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Brief Review: Climate Change and Its Impact on Mango Pests and Diseases

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Abstract

Climate change is negatively impacting the agricultural sector. This review focuses on the effects of climate change on mango pests and diseases, the unknown aspects of this problem, and possible mitigation measures. In addition, mango is susceptible to several pests and diseases infestation at all its stage of life. The major abiotic factors associated with climate change that affect mango pests and diseases include changes in precipitation, wind variability, increased temperature, increases in atmospheric CO_2, and changes in light intensity. These factors affect mango pests and diseases in various dimensions in one way or another, including increased activity, growth, development, reproduction, distribution, and migration. These abiotic factors also influence plant growth, development, and reproduction. These interacting factors are complex, and further studies are needed to obtain relevant data to understand the relationships between these factors and pests occurrence. Developing predictive models from these data and intercropping with aromatic plants will be useful for strategies to mitigate the devastating effects of pests and diseases occurrence on mango crops and food security.

Keywords: Tropical climate; Atmospheric CO_2; Temperature; Fungi; Precipitation; Light intensity.

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1. Introduction

Mango (Mangifera indica) is a fragrant evergreen fruit tree and mainly cultivated in Asia [1]. It is well adapted to tropical and subtropical climate where rainy seasons alternate with a well-marked dry period [2]. Nevertheless, mango is susceptible to several pests and diseases infestation at all its stage of life. Leaf hoppers, stem borer, fruit fly, thrips, midges, mango stone weevil, and mites are some of the pests that heavily impact mango trees [3]. The findings of previous studies suggest that the development of insect pest is very sensitive to temperature changes [4]. However, the information on temperature changes on the mango pests and diseases are limited. On the other hand, most mango diseases are caused by fungi, such as Anthracnose, black mildew, and leaf blight [5, 6]. The humid weather favours the growth of fungi and causes the significant loss or decrease in mango production.

The changes in the tropical climate is expected to exacerbate the pests and diseases infestation on mango. More frequent scorching heat events and intense precipitation are expected in the tropics and subtropics regions [7]. Temperature and precipitation are the major drivers on the pests and diseases abundance [8, 9]. Relative humidity, light, and wind intensity also influence the life cycle stages of crop pests and diseases [10]. In the tropics, the El Nino Southern Oscillation (ENSO) causes irregular temperature and precipitation and this manifests in extended episodes of droughts or floods [7]. The tropics are experiencing higher intensity and/or duration of droughts and intense tropical cyclones. Not only drought inflicts major abiotic stress, heavy precipitation events favour growth and incidence of pests and diseases, resulting in significant crop yield losses [11-13].

Nevertheless, climate change positively impacts on the agro-ecosystems have also been reported. For instance, an increase in atmospheric CO_2 can increase the photosynthesis rate of plants which in turn increase the yield [14]. Furthermore, elevated CO_2 could decrease the plant's protein and reduce the food resources for chewing insects which indirectly control the plant pests [15]. The ultraviolet radiation is strong in southern Asia, so the effect on the growth of tropical crops is particularly notable [16]. According to the International Panel on Climate Change [17], global warming could improve the wheat and corn productivity in northern Europe as high temperature and full sunlight conditions are suitable to grow the grain crops. Extremely low temperatures can have detrimental effects on crop development, growth, and yield, especially during critical phenophases (anthesis). In addition, global warming is more harmful for physiological development of tropical insects compared with the insects at higher latitudes [18]. Hence, climate changes significantly impact on the agro-ecosystems, some have positive impacts on the agro-ecosystems but negative impacts exceed the positive one. Climate change phenomena will exert the pressure on the human activities including water management, plant diversity and socio-economic productivity.

Few studies have examined the effects of climatic variables on mango tree development and production however, little information is reported on the effects of climatic variables on mango pests and diseases. In this review, we present the multiple impacts of climate change on particularly the mango crop pests and disease in the light of the most recent publications. We look into the impact of the climatic parameters, namely temperature, precipitation, wind, atmospheric composition, and light on the common pests and diseases in mango. Furthermore, these climatic factors can influence the life cycle (survival, reproduction and dispersal) of pests which we will be discussing in this paper too. To this end, the objectives of this paper were to: (i) highlight trends for some mango pests and diseases outbreaks and their relationships with selected climatic factors, (ii) identify un-knowns on this aspect, and (iii) suggest approaches to close the gaps.

2. Changes in Precipitation, Wind, and Temperature on Mango Pests and Diseases

In the tropics, the major mango pests are the fruit fly and thrips whereas the most serious diseases are anthracnose and powdery mildew. Fruit flies always attack mango fruits during fruit ripening stage [19]. It had been reported that fruit flies accelerate the yield loss in heavy rainfall region [20]. Weldon, *et al.* [21], discovered that warmer temperature improves the sexual performances of male fruit fly but it reduces the fruit fly sperm storage at the highest test temperature of 28 °C. Hence, temperature changes can lead to depletion of nutrient reserves and change of insects mating behaviour, which then affects the survival and reproduction. However, high temperature which reduces mango fruit size increases wasp parasitism rate to biocontrol fruit flies [22]. Similar findings also discovered that warmer temperatures favour wasps development [23, 24]. According to Zala and Bharpoda [25], the natural enemies (ladybug and spider) in mango ecosystem also seem increasing their activities during the summer. The responses of insect pests to climate change are complex because they may also be indirectly impacted by the responses of their host plants, competitors, and natural enemies [26, 27]. Leaf hopper reduces the mango yield by feeding on mango leaves and transmitting virus. The feeding activities of leafhoppers increased with increasing temperature from 15 to 35°C but their development declined when the temperature exceeded 35°C [28].

Another universal mango pest is thrips. The female thrips lay eggs in the mango plant tissues including stems, foliage, flowers, and fruits. Thrips population always expand in the summer. Female thrips multiple their eggs between 25°C and 30°C and has shorten time of adult development [29]. Thrips species might undergo reproductive diapauses inflicted by critical photoperiod but the effects of photoperiod on the thrips reproduction remains unexplored. Climate change might have increased thrips pest risks by prolonged summer. Nevertheless, Antignus, *et al.* [30] found that greenhouse system with high intensity of UV light can suppress the pest thrips population. The ambient UV radiation responses mechanism of thrips affected by climate change still remain unclear. In an open system, the variability of the atmosphere and uncertainty of measurements increase the complexity of assessing the UV radiation effect on the mango pests and diseases.

Extreme precipitation events are expected to be more intense and frequent in certain areas [31]. Mango is moderately flood-tolerant and flooding leads to a rapid decrease of transpiration and stomatal conductance [18]. An increase frequency of rainfall raises flood intensity does not only damage mango seedlings growth but it also increases pest and disease incidence [32]. Intense rainfall and subsequent splashing of raindrops can be effective carriers of microorganisms to the leaves surfaces. Shady and high humid condition favour mango hopper multiplication [33]. In contrast to the finding of Cilas, *et al.* [34] who revealed that heavy rainfall may limit insect flying or mating success. Mango suffers from many diseases mainly caused by fungi. One of the major diseases is anthracnose which the fungi affects all phenological stages of mango, resulting in high yield loss [35]. High relative humidity and temperature promote the incidence of anthracnose disease [36, 37]. In addition, the spores of anthracnose are dispersed by rain and irrigation water splashes [35]. Other diseases outbreak such as black mildew is also strongly related to the relative humidity duration [38]. The growth and sporulation of the fungus come to a halt as soon as dry, hot weather sets in and resume only after the return of humid weather. Erratic rainfall and high relative humidity increases fungul spore formation and longevity. Yet, there is scarce information on how long the wetting duration is required for fungul spore longevity on the mango crop. Moreover, some reported that lack of water in the soil can cause plants to lose their biological functions and become even more susceptible to diseases and pests [39].

Wind affects pests and diseases development because wind direction positively interacts with resource distribution and insect pest density. Conidia of anthracnose on senescent plants splashed by wind and rain can serve as the primary infection source to infect fruit and turn up as secondary inocula on the plants with anthracnose lesions [40]. However, wind sometimes prevents pest occurrence by accelerating drying of wet plant surfaces. This reduces succulence of plants and their susceptibility to certain pests [41]. Raut, *et al.* [42], revealed that the population of hopper declines with increasing wind speed. The most recent report by the UN's Intergovernmental Panel on Climate Change [17] expects that, in most regions, the wind speed will decrease as a result of climate change. The change of wind pattern will impact on pests and diseases control in the farms. According to Zhang, *et al.* [43], trees can perform windbreak with their canopy thickness and canopy shape. As mango is an evergreen tree, it over grows the branches and forms dense canopy. Therefore pruning is essential practice to manage the mango canopy to obtain new vegetative growth and early flowering as well as good yield [44]. Furthermore, pruning creates a free movement of air and sunlight penetration into trees and thereafter protects the mango trees from pest and disease infestation [44]. Nevertheless, the airflow after pruning impact on mango pests and diseases remains poorly understood. Understanding the velocity of airflow would assist farmers to better shape their mango tree canopy to achieve maximum yield and good control of pests and diseases.

3. Changes in Atmospheric Composition on Mango Pests and Diseases

Increasing concentrations of atmospheric carbon dioxide (CO_2) on the earth's surface is the most prominent impetus for the global warming. The rising atmospheric CO_2 concentration is not only affecting the plants photosynthesis rate but it also affects the feeding behaviour and growth of herbivorous insects. However, different literature reported that CO_2 will significantly affect C3 plants including mango plant [45] whereas, Rötter and Van De Geijn [14] found that C3 plant will benefit from an increase in atmospheric CO_2 concentration. It has been reported that elevated CO_2 concentration increased the soluble sugar content in plants which for example, indirectly increases thrips infestation [46]. In contrast to the findings of Seki and Murai [47], the mortality of thrips eggs was high when they were exposed to 60 % CO_2 at 30°C for 12 hours. Similar literature also reported that long hours of exposure to CO_2 at 25 °C can lead to high mortality of thrips [48]. Time exposure of high concentration of CO_2 determine the efficacy of CO_2 on suppressing the thrips.

Other findings reported that the parasitoid wasp is increasing with the increasing CO_2 level [49]. Elevated CO_2 could decrease foliar nitrogen, which will reduce insects preferences, thus it will reduce the growth of chewing insects [15]. Most plant hoppers have also been negatively affected by the elevated CO_2 because of the decline in foliar nitrogen and increase in carbon and nitrogen ratio [50]. However, plant hopper feeding patterns are varied depending on species [51]. The elevated CO_2 level increases the ambient temperature besides affecting insect physiology [50]. Elevated atmospheric CO_2 and associated increases in global mean temperatures would have detrimental effects on the plant yield and quality as extreme temperatures provoke damages to the plant photosynthesis machinery.

Some studies have revealed that plants develop carbon-based defensive compounds against insects under an elevated CO_2 condition [52, 53]. Elevated CO_2 level induces changes in emissions of volatile organic compounds from plant to defense against herbivores attack or to attract parasitoids and predators, and also influences pests-natural enemies' interactions [54]. However, Boullis, *et al.* [55] reported that atmospheric ozone (O_3) is more responsible for modifications to plant secondary metabolites (terpenoids and phenols) and foliar composition than CO_2. These terpenoids and phenols are responsible in the attraction of natural predators [55]. The changes in atmospheric composition can influence the emissions of volatile organic compounds of plants which in turn, reducing the host recognition by herbivores and natural enemies. In contrast to the findings of Zhang, *et al.* [56] who documented that the plant defense mechanism depends also on crop species although elevated CO_2 has profound effects on plant physiology. Research on the effects of elevated CO_2 on mango tree defense mechanism is still in its infancy.

Most of the researches focus on the effect of elevated CO_2 on mango fruit fly during post harvesting. This is because the mango fruit fly infestation is closely related to changes in peel texture and volatile chemicals during ripening which facilitate fruit puncturing by the fly's ovipositor [57]. A literature reported that the use of high level CO_2 (50–82%) for a period of four to five days at low temperature during storage can inhibit fruit fly infestation on mango [58]. Some suggested that low O_2 concentrations (<0.5%) and high CO_2 concentrations (>50%) can effectively control insects in fresh fruit crops [59, 60]. Nevertheless, most of the researches are focusing on the effect of CO_2 concentration on pests infestation in closed systems. Limited studies exist on the complex mango-insect interactions in the open field influenced by elevated CO_2. Experimentally, determining the impacts of elevated CO_2 on the mango pest and diseases is not simple because it is influenced by many factors including the age of mango tree and micro-climate effects.

4. Effects of Changes in Light Intensity on Mango Pests and Diseases

The biological impact of solar radiation has attracted considerable attention because depletion of stratospheric ozone leads to an elevation of ultraviolet-B (UV-B) (280-315 nm) irradiance [61]. Ohtsuka and Osakabe [61], found that the ambient UVB radiation causes lethal damage to spider mites. Furthermore, low oviposition activities of female fruit flies in mango under exposure of intense sunlight has been reported by Guillen, *et al.* [62]. Some even applied low doses of UV-C in mango to limit the growth of fungi in order to extend the fruit shelf life during the post-harvesting [63]. Light indirectly modify moisture on leaf surfaces [64] and reduce the wetness of leaf surface might reduce the fungal disease. However, the mango yield and the fruit flavor quality declined with increasing UV-B as high dose of UV-B decrease the plant photosynthesis rate [16]. Other documented the intensity of insect herbivory which frequently increases when the UV-B component of solar radiation is experimentally attenuated because of increase in plant photosynthesis which indirectly increasing the food resources to the insects [50]. Thrips can directly detect and react behaviourally to natural and augmented UV-B [65].

Light intensity is essential in accumulating phenolics in plants. Previous studies reported that UV radiation stimulates phenolics production which the phenolics play essential role in plant defense against pests [66, 67]. UV light also triggers changes in plant tissues, such as increase the synthesis of lignin which fortifying the plant cell wall against fungal invasion [68]. According to Linatoc, *et al.* [69], higher concentration of phenolic accumulate in sun exposed mango leaves compared with the shaded leaves. However, there are different literature on the effectiveness of phenolic contents on protecting the mango plant against the fruit fly. Verghese, *et al.* [70] discovered that high phenolic levels in mango can effectively prevent fruit fly infestation whereas Rashmi, *et al.* [71] reported that the fruit fly infestation correlated negatively with mango phenolic content. The different effects of phenols on mango in preventing the fruit fly infestation depending on the mango variety and fruit ripening [71].

Few studies have been conducted to observe the responses of different insects to light irradiation/ wavelengths. According to Carvalho and Castillo [64], abundance of fungal microbiome was lowest when the plants were exposed to white light emitting diodes (LEDs). In addition, the plants exposed to short UV wavelengths could inhibit the leaf dwellers growth [64, 72], and thereby introducing the UV LEDs technology in crop systems can increase the efficiency of plant disease prevention. It appears that moderate exposure of plants to UV-B at early growth stages to induce defense mechanisms and not affect plant growth and yield, and later suppression of UV light to restrict insect entrance and herbivore attack is good approach to prevent the plants against pest and disease. Besides that, Shibuya, *et al.* [73] documented that high intensity of blue light is lethal to fruit flies. Field trials conducted at night demonstrated that higher light intensities of 70−130 lux is effectively to control the fruit stem borer [74]. It appears that high irradiance could control pests but all are limited to the laboratory study or artificial light. High light intensity could negatively affect mango seedlings production [32]. Therefore, farmers prefer growing mango seedlings in the shade [32]. Wang, *et al.* [16], also revealed the harmful effects of UV-B radiation on mango plants' photosynthesis and fruit yield. Time exposure to the UV and frequency of exposure are essential in determining the efficacy of UV against the fungal disease like powdery mildews [75]. There is no known previous research on the effects of light intensity on the mango diseases.

5. Adaptation Strategies to Address the Impact of Climate Change on Mango Pests and Diseases

Climate change trigger major changes in mango ecosystem in which a pest species lives, the host plants, the predators, and the interactions between all organisms. Climate change is predicted to have both positive and negative impacts on agricultural systems at the global level, with negative impacts outweighing the positive ones [76]. Various efforts have been made to address the climate change impact on the crop productivity such as introducing quality seedlings and variety which are more resistant against the pests and diseases [77, 78]. Genetic improvement of mango plant materials with respect to climate change is a promising way of adaptation. A cultivar or rootstock selection should aim at developing tolerance to extreme weather and has a strong root system with high water uptake efficiency. Additionally, mango seedling producers implement adaptation strategies to mitigate climate change risk effects such as practicing irrigation farming, and creating gutters, providing shelter, and mixing soil with mulch [32].

One of the environmental friendly strategies to reduce the risks of spreading new pests and diseases is application of integrated pest management (IPM) [79]. Integrated pest management approach emphasizes on preventive or indirect measures in plant protection to reduce the negative impact on the environment while maximizing crop yields. Although the IPM approaches are in place for some pests, insecticides still remain the preferred option for farmers in mango pest management. Implementation of low pesticide input pest management approaches generally requires a comprehensive knowledge of the biology of pests and their interactions with the crop and the environment. Understanding the factors that affect crop infestation including the host-pest relationship is the basis for efficient pest management.

Intercropping practices are needed to reduce the impact of agricultural pests on crops in a changing climate. Planting different crop varieties to minimize exposure to pest outbreaks. Mango farmers have been practiced intensive monocropping in decades. However, intensive monocropping occupies a large space and easily gave rise to outbreak of pests, diseases, and weeds, which were treated with increased use of external chemicals [80]. Intensive use of pesticides poses a health threat to both farmers and consumers, as well as disruption to ecosystems. Intercropping mango with aromatic plants is a new approach to be practiced in a mango crop plantation. Previous literature reported that intercropping crops with aromatic plants can significantly improve soil quality and reduce certain pest population densities [81, 82]. The strong fragrant leaves of the aromatic plants can emit volatile aromatic compounds to the atmosphere to protect against biotic stress and repel pests. Nevertheless, the ecological mechanisms underlying the aromatic plants-based intercrop system sustainability have not been studied in detail and reports are scarce, especially on multiple aspects of aromatic plants-based integrated mango agro-ecosystems.

A few models have been developed for predicting the effects of climate change on mango production and mainly focus on the photosynthesis, stomata conductance, and mango fruit growth and quality [83-85]. The use of modeling predictions tools is also essential to address the climate change impact on mango pests and diseases. Yet, it is difficult to develop models based on knowledge of phenological processes obtained through long term monitoring of insects, their associated natural enemies and host plants, and their responses to the current climate and climate change. In addition, a reliable and good-fit model only can be developed by also involving decision makers and other stakeholders [86, 87]. Long-term monitoring of pest populations and behaviour, particularly in climate change-sensitive regions, is vital to increase the efficiency of management decision making and practices.

6. Conclusions

Mango is susceptible to several pests and diseases infestation at all its stage of life, and it is mainly cultivated in tropical region. The tropical warm and humid climate favour the development and proliferation of pests and diseases in mango ecosystem. The changes in the tropical climate is expected to exacerbate the pests and disease infestation on mango. Availability literature suggests that climate change has positively and negatively impacted on mango agro-ecosystems, with negative impacts outweighing the positive ones. Experimentally, determining the impacts of climate change on the mango pests and diseases is not simple because it is influenced by several other factors including the natural enemy, mango variety, fruit ripening, and age of mango tree. In addition, the variability of the atmosphere and uncertainty of measurements increase the complexity of assessing climate change effects on mango pests and diseases. Understanding these atmospheric phenomena effects would enable the farmers in decision making and farm management activities to achieve maximum yield and good control of pests and diseases. It might be particularly hard to control the natural environment variability but a good and prudent farm management practice is necessary to minimize the negative effects of climate change on pests and diseases in mango. Furthermore, given the complexity of climate change and the linkages with mango pests and diseases, the entire life cycle of these pests and diseases must be examined to better understand and address them in an integrated manner. This integrated approach will enable mitigating the devastating effects of improper pest management on crops and food security. Thus, there is a need for long-term research on the effects of climate change on mango pests and diseases, both in controlled and field experiments, to collect sufficient data to enable develop accurate predictive models for this relationship. Plus, the decision makers and stakeholders should involve in developing the model so that it is more relevant and reliable to the real field. A climate-intelligent approach is a way forward to ensure that our food security is not compromised in the future by pest infestations on our crops. Sustainable management of pests will play a significant role in this approach.

7. Future Directions

The responses of pests and diseases to climate change are complex as they are indirectly impacted by the responses of their host plants, competitors, and natural enemies. Furthermore, the variability of the atmosphere and uncertainty of measurements in an open system increase the complexity of assessing the responses of mango pests and diseases to climate change. The mango tree variety, age, growth stages, canopy are also the factors need to be considered in the assessment of mango pest and disease responses to climate change. Hence, a simulation model of study on the relationship between the mango tree physiology, growth, insect pests, diseases and microclimate effects are urgently needed to analyse specific crop-pest systems in specific environments, followed by adaptation and vulnerability analysis.

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Conflicts of Interest

The authors declare no conflict of interest.

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