cropro.2022.105945

Plazas, M.C., de Rossi, R.L., Brücher, E., Guerra, F.A., Vilaro, M.L., Guerra, G.D. and Broders, K., 2018. *First report of* Xanthomonas vasicola *pv. vasculorum causing bacteria leaf streak of maize* (Zea mays) *in Argentina*. https://doi.org/10.1094/PDIS-10-17-1578-PDN

Ribeiro, G.D., de Holanda, P.L. and Eleutherio, E.C.A., 2024. Trehalose promotes biological fitness of fungi. *Fungal Biol.*, **128**(8): 2381-2389. https://doi.org/10.1016/j.funbio.2024.03.004

Saeed, M., Ilyas, N., Sarfraz, S. and Chanda, S., 2024. Role of crop microbiomes in crop production under changing climate: Past, present and future. In: *Plant holobiome engineering for climate-smart agriculture*. Singapore: Springer Nature Singapore. pp. 87-98. https://doi.org/10.1007/978-981-99-9388-8_6

Sahgal, M., Saini, N., Jaggi, V., Brindhaa, N.T., Kabdwal, M., Singh, R.P. and Prakash, A., 2024. Antagonistic potential and biological control mechanisms of Pseudomonas strains against banded leaf and sheath blight disease of maize. *Sci. Rep.*, **14**: 13580. https://doi.org/10.1038/s41598-024-64028-1

Samuel, F.U., Afolabi, M.S., Njideka, A., Ogunkunle, N., Bamidele, K.J. and Kolo, H.N., 2024. Diseases of the scrotum-chapter 20-In: Element of reproduction and reproductive diseases of goats. John Wiley and Sons, Inc., https://doi.org/10.1002/9781394190089.ch20

Savov, S., Marinova, B., Teofanova, D., Savov, M., Odjakova, M. and Zagorchev, L., 2024. Parasitic plants potential vectors of phytopathogens. *Pathogens*, **13**: 484. https://doi.org/10.3390/pathogens13060484

Savary, S., Willocquet, L., Pethybridge, S. J., Esker, P., McRoberts, N. and Nelson, A., 2019. The global burden of pathogens and pests on major food crops. *Nature Ecol. Evolut.,* **3**(3): 430-439.

Sharma, D., Gautam, H.R., Chandel, S., Thakur, K. and Sharma, P.L., 2024. Seed biopriming with antagonistic microbes and their defense activity against damping-off disease in solanaceous vegetable crops. *Indian Phytopathol.*, pp. 1-7. https://doi.org/10.1007/s42360-024-00748-8

Soliman, A., Gulden, R.H., Tambong, J.T., Bajracharya, P., Adam, L.R., Xu, R. and Daayf, F., 2018. Developed and validated inoculation and disease assessment methods for Goss's bacterial wilt and leaf blight disease of corn. *Crop Prot.*, **112**: 159-167. https://doi.org/10.1016/j.cropro.2018.05.022

Telichko, O.G., Belova, T.Y., Syrmolot, O. and Lastushkina, E., 2024. Field evaluation of specimens from a corn collection for resistance to *Helminthosporium turcicum* pass and *Fusarium moniliforme* Scheldon. In: *E3S Web of conferences*. EDP Sciences. **480**: 03008. https://doi.org/10.1051/e3sconf/202448003008

Toaza, A., Caiza, R.B., Garrido, A.D., Moreno, C.R., Guevara, J., Regalado, H. and Garrido, P.A., 2021. First report of *Pantoea ananatis* causing leaf spot disease of maize in Ecuador. *Pl. Dis.*, **105**: 3286. https://doi.org/10.1094/PDIS-02-21-0298-PDN

Trinidad-Calderon, P.A., Acosta-Cruz, E., Rivero-Masante, M.N., Diaz-Gomez, J.L., Garcia-Lara, S. and Lopez-Castillo, L.M., 2021. Maize bioactive peptides: From structure to human health. *J. Cereal Sci.*, **100**: 103232. https://doi.org/10.1016/j.jcs.2021.103232

Usanga, D.A., Owolabi, A.T. and Eyong, O.I., 2024. Biological, serological and molecular characterization of Cucumber mosaic virus (CMV) infecting cucurbita moschata (duchene ex. Poir) (summer squash) in Itu and Uyo local governments areas, Akwa Ibom State, Nigeria. *Asian J. Biochem. Genet. Mol. Biol.*, **16**: 19-31. https://doi.org/10.9734/ajbgmb/2024/v16i6379

Wang, R., Du, C., Gu, G., Zhang, B., Lin, X., Chen, C. and Xie, X., 2024. Genome-wide identification and expression analysis of the ADH gene family under diverse stresses in tobacco (*Nicotiana tabacum* L.). *BMC Genom.*, **25**: 13. https://doi.org/10.1186/s12864-023-09813-4

Wu, Q., Xu, F., Liu, L., Char, S. N., Ding, Y., Je, B. I. and Jackson, D., 2020. The maize heterotrimeric G protein β subunit controls shoot meristem development and immune responses. *Proceed. Natl. Acad. Sci.,* **117**: 1799-1805.

Xavier, C.A., Tyson, C., Kerner, L.M. and Whitfield, A.E., 2024. RNAi-mediated knockdown of exportin 1 negatively affected ovary development, survival and maize mosaic virus accumulation in its insect vector *Peregrinus maidis*. *Insect Mol. Biol.,* **33**(4): 295-311. https://doi.org/10.1101/2023.09.19.558515

Xu, X., Zhang, L., Yang, X., Cao, H., Li, J., Cao, P. and Xiang, W., 2022. *Alternaria* spp. associated with leaf blight of maize in Heilongjiang Province, China. *Pl. Dis.*, **106**: 572-584. https://doi.org/10.1094/PDIS-06-21-1151-RE

Xu, Z., Li, C., Zhang, C., Yu, Y., van der Werf, W. and Zhang, F., 2020. Intercropping maize and soybean increases efficiency of land and fertilizer nitrogen use; A meta-analysis. Field Crops Res., **246**: 107661. https://doi.org/10.1016/j.fcr.2019.107661

Yang, X., Xiong, J., Du, T., Ju, X., Gan, Y., Li, S. and Butterbach-Bahl, K., 2024. Diversifying crop rotation increases food production, reduces net greenhouse gas emissions and improves soil health. Nat. Commun., **15:** https://doi.org/10.1038/s41467-023-44464-9

Yin, K. and Qiu, J.L., 2019. Genome editing for plant disease resistance: Applications and perspectives. *Philos. Trans. R. Soc. B*, **374**: 20180322. https://doi.org/10.1098/rstb.2018.0322

Yin, P., Fu, X., Feng, H., Yang, Y., Xu, J., Zhang, X. and Yang, X., 2024. Linkage and association mapping in multi- parental populations reveal the genetic basis of carotenoid variation in maize kernels. *Plant Biotech. J.*, **22**(8): 2312-2326.

Zaidi, S.S.E.A., Mukhtar, M.S. and Mansoor, S., 2018. Genome editing: Targeting susceptibility genes for plant disease resistance. *Trends Biotechnol.*, **36**: 898-906. https://doi.org/10.1016/j.tibtech.2018.04.005

Zhong, T., Zhu, M., Zhang, Q., Zhang, Y., Deng, S., Guo, C. and Xu, M., 2024. The ZmWAKL–ZmWIK–ZmBLK1–ZmRBOH4 module provides quantitative resistance to gray leaf spot in maize. *Nat. Genet.*, **56**: 315-326. https://doi.org/10.1038/s41588-023-01644-z