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Review Article

Effects of Environmental Factors on Crop Diseases Development

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ABSTRACT

Environmental factors are triggering simultaneous effects on the disease incidence and severity of crop diseases in agriculture. These both aspects are affected by various environmental factors viz. temperature, soil moisture, humidity, light, soil properties (pH and nutrients) and atmospheric carbon dioxide. The effect of environmental constraints on host and pathogen has positive, negative or neutral effects on crop disease incidence. Sometimes sole factor is responsible for profused disease incidence. On the other hand, interaction of various environmental factors causes huge intensity of diseases. Crop disease is the result of three way interaction between susceptible host, virulent pathogen and favourable environment. Elevated CO_2 concentration and increased temperature influence the plant disease interaction. This review article focuses the relationship between various environmental factors and crop diseases and their role in increasing or decreasing the disease severity.

Keywords: Crop disease; Environmental factors; Host; Pathogen; Temperature

INTRODUCTION

Pathogens in field experience various environmental effects. Almost all plants require favorable environmental conditions for better growth, development and subsequent production. Occurrence of different levels of diseases and intensity of plant pathogens are determined by various biotic and abiotic factors [1]. A crop disease is the dynamic relationship between host and a pathogen that are intimately related with the environment mutually influencing and resulting in physiological and morphological deformations. It results from a three way interaction between susceptible host, virulent pathogen and favorable environment. Changes in environmental conditions are favored to trigger crop diseases and are responsible for 44% diseases emergence [2]. About 10% of global food production is lost by the crop diseases, signifying a threat to global food security [3].

Individual factors

Temperature

Temperature is one of the cardinal factors which influences the occurrence and development of many diseases. Most of the fungal diseases are more severe at lower temperature and bacterial diseases are more severe at slightly higher temperature than that of fungal diseases. However, temperature becomes more precarious when it deviates from optimum level. Plant growth and development, as well as disease severity is directly affected by temperature stress resulting from climate change [4]. When plants susceptible to pathogens are grown in areas, various pathogens are capable of causing diseases as they can resist wide range of environmental variabilities.

Onion smut caused by *Urocystis cepule* is more prevalent at 10-12°C which is as low as will allow the onion germination. Temperature directly affects the susceptibility of plant host to diseases and it also alters germination of spores, rate of inoculum production and growth of hypha [5]. Temperature alters the visual symptoms of diseases. e.g. Yellow Dwarf Virus (YDV) in barley produces significant symptoms at 16°C whereas symptoms are masked at 32°C but at 32°C symptoms of aster yellows on barley are prominent and masked at 16°C [6]. Tripartite interaction between pathogen, vector and host plant, temperature profundly influence the disease development mainly for viruses [7].

Pentalonia nigronervosa, an aphid which transmits Banana Bunchy Top Virus causing bunchy top of banana, can grow faster at 25°C which is an equivalent temperature for development of bunchy top. Pre-emergence and post-emergence death of seedlings of cereal crops (by *Fusarium nivale*) is mainly due to low temperature while many seedlings bears leisons and little pre-emergence death occurs at higher temperature [8]. Some host species are susceptible to pathogens at temperature above the maximum for infection of other species. e.g. *Agrobacterium tumefaciens* does not induce galls on herbaceous hosts at 31°C for 4 days after inoculation whereas galls are formed on cherry at 37°C held for 4-6 days after inoculation [9] (Table 1 and Table 2).

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Moisture

Most of the plant diseases are predisposited in condition where there is often soil water deficit. However, most plant diseases are more severe in dry soils and some in wet soils. e.g. Club root of cabbage (by *Plasmodiophora brassicae*) is more serious in wet conditions. On other hand, *Streptomyces scabies* in potato, *Uromyces agropyrion* on wheat, *Fusarium* in cereals, *Pyricularia oryzae* in rice, *Sclerotium* in onion are more severe in dry soil. Some pathogens show their vigorous activity in intermediate soil moisture. e.g. Pea foot rot (by *Fusaium solani*) is seen in intermediate soil moisture. It is due to the fact that poor germination of chlamydospores occurs in dry soil and poor germling growth in wet soil [10].

Pathogens attack and develop in the host plant when there is increases water stress condition and host becomes susceptible due to reduced photosynthesis (inhibits the production of phytoalexins) and reduction in growth of plant without affecting multiplication of pathogens [11]. Likewise temperature, moisture content of soil also affects the severity of plant diseases. Some fungal pathogens like *Phytophthora infestans*, *Pythium debaryanum* and downy mildew fungi are less prominent at lower moisture content [12] but majority of aboveground diseases (leaf rust, powdery mildew, leaf spots etc.) require sufficient leaf wetness period for infection [5]. For soil inhabiting pathogens, soil moisture becomes more critical than atmospheric humidity. Infection of *Ralstonia solanacearum* in tomato decreases when soil has low moisture content [13].

Humidity

Humidity triggers the disease progressing mainly by altering infection process, germination of spores and dissemination of spores [14]. Rain and high humidity triggers the infection of aerial plant tissues by the pathogens. Relatively high (>85%) atmospheric humidity is favorable for infection to occur and diseases development. For most of the fungal pathogens, leaf wetness (time period in which leaf has water on its surface) is critical for development of disease. e.g. *Pyricularia oryzae* for rice blast and *Puccinia striformis* for striped rust of wheat require minimum of 5 hours for diseases development and infection to occur [15]. In some cases, high humidity does not directly reduce the crop yield but its effect is seen in marketibility of product. *Fusarium graminearum* in wheat produces large number of mycotoxins, deoxynivalenol at high humidity which reduces the probability of grains being sold [16]. High atmospheric humidity influences resistance to invasion by Botrytis cinerea and Penicillium expansum during development of apple by modifying lenticels [17]. Temperature, light and moisture often interact with humidity for releasing ascospores in ascomycetes.

Atmospheric CO_2 concentration

Rate of photosynthesis and crop yield is supposed to increase with elevated CO_2 concentration of C_3 plants. Due to accumulation of greater amount of photosynthates in host plants, biotrophic fungi like rust promote the development of symptoms [18]. Consequensly, the probability of disease severity in rice (*Oryza sativa*) and wheat (*Triticum aestivum*) increases [19]. Susceptibility of wheat also increased for *Fusarium graminearum* with increased CO_2 level. On the

Table 1: Optimum temperature for disease development of different crops.

S. No	Crop Disease	Pathogen	Optimum temperature (°C)
1.	Cyst nematode of potato	*Globodera pallida*	15
2.	Early blight of potato	*Alternaria solani*	28-30
3.	Late blight of potato	*Phytophthora infestans*	12-20
4.	Bacterial leaf blight of rice	*Xanthomonas oryzae*	27
5.	False smut of rice	*Ustilaginoidea virens*	20
6.	Papaya ring spot	*Papaya Ring Spot Virus (PRSV)*	26-31
7.	Black rust of wheat	*Puccinia graminis*	25-30
8.	Stripped rust of wheat	*Puccinia striformis*	18-30
9.	Loose smut of wheat	*Ustilago nuda var, tritici*	16-22
10.	Bunchy top of banana	*Banana Bunchy Top Virus (BBTV)*	25
11.	Brown spot of rice	*Helminthosporium oryzae*	28-30
12.	Sheath blight of rice	*Rhizoctonia solani*	28-32
13.	Damping off	*Pythium, Phytophthora, Rhizoctonia, Fusarium, Sclerotia*	< 24
14.	Club root of cabbage	*Plasmodiophora brassicae*	18-25
15.	Leaf spot of cole crops	*Alternaria brassicicola*	28
16.	Downy mildew of cole crops	*Peronospora parasitica*	12-27
17.	Downy mildew/crazy top of maize	*Peronosclerospora sorghiis*	21-33

Table 2: Effects of elevated temperature on host pathogen interaction.

Disease and host	Pathogen	Change in temperature	Change in severity	References
Late blight of potato	*Phytophthora infestans*	Elevated temperature	Increase	(Hannukala, 2007)
Anthracnose of citrus	*Colletotrichum acutatum*	Elevated temperature	Increase	(Jesus Junior, 2007)
Bunt of wheat	*Tilletia controversa*	Elevated temperature	Increase	(Boland, 2004)
Striped rust of wheat	*Puccinia striiformis*	Higher temperature	Increase	(Milus E. , 2006)
Root knot of coffee	*Meloidogyne incognita*	Elevated temperature	Increase	(Ghini, 2008)

other hand, interaction between *Peronospora manshurica* and soybean decreased due to increased CO_2 concentration by 50% resulting in alleviated disease development [20]. Growth and development of conidia, germ tube and appresorium of *Colletotrichum gloeosporiodes* is retarded at high CO_2 concentration (700 ppm) [18].

The number of conidia was lower and acclimation of photosynthesis at elevated CO_2 concentration (700 ppm) than in low concentration of CO_2 (350 ppm) [21]. The modeling research on elevated CO_2 and infection conducted on Scotland showed that the severity of late blight of potato by *Phytophthora infestans* increased in first half of the season and decreased in second half of the season [22]. Effects of CO_2 concentration on host pathogen interaction literally do not provide the unifying principles and results through different research. Therefore, it underscores the necessity to extend works and researches in this field (Andre C, 2018). Elevated CO_2 concentration influences both the host and the pathogen in *Stylosanthes scabra* causing anthracnose by *Colletotricum gloeosporioides* differences in the disease resistance expression under these conditions [23] (Table 3).

Light and photoperiod

Light is the most momentous environmental factor for circadian regulation [24]. Various studies have shown that light has direct impact on sporulation of different oomycetes and other fungi, and pathogen's virulence has been closely linked to circadian clock of fungal pathogen. *Plasmopara viticola*, causing downy mildew of grapevine, immature shape of sporangia was observed in continuous light and has no effect on formation of sporangia and growth of mycelium [25]. Sexual and asexual spore formation in *Phytophthora infestans* is regulated by light. Uredospores of *Uromyces phaseoli* germinate spontaneously in both light and darkness [26] but uredospores of *Puccinia gramini* have greater affinity to darkness [27]. Low light intensity is best suited for *Puccinia graminis* to cause rust disease but high intensity of light (8000 lux) is found to be best conducive for *Septoria tritici* on wheat. However, stomatal penetration by *P. graminis* on wheat leaves reduces in darkness. Photoperiod of more than 12 hours resists barley plants to *P. striiformis* and plants are susceptible to pathogen at lower intensity of light [28]. Short photoperiod and low light intensity is conducive for *Fusarium* wilt in tomato [29]. Light intensity and day length during pre-inoculation and post-inoculation of inoculum also affect the severity of diseases development.

Soil pH

Soil pH is the important factor which controls the severity of plant disease caused by soilborne pathogens. Occurance of club root of crucifers is severe in acidic soil which can be controlled by liming. The spores of *Plasmodiophora brassicae* are unable to germinate in alkaline soil and can't survive in such modifications. For successful disease development, soil pH is also necessary as above mentioned factors. *Streptomyces scabies* is more prominent at pH of 5.2 and severity of scab lesions is decreased at pH 8.5 [30]. *Fusarium* wilt of flax is almost controlled at neutral soil pH i.e., 7. More disease incidence occurs although pathogens grow in their favourable pH [12]. Club root of cabbage is found more widely in acidic soil than in alkaline soil. If disease has to occur in alkaline soil, there should be high temperature (23°C), high moisture (70%) and high crop load (10^5-10^7 spores / gram of soil) [31].

Some saprophytic organisms in soil show antagonistic effects to some soil borne pathogens. Moreover, soil reaction may influence the availability of soil nutrients and affects plant growth and vigour affecting a change in the microclimate within a crop, indirectly affects infection and disease development [4].

Soil nutrients

Major nutrient elements, nitrogen, phosphorus and potassium sometimes increase or decrease the susceptibility of diseases. The effects of nutrients on disease development can be subjected to a) rate of growth of host, b) effects on vigour of plant, c) effects on cell wall and tissue and d) effects on pathogen through the alteration of soil environment. Susceptibility of plant roots to the pathogen differs due to alteration in plant nutrients. This case occurs in root rot of chrysanthemum caused by *Phoma chrysanthemicola*. This root rot is found to be suppressed at high level of nitrogen and phosphorus [32]. Microelements also influence disease development but they are not much concerned as major elements. Some deficiency disorders viz a) whiptail of cauliflower due to Mo deficiency, b) khaira disease of rice due to Zn deficiency, c) blossom end rot of tomato due to Ca deficiency, d) hollow heart of cauliflower and internal browning of tomato due to B deficiency, e) marsh spot of peas due to Mn deficiency. In some extent, minor elements favour pathogen incompetence towards host plants. Potatoes are found resistant towards Alternaria solani and *Phytophthora infestans* where nickel and cobalt are in excessive amount [33].

Interaction of multiple environmental factors

Although effects of individual factors are regarded as the foremost importance in the study of interactions of those factors to crop diseases, numbers of factors contribute simultaneously for disease development. Severe reduction in turnip growth can be observed when combined effects of heat, drought and Turnip Mosaic Virus (TuMV) infection are subjected than exposure of individual factors [34]. Most of the fungal pathogens infect severly in the combined effects of high humidity and warm temperature [35]. *Plasmodiophora brassicae* develops more club roots in cabbage at the combination of acidic soil, soil moisture of 70-80% and temperature of 18-25°C. *Botrytis cineria* develops prominent grey brown leisons on grapes at 20-25°C temperature and 100% relative humidity and infection decreases when conditions deviate from optimum [36].

Table 3: Effects of elevated CO_2 concentration on interaction between host and pathogen.

Disease and host	Pathogen	Climate change	Change in severity	References
Stripe rust of wheat	*Puccinia striiformis*	Elevated CO_2	Decrease	(Milus, 2006)
Crown rot of wheat	*Fusarium pseudograminearum*	Elevated CO_2	Increase	(Melloy, 2010)
Smut of barley	*Ustilago hordei*	Elevated CO_2	Increase	(Manning & Tiedman, 1995)
Powdery mildew of barley	*Blumeria graminis*	Elevated CO_2	Decrease	(Hibberd J. , 1996)
Barley yellow dwarf	*Yellow Dwarf Virus*	Elevated CO_2	Decrease	(Hibberd J. , 1996)

The importance of the interaction of various environmental factors on disease has been commended by number of researchers, but more intensive work would be profitable in respect to many diseases. During study of late blight of potato by *Phytophthora infestans*, the minimum, optimum and maximum temperature, leaf wetness duration and concentration of inoculum each depended on other two factors, sometimes on one and often on balance of both.

Environmental impacts on PAMP-triggered immunity (PTI)

Pathogen-Associated Molecular Pattern-Triggered Immunity (PTI) is concerned with prevention of proliferation of non-pathogenic microorganisms. Virulent microorganisms (i.e., bacteria) cause infection by causing leaves apoplast to be water-soaked [37]. Under high humidity, water soaked condition in apoplast favours non-pathogenic bacteria like *Pseudomonas* which induces PAMP-triggered immunity. These PTI inducing bacteria develop in host plants like tobacco, Arabidopsis and bean plants [38]. PTI is the mechanism in which conserved molecules of pathogens or microbes (PAMP or MAMP) are recognized by plant plasma membrane-localized pattern recognition receptors (PRR). Activation of PTI enhances the closure of stomata after recognizing MAMP by guard cells of stomata indicating plant defense mechanism against microorganisms into leaf apoplast [39]. High atmospheric humidity blocks PTI-induced stomatal closure in bean plant and Arabidopsis. Likewise, temperature can also alter PTI signals in both short term and long term [40].

Environmental impacts on Effector-Triggered Immunity (ETI)

Effector-triggered immunity (ETI) is the genetic method of resistance control mechanism against pathogens. Plant resistance (R) proteins like Leucine Rich Repeat (LRR) and Nucleotide binding domain detect the virulent pathogen inside the plant host [41]. This recognition is similar to hypersensitive (HR) response, a type of programmed cell death. ETI and cell death are continuously activated by the impact of elevated temperature on ETI.

Disease control

Abovementioned environmental factors influence the disease management strategies. Change in precipitation, temperature and light alter fungicide residue in foliage and products degradation can be modified. Physiological and chemical changes in crop cultivars obtained by both GE and traditional methods can alter the resistance mechanisms [42]. Biological disease control mechanisms are not normally implicated in effects of environmental factors. Soil microorganisms can be made inactive by modifying soil temperature, soil moisture and soil nitrogen content. Diseases in acidic soil can be controlled by treating with lime and that of alkaline soil can be controlled by treating with gypsum. Many physiological changes can potentially enhance the resistance to different diseases.

For prevention, control and eradication of crop diseases, regulatory measures are initiated by various countries. Phytosanitary regulations are adopted to eradicate and prevent pathogens affecting plants. Quarantine mechanisms control the movement of pathogens from an affected area to newer one which directly restrict and delay introduction of pathogens.

CONCLUSION

Evaluation of contemporary management strategies and formulation of alternatives against the challenges of environmental change are needed to mitigate the crop diseases. Relevant researches on environmental effects on crop diseases should be carried out in accordance with current host pathogen interaction. Qualitative and quantitative evaluations of diseases are needed to be assessed to know the occurrence and dissemination of pathogens and their influence on crops. Formulation of policies and cooperation with national and international organizations would be crucial to alleviate the threat of pathogens.

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