

Seed-Borne Diseases and Their Prevention

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Abstract

Seed-borne diseases represent one of the most significant constraints to sustainable agricultural production worldwide. Seeds act as efficient carriers of numerous fungal, bacterial, viral, and nematode pathogens, facilitating their survival, dissemination, and transmission across geographical regions and cropping seasons. The presence of seed-borne pathogens adversely affects seed germination, seedling establishment, crop growth, yield, and quality, while also posing challenges to international seed trade due to stringent phytosanitary regulations. In modern agriculture, where quality seed forms the foundation of profitable crop production, the management of seed-borne diseases has become increasingly important. Effective prevention requires an integrated approach involving the production of pathogen-free seeds, accurate diagnosis, seed health testing, chemical and biological seed treatments, resistant cultivars, and appropriate storage and handling practices. Recent advances in molecular diagnostics, nanotechnology, biological control agents, and precision seed treatment technologies have significantly improved the detection and management of seed-borne pathogens. This article discusses the nature of seed-borne diseases, their modes of transmission, major causal organisms, economic significance, diagnostic methods, and integrated prevention strategies, highlighting the importance of maintaining seed health for sustainable agricultural productivity and global food security.

Introduction

Seeds serve as the primary planting material for agricultural crops and represent the starting point of the entire crop production system. The genetic potential of a crop can only be realized when seeds are healthy, vigorous, and free from pathogens. Unfortunately, numerous microorganisms survive either externally on the seed coat or internally within seed tissues, making seeds an effective vehicle for the transmission of plant diseases. Such pathogens are collectively referred to as seed-borne pathogens, and the diseases they cause are known as seed-borne diseases.

Seed-borne diseases have been recognized since the early development of agriculture. Historical epidemics such as loose smut of wheat, bacterial blight of rice, and bean anthracnose have demonstrated how infected seed lots can introduce devastating diseases into previously disease-free areas. In addition to reducing crop productivity, seed-borne pathogens affect seed quality, marketability, germination percentage, seedling vigor, and storage life. According to estimates, seed-borne diseases account for significant annual yield losses in major cereal, pulse, vegetable, oilseed, and horticultural crops throughout the world. The globalization of agriculture and international movement of seeds have further increased the importance of seed health. Modern seed certification systems, quarantine regulations, and phytosanitary measures emphasize the necessity of preventing pathogen dissemination through seeds. Consequently, the study of seed pathology has emerged as an important discipline integrating plant pathology, seed technology, microbiology, molecular biology, and crop management. Understanding the biology of seed-borne pathogens and adopting integrated preventive measures are essential for ensuring sustainable crop production and maintaining food security.

Seed-Borne Diseases and Their Characteristics

A seed-borne disease is defined as a disease in which the pathogen is carried by or associated with the seed and is capable of infecting the developing seedling or subsequent crop. Pathogens may contaminate the seed surface externally or invade internal tissues such as the seed coat, endosperm, embryo, or cotyledons. Internal infections are generally more difficult to detect and eliminate because the pathogens remain protected within seed tissues.

Seed-borne pathogens include fungi, bacteria, viruses, phytoplasmas, and nematodes. Fungi constitute the largest group and include economically important genera such as *Fusarium*, *Alternaria*, *Aspergillus*, *Penicillium*, *Colletotrichum*, *Bipolaris*, *Ustilago*, and *Tilletia*. Bacterial pathogens include species of *Xanthomonas*, *Pseudomonas*,

Clavibacter, and *Acidovorax*. Several plant viruses, including Bean common mosaic virus, Cucumber mosaic virus, and Lettuce mosaic virus, are transmitted through infected seeds. Certain nematodes, particularly *Anguina tritici* responsible for ear cockle disease of wheat, are also disseminated through seeds.

Depending on their location within the seed, pathogens may be classified as externally seed-borne or internally seed-borne. External contamination occurs when spores, bacterial cells, or viral particles adhere to the seed surface during harvesting, threshing, or storage. Internal infection results from pathogen invasion during flowering, seed development, or maturation, allowing the pathogen to survive within the seed tissues until germination. The severity of seed-borne diseases depends upon several interacting factors including the level of seed infection, pathogen virulence, environmental conditions, host susceptibility, seed storage conditions, and cultural practices adopted during crop cultivation.

Modes of Seed Transmission

Seed transmission occurs through several mechanisms. In many crops, pathogens infect floral organs and subsequently invade developing seeds. The pathogen survives within the embryo or endosperm and becomes active during seed germination. In other cases, pathogens contaminate seed surfaces during harvesting or post-harvest operations. Upon sowing, infected seeds become primary sources of inoculum. Germinating pathogens colonize emerging roots, shoots, or cotyledons, resulting in seed rot, damping-off, seedling blight, vascular infections, or systemic colonization. Some pathogens remain latent during early growth stages and express symptoms only during flowering or grain formation, making disease management particularly challenging.

Seed-borne pathogens may also establish secondary disease cycles after primary infection. Airborne spores, rain splash, insect vectors, irrigation water, or mechanical operations facilitate further spread within the crop, thereby amplifying disease severity throughout the growing season.

Major Seed-Borne Diseases of Agricultural Crops

Numerous economically important diseases are transmitted through seeds. Loose smut of wheat caused by *Ustilago tritici* survives within the embryo and produces characteristic black spore masses in place of grains. Karnal bunt and common bunt also represent important seed-associated fungal diseases affecting wheat production and grain quality. Rice is affected by bacterial leaf blight caused by *Xanthomonas oryzae* pv. *oryzae*, brown spot caused by *Bipolaris oryzae*, and bakanae disease caused by *Fusarium*

fujikuroi, all of which can be transmitted through infected seeds. Bakanae disease is characterized by abnormal elongation, chlorosis, and eventual death of seedlings.

In legumes, anthracnose caused by *Colletotrichum lindemuthianum* and bacterial blights are important seed-transmitted diseases. Groundnut seeds frequently carry *Aspergillus flavus*, which not only reduces germination but also produces aflatoxins, posing significant food safety concerns.

Vegetable crops experience considerable losses due to seed-borne bacterial pathogens. Black rot of crucifers caused by *Xanthomonas campestris* pv. *campestris*, bacterial canker of tomato caused by *Clavibacter michiganensis*, and bacterial fruit blotch of watermelon caused by *Acidovorax citrulli* are examples where infected seed serves as the principal means of disease dissemination.

Fruit and ornamental crops are also vulnerable to seed-borne fungal pathogens, although vegetative propagation often predominates in these crops. Nevertheless, nursery production relies heavily on pathogen-free seeds to prevent disease outbreaks during seedling establishment.

Economic Importance

The economic impact of seed-borne diseases extends beyond direct yield reduction. Infected seeds often exhibit poor germination, reduced vigor, and weak seedling establishment, leading to uneven crop stands and lower plant populations. Reduced photosynthetic efficiency, impaired nutrient uptake, and premature plant death further contribute to yield losses.

Quality deterioration is another major concern. Grain discoloration, shriveled seeds, toxin contamination, and poor milling quality significantly reduce market value. In export-oriented agriculture, seed lots contaminated with quarantine pathogens may be rejected, resulting in substantial economic losses for seed producers and exporters. Additional expenditures arise from repeated sowing, increased fungicide applications, crop monitoring, disease surveillance, and certification requirements. Therefore, investment in preventive seed health management is considerably more economical than managing disease outbreaks after crop establishment.

Detection and Diagnosis of Seed-Borne Pathogens

Accurate diagnosis forms the cornerstone of effective disease prevention. Conventional seed health testing methods include dry seed inspection, washing tests, blotter tests, agar plate methods, embryo examination, and grow-out tests. These techniques facilitate the detection of fungal growth, bacterial colonies, symptom expression, and seedling abnormalities.

Microscopic examination enables the identification of fungal spores and bacterial structures associated with infected seeds. Serological techniques such as enzyme-linked immunosorbent assay (ELISA) provide rapid detection of viral and bacterial pathogens using antigen-antibody reactions. Recent advances in molecular biology have revolutionized seed health diagnostics. Polymerase chain reaction (PCR), quantitative PCR (qPCR), loop-mediated isothermal amplification (LAMP), DNA sequencing, and next-generation sequencing enable highly sensitive and specific detection of pathogens even at very low infection levels. These techniques support rapid certification of pathogen-free seed lots and facilitate early intervention before disease outbreaks occur.

Artificial intelligence-assisted image analysis, hyperspectral imaging, biosensors, and machine learning algorithms are emerging as promising tools for non-destructive and high-throughput seed health assessment, improving the speed and accuracy of pathogen detection.

Prevention and Management of Seed-Borne Diseases

Successful prevention of seed-borne diseases relies on integrating multiple management strategies rather than depending on a single approach. The use of certified disease-free seed remains the most effective preventive measure. Certified seeds undergo rigorous field inspection, laboratory testing, and quality assurance procedures to ensure minimal pathogen contamination. Healthy seed production begins in the field through proper crop rotation, sanitation, balanced fertilization, irrigation management, and timely disease control. Removal of infected plants, destruction of crop residues, and elimination of volunteer hosts reduce the initial inoculum available for seed infection. Isolation distances should be maintained during seed production to minimize cross-contamination from neighbouring infected fields.

Seed treatment continues to be one of the most economical and efficient methods of disease prevention. Chemical seed dressers containing fungicides such as carbendazim, thiram, captan, metalaxyl, tebuconazole, difenoconazole, and fludioxonil effectively suppress numerous fungal pathogens. Bactericides and disinfectants may also be used where bacterial seed-borne diseases are prevalent. However, indiscriminate use of chemicals should be avoided due to concerns regarding pathogen resistance, environmental contamination, and human health.

Biological seed treatment has gained considerable attention as an environmentally sustainable alternative. Beneficial microorganisms including *Trichoderma harzianum*, *Trichoderma viride*, *Pseudomonas fluorescens*, *Bacillus subtilis*, and *Bacillus amyloliquefaciens* colonize the seed surface and

rhizosphere, suppress pathogen growth through competition, antibiosis, and induced systemic resistance, and enhance seedling vigor. These biological agents contribute to long-term soil health while reducing dependence on synthetic pesticides.

Physical seed treatment methods such as hot water treatment, dry heat treatment, steam treatment, electron beam irradiation, ultraviolet irradiation, and plasma technology are increasingly being adopted for high-value vegetable and horticultural seeds. Proper optimization of treatment temperature and duration is essential to eliminate pathogens without compromising seed viability. The development and cultivation of resistant varieties constitute another sustainable preventive strategy. Plant breeding programs have successfully incorporated resistance genes against several seed-borne pathogens, thereby reducing disease incidence and minimizing pesticide usage. Marker-assisted selection and genomic technologies are accelerating the development of resistant cultivars with durable disease resistance. Appropriate seed storage practices also contribute significantly to disease prevention. Seeds should be dried to safe moisture levels before storage and maintained under cool, dry conditions with adequate ventilation. High temperature and humidity promote the proliferation of storage fungi such as *Aspergillus* and *Penicillium*, leading to deterioration in seed quality and mycotoxin contamination.

Strict quarantine measures are indispensable for preventing the introduction of exotic seed-borne pathogens into new geographical regions. National and international phytosanitary regulations require seed testing, inspection, certification, and documentation before seed movement across borders. These regulatory measures protect agricultural ecosystems from invasive diseases capable of causing widespread economic losses. Recent innovations involving nanoformulations, RNA interference technology, microbial consortia, CRISPR-based diagnostics, and digital seed health monitoring systems offer promising opportunities for future seed disease management. These technologies aim to improve treatment efficacy while minimizing environmental impacts and ensuring sustainable agricultural production.

Conclusion

Seed-borne diseases continue to pose a serious threat to agricultural productivity, food security, and international seed trade by reducing seed quality, crop establishment, yield, and product safety. Since infected seeds serve as the primary source of inoculum for many economically important diseases, preventive measures remain considerably more effective and economical than post-infection management.

Advances in seed pathology have substantially improved the understanding of pathogen biology, transmission mechanisms, and diagnostic methodologies, enabling early detection and timely intervention. The integration of certified disease-free seeds, efficient seed health testing, biological and chemical seed treatments, resistant cultivars, proper storage practices, field sanitation, and quarantine regulations provides a comprehensive framework for minimizing seed-borne disease incidence. Emerging

molecular diagnostic tools, nanotechnology-based seed treatments, and precision agriculture approaches are expected to further strengthen seed health management in the coming years. Ensuring seed health should therefore be regarded as a fundamental component of sustainable crop production systems, supporting higher productivity, enhanced profitability, environmental protection, and global food security.

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