Challenges Faced by Farmers in Crops Production Due to Fungal Pathogens and Their Effect on Indian Economy

24

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Abstract

Indian agriculture is considered a global powerhouse. It is the second largest producer of rice, wheat, sugarcane, fruits, vegetables, cotton, and tea. In India, the agri sector employs around 60% of the population and contributes about 17% to the total GDP. One of the major constraints Indian agriculture facing is its low yield, which is 30-5% lower than those of developing countries. The challenges stagnating agricultural productivity in India include outbreaks of pests and diseases, poor soil fertility, unavailability of sufficient water, and climate change. Among all the factors, plant pathogens especially fungal pathogens are of key concern, and they are a major yield-limiting factor in agriculture. According to Punjab Agricultural University in 2007, 26% of yields got lost due to plant diseases. Pest and diseases cause over INR 290 billion per annum losses of crops in India. Out of 30,000 plant diseases recorded from different countries, around 5000 occur in India. The fungal infections related decline in crop yield in India is believed to be 5 million tons per year, approximately. In 2012, fungal diseases ruined at least 125 million tons of the crops like wheat, rice, soybeans, maize, and potatoes. The global damage to rice, wheat, and maize by the fungi accounts for \$60 billion each year. This shows serious economic implications, resulting in production losses, market declines, and increased unemployment in

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the food and agriculture sector. Thus, there is an urgent need to emphasize the problem of plant diseases so that preventive measures can be taken up. Plant pathology has a special role to meet new challenges for sustainability and advancements of Indian agriculture.

Keywords

Agriculture · Plant pathology · Fungi · Economy · Challenges

24.1 Introduction

Microorganisms such as molds, yeasts, and several others are used since historic times. They survive in the tissues of dead or alive plants. Fungi differ greatly from the other organisms of the biological system; they constitute the principal decomposers of organic matter. Fungi are huge components of organic waste and target cellulose, lignin, gums, and some other complex organic substances. Fungi are an ensemble of eukaryotic cells, source of food supply, alcohol, antibiotics, enzymes, and amino acids. They also play an important role in various physiological processes such as mineral and water uptake, chemical transition, stomatal movement, and biosynthesis of compounds such as biostimulants, auxins, lignan, and ethylene to improve plant flexibility in detecting and coping with ecological stress such as drought, salinity, extreme temperature, and significant metals. Fungi can also be involved in a large variety of soil responses from acid to alkaline. In various physiologies, fungi perform a fundamental function together (Yuvaraj and Ramasamy 2020). Fungi have also evolved a variety of techniques for colonizing plants, and such interactions produce a wide range of effects, from good interactions to mortality in host countries. In terms of plant diseases, fungi are likely the most complex category of ecologically and economically significant threats. Phyla Ascomycota and Basidiomycota typically include fungal plants pathogens. Plant fungal pathogens of Ascomycota are grouped into different classes such as Dothideomycetes (e.g., *Cladosporium* spp.), Sordariomycetes (e.g., *Magnaporthe* spp.), and Leotiomycetes (e.g., *Botrytis* spp.). Similarly, rusts and smuts are the two principal groups of plant pathogens in Basidiomycota (Doehlemann et al. 2016).

24.2 Crop Losses in India

The crop loss, which is the difference between the healthy crop yield and the sick crop yield, is mostly stated in financial terms. An evaluation of crop loss is the main objective of the disease evaluation. However, it is a tough task due to the non-availability of an easy methodology to quantify the amount of loss of income due to diseases. The difference in yield of crop, quality, and loss of market value should be assessed in determining the yield loss of any disease. The estimation of losses in diseases such as smuts, root rots, ergot, etc., which cause nearly 100%

damage to crops, is easy to make. However, it is difficult to determine losses for diseases, which partially impair production in many respects (Sharma and Karthikeyan 2017).

Comparisons between crops cultivated in various crop seasons or locations are not valid in calculating the loss of output owing to diseases, because other factors are not the same. For accurate comparisons, the disease-free plots should be compared with those having different diseases in nearby. To evaluate the yield loss on a regional level, it is possible to use formulas based on fungicide trials to use the disease incidence data collected from the study. These data are generally used in the model of the critical point and the regression equations. Various models based on loss estimates of many diseases appear to be more reliable. The data are utilized to build a multi-dimensional model that measures the start date, the form of the pattern of disease, the host variety, and the loss of yield as the dependent variables.

Wheat rusts annually cause an economic loss of INR 4 billion. In outbreak years, there are greater losses of INR 50 billion. The total annual loss of wheat from loose smut (which is roughly INR 5 billion) is expected to be 3%. Some other fungal diseases like red rot in sugarcane, rice blast and blight, Karnal bunt in wheat, apple scab, and mango malformation are the causes of massive losses.

Mycotoxins like aflatoxins, fumonisin, etc. occurring in the infected fruits and grains may cause insanity, paralysis, stomach disease, and hepatic cancer in animals and humans when consumed. The money expended on plant disease control is also a waste as this money can be avoided in the absence of diseases. Besides the yield loss due to plant diseases, there are several other consequences for the transport and agri-based industry. For instance, the farm products containing pathogens and pesticide residues are always at risk of quarantine causing additional losses (Sharma and Karthikeyan 2017).

24.3 Major Crops Affected by Fungi

The study conducted at the Indian Institute of Technology, Chennai claims that fungi cause more harm to main crops—such as rice, potato, tomato, and ginger—than bacteria and viruses (Yadav et al. 2020). Plant diseases triggered by fungi restrict plant growth, generate marks, influence blossoms and fruits, and eventually kill the infected plants. Fungi are the cause of around 8000 types of plant diseases, of which prominent have been mentioned in Table 24.1. Between 1998 and 2018, scientists led by Sachin S. Gunthe collected data from different sources and reported 4000 records of plant disease associated with fungi in India. In the previous 20 years, it has been noticed that 69 fungal infections have negatively affected 39 plants (Yadav et al. 2020).

The *Puccinia striiformis* affected wheat crops 12 times throughout this period. Additionally, nine kinds of fungi including *Pyricularia oryzae* were discovered to harm paddy. The *Phytophthora infestans* devastated plants such as potatoes, tomatoes, and ginger at 14 sites in India. The incidence of fungal diseases is connected to the mixture from surface air with top layer air and so increases the

Table 24.1 Major crop/plant affected by fungal diseases

S. No.	Crop/plant	Disease
1.	Sugarcane	Red rot
2.	Soybean	Rust
3.	Cotton	Wilt
4.	Rice	Blast
5.	Wheat	Rust, powdery mildew
6.	Potato	Late blight
7.	Maize	Downy mildew

Table 24.2 Major fungal diseases of wheat

S. No.	Disease	Pathogen
1	Stem rust (black rust or cereal rusts)	*Puccinia graminis* f. sp. *tritici*
2	Leaf rust or brown rust	*Puccinia triticina* (Syn. *Puccinia recondita* f. sp. *tritici*)
3	Stripe or yellow rust	*Puccinia striiformis* f. sp. *tritici*
4	Hill bunt or stinking smut or common bunt	*Tilletia caries* and *Tilletia foetida*
5	Karnal bunt or partial bunt	*Tilletia indica* (Syn. *Neovossia indica*)
6	Loose smut	*Ustilago nuda* var. *tritici.* (Syn. *U. segetum* var. *tritici)*
7	Flag smut	*Urocystis agropyri* (Syn. *U. tritici*)
8	Powdery mildew	*Blumeria graminis*

concentration of fungal bioaerosols. The concentration of bioaerosol peaks in January and begins to fall in February (Yadav et al. 2020).

24.3.1 Wheat

Wheat (*Triticum aestivum* L.) is the second largest cereal crop in India, just next to rice. It is one of the main food grains of Indian diet. It is rich in carbohydrates, proteins, and vitamins and offers equitable nutrition. Globally, India is the fourth-largest producer of wheat after Russia, the USA, and China and represents 8.7% of total wheat global output. It is grown in many states of India generally from September to December. Weeds, diseases, and pests significantly affect the quality as well as production of wheat. There are varieties of fungal diseases causing output losses in wheat that are very difficult to identify by the farmers (Table 24.2) (https://icar.org.in/node/8098).

24.3.2 Rice

Rice is one of the major food safety plants. It feeds about 2.7 billion people worldwide. A nasty disease caused by *Magnaporthe oryzae* and called rice blast,

Table 24.3 Major fungal diseases of rice

S. No.	Disease	Pathogen
1.	Blast	*Pyricularia grisea* (*P. oryzae*)
2.	Brown spot	*Helminthosporium oryzae*
3.	Sheath rot	*Sarocladium oryzae*
4.	Sheath blight	*Rhizoctonia solani*
5.	False smut	*Ustilaginoidea virens* (telomorph *Villosiclava virens*)
6.	Grain discoloration	*Ustilaginoidea virens*

Table 24.4 Major fungal diseases of soybean

S. No.	Disease	Pathogen
1.	Stem rot	*Rhizoctonia solani*
2.	Rust	*Phakopsora pachyrhizi*
3.	Stem rot	*Sclerotinia sclerotiorum*
4.	Leaf blight	*Septoria glycines*

despite the finest management methods, has afflicted the crop. This fungal pathogen damages practically every part of the plant but is most harmful during planting phase. In India, rice blast is a common disease, which is more widespread in locations having high humidity and low temperature at night (https://icar.org.in/node/4461). Other important fungal diseases of rice are given in Table 24.3. In the near future, there is little opportunity to increase the area under paddy cultivation. Thus, the extra demand of rice must be met with an increase in the crop productivity (Kumar and Ladha 2011). The maximum yields can only be attained per unit of the land area if there is a provision for the protection of the crop from its enemies coupled with high-yielding crop varieties (Srivastava et al. 2010).

24.3.3 Soybean

Soybean (*Glycine max*) is a Chinese crop that was brought to India millennia ago via Himalayan routes. Therefore, on a modest scale soybean has historically been grown in Himachal Pradesh, Uttar Pradesh, Uttarakhand, Eastern Bengal, the Khasi Hills, Manipur, the Naga Hills, and areas of central India including Madhya Pradesh. At present, it is an important oilseed crop of India. The area under soybean cultivation is increasing. For instance, soybean cover in 2003 was 6 million hectares, which increased in 2011–2012 up to 9.33 million hectares. Consequently, India has become the world's fifth-largest soybean producer (Dutta et al. 2013).

Madhya Pradesh and Maharashtra are the two topmost soybean-producing states followed by Rajasthan in India and account for 86% of the country's total acreage and production (Dutta et al. 2013). The majority of soybean crop in India is planted in the month of July but in the central and southern states, it is planted in the spring.

Among major fungal diseases of soybean (Table 24.4), the Asian soybean rust disease caused by *Phakopsora pachyrhizi* was discovered for the first time in India, in 1951 (Sharma and Mehta 1996). In the Northeastern Hill region, frogeye leaf spot

(*Cercospora sojina*), rust (*Phakopsora pachyrhizi*), powdery mildew (*Microsphaera diffusa*), and purple seed stain (*Cercospora kikuchii*) have all been observed in moderate to severe forms (Prasad et al. 2003).

24.3.4 Potato

Globally, after wheat, rice, and maize, potato is the most important food crop. Farmers in developing nations will have to treble their productivity to feed the expanding population during the next three decades, when the world population is estimated to expand by about 100 million per year, putting further strain on land, water, and other resources (Zandstra 2000). For such situation, the potato has great potential as a source of food for millions of people, particularly in developing nations including India. In the majority of emerging nations including India, potato production and consumption are growing. In fact, developing-countries potato production has surpassed that of developed-countries potato production. Potatoes are farmed in India under several weather conditions, from tropical, subtropical to humid highlands (Sharma 2013).

Diseases may strike potatoes at any stage of development, including storage. They may have an impact on the foliage, tubers, or both. Pathogens that thrive in a warm environment can damage the crop. The consequences of the historical potato famines in Europe, especially in Ireland, caused by late blight, have been widely chronicled (Woodham-Smith 1962). Tuber diseases such as common scab, black scurf, dry rots, and soft rot may not completely destroy the crop, but they can significantly affect its quality and marketability. The disease situation may vary from time to time as resistant cultivars and improved cultural methods are introduced, necessitating frequent inspection (Khurana 1998). Any environmental changes, such as global warming, may potentially influence diseases (Khurana 1998). A number of reviews related to fungal and bacterial diseases are accessible in Indian context (Khurana 1998). Around 160 diseases can harm the potato crop, of which fungi, bacteria, and viruses cause 50, 10, and 40, respectively, and the rest by non-parasitic or unknown causes. Some of the major fungal diseases of potatoes, which are commonly found in India, are listed in Table 24.5.

24.3.5 Maize

In terms of area, India is the world's fifth-largest country to cultivate maize, yet it falls to the tenth position based on production. In the Asia region, 37% of the acreage and 34% of output are next to China (Anonymous 1973). In India, maize is attacked not just by downy mildews, but also by leaf and sheath, stalk reds, rust and smuts and ear-reds, all of which sum to around 35 in number. Payak and Renfro (1973) calculated the national yearly decrease in grain yield, ascribable to diseases, at 3,706,450 quintals. Some major fungal diseases of maize, which are common in Indian states, are listed in Table 24.6.

Table 24.5 Major fungal diseases of potato

S. No.	Disease	Pathogen
1.	Late blight	*Phytophthora infestans*
2.	Early blight	*Alternaria solani*
3.	Black scurf	*Rhizoctonia solani*
4.	Charcoal rot	*Macrophomina phaseolina*
5.	Silver scurf	*Helminthosporium solani*
6.	Fusarium wilt and dry rot	*Fusarium* spp.
7.	Verticillium wilt	*Verticillium albo atrum*
8.	Sclerotium wilt	*Sclerotium rolfsii*
9.	Sclerotinia wilt	*Sclerotinia sclerotiorum*

Table 24.6 Major fungal disease of maize

S. No.	Disease	Pathogen
1.	Banded leaf and sheath blight of maize	*Rhizoctonia, solani* f. sp. *sasakii*
2.	Northern maize leaf blight or Turcicum leaf blight of maize	Anamorph (asexual phase): *Exserohilum turcicum* (syn. *Helminthosporium turcicum*)
		Teleomorph (sexual phase): *Setosphaeria turcica*
3.	Brown spot of maize	*Physoderma maydis*
4.	Head Smut of maize	*Sporisorium reilianum* (Syn. *Sphacelotheca reiliana*; *Ustilago reiliana*)
5.	Common smut of corn (Syn. boil smut, blister smut)	*Ustilago maydis* (Syn. *Ustilago zeae*)
6.	Downy mildew of maize	*Peronosclerospora philippinensis*, *P. sorghi*, *P. sacchari*, *P. maydis*, *Sclerospora graminicola*, *S. rayssiae*
7.	Brown stripe downy mildew of maize	*Sclerophthora rayssiae* var. *zeae*
8.	Philippine downy mildew of maize	*Peronosclerospora philippinensis*

24.4 Impact of Diseases on Indian Economy

Fungi symbolize a huge danger to food safety given that they cause diseases in crops, which make up the largest proportion of worldwide food consumption. It has been estimated that fungal infections are one of the damaging diseases in paddy cultivation. For example, *Magnaporthe oryzae* causing rice blast has been ranked on the top in the most academically and commercially relevant "top ten" list of fungal infections for its catastrophic ability to disrupt world food supplies (Ou 1980; Dean et al. 2012). Other important fungal plant diseases are soybean rust (*Phakopsora pachyrhizi*), wheat stem rust (*Puccinia graminis*), maize corn smut (*Ustilago maydis*), and potato late bite (*Phytophthora infestans*).

In the agriculture history, there are many examples of fungal diseases that have hampered food safety, substantially. The oomycete *P. infestans*, for instance, caused the famine of Irish potatoes in the 1840s, which resulted in one million deaths from hunger and one million displaced, and led to a 20% fall in Ireland's population (Fry and Goodwin 1997). This catastrophe was not only a humanitarian disaster but also altered the political and economic history of Europe. In India, the 1943 Bengal famine caused by *Cochliobolus miyabeanus* led to the deaths of 2–3 million people because of population dependency on rice as a key source of sustenance (Padmanabhan 1973). Similarly, the outbreak of southern corn leaf blight (*Cochliobolus heterostrophus*) led to major crop failure in the USA (Ullstrup 1972).

In India, on average 20–30% of the food produced by the farmers is lost annually because of pests and diseases. The fungal diseases cost $60 billion per annum to rice, wheat, and maize alone. Annually, fungal diseases annihilate 125 million tons of rice, wheat, maize, potato, and soybean, which is sufficient to feed more than 600 million people (Fisher et al. 2012). Consequently, management of pests and diseases via primary plant protection is crucial for food safety of the rising human population of the country. In the 1960s and 1970s, the "Green Revolution" raised crops productivity significantly and made India independent on food supplies. Apart from high-yielding crops, chemical fertilizers and irrigation pesticides have played an important role in the success of the Green Revolution. The availability and application of safe and efficient pesticides are important for the continuous improvement in farm productivity and production. Among three varieties of wheat rust diseases, leaf rust (*Puccinia triticina*) is more common, world over and thus leads to larger production losses than any other wheat rust. Leaf rust may cause grain production losses above 50% in the event of severe outbreaks, if no fungicides are administered. During the 1970s and 1980s, Indian wheat production encountered major rust related issues, which were eventually controlled efficiently (https://icar.org.in/node/4531). Worldwide, over 678.7 million tons of rice is produced on 161 million hectares, yearly (FAO-Food and Agriculture Organization 2009). The contribution of Asia in total rice production is around 90% (143 million hectares of production area, 612 million tons) (FAO-Food and Agriculture Organization 2009). Rice provides more than 3 billion Asians between 30 and 75% of their total calories (Braun and Bos 2004; Khush 2004). To fulfill world rice demand, rice production must be increased almost 114 million tons, which is the equivalent of a total 26% increase, by 2035. Paddy infections are one of the major important biotic variables affecting rice production. The world's average annual losses from rice diseases are estimated at 10–15% that reach up to 75% in epidemic conditions. Rice diseases were almost inconsequential in the tropical Asia when old cultivars, which were disease resistant but low yielding, were routinely cultivated on low-fertility soils (Areygunawardena 1968). However, with growing need for worldwide rice supplies and green revolution high-yielding varieties are being now preferred. Further, high fertilization, irrigation, and intense cultural behavior have led to a substantial increase in the incidence and severity of rice infections in several nations or countries (Teng 1990). Rice blast (*Magnaporthe grisea*), sheath blight (*Rhizoctonia solani*), bacterial blight (*Xanthomonas oryzae*), and tungro virus disease are the principal rice diseases caused by various pathogens that cause severe economic losses, mainly in Southeast and South Asia (Ling 1980). The main fungal diseases observed during pre-independent India and before the introduction of high-yielding varieties were the rice blast and brown spot. However, after introduction of high-yielding varieties bacterial blight, tungro, and sheath blight became serious diseases. Recently there has been a significant loss of output due to fungal diseases such as sheath red, false smut, stem rot, and grain discoloration that were once less important and appearing intermittently. Of the total loss of yield owing to rice diseases, 35% is attributable to blast, 25% to sheath-bull, 20% to bacterial blight, 10% to tungro, and 10% to other diseases. Fungicides of INR 380 crores were used on rice, of which INR 280 crores were spent on blast and sheath blight, and the proportion of fungicides employed against brown spot, blackened grain, stamping red, and false smut was INR 100 crores, in India for the year 2010–2011 (Prasanna et al. 2011).

24.5 Conclusions and Future Prospective

The task of agriculture, which has received attention, is to satisfy the food security demands of the country. Besides this, other goals are to enhance food quality, as well as to safeguard the ecological and natural environment. High crop productivity is a necessary component of a thriving agriculture business. There are several reasons that lead to decline in the crop yield. Application of improved pre- and post-harvest technology is essential to reduce the losses in crop productivity and to increase the income of farmers. For effective management of plant diseases, their impact on economy and sociology and ecology of management approaches through a full understanding of plant epidemic mechanisms and healthy agro-ecosystems functioning are required to make plant disease management sustainable.

The general impact of fungal diseases on human health goes beyond human infections as fungi damage one-third of food crops yearly that results in economic losses and worldwide poverty (Fisher et al. 2012). Fungal diseases induced losses in five major crops, namely rice, wheat, maize, potatoes, and soybean are evident from world harvest statistics for the year 2009–2010 (www.fao.org/FAOSTAT1). Almost 61% of the world's human population does not have sufficient food. The current crop production would be sufficient to feed 8.5% of seven billion people by simply mitigating the ongoing crop losses (Fisher et al. 2012). In addition to major food crops, there are other numerous high-value tropical plants such as banana, coffee, cacao, and mango and several nuts and spices in which fungi cause infection (Drenth and Guest 2016). All these have worldwide economic ramifications because of our dependency on crops grown in tropical regions, which further exacerbate due to lack of biodefense and preparation.

Fighting against fungal diseases will remain the major problem of plant pathology. Fungi are a varied group of organisms that have a significant agricultural impact, as they have a wide range of lifestyle and significant genetic flexibility, allowing pathogens to invade new hosts fast, to acquire pesticide resistance, or to break apart the resistance of R-gene mediated seedlings. The battle against fungal infections will thus continue to be a key problem in future plant pathology. We need to improve our knowledge of the processes for fungal virulence, the way pathogenic characteristics evolve, the molecular foundation for host adaptability, how to make crop resistance more sustainable, and to create novel approaches to manage pathogenic plant fungi. Apart from these qualities, pathogenic plant fungi are also intriguing creatures, which have a vast array of colonization methods. Studying the molecular mechanisms behind these intricate interactions is a good approach for understanding host–parasite relationship. Effector proteins are useful molecular instruments to research plant pathways because they are precisely suited to specific cellular activities in the host. In addition to effector proteins, the activities of micro RNAs in plant–fungus interactions are little recognized. Similarly, the role of secondary metabolites in biotrophic interactions also requires extended focus. As of now, the interactions between plants and fungi have mostly been examined individually, but this is quite unnatural since plants are constantly colonized by a complex microbiome, in which different microorganisms affect one another and affect the plants in several ways. The results of pathogenic infections are becoming increasingly obvious with multitrophic interactions. For this reason, the impact of microbial communities on pathogen growth and plant healing should be considered in the future research on plant diseases. Considering ecological aspects of plant diseases, future studies need to focus on: (a) epidemic and evolutionary plant disease patterns in changing environment, (b) philosophy on agricultural production, and (c) the role of ecological aspects in agricultural productivity and crop health.

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