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Review Article

Impression of the Effects of Climate Change on Genetic Resources and Coffee (Coffea arabica L.) Production

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Abstract

One percent of the overall value of international trade is made up of coffee, one of the most significant traded commodities. Around the world, 25 million farmers rely on coffee as their main crop. Coffee production and genetic resources are seriously threatened by rising temperatures and increased precipitation that would follow from climate change, despite the fact that coffee is important for the economies of many countries. The examination of the effects of climate change on coffee production and genetic resources, as well as the recommendation of potential measures for their mitigation and adaptation, are the goals of this research. High temperatures and unpredictable rainfall brought on by climate change directly lower coffee yield by impacting plant growth and development. Additionally, it indirectly lowers the yield and quality of coffee and fosters the occurrence of more coffee-related diseases and pests. Furthermore, it was predicted by global circulation models that the distribution of places with the right climate for Arabica coffee could be affected by changes in temperature and precipitation, making many of those regions unsuitable. Additionally, there is a high risk of extinction for wild coffee and coffee germplasm accessions of Arabica coffee, which have been preserved in Ethiopia and many other nations' ex-situ field gene banks. These factors will have a significant impact on the majority of top coffee producers in the future. As a result, countries that cultivate coffee should be aware of how changing climatic factors affect coffee output and genetic resources and implement the necessary mitigation and adaptation measures.

Keywords

Climate Change, Coffee Yield, Gemplasm, Mitigation and Wild Coffee

1. Introduction

The second-most significant commodity on the global market after oil is coffee, which is grown on more than 11 million ha of land in more than 60 tropical nations. It contributes significantly to the foreign exchange earnings of many developing nations, and the stability and growth of the economies of many nations in Africa and South America depends on the income from coffee production. Despite being important for millions of people worldwide, there are currently a number of obstacles that limit coffee output in the producing nations. According to the RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 scenarios, the average global surface temperatures for 2081-2100 are expected to rise by 0.3 ℃ to 1.7 ℃, 1.1 ℃ to 2.6 ℃, 1.4 ℃ to 3.1 ℃ and 2.6 ℃ to 4.8 ℃, respectively, [26]. There are several detrimental implications of climate change on coffee production. By 2050, it's anticipated that crop yields will fall 10 to 20% globally [25]. Since coffee is a major source of

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income for many farmers in underdeveloped nations, the consequence will be quite dangerous for crops like that one. In addition, the effects of illnesses and insect pests on coffee may have an indirect impact from climate change. Arabica coffee has been under attack by coffee leaf rust in all of the areas where it is grown, and this is the major hazard to coffee that is directly related to climate change. Despite the fact that farmers chose to produce coffee in highland regions to avoid attacks from rust, coffee leaf rust is becoming more common at higher altitudes as a result of the favorable conditions provided for the fungus by climate change [32]. The coffee berry borer, also known as Hypothenemus hampei or H. hampei, is also emerging as the major threat to coffee plants [28]. Further, because Arabica coffee must be served at a precise temperature, even little temperature rises run the risk of ruining the beverage and having a catastrophic effect on the coffee business [28]. They have also cautioned that most of the current appropriate locations for coffee production will experience a severe decline if climate change continues as the current trend. The wild Arabica coffee species, which are the source of many resistant genes, would also face a significant challenge due to climate change, and predicted that this will happen by the year 2080. Similar to this, even though there are roughly 21,407 coffee Arabica germplasm accessions in the many ex-situ field gene banks around the globe, with the bulk being located in Ethiopia [33], these enormous coffee genetic resources are at serious risk as a result of climate change. Therefore, it is crucial to find quick solutions to determine the best conservation techniques against the potential effects of climate change on coffee genetic resources. The sustainability of the coffee business is predicted to encounter significant issues as a result of the aforementioned factors, and even now, a rising temperature is having an impact on many farmers who grow coffee [2]. Therefore, if coordinated measures are not made to safeguard this priceless crop, the livelihoods of many coffee-producing farmers and countries whose economies rely heavily on coffee will suffer greatly. Therefore, it is crucial to determine how global climate change is affecting coffee productivity, quality, and genetic resources. The effects of climate change on coffee production and genetic resources will therefore be the main focus of this review. The paper also discusses potential adaption tactics to use, and it concludes by outlining research gaps that need to be filled in the future. The impacts of climate change on coffee production, coffee disease and pest epidemic, projected shifts in the area suitable for growing coffee as a result of climate change, the impact of climate change on coffee genetic resources, and strategies for climate change mitigation and adaptation are some of the topics covered.

2. A Review of Climate Change and How It Affects Coffee (Coffea arabica L.)

Climate change is defined by a study [42] as a change in climate that was caused by human activity in addition to natural climate variability that was seen throughout comparable time periods. Agriculture and other human-made activities produced greenhouse gases (GHG) like CO_2, CH_4, and N_2O, which helped to raise the earth's temperature. For the past 200 years, burning fossil fuels and deforestation have both contributed to an increase in the global temperature [21]. It is acknowledged that coffee plants are vulnerable to climate change because the vast majority of coffee is cultivated and manufactured in developing nations [27]. The significant effects of climate change on coffee (Coffea arabica L.) production and genetic resources are covered in this section. Globally, climate change has several detrimental effects on coffee output, quality, and genetic resources.

2.1. The Effects of Climate Change on Coffee Production

Similar to other crops, drought and unfavorable temperatures are the main factors that limit coffee production. Due to the widespread expansion of coffee growing onto marginal lands and the two key factors of known global climate change and considerable production restrictions, rainfall and temperature are projected to have a significant impact in many coffee-producing locations [10]. The ideal air temperature range for Coffea arabica is thought to be between 18 and 21 ℃ [3]. The yield of Arabica coffee plants can be significantly impacted by extreme temperatures in a variety of ways: At temperatures above 25 ℃, the photosynthetic rate decreases [14, 43]. When exposed to temperatures above 30 ℃, growth is slowed and anomalies in the leaves, stems, flowers, or plants may develop, lowering coffee production [9, 15, 17]. However, with certain cultivars and rigorous management techniques, Arabica coffee might provide reasonable yields in marginal areas with typical temperatures as high as 24–25 ℃. [9]. As reported by [8] that the most significant climatic factor causing declining C. arabica yields is rising nighttime temperatures in their study to assess the loss in coffee yields due to climate change in the northern Tanzanian highlands. They have also predicted that by 2060, the average amount of coffee produced per hectare will fall to 145 kg, and many coffee producing regions that have comparable minimum temperature trends will be severely impacted. Temperatures above 23 ℃ typically hasten the development and maturation of coffee berries, which frequently results in a reduction in coffee quality. In contrast, development is severely constrained in areas where the mean annual air temperature is below 18 ℃. Frosts have a significant negative economic impact on the crop, and when water stress develops, the process of photosynthesis is constrained due to the coffee plant's reduced physiological activity and stomata closure [7]. Hail damage results from violent rains that stop the flowering of coffee. The unpredictable rains will cause the coffee to flower all year long, making harvesting challenging and forcing the growers to repeatedly harvest modest amounts. High precipitation

brought on by climate change is particularly beneficial for the growth of coffee diseases like coffee beery disease, which need a lot of moisture. The change in the rainy seasons will have a significant impact on the activities involved in drying and processing coffee.

2.2. Climate Change's Effects on the Coffee Disease and Insect Pest Epidemic

For the economies of many areas, coffee is absolutely essential. Millions of people in underdeveloped countries depend on coffee as a source of income, either directly or indirectly [18]. However, due to climate change, the coffee crop is in danger from numerous pests. The main pests that can drastically lower crop yields and quality are berry borers, coffee leaf rust, coffee berry disease, bacterial blight, nematodes, Antestia bug, coffee thrips, and leaf miners.

2.2.1. Climate Change's Effect on Coffee Illness

One of the major coffee illnesses that can seriously harm coffee yield and quality is coffee leaf rust. A survey carried out by [4] in Rwanda to determine the relationship between the severity of CLR and elevation, and they found that coffee farms at higher elevations had less CLR than those at lower elevations. The illness is currently migrating up to high land mountain slope as a result of favorable conditions generated by climate change. However, coffee leaf rust was widespread at higher altitudes where the environmental conditions were unfavorable for the fungus [31, 32]. This result perfectly corroborated) [6] that when the climate changes, new rust races arise and even the most tolerant varieties are susceptible to coffee rust. In Sidama and Gedeo Zone of Southern Ethiopia Regional State, Pseudomonas syringae pv garcae van Hall-caused bacterial blight of coffee, also known as Elgon or Solai dieback, is becoming a significant pest. The recent survey's findings also showed that all coffee cultivars issued at various regions displayed varying degrees of disease severity [13].

2.2.2. How Climate Change Affects Coffee Insect

Hypothenemus hampei (Ferrari), a frequent coffee berry borer in central Africa, is the primary global limitation on coffee production [11, 19]. Coffee berry borer has just recently discovered attacking and harming coffee farms above a height of 1500 meters [1]. However, the insect is now common at greater elevation above 1500m due to the pest's ideal environmental conditions generated by the world's majority of coffee-growing regions seeing a rise in temperature. One of the main insects that eat on coffee berries is the coffee berry borer (Hypothenemous hampei), according to [28], the population of coffee berry borer increases exponentially by 8.5 % for every 1 ℃ rise in temperature. In order to anticipate hazards and prioritize pest management strategies under future emission scenarios, [29] predicted the number of coffee berry borer generations in East Africa. They found that now, 1 to 4 generations are born per fruiting season. The population increases of the coffee berry borer are expected to be more pronounced in both scenarios, and the pest is predicted to affect the current Coffea arabica production regions of the majority of Eastern African countries. Despite the fact that studies carried out in Ethiopia in 1967 found no evidence of coffee berry borers due to the inhospitable climate in the coffee-growing regions of the Ethiopian highlands, surveys carried out in 2003 showed that the berry borer was common in the southwest of the country. This might occur as a result of the pest-friendly atmosphere that the rising temperature has created. As a result, this insect poses a significant challenge to the struggling coffee industry and will have negative effects on East African livelihoods and the output of C. arabica. Therefore, creating coordinated long-term strategy is essential for managing coffee berry borer. Similar to this, a survey was carried out in Southwest Ethiopia in 2015–16 to evaluate the severity of the blotch leaf miner and Antestia bug. The results showed that 35.11 and 28.3 % of the blotch leaf miner (Leucoptera caffiana) were detected at Bebeka and Agaro, respectively. As described by [20] the damage to coffee plantations by these pests will be greater under the future scenarios compared to the current climatic conditions in a study conducted in Brazil to analyze changing climatic variables on nematodes (Meloidoygne incognita) and coffee leaf miners (Leucoptera coffeella). The conclusion that increasing temperatures will be one of the biggest difficulties for coffee industry globally may be drawn from the aforementioned facts.

Projected Changes in the Coffee Suitability Zone Climate Change is to blame. All countries that produce coffee will see negative effects from climate change, according to scientists. The alterations in climatic factors might cause some regions to become less suitable while benefiting others. Few researchers projected the future climatic appropriateness of Arabica coffee, and all claimed that coffee-producing areas are decreasing internationally, putting the coffee industry at risk unless the essential steps for mitigation and adaptation are implemented. For instance, [39] reported that climate change would make coffee production in current potential producing areas (Southeast region of Brazil) unfeasible and that by 2070 the coffee crop will migrate to the South region where it is not currently suitable for coffee production. This study was done to forecast the future suitability area of coffee in Brazil. Similar to this, [40] study of eight East African courtiers shows that climate change would affect future Coffea arabica suitability areas, and the author predicts a constant drop in the number of ideal Arabica coffee growing regions in East Africa after 2020.

By 2050, there are no optimum places in Uganda and all optimal spots in Zambia have vanished. There are fewer ideal locations in Rwanda and Burundi. In West Ethiopia, there are fewer areas that are appropriate for producing Arabica coffee by 2080. According to [38], the future decrease of Arabica

coffee suitability area will occur worldwide and will look something like this: Countries in Mesoamerica, South America, and Africa would have average declines in the area appropriate for Arabica coffee of up to 30%, 16–20%, and 9–25%, respectively. A significant portion of the currently acceptable lands for coffee would be lost by 2050 in Mexico (29%) from Mesoamerica, Brazil (29%) from South America and Uganda (25%) and Tanzania (22%) from Africa. The bulk of East African nations, including Ethiopia, would reportedly be least impacted by climate change in the future. India and Vietnam would lose suitable regions and be severely impacted in the pacific nations.

In contrast to the findings above, [35] found that, absent major intervention, between 39 and 59 % of Ethiopia's existing coffee-growing regions would become unfit for coffee cultivation. Few researchers have examined the future suitability area of these two significant coffee species globally using various models based on various emission scenarios. Projection on appropriate future coffee growing regions for two key coffee species (C. arabica and C. canephora) has only recently begun. In this regard, [36] predicted that climate change will have varying effects on the two main species of coffee, with most future locations being favorable for the cultivation of Robusta coffee as opposed to Arabica, which is in high demand on the global market. On the other hand, East Africa and the Pacific Island regions won't be significantly impacted by changing climatic variables in the future, according to [5], who also predicted that higher coffee suitability area will be lost for coffee Robusta than Arabica. The results of [12], who predicted a significant drop in the climatically acceptable area for native Arabica coffee in Eastern Africa, contradict the findings of [5, 40], which showed that East African countries are least affected by climate change. Additionally, the current findings of [5], who claimed that C. canephora will lose more of the current coffee-suitable areas than Arabica, conflict with the findings of [36], who asserted that Arabica will lose more of the current coffee-suitable areas than C. canephora. This discrepancy is likely caused by variations in the models used and the study area that was sampled. In general, all analyses showed that the current coffee-suitability region for C. arabica and canephora will significantly shrink in the future. All studies revealed that East African countries are less affected by changing climatic variables, despite the fact that researchers utilized several models to estimate the future coffee suitability areas. Brazil, the world's largest supplier of coffee, is particularly impacted by climate change. As a result, in order to maintain the coffee business, coffee producers in all coffee-producing nations are expected to implement climate change adaptation measures. Additionally, all research only used temperature and precipitation to forecast the locations where coffee would be suitable, therefore future studies should take soil characteristics and other climatic variables that have an impact on coffee suitability into account.

2.3. Climate Change's Effect on Coffee Genetic Resources

Although Arabica coffee is grown in many countries throughout Africa and Latin America, it actually comes from Ethiopia, and only Ethiopia, Uganda, and Kenya are home to its wild ancestors. [32]. Wild species serve as key sources of important genes for the enhancement of many agricultural crops. Given this reality, [12] predicted how native Arabica coffee would be distributed in the future. The findings revealed a noticeable and significant decline in the number of bio-climatically ideal locations for locally grown Arabica coffee. According to the authors, in the scenario with lower energy requirements, there will be a reduction of 65% of the regions that are currently appropriate for Arabica coffee. However, by 2080, there will be a decline of 85% of the regions that are currently suitable for Arabica coffee under high emission scenarios. Aside from affecting wild coffee species, the coffee germplasm accessions preserved in ex-situ field gene banks of various coffee research organizations worldwide are also impacted by changing environmental variables brought on by climate change. 21087 coffee accessions have been preserved worldwide in the field gene banks of Costa Rica, Colombia, Brazil, Côte d'Ivoire, Cameroon, Ethiopia, Kenya, Tanzania, Madagascar, India, and Indonesia, according to [16] However, because to climatic change, these accessions face a major threat of genetic loss [33]. Therefore, it is essential to look for urgent measures to determine the best conservation strategies. Additionally, because semi-forest, garden, and even plantation coffee is grown within the same bioclimatic envelop, the effects of climate change will have a significant impact on them. As a result, some regions can anticipate to see a significant decline in the genetic variety of coffee [12]. Therefore, it is crucial and urgent to conserve the genetic resources present in wild, semi-forested, and garden coffee by gathering and storing in locations identified as being adaptable to climatic change. Utilizing these vast genetic resources for coffee through genetic diversity research utilizing contemporary biotechnological technologies is also of utmost relevance.

3. Recommended Strategies for Mitigation and Adaptation to Climate Change

Future coffee production will confront significant obstacles, which will have a negative impact on many countries' economies and future prospects because of their reliance on coffee exports. Therefore, all coffee-producing nations should implement the necessary steps to lessen the harm to the crop. Additionally, in order to support the struggling coffee plant, countries that produce coffee must incorporate climate change mitigation and adaptation measures into their policies.

3.1. Planting Coffee in Shade

Coffee shade trees have the power to lower temperatures ideal for Arabica coffee and lessen the effect of the sun on the plants. According to [29], shade trees can lower the temperature by up to 4 ℃. Due to the significant use of various coffee shade trees in Ethiopia and Colombia, the increase in the coffee beery borer population may be about 34% lower than anticipated [29]. As describe by [37] also claim that the construction of shade trees around coffee plants can reduce harmful environmental pressures like high soil temperatures and low relative humidity. Many farmers think that shaded systems will reduce yields, need more pruning and humidity control, which will lead to an increase in crop-devastating fungi diseases like coffee leaf rust [34, 41]. Nevertheless, shade can help ensure high-quality, sustainably produced coffee [24, 30]. Other strategies, such windbreaks, can be employed in conjunction with shade trees to lessen the influence of humidity on the incidence of fungal illness caused by increasing humidity. The pruning compensates for the higher maintenance costs associated with growing coffee because the trimmings are either sold as firewood or used by the employees. Therefore, using shade effectively and efficiently is crucial for reducing the effects of climate change on coffee.

3.2. Irrigation, Mulching and Close Spacing

Close spacing also lowers the stress on coffee plants and results in cooler air inside the plantation than in the surrounding area. Additionally, irrigation has been a crucial strategy for the establishment of coffee in remote locations where the average temperature is too high for Arabica coffee cultivation. By enhancing the physical qualities of the soil, maintaining mulch under coffee trees can be employed as an effective soil conservation method and help coffee production withstand challenging climatic conditions [22]. Therefore, it is possible to enhance the physical features of the soil and increase the feasibility of coffee growth in challenging climatic circumstances by using close spacing, mulching, and irrigation.

3.3. Development of Illness and Heat Tolerant Varieties

The development of disease, insect pests, and heat tolerance should be the emphasis of coffee's genetic enhancement in order to combat the effects of climate change. Planting pest-resistant cultivars lowers crop loss from disease and pests and lowers environmental pollution from pesticide use. According to [23] report, the Instituto Agronômico de Campinas (IAC) is working to transfer crucial coffee traits from Robusta to Arabica coffee, such as resistance to disease, insects, and higher temperatures. Additionally, the hybrid coffee cultivars created by a coffee breeding program led by CIRAD and PROMECAFE from traditional coffee kinds and wild Ethiopian coffee trees shown higher quality in low land locations and have greater adaptation to hotter drier climes [2].

3.4. Modifying the Location

Researchers advised that coffee growing areas be relocated to highland regions, where temperatures are typically lower, to mitigate the effects of the rising temperature [12, 29]. According to a study by [35], moving coffee growing areas along with protecting and re-establishing forests could increase the number of potential coffee-producing areas in Ethiopia by a factor of four.

3.5. Diversification

Farmers are extremely exposed to climatic hazards, such as protracted drought spells or destructive rainfall and storms, due to the significant dependence of coffee as a monoculture. It is important to identify options for diversifying production and farmers' income in order to lower this risk and improve the resilience of the agricultural production system. The key technique available to farmers for lowering the risk on any particular farm is diversification.

4. Summary and Conclusion

Despite the fact that coffee is crucial to many people's livelihoods around the world, production is limited by a variety of causes. Climate change-related droughts and unfavorable temperatures are two of the main elements that have an impact on coffee production. The irregular rains will force the coffee farmers to repeatedly harvest little amounts of coffee. Widespread droughts may result in flower abortion. Premature ripening of the beans due to high temperatures and sunshine can be detrimental to coffee productivity and quality. In addition, it is anticipated that coffee pests and illnesses would become more common and severe due to climate change. For instance, one of the coffee insect pests that is now growing quickly is the coffee berry borer. Similar to coffee leaf rust, which is one of the main coffee diseases in countries that produce coffee, it was more common during warmer months but is now known to be spreading to highland and cooler regions. The distribution of species will also be impacted by climate change, with already inhabited places becoming unsuitable and new regions with suitable climates arising. The number of ideal locations in the primary producing and exporting nations of coffee in Mesoamerica, South America, the Pacific islands, and Africa will drop as a result of changes in these climatic variables during the course of the next century. Another concern to coffee is the loss of genetic resources brought on by climate change. A high risk of extinction exists for more than 21,000 coffee germplasm accessions preserved in ex-situ field gene banks globally. As a

result, to assure coffee sustainability, producing nations will need to modify their agricultural practices to lessen the impact of upcoming climatic change. In general, the majority of the literature showed that future coffee output will be threatened by climate change. Despite the literature's discrepancies, it can be said that climate change will lead to the loss of areas that are suitable for growing coffee in the future. The majority of future coffee suitability estimates, however, were made by taking precipitation and rainfall into account, even though the best locations for growing coffee depend on a variety of characteristics, including soil type, humidity, and soil water content. Additionally, the results are conflicting since multiple models were employed to forecast the future suitability region for coffee as a result of climate change. Furthermore, because the suitability of the places for shade trees is changing along with future environmental variables, the majority of the studies undertaken did not take this into account. Furthermore, despite coffee producers continuing to experience yield losses due to changing climatic variables, the impact of climate change on productivity has not been measured at the regional or national level.

Abbreviations

GHG	Greenhouse Gases
CLR	Coffee Leaf Rust
RCP	Representative Concentration Pathway

Author Contributions

Meseret Degefa Regassa is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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