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Selected emerging and reemerging plant pathogens affecting the food basket: A threat to food security

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A R T I C L E I N F O

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A B S T R A C T

The introduction and spread of plant diseases and insect pests, mostly in horticulture and forestry, among food crops and other plant species have significant global repercussions for the farmers, seed industry, policy-makers, and the general public. It is important to increase the risk analysis, technical aspects of quarantine, and other control strategies. Programs to improve various protective measures against plant diseases and insect pests have been introduced by several agricultural ministries in various countries. It also offers an opportunity to raise public awareness of the need to deal with more serious issues connected to the threat posed by emerging and reemerging phytopathogens to food crops, forest trees, and other ecosystem services provided by the environment. Selected and significant developing diseases, their consequences, and potential sources of novel pathogens are addressed in this overview. The diseases reviewed include late blight of potatoes, Banana Xanthomonas Wilt (BXW), and black stem rust of wheat, which form a major food basket across the globe. Pathogen distribution and climate interactions, relationships between pathogenic virulence and climate, and the effect of climate on emerging pathogens are also discussed. Discussed also include changes in the ecological settings and atmospheric composition that favor infections but are unfavorable to host plants, this aggravating disease epidemics, as well as static management strategies that promote the creation of novel diseases and pests. Environmental change, particularly when coupled with introduction of new pathogen/host, may cause unprecedented outcomes. New pathogens affect the measures farmers apply to effectively manage the new pathogen in addition to the feasibility of cropping systems in various regions.

1. Introduction

Food security is vital for feeding the increasing populations of humans and animals [1]. According to Rivera-Ferre [2], food security is attained through four components: food availability, accessibility to food, food consumption, and food stability. According to FAO 1996, food security is defined as "when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". Food access, food availability, food utilization, and food stability are the four main pillars of food security [3]. And existing, emerging and reemerging plant pathogens impact negatively on these pillars. Emerging and reemerging plant diseases are described as new diseases with heightened virulence, host range and geographical spread and mostly result in epidemics. We run the risk of undermining other input investments in agriculture that reduce hunger if the negative effects of plant diseases on crop production aren't considered in policy discussions. In contrast to endemic diseases, which is typically managed, emerging and remerging phytopathogens can pose shocks to agricultural productivity. Agricultural systems suffer losses because phytopathogens

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rapidly affect these components (see Table 1, Figs. 3).

Food security is measured using several factors including affordability, availability, quality and safety and natural resources and resilience. According to the 2022 11th Global Food Security Index (GFSI), the world's food environment has worsened for the third year in a row, endangering food security. Different nations are vulnerable to shocks due to environmental structural challenges which have caused global food security to slow down. The other two pillars (availability, sustainability, and adaptation) suffered and weakened too because of reduction in trade freedom, increase in food inflation, and decreased financing for food safety nets.

Stability of food is often affected by impulsive crises in food production. Most of these food crises are as a result of major disease epidemics affecting plants whose causal agents include plant pathogens and arthropod pests (or/and a combination of these) [4]. Many ancient and modern diseases arise and threaten food crops and forests; indirectly, these diseases of food crops destabilize food security [5]. Emerging plant pathogens that cause devastation on cultivated crops are incorporated in international lists as quarantined pathogens. Abiotic (for instance, climate change, strong winds, global trade, hurricanes) and biotic elements (such as human relocation, human translocation of diseased plants and plant products) are promoting the spread of plant pathogens [4]. Recent study estimated that range from 10 % to 40 % or more of annual agricultural production value [6,7].

Climate change increases soilborne pathogens in rhizosphere, affecting crops and the economy. Chemical pesticides compromise soil health, while biological control offers sustainable alternatives with limitations [8]. Potatoes, declared the 2008 International Year by the FAO, are recognized for their nutritional value and climate adaptability, aiding in eradicating extreme poverty and hunger in developing countries [9,10].

Essentially, plant pathogens have the capacity of affecting food security and food safety. Owing to the growing need to feed the ever-increasing global population, research on plant pathogens primarily focusing on their effects on agricultural productivity and crop protection are inevitable. According to Hel et al. [4], plant pathogens are a key element affecting production of food as well as development of human societies throughout all the ages. During the early eras of agriculture, the incidences of epidemics of plant diseases were perceived as punishments from their deities [12] and categorical approaches for managing the epidemics were exceptionally limited. Given commonly low yields as well as the overall shortage of important food reserves, as soon as disease epidemics ensued, food shortages could definitely arise causing catastrophic effects on communities. For example, the *Phytophthora* late blight potato epidemic that caused the Irish Famine in the 1840s as well as the Bengal famine in 1943 initiated by rice brown spot. In spite of the scientific contribution and advances in technology to noteworthy decreases in the intensity and frequency of epidemics recently, 20 to 30 % of yield losses are still incurred annually as a result of plant diseases [13]. These losses in the yields reveal inadequate understanding of the causal agents and mechanisms leading to the development of an epidemic [14], a condition that obviously reveals a nonexistence of sufficient techniques to even competently manage the epidemics, leave alone eradicate them.

Table 1
Estimated annual losses in terms of quantity and money, based on the assumption that each developing infectious illness will result in a 1 % loss in production and the number of individuals who will likely suffer because of the shortage brought on by the losses across Africa [49].

Crop	Disease	Lost quantity (million MT)	Monetary value (billion US$)	Affected population (million)
Potatoes	Late blight	0.25	0.08	7.1
Banana	Banana Xanthomonas Wilt	0.20	0.07	8.7
Wheat	Black stem rust	0.26	0.09	5.4

Additionally, many management strategies of plant diseases along with many agricultural practices applied in modern agriculture have as well created unintentional complications such as environmental deterioration [15], loss of natural resources and biodiversity [11] in addition to accelerated development and spread of phytopathogens.

Over the history of agriculture, management of plant diseases has gone through four main stages. (i) Inadequate intervention in prehistoric farming systems. (ii) Temporal and mechanical approaches of disease suppression (e.g., rotations, ploughing, rogueing). (iii) Prevalent application of disease resistances through major genes as well as pesticides. (iv) Ecological management and integrated pest management emphasizing synergistic effects on populations, as well as the natural and agricultural environments [16]. Ecological plant disease management does not involve the mere return to ancient farming systems, instead, it targets to apply evolutionary intellect and principles to exploit the governing nature functions to create appropriate environments for healthy plants guaranteeing stable and high yields by efficiently utilizing the natural resources [17]. These resources include high resistance to diseases by creating environments hostile for the pathogen to establish infection, grow and reproduce, disperse and advance [18]. Furthermore, short/long-term economic impacts need to be assessed for management strategies for all plant diseases [19]. To realize the objective of sustainable management of plant diseases, multidisciplinary partnership involving biological and natural sciences such as agronomy, breeding, plant pathology, soil science, social science, economics as well as environmental science is necessary [20].

Risks of reemerging and new diseases arise because of a number of factors [21]. The leading factors include: (a) new pathogens moving within production systems; (b) more virulent strains moving in a system or appearance of a novel destructive strain within a region where the pathogen was found, (c) new vectors introduced in a production system with proficient ability of transmitting a pathogen, (d) changing farming practices which may favor some epidemic components of a categorical disease, (e) indiscriminate use of pesticides which leads to proliferation and development of strains that are resistant to pesticides, (f) agricultural intensification for maximization of production and profit, (g) cultivars variation, and (h) steady short term climate changes [22,23]. Some factors among these are inherent to crop agriculture, whereas others are extraneous, although significant forces e.g., international exchange, policy and trade play some role [22].

New climatic conditions [24], trade movements [25], host shifts [26], and a lack of inherent host resistance [26] have all been linked to the introduction of new pathogens. These factors are also thought to be contributing to a trend towards pathogen saturation in both crops and natural ecosystems [27]. To highlight the importance of quarantine procedures, pathologist training, and the introduction of crop resistance to slow the entry and establishment of pathogens in new countries, combined climate, crop growth, and disease modeling has been implemented in regions where pathogens are not already present.

Crop resistance is broken by emerging and reemerging phytopathogens, necessitating ongoing breeding for new resistance. The cost of this affects farmers as well as seed companies. Farmers are compelled to apply excessive amounts of chemical pesticides to manage and control the diseases when new pathogens emerge. Both the soil and the water bodies of the ecosystem are severely harmed by these chemical pesticides. Additionally, they affect non-target organisms including pollinators and beneficial soil microbial flora. Additionally, food products with chemical residues harmful to human health are rejected in lucrative markets. Continuous use of chemical pesticides causes the protectant to lose its effectiveness in the environment, requiring further breeding, which has a cost impact. Emerging and reemerging phytopathogens leads to decrease in food production which translates into increased food prices as well as change in eating habits.

The aim of this review paper is to provide some emphasis on some latest damaging diseases ascribed to phytopathogens and address the potential issues contributing to their advent. Furthermore, this review aims at providing more information about some new phytopathogens that are threatening several staple foods and having a detrimental influence on food security. Both the pathogens' sources and the environmental factors that facilitate their establishment are examined. The effect of these infections on farmers, seed producers, and various nations' food security. Moreover, how are farmers controlling these disease pandemics. The connections between infections and climate change as well as the potentially unforeseen results brought on by environmental change and the emergence of new pathogen/host interactions. The protection measures put out by various governments to stave off the introduction of new pathogens. In addition, owing to the international distribution of some phytopathogens, it is suggested that plant pathologists should build global networks in association with expert establishments, using public policies to address the most aggressive strains of pathogens, especially those categorized as quarantine pathogens.

2. Methods

2.1. Electronic databases

To finding unique studies on new phytopathogens of economic importance, a thorough screening of the pertinent literature was conducted utilizing a systematic review of the databases from Elsevier, BMC Springer, MEDLINE, Embase, Web of Science, and Ovid. Google Scholar was used to significantly improve the material [28]. However, the validity of papers collected through Google Scholar was established by linking readers to the pertinent active publisher.

2.2. Review question and the screening criterion

To make using the search criteria simpler, a review question was formulated. The authors formulated a review question and independently evaluated only primary study abstracts and English research titles in order to determine if the article should be included [29]. Strictly, all investigations on emerging and reemerging plant pathogens affecting food crops and without restricting the regions were included in the study. Titles and abstracts that met the basic satisfactory requirement after being deemed eligible by independent authors were chosen for full paper evaluation and afterwards used to provide the critical analytical data for the current analysis. To reduce potential bias issues, authors' independence was required while deciding whether or not to use the enlisted articles [30].

3. Examples of emerging and reemerging plant pathogens

3.1. Late blight of potatoes

Phytophthora infestans (Montagne) de Bary causes late blight (Plate 1) of solanaceous crops and is regarded as the most devastating disease of potatoes and tomatoes. The disease is considered a concern to global food security because it is predicted that late blight causes annual losses of over $5 billion globally [31]. This disease is also regarded as the most devastating disease of potatoes, causing up to 10 billion USD in yield loss and management costs. This disease caused a great famine in Europe that killed 0.7 M people and displaced another 1.5 M; affecting a quarter of the Irish population during the 19th century [32]. The disease is as old as the development of plant pathology as a science. However, it continues to be a threat due to regular emergence of new strains of the pathogen with increased virulence, and its encroachment in new regions with enhanced intensity [33]. This pathogen shows heterothallism whereby it requires two mating types A1 and A2 in order to complete sexual reproduction [34]. In regions where either of the two mating types is not available for sexual reproduction, the pathogen reproduces through asexual means producing clonal lineages or populations [35]. The movement of pathogenic strains between continents complicates the control and management of late blight. The movement of the pathogen across the continent has introduced strains with increased fitness, novel virulence and increased fungicide resistance [35]. [32]. Potato late blight has significant economic consequences, with a 25 % reduction in yields in Maine and potential industry collapse. Fungicide use alone costs $80 million, and the associated expenses are rising. A Delphi survey estimated late-blight fungicide expenditure at $77.1 million, leading to a revenue loss of $210.7 million for U.S. growers [36].

Managing *P. infestans* remains a key challenge, particularly amongst smallholder farmers in potato growing regions of Kenya. Farmers almost wholly rely on fungicides and resistant cultivars to control late blight. Most small-scale farmers do not adequately manage the disease due to resource constraints, making them incur huge losses while in some situations, they suffer 100 % crop loss. The pathogen develops resistance against effective fungicides and resistant varieties lose the resistance over a short time. New strains of *P. infestans* are emerging and spreading to new regions [35]. Potato cultivation faces late blight resistance from Phytophthora infestans, a significant economic threat. Genetic engineering techniques have enabled the direct transfer of resistance genes from wild potato species to cultivars, allowing easier pyramiding of multiple Rpi genes. This could increase potato resistance to rapidly evolving *P. infestans* strains [37].

3.2. Banana Xanthomonas Wilt (BXW)

Banana (*Musa* spp.) is the fifth primary food around the globe, after rice, wheat, maize and potatoes. The annual global production is approximately 100 million tons, and only 10 % is vended commercially, signifying how this crop is appreciated locally compared to its commercial importance [39]. Around a third of global production occurs in the Sub-Saharan Africa, in which the crop provides nearly 25 % of staple food to more than 100 million persons [40]. Banana Xanthomonas Wilt (BXW) poses a significant threat to East and Central Africa's banana production, causing up to 100 % yield losses if not controlled. The disease's economic impact on farmers and the economy is not well documented, but its huge impact on food security is significant. New research directions for sustainable management include developing resistant banana cultivars, exploring endophytes as biological control agents, fine-tuning cultural control practices, and educating farmers about BXW [41] Amidst the countless threats affecting banana crops, including infertile and poor soils, pathogenic and insect agents, the bacterial

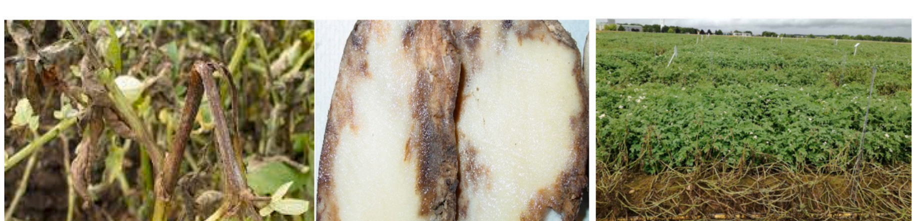

Plate 1. *Phytopthora infestans* on potatoes vines and tubers [38].

disease caused by *Xanthomonas campestris* pv. *musacearum*, called Banana Xanthomonas Wilt (Plate 2) is a very significant emerging threat. This pathogenic bacterium has spread swiftly throughout all regions cultivating bananas in Sub-Saharan Africa. No cultivars display comprehensive genetic resistance against the pathogen however, they have different degrees of susceptibility [42].

The disease causes entire crop loss, severely compromising the livelihoods and food security of millions of rural households [43]. Symptoms include a gradual withering and leaf chlorosis and necrosis, and swift, untimely fruit ripening, with brown internal stains, and rotting of the bunch, rachis, and male flowers. Eventually, the entire plant withers and dies. Symptoms appear rapidly, being visible as early as 3-4 weeks following infection; although it also depends on the pathogenic virulence, the conditions of the environment, and cultivar susceptibility (disease triangle). The bacterium is brought to the inflorescences by insect vectors such as fruit flies and stingless bees [44]. It can also be mechanically transmitted through infected farm tools, can be soil borne or from infected plant debris [42,45]. Rain droplets to neighbouring healthy plants can also spread the pathogen as well as infected propagating plantlets. The disease causes a distressing effect since it progresses very rapidly, producing severe symptoms, destroying the whole crop including propagation materials [46]. Furthermore, the pathogen persists for long periods in the soil; thus, it is prudent not to replant infested fields with banana until 6 months lapse. It is impossible to cure infected banana plantations upon initiation of infection [43]. Where the disease has established infection, yield losses of up to 60 % have been recorded threatening food security and livelihoods of millions of people in the East Africa region [47].

The cumulative annual loss is estimated at 0.8 M MT (worth US$ 0.28B), depriving roughly 35 million people in Africa of bananas in their yearly food supply. This estimate is based on a 1 % production loss by BXW in the banana industry. Bananas are also significant sources of income for many growers and retailers, and this amount of loss can destroy local economies. Innovative methods for battling Banana Xanthomonas Wilt (BXW) include early diagnosis by PCR and LAMP, stringent quarantine measures to stop its spread, farmer sanitary practices, and the creation of resistant banana types through breeding initiatives. Traditional breeding techniques are slow due to the sterile nature of the crop and lack of resistance in Musa germplasm. Genetic engineering has begun to address these issues, with transgenic bananas showing complete resistance against X. campestris pv. musacearum and enhanced resistance to mixed species nematodes [48].

3.3. *Wheat stem rust/black stem rust*

Regarding the quantity of calories consumed per person, the amount of food available, and the value of imports in Africa, wheat came in first. On more than 10 million acres of land around the continent, approximately 26 million metric tons (MT) of wheat are produced each year. Since domestic wheat production cannot keep up with demand, around 41 million MT worth of wheat imports worth US$ 12B each year, or 25.4 % of all wheat imports on the world market, are made.

Puccinia graminis f. sp. *tritici* is the pathogen responsible for wheat stem rust and is also called black rust because of the production of abundant shiny black asexual teliospores. It is a reemerging pathogen both in Africa and Europe although it has been endemic in African nations. It is a very severe disease in many wheat-growing regions around the globe [50]. Certainly, a field seemingly healthy through kernel expansion and fruition may be rapidly converted to a field of dark straws and wrecked withered kernels some few weeks before harvesting [51]. Effective breeding resistance programs have produced resistant cultivars and curtailed the losses associated with the pathogen, however, with time, the resistance is lost, demanding further breeding programs [52]. Wheat stem rust, also known as black stem rust, significantly impacts wheat production worldwide, causing yield reductions ranging from 10 % to 70 %. This disease also increases the cost of fungicides, monitoring expenses, and potential trade restrictions. The threat of new, virulent strains exacerbates these risks, making controlling and managing wheat stem rust a critical priority [53].

This rust is chiefly important during the final stages of growth of the wheat crop, on late maturing or late-sown crop. In humid and warm regions such as Sub-Saharan Africa, the pathogen can persist from one year to another on wild grasses and infected plant debris. The *P. graminis* spores are dispersed majorly through the air, where many spores are dispersed over short distances, giving rise to local epidemics [52]. Nevertheless, a small number of spores may be transmitted over long

Plate 2. BXW Aerial parts, the stem and banana fruits: premature ripening and rotting of sprouts and foliar symptoms caused bx BXW [49].

Plate 3. Black stem rust on leaves, stems and wheat grains [49].

distances where they cause and establish new infections [51].

A race known as Ug99, a hypervirulent prototype which originated from Uganda in 1999 has caused severe epidemics in wheat growing regions in East Africa. This protype is rapidly mutating with more than 13 races already described across Sub-Saharan Africa, Iran and Yemen. Most of the wheat varieties cultivated in Pakistan and India are highly susceptible to Ug99 [53]. These two countries produce around 20 % of the total wheat production in the world. Moreover, around 80 % of wheat varieties cultivated in Africa and Asia are possibly exposed to the rust fungus since its spores can be transmitted by wind even across continents [54]. Wheat, a major cereal, faces challenges from pests and diseases, particularly rust diseases. These diseases cause significant yield losses and can lead to food insecurity. To combat this, it is crucial to identify and deploy effective rust-resistant genes from diverse sources into pre-breeding lines and future wheat varieties. Genetic resistance is eco-friendly and can reduce rust pathogen evolution. Advances in next-generation sequencing (NGS) platforms and bioinformatics tools have revolutionized wheat genomics, enabling the identification of marker-trait associations, candidate genes, and enhanced breeding values [55].

According to Prank et al. (2019); Singh et al. (2015); and, yield losses of up to 50 % regionally and up to 100 % in wheat fields that suffered severe damage were documented in Sub-Saharan Africa. Savary et al. (2019) additionally reported annual production losses of 8.9 % from the same region. African nations that produce wheat might lose 0.26 M MT (equivalent to US$ 0.09B) yearly with a 1 % decrease in production, thus leaving 5.4 million consumers without staple food. 2.3 million MT of wheat might be lost, resulting in a shortage of wheat for more than 48.2 million consumers in Africa if output losses reach 8.9 % (Savary et al., 2019). With consequences for wheat prices around the world, this may mean raising wheat imports into Africa by 5.6 % of current import levels.

4. Potential sources of emerging pathogenic organisms

These are some of the postulates associated with the advent of first-hand insect pests, bacterial and fungal pathogenic organisms. a) The pathogen may be native and prevalent within the crop areas however, a new host has been discovered in recent times [56]. b) After being native and prevalent the fungi or bacteria turns into pathogenic, because of an escalation in the virulence of the organism, or because of a drop in the defense abilities of the crop host. c) The fungi or bacteria could possibly have been introduced within a new region and formerly unexposed crops and the pathogen becomes pathogenic to unique crops such as chili pepper. d) Insect vectors feeding upon or exploiting different plants, which harbor the pathogenic fungi or bacteria and pass them on to consequent plants [57].

Disease emergence is assumed as the consequence of numerous dynamics [58] including interactions amongst various pathogenic bacteria and fungi, interactions between pathogens and plants, interactions among insect-pathogen-plant, in addition to unfavorable conditions of environment [59] (e.g., prolonged droughts and erratic water regimes). Various authors indicate that adverse dynamics can act together and "aid" to consequently produce complex diseases. For instance, Pugnaire et al. [60] projected climatic dynamics could alter the microorganisms' nature and turn them into opportunistic pathogens.

5. Impact of climate change

The global climate changes are largely estimated to consist of a rise in the global average temperatures of between 1 and 2 °C by the year 2100 [61]. It is also projected that there will be a rise in the occurrence of extreme events such as periods of extreme temperature, droughts or storms, [62,63]. These climatic variations encourage the emergence of different pathogens in different regions. Climate changes the host's susceptibility to various pathogens other than influencing the cultivars of the host cultivated. Climate change too governs the host's distribution; both wild and cultivated, modifies the patterns of trade, in addition to determining the varieties of biocontrol and competitor species [64–66]. Climate change similarly influences the pathogen's virulence. In reaction to these climate variations as well as their associated impacts on crop plants and their phytopathogens, new varieties of crops might be developed; a process presently taking nearly on average, 20 years [67]. Nonetheless, where adaptation is feasible, it may be outcompeted by persistent, rapid changes.

The global warming or climate change, mirrored by mean temperature changes, decrease of annual rainfall, uneven distribution of rainfall and prolonged periods of drought, could alter the quality or growth of plants, and possibly result into mortality of crops [68]. Various authors agree that every time plants are stressed or weakened by environmental dynamics, bacterial and fungal organisms may comfortably encroach and take charge over these plants and in so doing cause their death [69]. Certainly, climate change has brought about the degeneration of the diversity of plant species globally [70]. Although a few authors theorized that exclusively the environmental dynamic effects result into emerging diseases, no solid proof has been presented to support these theories.

Changes in the geography and interaction process between pathogens and hosts are similarly dynamic in the occurrences of pathogen emergences [71]. It is well acknowledged that pathogenic organisms use specific structures to synthesize proteins to cause diseases in plants or make specific structures to release toxic substances to attack cells of plants [72]. In response to this attack, plants modify particles for their defense [73]. These adaptations in the relationship between the pathogen and the host is well illustrated in how *Persea americana* (avocado fruit) interacts with *Colletotrichum gloesporioides,* a fungal pathogen. In this interaction epicatechin, a flavonoid is produced by the fruit for protecting itself against the laccase protein synthesized by fungal species; *C. gloeosporioides* [74]. The geographical effect is evident, in which the inconsistency in the gene pathogenicity on the similar species is quite apparent in specific geographic regions. *Colletotrichum gloesporioides* isolates from Mexico displayed growing abilities to break down epicatechin, as contrasted with Israeli's isolates of the same pathogen [74].

McDonald & Stukenbrock [75] reported that variations in the functionality of the genes could as well add to the risks of emergence of new pathogens. The lateral transfer occurrence is properly documented amongst prokaryotic species as well as from prokaryotes to eukaryotes. This procedure is clearly illustrated when sequestered contrasting genes are lacking in species that are closely related but are found in distantly related species [76]. Nevertheless, the argument of lateral transfer of genes has some impediments. For instance, it is hypothesized that the orthological related genes could not be identified in related organisms [77]. However, it is likely that the genes could not be confirmed as identical but could still form huge rates of homologous relationship. Variations in the functionality of genes may as well be brought about by mutations over gene displacement and translocations, which could arise from copying huge numbers of genes [78]. Therefore, in a pedigree, a contrasting gene could be formed through biased gene losses. Differences in lineage loss and lateral gain can be more evident if many sequences of the genome could be available [79].

Further proof of gene functionality is that a few species strains might lack a certain gene. This may arise when a newly developed gene or a gene which possessed minimal evolutionary values is found [80]. These genes are well illustrated in instances where the organism possesses the alleged genes functioning as necrosis prompting and avirulence [81]. These scenarios are attributed to climate change, which might prompt species to develop coping mechanisms.

Usually, species possess a certain subclass of genetic disparity. Nonetheless, Fisher et al. [82] reported that this is likely because ToxA gene lateral transfer was effectively demonstrated through genetic disparity. Analysis of codon of transferred genes might display the predisposition on donor organism instead of on the recipient organism when microorganisms that are distantly related are compared. According to Casacuberta & González [83], mechanisms of transposons facilitate chromosomal rearrangements, since they are DNA segments with ability to shift positions within the genome. According to Zhang et al. [84], DNA movement from the donating organism is more likely if a gene is connected to a transposon, since the transposons propensity is inserting different recombination events or sequences which give rise to new genes [85]. For instance, the transposons associated with *Magnaporthe oryzae* have been demonstrated to produce high rates of recombination, which result into high rates of gene duplications and evolution of gene sequences [86]. Furthermore, the principal of transfer of lateral genes should dissect the purpose of b-chromosomes or supernumerary; the latter being validated amongst fungal strains isolated by Raffaele & Kamoun, [87].

6. Interactions between pathogen virulence and climate

The effect of the collective biotic and abiotic stresses on crop plants, imposed by a changing climate, will as well modify the susceptibility of the host plants to emerging pathogens as reported by Refs. [88–90]. These interactions occur at different levels, e.g., primary signaling centers, mitogen-activated and calcium-dependent protein kinases as reported by Refs. [91–93], signaling through reactive oxygen species [94], plant hormones signaling as reported by Ref. [95], in addition to other signaling molecules according to Refs. [96,97]. These signals regulate cell biology, gene transcription, as well as the appropriate physiological responses towards various stresses [88]. Cross-vulnerability and cross-protection amongst plant stresses are well documented. For instance, salinity stress boosts barley resistance against *Blumeria graminis* [98,99] while waterlogging stress increases resistance of barley/wheat to *Fusarium poae* [100]. On the other hand, water unavailability shields tomatoes from attack by *Botrytis cinerea* [101]. However, aerobic, drought-resistant rice varieties are easily attacked by root-knot nematodes [102] while beans become more susceptible to *Macrophomina phaseolina* during drought stress [103]. The defense mechanism of a plant is not fixed or static, however, it occurs in the setting of rapidly evolving pathogenic populations [104,105], that also react towards climate changes [106,107].

Abiotic stresses such as salinity, drought and extreme temperatures together with distressing plant growth similarly regulate the reaction of plants against attack by pathogens through either interfering with the pathogen as such or by suppressing or enhancing the defense mechanism of plants towards the pathogenic attacks [108]. Pathogens are armed with continually evolving mechanism of virulence, which enables them to successfully penetrate and initiate infections in their hosts [109]. The tussle between the pathogens and their hosts is extensively influenced by these abiotic factors, which regulate the mechanism of plant defense in addition to pathogen virulence, multiplication, survival and motility within the endosphere, phyllosphere as well as the rhizosphere regions [110]. This pathogen-host interaction at these regions modulates the net effect of the collective stresses on plants [111].

7. Pathogen distribution and climate interactions

Some pathogen groups infect healthy plants when environmental conditions are favorable. These pathogenic microorganisms are influenced directly by weather and climate, whereby they might require wet and warm conditions to cause infection [71]. High levels of carbon (IV) oxide and ozone in soybean, were reported to alter the manifestation of three diseases affecting soybean, viz., brown spots caused by *Septoria glycines,* downy mildew caused by *Peronospora manshuricà*, and sudden death syndrome caused by *Fusarium virguliforme* [112]. It was noted that response of the soybean plant towards the infections varied significantly. Changes as a result of elevated concentration of CO_2 such as papillae production, reduced density of stomata, and silicon accumulation at the appressorial penetration sites as well as altered leaf chemistry were reported to increase resistance in barley against powdery mildew caused by *Blumeria graminis* [113]. At high CO_2 concentrations, the severity and disease incidences of downy mildew were considerably reduced [114].

Some literature have demonstrated that predictions of impact and spread of pathogens are quite indeterminate to be applied in modeling policy, which implies that policy is better shaped when multiple scenarios are applied [115,116]. This observation is founded on the scarcity of current and past data on disease incidence, complexes of modelling and extrapolating the data for the future, in addition to intrinsic difficulties to understand the ways in which a pathogen's emergence prediction turns into a yield loss threat. The main aspect governing the distribution of pathogens is the host distribution [117,118], then alternative hosts distribution follows closely and finally the accessibility of predisposed hosts throughout the year. There exists some proof that pathogens will saturate their hosts in the end [119]. The rate at which the saturation of hosts by the respective pathogens will largely depend on transportation of hosts and trade [119,120]. The precision of prediction of diseases therefore hinges on the capacity to forecast choice of crop, land use activities and trade, and these factors depend on disease incidence and climate change. Distinct case investigations can yield valuable predictions, with more accurate parameters. Climate change does not simply involve steady rises or declines of rainfall or temperature, but gives rise to random temporary fluctuations of weather as well as extreme weather incidents [121]. These can modify how a pathogen can spread, establish, and cause epidemics within a new region.

8. Impact of new diseases and their unprecedented outcomes

Emerging pathogens such as viruses, fungi, bacteria, parasitic plants, noxious weeds and insect pests, in many cases infect the food crops reducing yields and availability of food to the human populations [3]. These continue as leading limitations to agricultural and food productivity in most developing countries. Emerging and re-emerging plant pathogens have the potential to reduce yields radically since the crop plants might not develop resistance faster [122]. New diseases might also cause decreased food production or total crop failure. Crop failures substantially shrink the food amounts accessible for consumption by human and animal populations, which directly contributes to poverty and food insecurity [123]. Furthermore, new pests for instance, insects might destroy the crop growth, reducing yields and affecting food security. New pest similarly negatively affect interior and exterior trade and marketing of agricultural products, reduce farmers' revenues, and obstruct alleviation of poverty among the communities [124]. The plant pests' control and management until now entails extensive use of synthetic pesticides, which generates adverse effects on environment and human health [125]. This is especially real for poor farmers who might not pay for or demand less toxic pesticides, fitting personal protection and appropriate application equipment [126].

The immediate effect of a new plant pest or pathogen in most cases has more social and political significance than agricultural aspects. In most cases, the farmers experience the fear of the unknown, since they do not know in what ways the new disease would affect their crops and the yield [127]. For instance, if a new fungal pathogen affects a cereal crop, the feed industry would be concerned regarding potential toxic alkaloids or aflatoxins being deposited on the cereal. Feed grain and seed exporters would possibly fear a potential closure of the export market. The farmers, the feed and seed industry, researchers and plant pathologists would be tasked to learn how to prevent, manage, control or coexist with the new disease [49].

The biggest threat to humanity is climate change, which costs the globe more than US$ 1.2 trillion annually and results in almost 0.4 million fatalities globally each year. Our agriculture is being impacted by climate change as a result of the 0.74 °C average global temperature increase over the past century and the increase in atmospheric CO_2 concentration from 280 ppm in 1750 to 400 ppm in 2013. The development and production of the many crops on Earth will be significantly impacted by such changes. The reproduction, spread, and severity of numerous plant infections are also be impacted simultaneously by these changes, putting our food security in jeopardy. Stem rust resistance due to Sr31 is also threatened by the Ug99 race of stem rust brought on by *Puccinia graminis* f. sp. *tritici* due to climate change [128]. Increased CO_2 levels and temperature are also perceived as greater threats by significant rice diseases such as sheath blight (*Rhizoctonia solani*) and blast (*Pyricularia oryzae*) and late blight (*Phytophthora infestans*) of the potato. Climate change has altered the disease picture, highlighting the necessity for future research on models that may foretell the severity of significant infections of vital crops in actual field settings. In addition, new approaches to sustainable food production should be combined with disease management measures to reflect the changing environment [128].

9. Ecological environments favorable for pathogens but adverse to host plants

Healthy soils are vital for sustaining agriculture along with the management of plant diseases through their effect on pathogen densities primarily the pathogens causing soil-borne diseases [129,130]. Additionally, healthy soils also influence the composition of valuable communities of microbes in addition to the accessibility of essential nutrients for the growth and development of plants [131,132]. Over the past years, air pollution, water originating from agricultural wastes, industrial emissions and indiscriminate use of synthetic chemicals to nurture crops as well as manage weeds and pests has created myriad and almost irreversible changes. This reduces the quality of farmland through compaction of soils, reduction of the organic material, imbalances in mineral nutrition, and contamination with pesticide residues and heavy metals [133,134]. Additionally, this deterioration in quality of the farmland might further decrease the immunity of the host plants against attack and infection by the pathogens. Strategies in agronomic management might produce a key effect on quality of the soil with consequential influences on disease incidences [135]. Therefore, many activities aimed at improving the quality of the soil through increasing microbial biodiversity and the valuable microorganisms in the farmland via practices such as supplementation with organic matter similarly help to suppress many diseases from developing [129]. Crop rotation characteristically enhances the soil's chemical and physical properties including nutrition balance along with the microbial community diversity [136]. Alternatively, production techniques and field management for instance, monocultures and constant cropping of one crop or variety intensify the threat of occurrence of diseases as well as epidemics because pathogens are allowed to amass in large inoculum loads [137]. This is particularly the situation of diseases that are soil-borne although it is similarly true for various diseases affecting the aboveground parts of crops. These strategies expedite the interruption of disease management strategies because of the application of restricted numbers of pesticides and resistant genes as a result of the improvement of selection pressures on pathogenic microorganisms. This is because of reduced diversity of the host crop and the overreliance and indiscriminate use of synthetic pesticides with rigid modes of action [18].

Excessive pesticide usage, monoculture cropping systems, and poor crop rotation patterns due to limited land resources, these factors interact synergistically to change the ecosystem and create favorable conditions that influence disease establishment more quickly and easily. Furthermore, any resistance to diseases is damaged as well as the natural immunity of crops. These elements contribute to the establishment of novel infections, especially in areas with vulnerable crops, favorable environmental conditions, and aggressive pathogen strains. The "disease triangle" refers to the interaction of these three elements. The monoculture cultivation of the three crops reviewed in this study—banana, wheat, and potato—increases the risk of novel infections, particularly those that cause the diseases BXW, black stem rust, and late blight, respectively.

10. Static management strategies

Due to rapid evolution and the speedy spatio-temporal dynamics of pathogens, they are quite difficult to control [138]. This management problem is linked to the short generation times and high genetic diversity, which together enhance the ability of pathogens to overcome the most effective disease management methodologies, based on industrial pesticides and resistance through major R genes [139]. Integrated pest management (IPM) methods promoted in recent times are envisioned for the management of plant diseases through pulling together various methods based on the individual diseases, locations and time. Nevertheless, the synthetic pesticides application has almost turned out as the chief and the only method of IPM strategy, predominantly for crops, which lack the R major genes for resistance [140]. Research has indicated that there is indiscriminate use of synthetic fertilizers and pesticides, which does not result to increased production of food in the recent times [141]. This indicates the decreased effectiveness and monetary return of the use of synthetic pesticides in the management of plant pathogens. Generally, pesticides are applied using a prescribed method, standardized type, time, dosage and frequency of application irrespective of the resistance status of individual crop plant, chemical sensitivity of the pathogen and environmental conditions [142]. Such a static and fixed approach of application of the pesticide reduces efficacy of management, increases production costs, and results into numerous unnecessary adverse environmental and societal effects for instance livestock and human toxicity as well as ecological degradation [142].

Chemical pesticide applications continue to be the most efficient method of controlling potato late blight in the major potato-producing regions worldwide. An example of static plant disease management includes use of chemical pesticides to manage the late blight of potatoes whereby around thirty-six fungicides and fungicidal mixtures are registered in Europe for late blight control. The economic and environmental dangers connected with regular chemical pesticide application have grown concerning despite their efficiency in controlling potato late blight. It is therefore unsurprising that pesticide expenses could represent 10-25 % of the marketable value of the potato crop in some places [143]. In some potato-producing regions, up to twenty rounds of pesticide application are needed per season for successful control.

Pesticide misuse has played a significant role in the emergence of pesticide-resistant populations of *P. infestans* all over the world. This has decreased the efficacy of chemical control of potato late blight and, as a result, increased the dosage and frequency of pesticide application, creating a vicious cycle. To mitigate this, adoption of integrated pest management (IPM) is encouraged. This includes carrying out proper crop rotation patterns, use of biological control methods, eliminating alternate hosts and clearing all plant debris where the pathogen spores could overseason, in addition to extermination of all diseases crops to avoid further spread and epidemic outbreaks. Furthermore, use of mixture of diverse pesticides with different modes of action could also be adopted [144].Additionally, use of cropping systems with a wide range of crop species, adjusting planting dates, using cultivars with higher tolerance and/or resistance to abiotic and biotic stress, effective quarantine systems and use of consistent tools to forecast disease epidemics, could also help mitigate the impact of emerging phytopathogens.

11. Quarantine and control strategies against new phytopathogens

The diseases covered in this review are all caused by quarantine pathogens. Fast, effective, and affordable diagnostic techniques that enable early detection and the deployment of countermeasures can be utilized to manage and even prevent the diseases brought on by quarantine pathogens. Because they enable earlier interventions to stop or limit the spread of infection, all-in-one diagnostic procedures that identify diseases and concurrently determine the pathogen genotypes in a quantitative manner are highly desired. This could reduce the quarantine periods for merchandise in transit. Next-generation sequencing (NGS)-based strategies are extremely promising since they enable the detection of pathogens with high sensitivity and provide the genomic sequence data required for quantitative genotype-specific proof of identity, including new genetic variations [145]. Illumina sequencing could be employed in locating and identifying specific fungal subspecies; while effective, this technique necessitates specialized lab equipment and qualified staff. The Oxford Nanopore Technologies (ONT) MinION device has the same benefits as other NGS platforms but is portable and reasonably priced, enabling more extensive in-field deployment. It also has the ability to resolve distinct isolates, strains, and subspecies by differentiating between single-nucleotide variants [146].

Different governments and respective ministries of agriculture in different countries are adopting protocols and high standards to keep at bay invasive pests and phytopathogens. In order to detect and accurately identify invasive phytopathogens, governments are allocating enough resources towards the same. This is to support high-throughput sequencing (HTS) methods, which are still in the early phases of development, are advised for the detection of regulated phytopathogens or those that were not previously identified. HTS technologies make it possible to screen plants and plant products more quickly and accurately than with conventional diagnostic techniques. Unfortunately, these technologies are not very effective because of limitation in funding capacities particularly in the developing countries.

12. The management of plant disease epidemics in the future

Sustainable management of plant disease epidemics entails a multi-dimensional deliberation of the effects of management strategies on finances, ecology and sociology by entirely understanding the disease epidemic mechanisms, how healthy agro-ecosystems function and collective and individual roles of policies on managing disease epidemics [147]. The policies of management of plant diseases attempt to improve productivity of agricultural products and raise the quality of food in addition to protecting the natural resources and ecological environment. To realize this objective, prospective research work in ecological management of plant diseases ought to emphasis on: (a) evolutionary and epidemic plant disease patterns in varying environments and agronomic production principles [18]. (b) The importance of ecological deliberations in crop health and agronomic productivity. (c) Social-economic scrutiny of plant disease management and epidemics. (d) Technological development for incorporating the key crop disease management with ecological perspectives [148].

13. Conclusion and future recommendations

It is important to understand how climate change affects agriculture, particularly the impacts on the prevalence of diseases and pests and severity since this influences food security. Climate change contributes significantly to the emergence and re-emergence of new pests and diseases, quality and yield of food-crops. New diseases and pests negatively influence the social and political aspects of populations. The available knowledge on the effects of climate change on emergence of new pathogens is inadequate and its effects on plant health. However, it is predicted that climate change might modify how pathogens grow and develop, alter resistance of host crops and transform physiological interactions between the host and pathogen, indirectly influencing plant disease severity. Indiscriminate use of synthetic pesticides is also contributing indirectly to the emergence of a generation of resistant pests and pathogens.

Declaration of competing interest

All the authors participated in developing the manuscript and declare no conflicts of interest on this work.

Data availability

No data was used for the research described in the article.

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