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The Effects of Climate Change on the Pests and Diseases of Coffee Crops in Mesoamerica

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Abstract

Coffee is an in-demand commodity that is being threatened by climate change. Increasing temperatures and rainfall variability are predicted in the region of Mexico and Central America (Mesoamerica). This region is plagued with pests and diseases that have already caused millions of dollars in damages and losses to the coffee industry. This paper examines three pests that negatively affect coffee plants: the coffee borer beetle, the black twig borer, and nematodes. In addition, this paper examines three diseases that can destroy coffee crops: bacterial blight, coffee berry disease, and coffee leaf rust. This paper will review the literature on how these pests and diseases are predicted to affect coffee crops under climate change models. In general, increased temperatures will increase the spread of pest and disease in coffee crops. Projected decreased rainfall in Honduras and Nicaragua may decrease the spread of pest and disease. However, these are complex issues which still require further study.

Keywords: Coffee; Pests and diseases; Mesoamerica; Climate

Introduction

Coffee is an important fixture in humans' daily lives. Not only do people rely on it for fuel to get through their day, several countries' economies and livelihoods depend on the success of coffee crops. Coffee grown in Mexico, Central America, Africa, and South America is exported all around the world. Coffee growth is sensitive to environmental factors such as sunshine duration, temperature, and rainfall [1]. Related to these factors are the pests and diseases that have the potential to destroy entire coffee crops. The area of focus for this review is Mexico and Central America (Mesoamerica). This paper will examine three pests (coffee borer beetle, black twig borer, and nematodes) and three diseases (bacterial blight, coffee berry disease, and coffee rust) that threaten the health of coffee crops and will also examine the ecophysiology of these pests/diseases and the effects of climate change.

Crops in Mexico and Central America affect the United States directly because we import a lot of agricultural goods from those regions. 12.6% of United States imports come from Mexico, which makes it the third largest supplier of imports to the US, and the second largest supplier of agricultural imports to the US (US Census Bureau 2017, USTR 2017a). In 2015, Guatemala (our 16th largest supplier of imports) exported $1.5 billion worth of agricultural goods to the US; 42.3% of that came from bananas and plantains and 17% came from unroasted coffee (USTR 2017b). The US also imports coffee from Panama, Nicaragua, Honduras, El Salvador and Costa Rica. Not only do these countries rely on these exports for their economies and livelihoods, we rely on the food and caffeine in our daily lives.

The most abundant coffee genus is the *Coffea arabica* L., more commonly known as arabica coffee, followed by *C. canephora*, more commonly known as Robusta coffee [2]. Coffee is grown all over the world, but especially in Africa, Asia, and the Americas [3]. In fact, Arabica coffee originated in Ethiopia sometime in the sixth century [4]. It was then exported all around the world, and now more than 70 countries grow coffee trees, mostly around the warm, tropical regions of the world. Brazil is the number one producer of coffee in the world, with Honduras number six, Mexico number nine, Guatemala number 10, Nicaragua number 12, and Costa Rica number 15 [5].

Coffee trees are generally grown at higher altitudes than other crops, ideally around between 2,500 and 4,000 feet above sea level. There are several mountain ranges in Mesoamerica, which is one of the reasons the area is ideal for growing coffee. Arabica coffee's optimal temperature is between 18-21°C (64-70°F), which matches with the mountain ranges of the coffee growing areas around the world [6]. That is a fairly narrow temperature range in which coffee thrives, and those conditions are not always met. Growth in a sub-optimal environment can negatively affect the quality of the coffee [7].

It is important to consider the general life cycle of a coffee tree and the coffee berries that form on the tree. Coffee trees take approximately three years to mature and produce good quality fruit [3]. The trees usually start out as seedlings in a tree farm, and once they have reached a certain height, are transferred to a coffee plantation. Each year, the coffee tree starts to flower after a period of rainfall followed by a dry spell. The flowering is a physiological response to water limitation [8]. After the tree flowers, it takes approximately 6-9 months for the coffee berries to mature. The berries first start out as green, then become red as they mature. Coffee berries are sometimes called coffee cherries because of their red color. Not every tree matures uniformly, and therefore hand picking the berries is sometimes preferred in order to sort the ripe from unripe coffee berries and therefore ensure the highest quality of coffee [3].

The coffee berry is the whole fruit, but that is not what we roast and grind to get our coffee. The coffee fruit has a skin, pulp, and parchment that cover the seed of the coffee [3]. Inside the fruit are two seeds, which is what we make our coffee out of. After the coffee berries are picked, the outer skin and pulp is removed with a machine called a de-pulper [3]. The seeds are then placed in a tub of water to ferment and remove any excess skin and pulp. Once the seeds have undergone fermentation, the coffee is washed and then put out under the sun to dry, where the beans are rotated frequently to ensure even drying of each seed/bean. After this, the beans are ready to be exported as is or roasted.

From the life cycle of coffee trees and the processing of the coffee beans, it is evident that environmental temperature, humidity, rainfall, and sunshine are important in all parts of coffee growing, harvesting, and processing. For example, coffee berries are also sensitive to sunlight, and often have shade trees planted in order to provide the correct amount of sunlight to reach the berries. These environmental factors also affect the pests and diseases that can destroy coffee crops. For example, coffee rust fungus thrives in wet, warm conditions [9]. Therefore, a summer with more rain and higher temperatures can cause the coffee rust fungus to spread rapidly and destroy entire coffee farms.

This paper aims to review studies about the six main pests and diseases that can destroy coffee crops, as well as link the meteorological conditions that exacerbate these pests and diseases. Another part of this paper will review the literature on how climate change will affect coffee crops and its pests and diseases. My hypothesis is that rainfall variability and higher temperatures associated with climate change will worsen the infestation of pests and diseases on coffee crops because it will create ideal conditions for the pests and diseases to grow. Therefore, climate change will most likely have a negative effect on coffee crops.

Results

Pests

Coffee borer beetle (CBB): The coffee borer beetle (CBB) is a small, black beetle 1.5 mm long with the official name of *Hypothenemus hampei* (Ferrari) [10]. The female coffee beetle drills a hole at the top of the coffee berry and lays her eggs inside. When the eggs hatch, the larvae feed on the inside of the coffee berry. This essentially destroys the coffee berry and makes it unusable. The CBB lays eggs in the coffee berries that are 20% dry weight and also prefers red berries. These conditions occur approximately 120-150 days after the coffee plants flower, which is also a delicate time for the growth of the coffee berry [10]. The coffee borer beetle has six life stages, with each complete life cycle lasting approximately 25 days. Because the CBB lives its entire life cycle within the coffee berry, it is difficult to use chemical sprays or pesticides to get rid of the pest.

Studies have looked at the densities of the CBB, and the conditions in which densities of the beetle are lower or higher. Teodoro et al. found that densities of the CBB were lower in complex agro forests [11]. They studied temperature, relative humidity, canopy cover, tree diversity, and coffee tree density in 22 sites in the coffee-producing region of Ecuador. These conditions represent potential abiotic and biotic stressors. They found that environmental conditions have a definite impact on the densities of coffee berry borers. Teodoro et al found that CBB density was negatively correlated with tree diversity, relative humidity, and canopy cover[11]. They also found that CBB density was positively correlated with temperature and coffee tree density. This means that the higher the temperature and the coffee tree density, the higher the CBB density. Agro forests with more tree diversity, higher relative humidity and more canopy cover had lower CBB densities. Therefore, more complex agroecosystems, ones that were more natural and less maintained, had lower densities of the CBB.

Ants, parasitic wasps, and entomopathogens are natural predators for the CBB and could possibly be used to control the CBB population [12]. Ants and coccids have a mutualistic relationship that occurs on coffee plants. Perfecto and Vandermeer studied coffee plants in southern Mexico and found that there was a negative correlation between the number of coccids on a coffee plant and the number of berries affected by the CBB [12]. This means that the more coccids there were, the less CBB there were on coffee plants.

The study concluded that the relationship between ants and coccids had an indirect effect of reducing the number of CBB on coffee plants.

The coffee borer beetle has an interesting symbiotic relationship which allows it to consume high levels of caffeine. Normally, these levels of caffeine would be toxic to insects. However, the beetle has gut bacteria called *Psuedonomas fulva* that helps the beetle digest the caffeine [13]. The bacteria are the symbionts and the beetles are the hosts in this symbiotic relationship. This is referred to as a detoxifying symbiosis because the beetles' gut bacteria de-toxify the caffeine in the coffee berries [13]. The gut microbiome, which relies on the caffeine for its carbon and nitrogen, degrades the caffeine as it travels through the beetle's gut [14]. When beetles were given an antibiotic during an experiment, the gut bacteria were eliminated and the caffeine was toxic to the beetles. They concluded that the gut bacteria were the key to the caffeine degradation. They found that this not only negatively affected their ability for caffeine degradation, but it also reduced fitness, with a 95% loss in eggs and larvae in beetles that were fed an antibiotic [14].

Black twig borer: The black twig borer is a black beetle that burrows and lays eggs inside small twigs or branches of a tree. Its scientific name is *Xylosandrus compactus* (Eichhoff). It is common in Florida, and in particular, within magnolia trees [15]. The female beetles carry a fungus in with them when they burrow, and that fungus is then cultivated by both the male and female borers. Once the eggs hatch, the larvae eat the fungi off the inside of the host plant/twig. Female twig borers are larger than males, and similar to the coffee borer beetle, it is the female that burrows into the host plant and initiates the interaction with the host. The burrowing of the beetles causes the twigs, branches, and leaves to wilt.

Nematodes: There are two types of nematodes that negatively affect coffee plants: root knot and root lesion nematodes [16]. Nematodes block the transport of water and essential nutrients to the main stem of the plant [17]. Barbosa et al. found that the root-knot nematode (*Meloidogyne exigua*) caused up to 45% yield loss to coffee crops in northwest Brazil in the 125 coffee plantations they conducted the study [18]. They specifically noted that this 45% yield loss was in the most maintained and well-managed of the coffee plantations, which had proper fertilization and used pesticides/fungicides. That study was followed up with a more detailed study of nematode infested versus nematode free coffee plantations with susceptible and resistant coffee cultivars [19]. They found that in the nematode infested coffee plantation, the nematodes negatively affected the development and productivity of the cultivars, in both the susceptible and resistance cases. Barbosa et al concluded that measures to prevent nematodes from spreading should be done prior to planting, such as planting nematode resistant cultivars [19].

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Diseases

Bacterial blight: Bacterial blight (*Pseudomonas syringae* pv garcae) is a leaf disease that thrives in cold, wet conditions [20]. This fungus prefers young, growing, RNA-rich leaves and is characterized by brown spots surrounded by a yellowish halo. Rainy and windy conditions help spread this disease [20]. Therefore, the opposite of those conditions (hot and dry weather) usually stop the spread of bacterial blight. Even though this disease is more commonly found on soybean and rice plants, it still can affect the leaves of coffee trees.

Ito et al studied 13 different Arabica coffee cultivars in an experimental field station in Brazil and tested each cultivars' resistance to the bacterial blight. They found only one cultivar that was partially resistant to bacterial blight that was also partially resistant to coffee leaf rust [21]. This particular coffee cultivar was characterized by medium canopy size and high coffee yield [21].

Coffee berry disease (CBD): Coffee berry disease (*Colletotrichum kahawae*) is another fungus which negatively affects coffee plants and affects all parts of the coffee tree including berries, leaves, and branches [22]. CBD can attack the coffee tree during all of the stages of the coffee development but is particularly damaging when the coffee berries are green [22]. Sunken, dark, black legions appear on the green coffee berries, causing them to drop prematurely from the coffee tree. CBD spreads easily, especially through rain, when the rain washes the spores from the top of the tree down to the bottom [16].

Coffee rust fungus: Coffee rust fungus (*Hemileia vastatrix*) is characterized by large, orange blotches on the coffee leaves [22]. It is likely one of the most damaging and concerning diseases to coffee crops. Not only can it affect the current year's crop, it can have lasting effects on the following year's crops [1]. Several coffee rust fungus events have been identified over the years, but a particularly bad year was the 2012/2013 season [23]. Coffee production in Central America decreased by 17% from 2011 to 2014 [24]. This then had snowball effects of leading to an economic downturn in the Central American region.

The causes of the coffee rust fungus are still being studied, but some potential culprits are decreased diurnal temperature and earlier onset of rainy season [1]. For example, an earlier onset of the rainy season usually means a longer rainy season, and therefore more rainfall. From previous sections, we know that certain diseases thrive in wet conditions. Rain splashes and wind are the main ways that spores from diseases are spread to other plants/trees. A reduction in the diurnal temperature range means that the lower temperatures are getting warmer and the higher temperatures are getting lower, so there is not as much variability in cold/warm temperatures as there once was.

Climate Change

In Mesoamerica, climate models are predicting a 2°C-2.5°C rise in mean annual temperature by the year 2050, with Mexico, Honduras, and Nicaragua experiencing the hottest temperatures [25]. Rainfall will also vary, with Honduras and Nicaragua experiencing a reduction in rainfall by 5%-10%. Farmers and resource managers want to know how climate change will affect the pests/diseases and therefore affect the coffee crops. Normally, coffee grows best at a specific altitude, fairly high up in the mountains. Climate change has the potential to increase the altitudinal range of the coffee berry borer and the coffee rust fungus [25]. This means that these coffee pests/diseases could thrive, whereas the coffee crops will not survive.

Jaramillo et al. tested eight temperature regimes on the life cycles of the coffee berry borers (CBB), and found that the CBB can survive between the extreme temperatures of 15°C and 32°C [26]. However, they also found that the CBB developed the fastest between 27°C -30°C, with a trade-off between reproduction success and developmental rate. In their climate models, they predicted that average temperatures of greater than 26°C could potentially reduce pest activity. They found that the 'maximum intrinsic rate of increase' increases exponentially below 26°C and decreases exponentially above 26°C. In other words, CBB growth is exponentially dependent on temperature.

Some select studies have shown that climate change will decrease coffee yields and affect coffee growth. Läderach et al. found that by 2050, growth of Arabica coffee will need to be moved up 300 m from current altitudes in Nicaragua to account for increasing temperatures and decrease in rainfall amounts [27]. Baca et al. found suitable areas of coffee growth would reduce up to 40% in El Salvador and Nicaragua due to climate change by 2050 [28]. On the global scale, Bunn et al. predicted a 50% reduction in suitable areas to grow coffee under the different climate change emission scenarios they tested [29]. Bunn et al. found that lower latitudes and lower altitudes would be negatively affected by increased global temperatures, and this would significantly impact Brazil's coffee-producing regions [29].

There are studies which investigate and suggest adaptation and mitigation strategies to combat climate change. For example, planting shade trees above coffee trees may cool the air temperature below and reduce stress on the coffee berries [7]. Jaramillo et al. used climate models to show that the coffee berry borer situation would worsen under climate change scenarios in coffee-producing areas of Eastern Africa [30]. They suggested one way to combat this is to introduce shade trees in full sun-growing coffee plantations.

Discussion

It is possible that in the near-future, there will be no more suitable areas of coffee growth in Mesoamerica. By 2050, some countries in Mesoamerica could see a reduction of 40%-50% in the land area that is suitable to grow coffee. As the air temperature increases, there will be less and less suitable altitudes for the coffee to grow in. Rainfall will become more variable, and it is uncertain exactly how that change will affect coffee. However, it is known that coffee is very sensitive to temperature, rainfall, and sunshine duration, and therefore it is implied that any substantial climatic changes will have a significant effect on coffee development and yields.

On the other hand, if there are no more coffee trees alive, there will be no more coffee berry borers. Since these beetles only live and breed in the coffee cherries, they can be considered specialists [31]. However, if there are less coffee berries, the beetles will migrate to look for food and there may be more competition for resources [32]. If the coffee tree becomes extinct, so will the coffee berry borer. The pest and the plant are intricately linked together.

With less rainfall predicted for Honduras and Nicaragua in climate change scenarios, the coffee berry disease (CBD) may have a harder time spreading its spores, which is good news for coffee trees. Less rainfall in general may mean less bacterial blight, CBD, and coffee leaf rust since these diseases thrive in wet conditions [33]. However, it remains unclear what effect the less rainfall will have on the coffee yield and quality.

Based on the large amount of literature on the subjects, the coffee berry borer (CBB) and the coffee leaf rust are the two most important and most threatening to the health of coffee trees. They have been the most thoroughly studied so far. Shade in general, seems to be a good way to combat pests that negatively affect coffee plants. Scientists are trying to discover and investigate coffee cultivars that are resistant to these pests and diseases. This is most likely the best way to combat the effects of climate change and its subsequent worsening of pests/disease infestation [1].

In general, from several studies mentioned above, more shade seems to be ideal conditions to prevent pests from invading coffee trees. Trees that provide shade above the coffee tree is good at keeping air temperatures moderate and shielding the plants from direct sunlight. Climate change will not be kind to coffee growth and development but may be kinder to the pests and diseases that feed and grow on the coffee.

Conclusion

Coffee is a sensitive crop that thrives in a narrow range of temperatures, with just the right amount of sunshine and rainfall. Disruptions in the normal conditions allow pests and diseases to grow and destroy entire coffee plantations. Climate change will move ideal growing conditions to higher altitudes, and also increase the altitudinal range of pests such as the coffee borer beetle. Less rainfall may decrease the prevalence of pests and diseases, but increased temperature has a more complicated effect. In general, pests and diseases prevalence will increase with increased temperature, but one study mentioned in this paper found that the intrinsic rate of increase declined in coffee borer beetles above 26°C. Clearly, there are optimal conditions for coffee growth that climate change will likely upset.

Adaptation strategies such as planting shade trees above the coffee trees, and planting pest resistant coffee cultivars are two main ways in which pests and diseases can be avoided.

Bacterial blight and coffee leaf rust both like wet conditions, so the amount of rainfall will be extremely important in how those diseases spread in future climate change. The amount of sunlight, air temperature, and ecosystem diversity are also important environmental factors that contribute to the health of coffee crops. These will be needed to be monitored closely over the next few years to ensure the health and safety of the coffee trees.

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