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REVIEW

Phytopathogens: A Future Risk of a COVID-like Pandemic in Agriculture

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The current global pandemic of COVID-19 has exposed the inadequacies of medical infrastructure of the most advanced nations andfastest-developing regions of the world. But have we ever thought about the possibility of a natural or man-made agricultural pandemic on the scale of COVID-19? There is sufficient evidence from thepast experiences which suggest that mankind is eager to develop a biological weapon capable of causing severe damage to a wide variety of agricultural products/crops. We have seen in the last century how destructive natural epidemics can be; with the Irish famine and the Great Bengal famine, leaving millions of people starving, dead, and forced to relocate. But if humans aresuccessful in development of biological weapons to use against food crops, dire consequences might ensue. Don't forget that we are still unable to provideenough food to feed the world's 7 billion people. Diseases with epidemic potential like Late blight of potatoes, Wheat rust and Wheat blast are very serious food and biosecurity threats and that could be used as a bio-weapon against agricultural crops. Others like the Corn leaf blight diseases, Banana *Xanthomonas* wilt, Maize lethal necrosis disease, Wheat streak mosaic disease (WSMD), and Tomato brown rugose fruit disease are just some of the plant diseases that could also discussed in this article that pose serious threats to global food security. Though the human healthcare sector is more advanced than the agriculture sector's infrastructure, we were not able to contain the spread of COVID-19. Therefore, now is the time to learn the lessons and put in place procedures,and implement stringent rules and strategies for the agricultural sector tocontrol the spread of these catastrophic plant diseases at both domestic and international levels.

Keywords: Biosecurity, bio-weapons, food security, phytopathogens, phyto-epidemic

INTRODUCTION

Infectious agents such as fungi, viruses, and bacteria are the subject of much speculation and discussion as potential bio-weapons in the 21st century against human. Nevertheless, as long as these theories persist, we must also ask, what if? Infectious plant pathogens are used against our primary food crops, which might lead to an indirect conflict between nations. The world's population is now over 7 billion and is projected to rise to over 9 billion in the next few decades, but we are still unable to provide enough food for everyone who needs it.

In the past, natural disasters such as the Great Bengal famine in 1945–1946 and the Irish famine (late blight of potato) in 1845–1846 caused mass hunger, death, and displacement. Some research programs in the 20th century concentrated on harmful plant diseases intended to destroy food harvests in fields and grain silos and were funded by nations who wanted to fight World War II (Suffert, 2003). To combat Iran's primary food source during the Iran-Iraq War of the 1980s, Iraq experimented with using wheat cover smut in the field to prove its efficacy as an anti-crop agent. Canisters were also manufactured in Iraq for dispersing the fungal agent over Iranian wheat fields (Foxell, 2001).

Urbanization and industrialization are now prioritized in every nation, despite their detrimental effects on the environment, the shrinking availability of farmland, which mount the urgency of feeding the world's growing population. In addition to the previously noted global concern, the secret race to develop biological weapons that threaten food supplies is high on the agenda of

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future generations of humans (Datta *et al.* 2020). Food crops are under increasing assault from many phytopathogens, including fungi, bacteria, viruses, phytoplasmas, viroids, and viroids. Some of these phytopathogens have been documented before, while others are either novel to the field of phytopathology or are variants of known diseases.The International Year of Plant Health (IYPH), observed in 2020 was an opportunity to increase awareness about the importance of healthy plants in achieving food security and sustainable development goals (Guha Roy, 2019).This article focuses on diseases or plant pathogens that have the potential to become future bio-weapon agents against the food security.

DISEASES WITH AN EPIDEMIC POTENTIAL

Wheat rust, Karnal bunt of wheat, late blight of potato, and brown leaf spot of rice are a few severe plant diseases attributed to fungal infections. Fungal spores are naturally dispersed via the air, grown in vast numbers, and are stable under various environmental conditions (Shawn *et al.* 2004). Some of the highlighted fungal infections can become future bio-weapons that threaten food security. Record shows that fungal pathogens like *Tilletialaevis*, *Tilletiatritici*, and *Aspergillus* spp. (Alfatoxin) wer planned to use by Iran in 1980 against Iraq, according to research by Whitby (2002). The USA has developed the potential bio-weapons with the passages of time like, in 1940's *Cochliobolu-smiyabeanus*, *Magnaporthe grisea* on rice (Madden and Wheelis, 2003), 1950s *Phytophthora infestans* on potatoes (Suffert, 2003), *Hemileia vastatrix* on coffee (Suffert *et al.* 2008), 1970's *Puccinia melanocephala* on sugarcane, and *Peronospora hyosciami* on tobacco.*Magnaporthe grisea*(Madden & Wheelis, 2003) and *Phytophthora infestans* (Suffert) were both well-celebrated bio-weapons in the Soviet Union in the 1950s.

These are few examples of the plant disease which are planned to make bioweapons out of them. In this paper we will be discussed about the diseases which could be too lethal to use as bioweapon in future.

Reemerging and Existing Diseases

Since ancient times, black stem rustof wheat has been a highly concerning disease of wheat, and as time goes on, new monster races of black stem rust have been identified. Wheat rust was a severe problem in ancient Italy and Greece, and urediniospores from stem rust discovered in Israel dating back to 1300 B.C. demonstrate that this is one of the earliest plant diseases. Epidemics in North America in 1904 and 1916 prompted researchers to learn more about the disease's transmission dynamics, sources of resistance, host-parasite interactions, and management strategies (Carver, 2009). In the primary wheat-producing states of the United States, about 500 million barberry bushes were eradicated between 1918 and 1980 (Madden and Wheelis, 2003). Countries like Mexico and the Indian subcontinent that have embraced contemporary wheat cultivars have seen a normalization of stem rust prevalence (Moore, 2012). Time has passed, infection rates have stabilized, and the fungus seems to be in a particularly nasty mood once again. In 1999, *Puccinia graministritici,* a collection of races, was reported from Uganda. Only the stem rust fungus race Ug99 has been shown to infect wheat resistant to the Sr31 gene. The Ug99 race poses a danger to 80-90% of the world's wheat because it has a unique mix of virulence to both known and undiscovered resistance genes of wheat (Moore, 2012).

There are ten races of the Ug99, and they have been documented in Uganda, Kenya, Ethiopia, Sudan, Tanzania, Eritrea, Rwanda, South Africa, Zimbabwe, Mozambique, Yemen, Iran, and Egypt (Patpour*et al.* 2016). However, identifying a resistance gene against Ug99 and other severe races of stem rust is encouraging (Babiker *et al.* 2016, 2017; Zhang *et al.* 2017). We needed generations of educated plant pathologists and breeders to provide long-term resistance against this re-emergence danger. The Soviet Union and the United States of America intended to prepare *Puccinia graministritici* as a biological weapon in the 1950s, first against one other and then against the United States and Korea (Line and Grifth, 2001; Whitby, 2002). In 1950, the Soviet Union and the United States also used leaf rust (*Puccinia triticina*) as a weapon. However, Afghanistan (Al-Qaeda) has been working on *Puccinia triticina* as a bioweapon against the United States and Europe for the last two decades (Whitby, 2002; Fletcher *et al.* 2006).

Yellow stripe rust has emerged as a significant danger to worldwide food supplies in recent years. Two novel *Puccinia striiformis* f. sp. *tritici* strains arose in North America, Australia, and Europe between 2000 and 2002, causing significant damage to wheat crops in all three regions (Hovmoller*et al.* 2010; Milus *et al.* 2009). The Middle East, North and Eastern Africa, Western and Central Asia, and China were all exposed to these novel strains of yellow rust in 2009. Hovmoller*et al.* (2010) state that this may be the fastest and most comprehensive spread of a significant agricultural disease ever recorded. Evidence suggests that the *P. striiformis* strains linked to recent disease outbreaks are more virulent, heat-tolerant, and spore-producing than other strains (Milus *et al.* 2009), which might explain their rapid spread bio-weapons comprising the fungal pathogens. Strict quarantine rules should be followed and resistant breeding programmes should be increased.

Brown leaf spotof rice was first recorded from India in 1922 caused by *Helminthosporiumoryzae*. Losses due to this disease was ranged between 50-90 % under severe conditions . Last century two epidemics were observed in India one in 1918-19 in the Krishna-Godavari delta in the southern part of India and another in 1942 in Undivided Bengal. In 1945 the Famine Enquiry Commission headed by Sir John Woodhead reported that 50-90% of losses of rice were governed by this disease.Resistance is one of the best and most environmentally safe ways of controlling disease. However, even though cultivars with varying levels of resistance have been found, no genes for complete resistance have yet been identified (Moriwaki *et al.,*2006; Mizobuchi *et al.* 2016). There a number of specific action mode chemicals applied against this disease. But in the last few recent years disease has been reported from the other parts of the world which a concerning issue (Aslam *et al.* 2020).

Late Blightis the majordisease of potato which is world wide spread. Potato is the 3rd major staple food crop of the world and consumed throughout globe that is why crucial for the food security of world, which provides the starch, proteins, vitamins and minerals (Devaux *et al.,* 2014).Irish famine was caused due the infection of potato crops with oomycete plant pathogen *Phytophthora infestans.* Globally, the management strategies for late blight of potato cost up around 6 billion dollars (Haverkort*et al.* 2009). It can rapidly destroy leaves and tubers, and its extremely high reproductive potential renders it one of the most challenging pathogens to manage (Khan *et al.* 2017). *Phytophthora infestans* is a hemi biotrophic pathogen. According to Kanneganti *et al.* (2006) this oomycete pathogen destroys the immune system of host plant in early infection and spread to other tissues of the plant without producing any symptoms. After the advancement of disease,it produces necrotic lesions, host induced cell death and the massive sporangia production leading to the spread of the diseases. A lot of management strategies including disease resistant varieties, breeding programmes, chemical sprays, prediction models and biotechnological interventions are utilized (Fry, 2008). Despite of adaptation of such management strategies resurgence of this oomycete's pathogen is reported from the different parts of the globe still remain a threat to food security (Kelley *et al.* 2010, Van Damme *et al.* 2012; Roy *et al.* 2023). In the current era, an approach of controlling Late Blight would be the use of genomics which can give accurate results (Guha Roy, 2023).

Novel Diseases

Wheat blastoccurred inan epidemic form on wheat in 2009, and it was initially observed in 1985 in the Brazilian state of Parana. After a few years, it was discovered that Triticale, barley, and black oats were susceptible to the illness in Bolivia, Paraguay, Argentina, Kentucky, and Uruguay (Callaway, 2016). There have been reports of wheat crop losses as high as 100% due to blast (Kohli *et al.* 2011). In 2016, a wheat blast epidemic broke out in Bangladesh due to a spate of grain imports from Brazil (Callaway, 2016; Malaker *et al.* 2016; Ceresini*et al.* 2018, Islam *et al.,* 2016). Prior to that, the disease had only been seen in South America. The news has sounded the alarm among numerous wheat-producing countries. The fungus responsible for the wheat blast, *Pyricularia graminis-tritici* (Pygt), is genetically different from the fungus responsible for rice blast, *Pyricularia oryzae* Pygt has a wide host range, allowing it to switch between wheat and other grass hosts and a high degree of genetic and phenotypic variability. The varied Pygt population seen in wheat fields is attributed to recombination, believed to occur mainly in the other grass hosts (Ceresini *et al.* 2018). Wheat blast, which primarily affects spike, may result in yield reductions of 40-100%, as was previously indicated. To prevent further transmission of the infection to disease-free nations, stricter quarantine, and bio safety measures are now the most pressing necessity. Breeders worldwide must work together to create wheat types with longer-lasting resilience (Ceresini *et al.* 2018). A 21st-century phytoepidemic might be avoided, but only if people act responsibly.

Xanthomonas wilt disease caused by *Xanthomonas campestris* pv. *Musacearum* is responsible for banana Xanthomonas wilt disease, which threatens banana cultivation in East and Central Africa (Nkuba *et al.* 2015). Banana's close relative, the enset (*Enseteventricosum*), was first reported to have been infected with this disease in 1968, followed by bananas in Ethiopia in 1974 (Yirgou and Bradbury). In 2001, the disease was reported again from Uganda, and in 2005, it was recorded from Rwanda, both in the Great Lakes area of East and Central Africa. Then, the disease reached the neighbouring countries of Tanzania, Burundi, Kenya, and the Democratic Republic of the Congo (Carter *et al.* 2010; Reeder *et al.* 2007). Without effective disease control, yield losses may approach one hundred percent and 60-80 % average losses may occur due to this disease (Uwamahoro *et al.* 2019). An analysis of data collected between 2001 and 2006 in Uganda and in six countries of the Great Lakes region in 2007 suggest that the number of newly affected areas declined between 2004 and 2005, and that the spread of the disease was changing from being more or less continuous to more isolated outbreaks (Bouwmeester *et al.* 2010). But the recent report on the spread of TR4 into the Indian subcontinent is of major concern since India is the largest producer of bananas worldwide. (Thangavelu, *et al.,* 2019). Intensive surveillance and reporting of new outbreaks with prompt action to investigate them and take action and strict control of the movement of plant material from infected areas to unaffected ones, have been proposed (Eden-Green, 2004).

Maize Lethal Necrosis Disease(MLND) was initially identified in the United States in 1977, and it causes severe systemic necrosis of leaves and shoots, ultimately leading to the death of the plant. Maize has become the staple food crop of the entire world. Since 2010, devastating pandemics of MLND diseases have been reported in the Democratic Republic of the Ruanda, Congo, Ethiopia, Kenya, Mozambique, South Sudan, Tanzania, Uganda, East, and Southeast Asia (China), Europe (Spain), and South America (Ecuador) (Redinbaughand Stewart, 2018; CABI, 2020; Boddupalli *et al.* 2020). Maize chlorotic mottle disease (MLND) is caused by a mixed infection of maize chlorotic mottle virus (MCMV; genus, Machlomovirus, family, Tombusviridae) and one or more of several different cereal viruses belonging to the Potyviridae, such as sugarcane mosaic virus (SCMV), maize dwarf mosaic virus (MDMV), and wheat streak mosaic virus (WSMV) (Redinbaughand Stewart, 2018). The only best control of the disease spread could be possible with resistance breeding programmes and quarantine measures.

Wheat streak mosaic disease(WSMD)causes striping on the leaves to appear yellow or light green, the tips of older leaves to become yellow, a tufted growth pattern, and stunted plant development. When infection is rampant early in the crop's life, yield losses might reach 80-100%. In addition, like Yellow dwarf disease, it results in shrivelled grain, which may lead to low seed quality and make any remaining wheat grain unsellable. CABI (2020), Bockus *et al.* (2009), Byamukama *et al.* (2014), Coutts *et al.* (2008,2014), Singh *et al.*(2018), and others have all shown that WSMD is most damaging when plants are cultivated in warm temperatures. The significance of the virus that causes wheat streak mosaic has been growing steadily during the last century. Both eriophyid mites and seeds may carry the virus (CABI, 2020; Singh *et al.* 2018). WSMD was first reported in the United States in 1922; it is sporadic and causes devastating losses in wheat-growing regions all over the world, including in Australia, Europe, the Middle East, Central Asia (Iran, Kazakhstan), East Asia (China), Sub-Saharan Africa (Nigeria, Zambia, South Africa), South America (Brazil, Argentina), and North America (USA, Mexico, Canada) (CABI, 2020; Bockus *et al.* 2009; Byamukama *et al.,* 2014; Coutts *et al.,* 2008; Coutts *et al.* 2014; Singh *et al.* 2018; Velandia *et al.* 2010).WSMD was avoided by sowing the wheat in cooler regions/months, development of and use of resistant varieties and follow of quarantine procedures.

Rice Tungro disease (RTD) causes partial or sterile grain production, leaf yellowing, striping, mottling, reduced tillering, and plant stunting. A combination of infections by RTBV and RTSV leads to rice tungro disease. Different species of leafhoppers, most notably *Nephotettixvirescens* (Bunawan*et al.,* 2014), spread RTD semi-persistently. As the most destructive viral diseases of rice, causing as much as 70-90% yield losses (Azzam and Chancellor, 2002), tungro infections have the potential to undermine global food security.Like the other viral disease management strategies resistant breeding programmes should be focused and strict quarantine measure implemented.

Tomato Brown Rugose Fruit Disease (ToBRFD) produces symptoms like Leaf chlorosis, mosaic and mottling, and necrotic spots on petioles and calyces are all signs of Tomato Brown Rugose Fruit Disease (ToBRFD) caused by the Tomato Brown rugose fruit virus.The virus causes severe crop losses and threatens tomato production worldwide.ToBRFV was discovered in greenhouse tomato plants grown in Jordan in spring 2015 and its first outbreak was traced back to 2014 in Israel. To date, the virus has been reported in at least 35 countries across four continents in the world. ToBRFV is transmitted mainly via contaminated seeds and mechanical contact (Zhang *et al.* 2022). Deformation, uneven ripening, yellow or brown spotting/bottling, and rugosity are among the issues that may arise in tomato fruits. Tomatoes with diseases exhibit these signs, making the fruit unsellable (Klap *et al.* 2020). In 2014, the virus was first reported in Jordan; since then, it has spread to the Middle East (Israel, Turkey), Europe (Germany, Greece, Cyprus, Czech Republic, France, Italy, Poland, Spain, the Netherlands, UK), East Asia (China), North America (Mexico, USA), South America (Chile), and North Africa (Egypt, Sudan) where it has caused a severe virus disease epidemic in protected cultivation (Salem *et al.* 2016; EPPO, 2018; Oladokun *et al.* 2019; Davino *et al.* 2020; Klap *et al.* 2020). Currently, there are no chemicals that can be used to cure ToBRFV infected plants and there are no resistant cultivars commercially available. Different phytosanitary and quarantine measure, breeding programmes, and Cross protection with attenuated variants should be focused to arrest the spread of this disease.

OTHER POTENTIAL DISEASES

Other plant diseases which has the global impact and found to be in outbreak form in certain parts of the world from time to time includes coffee rust in 1870s, 1960, and 2012 to till date prevalent in Sri Lanka, Central and South America, Panama wilt of banana in Asia, Australia, and Africa in 1990 to present time, Sigatoka leaf spot of banana in Central America (1900–65), powdery and downy mildews of grape in France (1851 and 1878), Fusarium wilts of cotton and flax in USA in early 1900's, southern corn leaf blight (1970) and southern bacterial wilt of tobacco in 1900s in the United States (Kelman *et al.* 2023).

Coffee Leaf rustis the major disease of the coffee throughout world it was first time found in epidemic form in Sri Lanka in 1857s cultivation then after reported form all coffee growing regions of the world. According to Hoffmann (2014) and ICO (2016) that the coffee is economically important agricultural commodity for more the 60 countries of the world with estimated value of 70 billion US dollars, which is the main source of earning for more than 100 million people of globe. Arabica coffee (*Coffea arabica*) is severely susceptible to Coffee leaf rust (CLR) and lead to one to two billion US dollars annually losses worldwide every year (McCook, 2006). The yield losses caused due to CLR are up to 35% which is a huge loss and directly affect the farmers, entrepreneur, middle man, industrialists, marketing persons and consumers (Silva *et al.* 2006). The countries like Colombia, Peru Ecuador, and Central America are facing the epidemic occurrence of CLR in recent time. The breeding of coffee plants for resistance to rust is considered to be the best disease management strategy, both environmentally and economically (Silva *et al.* 2006).

Panama wilt of bananais seriously threatening disease of banana. Banana fruit is the 10th staple food of the world in terms of production volume and trade (FAOSTAT, 2017). This Fusarium wilt (FW) disease of banana caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *cubense*. Earlier this disease was known as the as “Panama disease”, which wiped out the Gros Michel banana industry in Central America (Ploetz, 2005). This devastation in Central America was done by *Fusarium oxysporum* f. sp. *cubense*race 1 and to mitigate this a shift to resistant Cavendish cultivars, which are currently the source of 99% of banana exports. Recently a new starinof *Fusarium oxysporum* f. sp. *cubense*i.e. a tropical race(TR4) was reported. This tropical race of this pathogen was first reported form to East and parts of Southeast Asia for more than 20 years. But now its spread to Vietnam, Laos, Myanmar, India, Pakistan and middle east i.e. Oman, Jordan, Lebanon, and Israel. This new race of FW has generated a global concern and new demands for solution-oriented research on FW of banana. New resistant cultivars are not foreseen in the short-term, although clonally selected varieties with partial resistance have shown some promises (Hwang and Ko, 2004). Thus, research on epidemiology-based management programs has again become a high priority.

Sigatoka leaf spot of banana is globally distributed and first time recorded in the Indonesian Island of Java by Zimmermann in 1902, later reported from Sigatoka District of Fiji, in 1912 (Gomes *et al.,* 2013). Disease was wide spread to all banana growing regions of the world i.e., Asia, Africa, Central and South America and the Caribbean.Sigatoka leaf spot (SLS) was caused by different species of fungus *Mycosphaerella* i.e., *M. musicola*, *M. fijiensis*, and *M. eumusae*which lead to the 11-80% losses in banana yield (Shanthiyaa *et al.* 2013). SLS are considered as the major leaf spot diseases of banana, making banana farming less profitable and driving the popular cultivars out from cultivation. Carlier *et al. (*2000) have reported the presence of Eumusae leaf spot in South India; causing 20–40% yield losses.

Grape (*Vitis vinifera* L.) is one of the ancient fruits known to mankind and makes adequate mention in biblical records for its delicious fruits and wines prepared from its juice. Powdery and downy mildews of grape are the major diseases in earlier time. However, these diseases are manged by the adopting of resistant cultivars, use of different chemical and bioagents for the management. But there are cases of heavy disease occurrence in some regions of the world due to resistance development and undermanaged vineyards (Gessler *et al.,* 2011). This breach in the resistance repeatedly a matter of high concern.
The southern corn leaf blight(SCLB) epidemic of 1970–1971 destroying the 15% of the crop at a cost of US$1.0 billion due to dependence on cytoplasmic Texas male sterile (cms-T) lines in hybrid seed production and a natural mutation of a race of SCLB. In 1969 a mutant of the pathogen was reported in Philippines which is more destructive. The cms-T was discontinued in 1971 and hybrid seed production returned to using detasseling for the female parent (Burn, 2017).
Southern bacterial wiltof tobacco is a serious and devastating soil-borne disease caused by *R. solanacearum*, which is prevalent the tropical and subtropical regions (Yuliar and Toyota, 2015). The losses due to this disease in tobacco could be reached up to 60 %. Various breeding resistant varieties, chemical, agronomical methods and Biocontrol agents are utilized to control the diseases.The main biocontrol includes *Bacillus* spp., *Pseudomonas* spp., and *Streptomyces* spp.(Gamliel *et al,* 2000).

CONCLUSION

It can be concluded from the above discussion thatall the diseases despite of there nature like fungal, viral and bacterial etc., the most important strategies for diseases management is Integrated Disease Management (IDM). IDM includes cultural practices (change sowing date, sanitation of field etc.), and use of biological control agents as seed treatment, soil application and as sprays. The most important IDM strategies is development of resistant varieties and use of resistance source against the diseases. Apart from that at global level every region of the world has to behaves responsibly by strictly following the international, national and domestic quarantine measure.

DECLARATIONS

Conflict of interest: Authors declare no conflict of interest.

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