

Effects of Climate Change on Crop Pests and Diseases in The Tropics

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ABSTRACT

Climate elements exerts limitation on both plants and pests growth, reproduction capacity and their distribution in terms of ability to adapt to the prevailing environmental factors. The area of the world that lies within the Tropic of Cancer and the Tropic of Capricorn is generally referred to as the "Tropics". It includes Central America, northern part of South America, much of Central Africa, South Asia, and the northern part of Australia. The problems that prevail in these areas are prevalence of pests and crop diseases as one the most limiting factor to crop production. Majority of the food we eat comes from the domesticated plants, which are attacked by pests and diseases which are respectfully affected by extreme weather conditions occasioned by climate change. Studies have shown that climate change has exacerbated the effect of diseases, insects and weeds on crop production that lead to about 36.5% of yield loss estimated to the tune of \$220 billion dollars annually across the globe. In addition to monetary losses, yield loss causes malnutrition and hunger resulting to unprecedented social crises. To mitigate the effects of plant diseases, millions of kilograms of pesticides are used to treat seed, soil and harvested fruits every year, which increases production costs and environmental pollution. The aim of the paper to discuss Effects of Climate Change on Crop Pests and Diseases in the Tropics. The tropical region, climate change, causes of climate change, constituent of climate change, driver of climate change, interactions that lead to diseases, impact of climate change on some pests and their distribution in the tropics were discussed.

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INTRODUCTION

The existence of plants and their distributions all over the world are regulated by climatic factors. Climate elements exerts limitation on both plants and pests' growth, reproduction capacity and their distribution in terms of ability to adapt to the prevailing environmental factors (Chen *et al.*, 2011; IPCC, 2021). Crop production is keenly sensitive to climate change specifically to rainfall and temperature which are the main factors that determine the global distribution of food crops (Abbas *et al.*, 2014). Climate change effects is not limited to change in rainfall pattern and temperature volatility but increase in the likelihood of occurrence of extreme events like drought, floods and heat waves (IPCC, 2013). Extreme weather conditions will modify life on the planet, depending on their intensity and duration in the rain or the temperature, as well as the level of vulnerability of the society or an ecosystem, the impacts of climate can vary from imperceptible to catastrophic, with economic consequences (Garrett *et al.*, 2006). The nature, pattern, and ecological and societal consequences of land change will vary on all spatial scales as a result of spatial variation in human preferences, economic and political pressures, and environmental sensitivities (Carpenter *et al.*, 2007; Chen *et al.*, 2011)). Climate change was observed to weaken agricultural activities and food security in the global scale (IPCC, 2013). Majority of the food we eat comes from the domesticated plants, which are attacked by pests, diseases and extreme weather conditions. Pests are the insects of all species that attack plants and diseases includes fungi, bacteria, virus and nematodes that are pathogens to plants.

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Studies have shown that diseases, insects and weeds interfere with 36.5% of crop production around the world which represents an annual loss of \$220 billion dollars (Agrios, 2005). In addition to monetary losses, yield loss causes malnutrition and hunger resulting to unprecedented social crises. To mitigate the effects of plant diseases, millions of kilograms of pesticides are used to treat seed, soil and harvested fruits every year, which increases production costs and environmental pollution (Yang *et al.*, 2023). Plant diseases are abnormality caused by plant pathogenic organisms and those caused by other factors are termed disorder (Yang *et al.*, 2023). The malfunction result in negative changes in the form, function, or integrity of the plant and may results to partial impairment or death of plant parts or of the entire plant (Agrios, 2005; Yang *et al.*, 2023). A plant disease is the result of interaction between a susceptible host plant, virulent pathogen, and the favourable environment. The environment may affect plant pathogen, therefore, survival, vigor, rate of multiplication, sporulation, direction, distance of dispersal of inoculums, rate of spore germination and penetration can be affected (De Wolf and Isard, 2007; Chen *et al.*, 2011). Farmer's activities such as agronomic practices, fungicide treatments, movement of plant material in the global market and the presence of microbial antagonists to the pathogen may also play roles in the development of a disease (Yang *et al.*, 2023). Environment is paramount and significantly, influences plants, pathogens and their antagonists directly or indirectly which manifested in the level of losses caused by a disease, and environmental changes are often implicated in the emergence of new diseases (Anderson, *et al.*, 2004; Yang *et al.*, 2023). Changes associated with global warming such as increased temperature, changes in the quantity and pattern of precipitation, increase CO₂ and Ozone levels, drought, etc) may affect the incidence and severity of plant disease and influence the further coevolution of plants and their pathogens (Chakraborty 2005; Garrett, *et al.*, 2006; Crawl *et al.*, 2008, Eastburn *et al.*, 2011). Most crops parasites are limited in their distribution; they do not establish themselves, when introduced into areas, where either the maximum or minimum temperature prevails (Dalla *et al.*, 2006). The climate has become apparently extreme and volatile (Paul *et al.*, 2009), and climate change has profound effects on plants in both domesticated and in the wild ecosystems (Stern, 2007). Climate change is the prime factors that regulate the distribution of pests and diseases, which poses a threat to agriculture and food security globally (Rosenzweig *et al.*, 2001; Scherm *et al.*, 2000; IPCC, 2001; Paul *et al.*, 2009). Since 2020, in some countries, yields from rain-fed agriculture has reduced by up to 50% due to climate change (Yang *et al.*, 2023). Agricultural production, including access to food, in many tropical countries is projected to be severely compromised in warmer environments due to increased insect outbreaks, reduced yields due to heat stress has already heightened by increased global movement of goods and people, and warming climate is likely to increase the incidence and geographic spread of human, animal and plant diseases (Dalla *et al.*, 2006; De Wolf and Isard, 2007). Developing countries in the tropical region are highly dependent on the rain fed agriculture and hence especially vulnerable to changes in pest status (De Wolf and Isard, 2007). It has been established that plant pests is an important factor in agriculture (Agrios, 2005), however a limited amount of information on the potential impacts of climate change on plant pests is available. Understanding the potential effects of climate changes in agricultural pests will be a significant steps towards food security in the tropical region of the world (Rosenzweig *et al.*, 2001; IPCC, 2007). However, any attempt to generalize the effect of climate change will pose a big challenge owing to the fact the effects of climate change will differ by patho-system and geographical region. The aim of this paper was to discuss the tropical region, climate change, causes of climate change, constituent of climate change, driver of climate change, interactions that lead to diseases, impact of climate change on some pests and their distribution in the tropics.

The Tropical region

The tropics refers to the region of Earth around the equator. The area of the world that lies within the Tropic of Cancer and the Tropic of Capricorn is generally referred to as the "Tropics". It includes Central America, northern part of South America, much of Central Africa, South Asia, and the northern part of Australia (Tajudeen *et al.*, 2022). The curve of the planet leads to the tropics receiving more direct solar radiation than the rest of the Earth and more than the region re-radiates back to space. Because a substantial part of the Sun's heat energy is used up in evaporation and rain formation, temperatures in the tropics rarely exceed 95°F (35°C) (Tajudeen *et al.*, 2022). Besides high mean annual temperature and high amount of mean annual rainfall, the tropics also receive the highest amount of solar radiation annually (Hassall *et al.*, 2007). The humid tropical regions thus have a climate which is favorable for the cultivation of crops throughout the year (Hassall *et al.*, 2007). The problems that prevail in these areas is majorly the prevalence of pests and crop diseases (Chen *et al.*, 2011). Being around the equator, the climate of the tropics isn't as strongly affected by the orbital tilt of the planet and thus the high temperature is maintained with little variation throughout the year. Therefore, the seasons are not distinguished by warm and cold periods but by variation of rainfall and cloudiness. The vagaries of weather affect the availability, growth stage, succulence, and genetic susceptibility of many crop species to pest and diseases (Agrios, 2005; Tajudeen *et al.*, 2022). The problems that prevail in these areas are prevalence of pests and crop diseases as one the most limiting factor to crop production (Ghini *et al.*, 2008). Farmers in the tropics have to deal with an abundance of insect pests and diseases.

Climate change

Weather describes the conditions of the atmosphere over a short period of time - hour, day, up to several days. Climate determines the behavior of the atmosphere over a long period of time -usually a minimum 30-year period (Ansa, 2023). Climate change depicts changes in long term averages of daily weather. Climate change refers to a change in the state of the climate that can be identified

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(using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (IPCC, 2007). The United Nations Framework Convention on Climate Change (UNFCCC), defines climate change as a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability. As described in the report of the Intergovernmental Panel on Climate Change (IPCC, 2007), abundance scientific evidence suggests that the planet is witnessing climate change. The greatest effects of climate change may be noticed over long periods of time and involve series of interactions between natural (ecological and climatic facts), social, economic and political processes (IPCC, 2013). The world over, rates of changes in land uses will dramatically increase greatly in the next 20 to 50 years, and as long as human populations continue to grow (Alig *et al.*, 2004; Mina and Sinha, 2008). Noteworthy that crop production challenges especially the crop pest and diseases management are exceptionally difficult and expensive due to climate change and the impacts of climate change on the environment that are characterized by various types of uncertainty (Ebele Emodi 2016). Climate change is estimated has profound positive and negative impacts on agricultural systems at the global level, with negative impacts outweighing the positive ones (Oladipo, 2010). Climate change has made pest infestations more unpredictable and increase their geographic coverage (Ebele Emodi 2016). The challenges of yield losses due to increase pests and diseases may possibly increase due to climate change; however, production losses are seldom taken into consideration in climate assessments (Anderson *et al.*, 2004; Mina and Sinha, 2008). The classic disease triangle establishes the conditions for disease development, such as the interaction of a favorable environment and the virulent pathogen. A plant disease is a dynamic process in which a host and a pathogen intimately related to the environment and are mutually influenced, resulting in morphological and physiological changes in both the host and the pathogen (Oladipo, 2010; Tajudeen *et al.*, 2022). Since both pathogens and hosts plants are affected by the changing climate, dramatic changes are expected in; the magnitude of disease expression in a given patho-systems, the geographical distribution of particular plant diseases, economic importance of particular diseases in a given location, the set of diseases that affected each crops (Bharti *et al.*, 2023). The changes has affected the measures farmers used to effectively manage disease, as well as the feasibility of cropping systems in particular regions. Climate change is the prime factor driving the spread of pests and diseases and can affect the population size, survival rate and geographical distribution of pests; and the intensity, development and geographical distribution of diseases (Garrett *et al.*, 2006; Bharti *et al.*, 2023). Crops such as wheat, rice and maize in tropical and temperate regions, climate change is projected to negatively impact their production. Global temperature increases of about 4°C or more above late 20th century levels, combined with increasing food demand, was expected to pose large risks to food security globally (Mina and Sinha, 2008)

Constituents of Climate that Changes and their effects on pests

The most important environmental variables that really changes in climate are: Temperature, Atmospheric CO₂ concentration, Precipitation and Water/Humidity (Ansa, 2023). Global temperature rise - 1 – 3.5 0C, Global water vapour concentration rise – 6% per 1oC, Global precipitation rise - 2 – 5% per 1oC rise in temperature, Atmospheric CO₂ concentration - increased from 280 ppm in 1750 to 400 ppm in 2013 (Ansa, 2023). According to IPCC (2013), the warming of the climate is unequivocal and noted that each of the last three decades have been progressively warmer than the preceding decade since 1850 and that the period from 1983 to 2012 have been the warmest 30-year period of the last 1400 year. Anthropogenic greenhouse gases (GHGs) and other factors have been implicated and possibly to be the cause of the increased warming of the earth's surface (Ghini *et al.*, 2008; Tajudeen *et al.*, 2022). Emissions of these anthropogenic GHGs have been identified in the much increases in the atmospheric concentrations of carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). Over half of the anthropogenic CO₂ emissions between 1750 and 2011 have occurred in the last 40 years (Jeffrey *et al.*, 2022).

Drivers of Climate Change

Natural causes: Volcanic emissions, Intensity of solar radiation, Variations in the earth's orbit and changes in Ocean currents (Brown *et al.*, 2013).

Anthropogenic causes: Human-induced climate change is now affecting all regions of the world and has various impacts on most ecosystems, including the cultivated lands (Ghini *et al.*, 2008). Some of activities of man such as deforestation, urbanization and use of fossil fuel inadvertently generate Greenhouse gases – (Carbon dioxide (CO₂), Methane (CH₄), Nitrous oxide (N₂O), Chlorofluorocarbons (CFCs), Ozone (O₃), Water vapours (H₂O) (Brown *et al.*, 2013). Climate change is caused by global warming which in itself is caused by the greenhouse effect (Ghini *et al.*, 2008). Emissions of CO₂ from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution accounting for the increase during the period 2000 to 2010 (Tajudeen *et al.*, 2022; Yang *et al.*, 2023). Emissions of these anthropogenic GHGs have been implicated in the large increases in the atmospheric concentrations of carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). In world over, population size, economic activity, lifestyle, energy use, land-use patterns, technology and climate policy are the most important drivers of increases in CO₂ emissions from fossil fuel combustion (Ansa, 2023). Agricultural activities have also undergone many major changes (agricultural revolutions) which was a direct consequences human civilization, technology advancement and general human developmental effort (Ghini *et al.*, 2008). In addition, the unprecedented population growth in the last 100 years has had many dire consequences on the environmental conditions and impact

negatively on the security of food supply (Yang *et al.*, 2023). The increase in movement of people, animals, plants and goods has exacerbated the redistribution of animal and plant pests and diseases and climate change will create new ecological niches allowing for the establishment and spread of pests and diseases into new geographical areas (Ghini *et al.*, 2008). This spread will no doubt continue to result in huge financial losses and require large eradication programmes and control measures. The implications of climate change on pest and diseases of both animals and plants are foot-and-mouth disease in Northern Europe and South America, classical swine fever in Europe, Rift Valley fever in Africa, and the spread of coffee leaf rust throughout the world, soybean rust into the Americas, and citrus tristeza virus in South and Central America and now in the Mediterranean (Chakrabortya, and Newton, 2011). Although developing countries are already subject to an enormous animal disease burden, both developing and developed countries will be subject to increased incidence or newly emerging diseases that are difficult to predict (Yang *et al.*, 2023).

Temperature

Temperature is fundamental requirement for both plants and pests grow and multiply in a given environment. Temperature plays an important role in metabolism, metamorphosis, mobility, and host availability, which determines the possibility of changes in pest population and dynamics (FAO, 2015). However, the effect of temperature on plants and pests could be viewed as direct or indirect.

Direct effect.

There is an optimal temperature range for development of disease in every plant pathogen interaction. Temperature is considered one of the most cardinal factors affecting the distribution and abundance patterns of plants due to the physiological limits of each species (Agbo, 2012). It is a factor dictate the geographical areas where different crops can be grown, as well as a factor that affects the rate of development, growth and crop yields (Kang *et al.*, 2010; Tajudeen *et al.*, 2022). Agricultural crops have minimum and optimal temperature requirements to complete a particular pheno-phase as well as the entire life cycle (Yang *et al.*, 2023). In addition, extremely low and high temperatures can have detrimental effects on crop development, growth, and yield, especially during critical pheno-phases (such as anthesis) (Gornall *et al.*, 2010). Fluctuation in temperature could directly affect the spread of infectious disease and survival between seasons. Ultraviolet radiation plays an important role in natural regulation of diseases (Kang *et al.*, 2010). Evidence suggests that sunlight affects pathogens due to the accumulation of phytoalexins or protective pigments in host tissue (Yang *et al.*, 2023). A change in temperature may favor the development of different inactive pathogens, which could induce an epidemic (Yang *et al.*, 2023). Temperature is one of the most important factors affecting the occurrence of bacterial diseases such as *Ralstonia solanacearum*, *Acidovorax avenae* and *Burkholderia glumea* (Brown *et al.*, 2013). Insects are ectothermic, tend to generally have a short life cycle, and are more mobile than plants. As a consequence, insect species can potentially react faster to climatic variations than plants (Bing *et al.*, 2022). In particular, insects are well known to be very sensitive to temperature (Yang *et al.*, 2023). Insect physiology is very sensitive to changes in temperature, and their metabolic rate tends to approximately double with an increase of 10 °C (Wole-Alo *et al.*, 2016). In this context, many researchers have shown that increased temperature tends to accelerate insect consumption, development, and movement, which can affect population dynamics by influencing fecundity, survival, generation time, population size, and geographic range (Wole-Alo *et al.*, 2016). Species that cannot adapt and evolve to increased temperature conditions generally have a difficult time maintaining their populations, while other species can thrive and reproduce rapidly (Tajudeen *et al.*, 2022). In view of the distribution and behavior of many insects in response to climate change, it can be forecasted that surging temperatures should be accompanied by increased feeding capacity of insects' species (Anosike and Fasona, 2004), as well as changes in the growth rate of insect populations (Enete *et al.*, 2011; Bing *et al.*, 2022). Fluctuations of pest population is expected in the tropical regions due to the current temperature level, which is already close to the optimum for pest development and growth, while insects in temperate zones are expected to experience an increase in growth rate (Enete *et al.*, 2011). Pest of major cereal crops such as rice and maize have been predicted to reach epidemics level in the tropical (Enete *et al.*, 2011; Tajudeen *et al.*, 2022). Temperature rise directly affects pest's reproduction, survival, spread and population dynamics as well as the relationships between pests, the environment, and natural enemies (IPCC, 2013). It was observed that sunlight affects pathogens due to the accumulation of phytoalexins or protective pigments in host tissue and a change in temperature may favor the development of different inactive pathogens, which could induce an epidemic (Bharti *et al.*, 2023). Temperature is one of the most important factors affecting the occurrence of bacterial diseases caused by pathogens such as *Ralstonia solanacearum*, *Acidovorax avenae* and *Burkholderia glumea* (Rayees *et al.*, 2013). Similarly, the incidence of vector-borne diseases could be altered (Bing *et al.*, 2022). Changes may result in geographical distribution, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop-pest synchrony of phenology, changes in interspecific interactions and increased risk of invasion by migrant pests which may ultimately alter the food production patterns (Bharti *et al.*, 2023). Most insect's pest are poikilothermic, making their reproductive potential, mobility and physiological sensitivity to temperature very high, even modest climate change will have rapid impacts on the distribution and abundance of vectors (Yang *et al.*, 2023). Consequently, increase in temperature may be result in high rates of development of insects, obtaining a greater number of insect generations per cycle (Wang *et al.*, 2022). Increase in temperatures with sufficient soil moisture may increase evapotranspiration resulting in humid microclimate in crop and may lead to incidence of foliar diseases favored under these conditions (Rayees *et al.*, 2013). Elevated temperatures affect population dynamics of pathogens and pests and can affect survival

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and population growth rates and the number of generations of polycyclic pathogens (Tajudeen *et al.*, 2022). Climate change induced temperature is projected to increase abundance of many fungal soil-borne plant pathogens with significant negative effect on productivity of most crops species (Bharti *et al.*, 2023). Climate change on the other hand, can also be detrimental to insect pests: for instance, heat waves may be a limiting factor for some species that are already living close to their thermal limits (Tajudeen *et al.*, 2022), and heavy precipitation may also inhibit flying or mating success (Rayees *et al.*, 2013). To sum it, all crop–insect–pest interactions rely on specific climatic parameters, with either positive or negative impacts for pest species and in turn for crops, depending on the context and magnitude of the changing climate parameters.

Indirect effect.

The other possible effects of high temperature on pest was that, warmer temperature lowers the effectiveness of some pesticides thereby making pest resistant to pesticide commonly use in the tropical region (Yang *et al.*, 2023). Temperature influences crop growth and development through its impact on enzyme and membrane-controlled processes. Carbon acquisition by photosynthesis typically has a temperature optimum close to the normal growth temperature for a given crop, while the carbon loss via respiration increases with temperature (Kang *et al.*, 2010). Therefore, crop growth will be indirectly controlled by temperature due to the balance between photosynthesis and respiration rates. The relationship between temperatures and crop yields was used to derive the effects of changes in average weather on crop yields (Tajudeen *et al.*, 2022). Studies have shown that important impacts under climate change for corn, soybeans, and cotton imply a 79, 71, and 60% reductions in yields, respectively, under the rapid warming scenario and a 44, 33, and 25% under the slower warming scenario (Bing *et al.*, 2022; Bharti *et al.*, 2023).

Elevated carbon dioxide levels

Among the challenges posed by the climate change is the elevation of carbon IV oxide in the atmosphere. An increase in CO₂ levels may encourage the production of plant biomass that will lead to the production of more glucose and distribution to the rest of the plant, consequently increase levels of simple sugars in leaves and lower their nitrogen content (Rayees *et al.*, 2013; Brown *et al.*, 2013). These developments exacerbate the damage caused by many insects, who will consume more leaves to meet their metabolic requirements of nitrogen (Bharti *et al.*, 2023). Thus, any attack will be more severe as high CO₂ concentrations are expected to increase photosynthetic rate and crop yield of C₃ plants but the C₄ plants (maize, sugar cane, pineapples) will not benefit from this because of their inherent CO₂ mechanism. High concentration CO₂ could lead to changes, in chemical composition (C: N ratios), plant defenses, biomass, leaf area and canopy structure (Yang *et al.*, 2023). The subsequent dense canopy favors the incidence of rust, powdery mildew, Alternaria blight, Stem phylidium blight and anthracnose diseases (Tajudeen *et al.*, 2022). In general, high disease incidence and severity is expected due to changes in host morphology (Yang *et al.*, 2023). Atmospheric CO₂ impacts plant immune responses and hormone levels that can influence plant–pathogen interactions as plant defenses decrease with increase level of CO₂. For example, increased basal expression of jasmonic acid responsive genes under elevated CO₂, enhanced resistance to the necrotrophic leaf pathogen *Botrytis syringae* pv. tomato (Chakrabortya, and Newton, 2011). Reduction in the effectiveness of plant defense pathways under elevated CO₂ increased the susceptibility of wheat against the two major pathogens *Z. tritici* and *F. graminearum* that cause *S. tritici* blotch and Fusarium head blight, respectively (Tajudeen *et al.*, 2022; Bing *et al.*, 2022). The atmospheric concentration of CO₂ has risen significantly and has reached its highest level in the last 650,000 years (Siegenthaler *et al.*, 2005; Shin and Yun 2010). Since 2000, the increase of CO₂ concentration is greater than that of previous decades (Canadell *et al.*, 2007). Similar trends have been observed for the concentration of methane (CH₄), nitrous oxide (N₂O) and other greenhouse gases (Spahni *et al.*, 2005; Rayees *et al.*, 2013).

Climate-induced Relative Humidity in the environment

Variations in humidity and soil moisture have significant effect on infectivity and abundance of plant pathogens, thus likely to affect future disease outbreaks as Fungal diseases require high humidity for spore germination, longevity and infection (Rayees *et al.*, 2013; Bharti *et al.*, 2023). Bacterial disease incidence is higher under high humidity conditions, distribution and spread of many pathogens on the same plant and from plant to plant in the same field or to other fields are respectively increases under high rainfall conditions (Chakrabortya, and Newton, 2011; Yang *et al.*, 2023).

Climate-induced high rainfall levels

Accompanied with the climate change is the unpredictable high rainfall and distribution in the tropical region of the world. This has profound effect on some insects and diseases such as Late blight of potato, Downy mildew and other diseases are more severe in areas of high rainfall or high relative humidity (Mina and Sinha, 2008; Chakrabortya, and Newton, 2011). Many soil pathogens (Phytophthora and Rhizoctonia) and some bacteria (*Pectobacterium*, *Ralstonia*) and most nematodes usually cause their most severe symptoms on plants when soil is wet but not flooded (Rayees *et al.*, 2013; Bing *et al.*, 2022). Excess soil moisture support soil-borne diseases caused by Phytophthora, Pythium, Rhizoctonia solani and Sclerotium rolfsii (Mina and Sinha, 2008; (Tajudeen *et al.*, 2022). High rainfall rendered fungicide and insecticide sprays washed off from plants thereby increasing the cost of management of disease (Garrett *et al.*, 2006). Elevated humidity does not only reduce yield but affects marketability of produce, for instance *Aspergillus* spp. and *Fusarium* spp. produce mycotoxins that reduce market value of produce (Bharti *et al.*, 2023).

Interactions leading to diseases

Plants are infected by many biotic agents among insect, fungi, bacteria, viruses, nematodes, viroids and phytoplasmas (Bing et al., 2022). Agricultural crops and their corresponding pests are directly and indirectly affected by climate change (Evans et al., 2007; Chakrabortya, and Newton, 2011). Direct impacts are on pathogens' reproduction, development, survival and dispersal, whereas indirectly the climate change affects the relationships between pathogens, their environment and other diseases species such as natural enemies, competitors and vectors (Yang et al., 2023). The Disease Triangle conceptualizes the interaction of plants and pathogens with the environment (Kang et al., 2010; Chakrabortya, and Newton, 2011). For disease to occur, a susceptible host, a virulent pathogen and favorable environmental conditions must be present at the same time, the absence of any of these factors means disease will not occur. (Bharti et al., 2023). The environment exerts significant effect on the plant host and the pathogen and both them have optimal environmental conditions for growth and reproduction and for disease development. (Garrett et al., 2006; Tajudeen et al., 2022). The effect of environmental variables –temperature, water, light, wind – on the plant host and the pathogen, can have outcomes on disease development that are negative, neutral or positive (Jeffrey et al. 2022). Environmental factors can have significant effects on the physiological state of the plant including growth, response to abiotic stress and immune signaling (Tajudeen et al., 2022). Environmental factors, also, affect the pathogen' germination, survival and expression of virulence factors, and ultimately can render the plant susceptible or resistant or the pathogen is either able to cause severe disease or is weakly pathogenic (Garrett et al., 2006; Bing et al., 2022). New disease complexes may be developed, and some diseases may cease to be economically important and many pests will follow migrating hosts and infect vegetation in natural plant communities not previously exposed to the often more aggressive strains from agricultural crops (Mina and Sinha, 2008; Yang et al., 2023). Plant pathogens have three general options to adapt to a changing environment and they are; i) Exploit the existing phenotypic plasticity ii) Migrate to areas with suitable climate iii) Evolve new attributes (Chakraborty, 2013; Bing et al., 2022). In general, high moisture and temperature must be favorable and act together in the initiation, development of plant diseases, as well as germination and proliferation of fungal spores of the vast majority of pathogens (Agrios, 2005; Bing et al., 2022). The most likely effect of climate change in poleward shift of agro-climates zones, this causing a shift in the geographical distribution of host pathogens (Mina and Sinha, 2008; Yang et al., 2023). Therefore, new diseases may become prevalent in northern areas, causing considerable losses in agricultural production (Kocmánková et al., 2009; Bing et al., 2022).

Climate change effect on pests and their distribution in the tropics

Global climate changes have far reaching impacts on agriculture and also on agricultural insect pests in such a way that agricultural crops and their corresponding pests are directly and indirectly affected by climate change (Mina and Sinha, 2008; Chakrabortya, and Newton, 2011; Tajudeen et al., 2022). Insects are poikilothermic organisms; the temperature of their body depends on the temperature of the environment and thus, temperature is probably the most important environmental factor affecting insect behavior, distribution, development and reproduction (Aina et al., 2007; IPCC, 2013; Sandra et al., 2021; Bing et al., 2022). Climate change creates new ecological niches that provide opportunities for insect pests to establish and spread in new geographic regions and shift from one region to another (Aina et al., 2007; Wilson et al., 2017; Tajudeen et al., 2022). The complexity of physiological effects exerted by rising temperatures and CO₂ can profoundly affect interactions between agricultural crops and insect pests (Alabi et al., 2006; Deutsch et al., 2018; Akinfenwa, 2019). Therefore, farmers can expect to face new and intense pest problems in the coming years due to the changing climate and consequently, crop pests across physical and political boundaries threatens food security and is a global problem common to all countries and all regions (Aina et al., 2007; Bing et al., 2022).

Coffee Rust

Rust is one of the most serious fungal diseases affecting *Coffea arabica* and a major epidemic has been developing in recent years in Latin America (Rayees et al., 2013). The factors determining recent rust epidemics in Central America are economic, but climatic factors are also strongly suspected in light of the unusual severity of the epidemics. Several meteorological anomalies (temperature, rainfall, sunshine duration) were noted over the 2008–2013 period, which resulted to major epidemics (Wilson et al., 2017). The mean annual temperature in 2012 in the region was close to the average for the 1981–2010 period, but very little variability was observed. Low temperatures which hamper rust development are less frequent. Epidemics are now occurring in highland regions where high quality coffee is grown and where rust outbreaks seldom occurred in the parts of the world (Kouakou et al. 2012; Tajudeen et al., 2022).

Cotton pod borer

Cotton pod borer (*Helicoverpa armigera*) a serious pest in West Africa. The life cycle of this pest species is closely linked with the climatic conditions and it may undergo up to 10 generations a year under tropical climates (Sandra et al., 2021). The length of each stage during the life cycle depends on the environmental conditions (resource availability, rainfall and temperature). The caterpillar enters diapause when the conditions are unfavorable (resource availability, rainfall and temperature), which lengthens the cycle and reduces the number of generations (Bing et al., 2022). In northern Benin, during infestation peaks in cotton plots, it was reported that the pest abundance was dependent on the extent of heterogeneity of host plants (cotton, maize, tomato, sorghum) in the landscape around the plots (Bing et al., 2022; Jeffrey et al. 2022). This heterogeneity is dependent on the cropping calendar, which

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in turn is closely related to variations in temperature and rainfall. The pest is expected to change their migratory routes and geographical distribution because of climate change and climate change-induced pest dispersal and intensity threaten food security in most regions in the tropics (Jeffrey *et al.* 2022).

Fall armyworm

Fall armyworm (*Spodoptera frugiperda* J E Smith, Lepidoptera: Noctuidae) which feeds on a growing number of crops, including maize, sorghum and millet, have already spread due to the tropical region west Africa due climate change (FAO, 2020; Sandra *et al.*, 2021; Amodu *et al.*, 2024). Maize (*Zea mays* L.) is one of the main and popular cereal crops due to its high value as a staple food, as well as its stover demand for animal feed and fuel and even for construction purposes (Abebe and Feyisa 2017; Abdullahi *et al.*, 2020). FAW a voracious agricultural pest native to North and South America, was first detected on the African continent (Goergen *et al.*, 2016). FAW is known to have over 350 host plant species (Montezano *et al.*, 2018) but considering just maize, rice, sorghum and sugarcane it has been estimated that FAW could cause up to \$US13 billion per annum in crop losses across sub-Saharan Africa (SSA) (Abrahams *et al.*, 2017). FAW has assumed the leading pest that contributed to the low productivity of maize in Nigeria since its outbreak was first reported in February 2017 due to surging climate change. They mainly feed on leaf whorls, tassels, ears and cobs of maize, resulting in total yield loss (Sarmiento *et al.*, 2002). FAW is a migratory insect pest known to cause serious damage to maize crops under warm and humid conditions in the Americas (Clark *et al.*, 2007; Ayala *et al.*, 2013; Chapman *et al.*, 2015).

Desert Locust

Desert locust (*Schistocerca gregaria*) outbreaks are spectacular natural phenomena of extraordinary adaptation that make the pest important and dangerous to agricultural activities in arid and semi-arid landscapes with the reputation as (the world's most destructive migratory pest) (Sarkar *et al.*, 2023). Although the pest has caused epidemics in parts of the world right from time, yet the desert locust upsurge from 2019 to 2021 was one of the most severe in decades, causing widespread destruction of crops and pastures across the Horn of Africa, worsening the region's food insecurity as a result of worsening effect of climate change (Joshi *et al.*, 2020). When outbreaks occur on a large-scale, they can devastate agriculture in countries already on the frontlines of climate change. The 2019–2021 desert locust outbreak devastated the Horn of Africa, resulting in billions of dollars in damages (Jeffrey *et al.* 2022; Biswarup *et al.*, 2024). The Horn of Africa, covering 5.2 million square kilometers and home to 282 million people, is increasingly vulnerable to extreme weather events (Biswarup *et al.*, 2024). This is particularly evident in the region's arid and semi-arid lands, where small-scale agriculture and livestock are the primary sources of livelihood. Unusually heavy rains, driven by cyclones in the warming Indian Ocean, created favourable breeding conditions for the desert locusts (Biswarup *et al.*, 2024). These ideal conditions enabled the locusts to multiply exponentially, causing swarms to develop and spread across countries such as Kenya, Ethiopia, Somalia, and Sudan (Song *et al.*, 2017). While the upsurge was driven by climatic conditions, human factors played an important role for its escalation into a full-blown regional crisis. Locust outbreaks significantly threaten the livelihoods of billions of people globally, and this number continues to increase (Biswarup *et al.*, 2024). Latest projections show that crop losses due to insect infestations will increase by up to 50% with a 2 °C increase in global warming (Biswarup *et al.*, 2024). Geomorphology also plays a significant role in creating conditions conducive to locust breeding. It has been established that five major environmental factors, i.e., surface temperature, precipitation, soil moisture, soil sand content, and greenness, influence locust breeding, maturation, concentration, and migration (Atkinson and Porter, 1996; Biswarup *et al.*, 2024).

CONCLUSION

Climate change refers to a change in the state of the climate that can be identified (using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate influences all stages of development of host plants and pathogen. Climate influences incidence and severity of various plant diseases and major role in dispersal of inoculum and consequently in spread of diseases. The area of the world that lies within the Tropic of Cancer and the Tropic of Capricorn is generally referred to as the "Tropics". It includes Central America, northern part of South America, much of Central Africa, South Asia, and the northern part of Australia. The problems that prevail in these areas are prevalence of pests and crop diseases as one of the most limiting factors to crop production. The aim of the paper is to discuss Effects of Climate Change on Crop Pests and Diseases in the Tropics. Climate change can create conditions that favor the spread of pests, leading to increased risk of pest outbreaks and epidemics. The most important environmental variables that really change in climate are: Temperature, Atmospheric CO₂ concentration, Precipitation and Water/Humidity. Changes in temperature, CO₂ and the intensity of rains and floods will have significant effect on crop yields. Higher temperature and humidity levels could lead to higher levels of infection, incidence and severity of diseases. New strains of pathogens adapted to new and higher temperatures would make crops more vulnerable to infection. The incidence and severity of Coffee Rust, Cotton pod borer, Fall Armyworm and Desert Locust were reported as a direct effect of climate Change in the Tropical region of the world.

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