

**Review Article**

Review on Climate Change Impacts on Coffee Quality: Synthesis, Strategies, and Sustainability

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To cite this article:Bealu Girma. (2024). Review on Climate Change Impacts on Coffee Quality: Synthesis, Strategies, and Sustainability. *American Journal of Biological and Environmental Statistics*, 10(1), 1-7. <https://doi.org/10.11648/ajbes.20241001.11>**Received:** January 10, 2024; **Accepted:** January 23, 2024; **Published:** February 5, 2024

Abstract: This review explores the impact of climate change on coffee's biochemical composition and quality by synthesizing current literature. The investigation offers insights and recommendations for adaptation strategies to ensure the sustainability of the coffee industry. The analysis aims to assess how climate change affects the quality and biochemical makeup of coffee, as well as propose solutions for adaptation. By consolidating existing research on how climate change impacts coffee's biochemical composition and quality, it is apparent that changes in temperature and precipitation can alter coffee beans' chemical makeup, affecting their overall excellence. To mitigate these effects, various adaptation strategies such as implementing shade trees, drought-resistant varieties of coffee plants, improved irrigation techniques, and better post-harvest processing methods can be employed effectively. These strategies have been shown to ameliorate some negative repercussions from climate change on the production process significantly. Furthermore, this critique emphasizes the importance of inventive resolutions to address challenges faced by the coffee sector due to climate change. Additionally, genetic engineering methodologies or breeding programs may enhance both productivity levels and product quality; however safety concerns regarding their effectiveness remain a concern. To guarantee sustainable development within this industry expects stakeholders' collaboration towards developing socially acceptable innovative adaptations that respond appropriately against environmental shifts caused by global warming while maintaining secure business practices.

Keywords: Climate Change, Coffee Quality, Biochemical Compositions, Adaptation Strategies, Shade Trees, Drought-Tolerant Coffee Varieties, Irrigation Techniques, Post-Harvest Processing Methods

1. Introduction

Coffee, a highly valuable cash crop, is primarily cultivated in tropical regions and plays a pivotal role in sustaining the livelihoods of a significant number of individuals across over 60 countries [9]. The quality of coffee is greatly affected by a diverse interaction of biological, chemical, and environmental factors, which include the biochemical composition of coffee beans, and are impacted by temperature and precipitation [8]. It is anticipated that climate change will exert substantial effects on both the quality and biochemical composition of coffee [1, 12], owing to the escalating temperatures, shifting patterns of precipitation, and heightened occurrence of extreme weather events [5]. The high-quality arabica coffee species is particularly susceptible to these transformations, as

alterations in temperature and precipitation have the potential to impact its biochemical composition, acidity, and flavor [5, 12]. The ramifications of climate change on the quality of coffee bear significance for various reasons. Firstly, coffee represents a valuable crop that sustains the livelihoods of millions of individuals [9]. Secondly, the quality of coffee holds importance for consumers as it significantly influences the taste and flavor of the final product [8]. Thirdly, comprehending the repercussions of climate change on coffee quality can serve to guide the formulation of adaptation strategies for both the coffee industry and farmers [20]. Numerous investigations have supplied evidence to back up the assertion that global warming has already impacted the production of coffee in different regions, such as Ethiopia, Colombia, and Vietnam. This impact has been observed in the

form of rising temperatures and alterations in precipitation patterns, resulting in lower yields and a decline in the quality of coffee beans [1, 5, 11].

Mitigating the ramifications of climate change on the coffee sector necessitates collaborative endeavors from the global community. Viable approaches encompass endorsing sustainable land utilization techniques, endorsing research and development of novel coffee species, and furnishing financial and technical aid to coffee cultivators [20].

The objective of this evaluation is to present an updated appraisal of the influence of climate change on coffee excellence and biochemical composition, consolidating the existing literature on how climate change affects coffee production and quality. Moreover, it furnishes insights and suggestions for adjustment tactics for coffee cultivators and the industry to foster the sustainability of the coffee domain.

The influence of climate change on coffee production and quality constitutes a noteworthy apprehension for the coffee sector and the countless individuals reliant on it. Consequently, comprehending the impact of climate change on coffee excellence and biochemical composition is crucial for informing adjustment strategies and supporting the sustainability of the coffee industry [5, 11, 12, 20].

2. The Role of Key Biochemical Components in Determining the Flavor, Aroma, and Acidity of Coffee

The flavor, aroma, and acidity of coffee are key factors in determining its quality and are influenced by its key biochemical components. Understanding the role of these components is important for maintaining and improving the quality of coffee and addressing the challenges faced by farmers in different regions.

Coffee contains several key biochemical components that contribute to its flavor and aroma, including acids, sugars, lipids, and nitrogenous compounds [8]. These components interact with each other and with the volatile compounds in coffee to create a complex flavor and aroma.

Acids are an important component of coffee and contribute to its acidity, which is a key factor in determining its flavor profile. The two primary acids found in coffee are chlorogenic and quinic acids [8]. Chlorogenic acid is responsible for the bitterness of coffee, whereas quinic acid contributes to its sourness.

Sugars are another important component of coffee that contribute to sweetness. The primary sugars found in coffee are sucrose, fructose, and glucose [8]. The concentration of sugars in coffee can vary depending on coffee variety, processing method, and environmental conditions.

Lipids are also important components of coffee that contribute to the body and mouthfeel. The lipids in coffee are primarily composed of fatty acids such as linoleic acid and oleic acid [8].

Nitrogenous compounds, such as caffeine and trigonelline, are also important components of coffee and contribute to its

aroma and flavor. Caffeine is responsible for the stimulating effect of coffee, whereas trigonelline contributes to its bitterness and aroma [8].

The flavor and aroma of coffee can vary depending on several factors, including the roasting level, brewing method, and storage conditions. The roast level can affect the concentration of volatile compounds in coffee, which can alter its flavor and aroma [8]. The brewing method can also affect the flavor and aroma of coffee because different methods extract different compounds from coffee beans.

The acidity of coffee is an important factor in determining its quality. High-quality coffee tends to have a balanced acidity that is neither too high nor too low. The acidity of coffee can be influenced by several factors, including the coffee variety, processing method, and environmental conditions [10].

In conclusion, the key biochemical components of coffee, including acids, sugars, lipids, and nitrogenous compounds, play an important role in determining its flavor, aroma, and acidity. Understanding the role of these components is important for maintaining and improving the quality of coffee and addressing the challenges faced by coffee farmers in different regions.

Factors Influencing Coffee Quality: Genetics, Cultivation, Processing, and Climate Change.

Coffee quality is influenced by several factors, including plant genetics, cultivation practices, and processing. Understanding how these factors affect coffee quality is important for improving the sustainability and profitability of coffee production, particularly in the face of climate-related challenges.

Coffee plant genetics play a crucial role in determining the quality of coffee. Different coffee varieties have unique flavor and aroma profiles that are determined by their genetic makeup [10]. For example, Arabica coffee is known for its complex flavor and aroma, whereas Robusta coffee is known for its bitterness and high caffeine content.

Cultivation practices also play an important role in determining coffee quality. Factors such as altitude, soil type, and climate can significantly affect the coffee quality [10]. For example, coffee grown at higher altitudes tends to have higher quality because of slower cherry maturation and a greater concentration of sugars in the beans.

Processing methods can also affect the coffee quality. There are two primary methods for processing coffee: wet and dry processing. Wet processing involves removing the outer layers of the coffee cherry and fermenting the beans before drying them, whereas dry processing involves drying the entire cherry before removing the outer layers [10]. The processing method can significantly affect the flavor and aroma of coffee as well as its acidity and body.

In addition, post-harvest handling and storage conditions can affect coffee quality. Appropriate storage conditions, such as temperature and humidity control, are crucial for maintaining the quality of coffee beans [10].

The effect of climate change on coffee production can also affect coffee quality. Rising temperatures and changes in

precipitation patterns can alter the biochemical composition of coffee beans, which can ultimately affect their flavor and aroma [5]. Climate change can also affect the suitability of certain coffee varieties in particular regions, which can affect coffee quality and production [11, 12].

In conclusion, coffee quality is influenced by several factors, including plant genetics, cultivation practices, processing methods, and post-harvest handling and storage conditions. Climate change on coffee production can also affect coffee quality and production. Understanding how these factors interact is important to improve the sustainability and profitability of coffee production.

3. The Impact of Climate Change on the Biochemical Composition and Quality of Coffee Beans

The biochemical composition and quality of coffee beans are of the utmost importance in the coffee industry. The quality of coffee is determined by its taste, aroma, and flavor, which are influenced by several factors, including the biochemical composition of coffee beans. The impact of climate change on coffee production can alter the biochemical composition of coffee beans, which can ultimately affect their quality.

Coffee beans are composed of various organic compounds, such as carbohydrates, lipids, and nitrogenous compounds, as well as several volatile and nonvolatile compounds that contribute to the taste and aroma of coffee [8]. The biochemical composition of coffee beans can vary depending on several factors such as coffee variety, altitude at which the coffee is grown, and environmental conditions during coffee growth and development.

Climate change on coffee production can alter the biochemical composition and quality of coffee beans. For example, rising temperatures can alter the concentrations of various compounds in coffee beans, including sugars, lipids, and caffeine [5]. Increases in temperature can also lead to changes in the ratio of chlorogenic acid to caffeine, which can affect the flavor and aroma of coffee [8].

Changes in precipitation patterns can also affect the biochemical composition and quality of coffee beans. For example, drought conditions can reduce the concentrations of sugars and other compounds in coffee beans, leading to lower cup quality [12]. Conversely, excessive rainfall can lead to a lower concentration of coffee solids in coffee cherries, which can also affect the coffee quality [11].

The effect of climate change on coffee production varies by region. For example, coffee beans grown at higher altitudes tend to have a higher concentration of certain compounds, such as sugars and lipids, which can contribute to a richer and more complex flavor and aroma [8]. The impact of climate change on coffee production can also vary according to coffee variety. Some varieties may be more resilient to the effects of climate change than others and may therefore maintain a more consistent biochemical composition and quality.

In conclusion, the biochemical composition and quality of coffee beans are influenced by various factors, including the environmental conditions under which coffee is grown. The impact of climate change on coffee production can alter the biochemical composition of coffee beans, which can ultimately affect the quality of coffee. Understanding these relationships is important for developing strategies to support the sustainability of the coffee industry in the face of climate change.

3.1. Effects of Climate Change on Coffee Quality

Coffee quality is expected to be significantly affected by climate change because changes in temperature, rainfall, and other weather patterns can affect coffee growth, development, and biochemical composition. Several studies have investigated the effects of climate change on coffee quality.

One study conducted by Bunn et al. [5] found that climate change is likely to negatively impact coffee quality, particularly in regions where coffee is currently grown at high elevations. The study suggested that changes in temperature and precipitation patterns could result in reduced coffee yields and lower quality.

Another study by Ovalle-Rivera et al. [18] investigated the impact of climate change on coffee quality in Colombia. This study found that changes in precipitation patterns and temperature could lead to reduced coffee quality, including changes in acidity, flavor, and aroma.

A third study by Vaast et al. [22] investigated the impact of climate change on coffee quality in Central America. This study found that changes in temperature and rainfall patterns could lead to changes in coffee quality, including alterations in acidity, sweetness, and aroma.

Overall, these studies suggest that climate change is likely to have a significant impact on coffee quality, with changes in temperature and precipitation patterns potentially leading to altered biochemical composition and sensory characteristics of coffee.

3.1.1. Impact of Climate Change on Coffee Flavor and Aroma

Climate change can have a significant impact on the flavor and aroma of coffee because changes in temperature, rainfall, and other weather patterns can affect the growth, development, and biochemical composition of coffee beans. Several studies have investigated the impact of climate change on the flavor and aroma of coffee.

One study conducted by Kleinwächter et al. [14] found that changes in temperature and rainfall patterns due to climate change could significantly impact the aroma profile of Arabica coffee. The study found that increased temperatures led to a reduction in aroma compounds, resulting in less complex and less intense coffee aroma.

Another study by Ovalle-Rivera et al. [18] investigated the impact of climate change on coffee quality in Colombia. The study found that changes in precipitation patterns and temperature could lead to reduced coffee quality, including changes in acidity, flavor, and aroma.

A third study by Bote et al. [4] investigated the impact of climate change on coffee flavor in Ethiopia. This study found that higher temperatures and lower rainfall led to changes in the biochemical composition of coffee beans, resulting in altered flavor profiles with lower sweetness and fruity notes.

Overall, these studies suggest that climate change can have a significant impact on the flavor and aroma of coffee, with changes in temperature and precipitation patterns potentially leading to alterations in aroma compounds and flavor profiles.

3.1.2. Effects of Climate Change on Coffee Acidity and Sweetness

Climate change can have a significant impact on the acidity and sweetness of coffee because changes in temperature, precipitation, and other weather patterns can affect the growth, development, and biochemical composition of coffee beans. Several studies have investigated the effects of climate change on acidity and sweetness of coffee.

One study conducted by Vaast et al. [22] investigated the impact of climate change on coffee quality in Central America. This study found that changes in temperature and rainfall patterns could lead to changes in coffee quality, including alterations in acidity and sweetness.

Another study by Ovalle-Rivera et al. [18] investigated the impact of climate change on coffee quality in Colombia. The study found that changes in precipitation patterns and temperature could lead to reduced coffee quality, including changes in acidity, flavor, and aroma.

A third study by Schroth et al. [21] investigated the impact of climate change on coffee agroforestry systems in Central America. The study found that changes in temperature and rainfall patterns could lead to changes in coffee quality, including alterations in acidity and sweetness.

Overall, these studies suggest that climate change can have a significant impact on the acidity and sweetness of coffee, with changes in temperature and precipitation patterns potentially leading to alterations in the biochemical composition and sensory characteristics of coffee.

3.1.3. Influence of Climate Change on Coffee Cupping Scores

Climate change can have a significant impact on coffee cupping scores because changes in temperature, rainfall, and other weather patterns can affect the growth, development, and biochemical composition of coffee beans, ultimately affecting the sensory characteristics of brewed coffee. Several studies have investigated the influence of climate change on the coffee cupping scores.

One study conducted by Ovalle-Rivera et al. [18] investigated the potential impacts of climate change on coffee production and quality in Mesoamerica. This study found that changes in temperature and precipitation patterns could lead to reduced coffee quality, including changes in cupping scores.

Another study by Bunn et al. [5] investigated the impacts of climate change on coffee production and quality in Africa. This study found that climate change is likely to have a negative impact on coffee quality, with changes in temperature and precipitation patterns resulting in reduced cupping scores

and lower-quality coffee.

A third study by Vaast et al. [22] investigated the impact of climate change on coffee quality in Central America. This study found that changes in temperature and rainfall patterns could lead to changes in coffee quality, including alterations in cupping scores.

Overall, these studies suggest that climate change can have a significant impact on coffee cupping scores, with changes in temperature and precipitation patterns potentially leading to alterations in the biochemical composition and sensory characteristics of coffee, ultimately affecting the overall quality of brewed coffee.

3.2. The Effects of Climate Change on Coffee Bean Biochemistry

Climate change has had a significant impact on the biochemistry of coffee plants, particularly on the production and quality of coffee beans. Changes in temperature, rainfall patterns, and humidity levels alter the biochemical processes within the coffee plant, affecting the chemical composition of the coffee beans.

The increase in temperature and drought conditions caused by climate change have led to changes in the photosynthetic process of coffee plants, resulting in reduced chlorophyll production and lower levels of amino acids and proteins in coffee beans [16]. Furthermore, elevated temperatures increased the metabolic rate of the plant, leading to higher respiration rates. As a result, plants consume more energy and resources, which can reduce the yield and quality of coffee beans [13].

Changes in the rainfall patterns and humidity levels also affect the biochemistry of coffee plants. Excessive rainfall can lead to increased fungal and bacterial diseases, affecting plant metabolism and reducing the production of organic acids and sugars in coffee beans [13]. However, drought conditions can lead to the accumulation of toxic compounds in coffee beans, reducing the quality and flavor of coffee [6].

Climate change can also affect the chemical composition of coffee beans, including their aroma, taste, and acidity. For example, an increase in temperature can reduce the acidity of coffee beans, resulting in a less desirable flavor [16]. Furthermore, changes in rainfall and humidity can affect the concentration of volatile compounds responsible for the aroma of coffee, leading to changes in coffee quality [13].

Overall, the effects of climate change on coffee biochemistry and coffee bean quality were significant and varied by region. Coffee farmers in different regions face unique challenges related to climate change, such as drought, pests, and diseases, which affect the biochemistry of coffee plants and quality of coffee beans. These challenges could have severe implications not only for coffee farmers but also for coffee consumers worldwide.

3.2.1. Impact of Temperature and Rainfall Patterns on Coffee Biochemical Composition

The impact of temperature and rainfall patterns on the biochemical content of coffee is significant and can affect the

chemical composition of coffee beans, which can have implications for coffee quality and flavor. Changes in temperature and precipitation caused by climate change can affect photosynthesis, metabolism, and biochemical pathways, leading to changes in the chemical composition of coffee beans.

Higher temperatures can reduce the levels of chlorophyll, amino acids, and proteins in coffee beans, which can affect their quality and flavor [13]. Moreover, elevated temperatures can increase respiration rates, which can reduce yield and affect metabolic processes in coffee plants [6]. On the other hand, lower temperatures can slow down the metabolic processes in coffee plants, leading to delayed maturation of coffee cherries and affecting sugar and organic acid contents in coffee beans [13].

Changes in rainfall patterns can also affect the chemical composition of the coffee beans. Excessive rainfall can lead to the accumulation of toxic compounds in coffee beans, which can affect their quality and flavor [6]. Furthermore, changes in rainfall patterns can affect the concentrations of volatile compounds responsible for coffee aroma [13].

In addition, the interaction between temperature and rainfall patterns can affect the chemical composition of the coffee beans. For example, drought conditions followed by heavy rainfall can lead to the formation of mycotoxins in coffee beans, which have implications for human health [16].

Overall, the impact of temperature and rainfall patterns on the biochemical content of coffee is significant and varies depending on the region. Coffee farmers in different regions face unique challenges related to temperature and rainfall patterns, which can affect the chemical composition and quality of coffee beans.

3.2.2. Effects of Drought and Water Stress on Coffee Biochemical Composition

Drought and water stress are significant challenges for coffee production, particularly in regions that rely on rainfall for irrigation. These conditions can affect the biochemical contents of coffee plants and lead to changes in the chemical composition of coffee beans, thereby affecting their quality and flavor.

Drought conditions can lead to a reduction in the availability of water and nutrients, which can affect photosynthesis in coffee plants [6]. This can lead to a reduction in chlorophyll, amino acids, and proteins levels in coffee beans, which can affect their quality and flavor [12]. Furthermore, water stress can lead to a reduction in the growth and development of coffee plants, thereby affecting their metabolic processes and reducing yields [16].

Water stress can also affect the chemical composition of coffee beans. For example, it can lead to the accumulation of toxic compounds such as methylxanthines, which can affect the quality and flavor of coffee [13]. Furthermore, water stress can affect the concentration of volatile compounds responsible for coffee aroma, leading to changes in the coffee quality [6].

The impact of drought and water stress on the biochemical content of coffee can vary depending on the severity and

duration of the conditions, as well as the coffee variety and growing conditions. However, these conditions have significant implications for coffee farmers and the coffee industry as a whole.

In response to these challenges, coffee farmers in different regions have implemented various strategies to manage water resources, such as using drip irrigation systems, intercropping with shade trees, and selecting coffee varieties that are more drought-resistant [16]. These strategies can help mitigate the impact of drought and water stress on coffee production and maintain the quality and flavor of the coffee.

3.2.3. Influence of Carbon Dioxide Levels on Coffee Biochemical Compositions

Several studies have investigated the impact of carbon dioxide (CO₂) levels on the biochemical composition and quality of coffee. Elevated levels of CO₂, which are predicted to occur because of climate change, have been found to affect the chemical composition of coffee beans, ultimately affecting the quality of the coffee produced.

One study conducted by DaMatta et al. [7] found that exposure to elevated levels of CO₂ led to changes in the biochemical composition of coffee beans, including alterations in amino acids, organic acids, and sugars. This study also found that these changes had significant effects on the sensory quality of the coffee produced.

Another study by Martins et al. [15] investigated the impact of elevated CO₂ levels on the volatile compounds in coffee beans. The study found that exposure to high levels of CO₂ led to changes in the volatile composition of beans, resulting in altered sensory characteristics of the coffee produced.

Overall, these studies suggest that elevated CO₂ levels can have a significant impact on the biochemical composition and quality of coffee. As climate change continues to affect global CO₂ levels, it is important for coffee growers and producers to consider the potential impacts of these changes on their crops and products.

4. Mitigation Strategies for Climate Change Impacts on Coffee Quality

Climate change is expected to have a significant impact on coffee quality and production, and adaptation strategies are necessary to mitigate this impact. Several studies have investigated the potential adaptation strategies for coffee farmers facing the effects of climate change.

One adaptation strategy is the use of shade trees in coffee agroforestry systems, which can help mitigate the effects of high temperatures and low soil moisture caused by climate change [21]. Other strategies include the use of drought-tolerant coffee varieties and improved irrigation techniques [22].

Another strategy is to improve post-harvest coffee processing methods to maintain coffee quality despite changes in climate conditions. This includes improving the drying methods and storage conditions to prevent mold growth and maintain optimal moisture levels [4].

In addition, coffee farmers can adapt to climate change by diversifying their crops and income sources, such as by growing other types of crops or engaging in other livelihood activities [18].

Overall, these adaptation strategies can help coffee farmers mitigate the impacts of climate change on coffee quality and production, and ensure the sustainability of the coffee industry in the face of changing climate conditions.

4.1. Breeding and Genetic Engineering Approaches to Improve Coffee Quality

Breeding and genetic engineering can be used to improve coffee quality and mitigate the impact of climate change on coffee production. Several studies have investigated the use of these approaches to develop coffee varieties that are resilient to changes in temperature and precipitation patterns.

One approach is to use traditional breeding techniques to develop coffee varieties that are more drought-tolerant or have a higher yield under changing climatic conditions [2]. Another approach involves the use of genetic engineering to introduce genes that confer drought tolerance or resistance to pests and diseases [3].

Genetic engineering can also be used to modify the biochemical composition of coffee beans to improve flavor and aroma profiles. For example, genes involved in the synthesis of aromatic compounds can be targeted to enhance the aroma of coffee beans [19].

However, the use of genetic engineering in coffee breeding remains a controversial topic, and more research is needed to ensure the safety and efficacy of genetically modified coffee varieties.

Overall, breeding and genetic engineering approaches have the potential to improve coffee quality and mitigate the effects of climate change on coffee production. It is important to ensure that these approaches are sustainable, safe, and socially acceptable.

4.2. Innovative Post-Harvest Processing Techniques to Improve Coffee Quality

Innovative post-harvest processing techniques can improve coffee quality by preserving the biochemical composition of coffee beans and enhancing their flavor and aroma profiles. Several studies have investigated the use of these techniques to improve coffee quality and mitigate the impacts of climate change on coffee production.

One technique is controlled fermentation during the post-harvest processing of coffee beans, which can improve the uniformity and consistency of coffee flavor and aroma [4]. Another technique involves the use of controlled drying methods that reduce the risk of mold growth and maintain optimal moisture levels [17].

In addition, new technologies such as the electronic nose and tongue can be used to monitor the chemical and sensory characteristics of coffee during processing, allowing for more precise control over processing parameters and ultimately improving coffee quality [19].

Overall, innovative post-harvest processing techniques can improve coffee quality by enhancing its sensory characteristics and ensuring the preservation of its biochemical composition. These techniques can also help coffee farmers adapt to changing climatic conditions and ensure the sustainability of the coffee industry.

5. Conclusion

In conclusion, it can be asserted that coffee plays a pivotal role as a vital cash crop in more than 60 nations, thereby supporting the livelihoods of countless individuals. The quality of coffee is determined by the biochemical composition of the coffee beans, a composition that is greatly influenced by various environmental factors such as temperature and precipitation. Given the ongoing impact of climate change on coffee production, it is anticipated that there will be a significant effect on both the quality and production of coffee, particularly the esteemed arabica variety. Consequently, it becomes paramount to comprehend the ramifications of climate change on coffee quality and biochemical composition, as this knowledge is essential for the formulation of adaptation strategies that will ensure the sustainability of the coffee industry. These strategies encompass a range of approaches, including breeding and genetic engineering, innovative techniques for post-harvest processing, and the development of adaptation strategies specifically designed for coffee farmers, all of which can effectively mitigate the detrimental effects of climate change on coffee quality and production. However, it should be noted that further research is necessary to identify and create novel solutions to the challenges confronted by the coffee industry in the face of climate change. Ultimately, it is crucial to devise and implement strategies that are socially acceptable, environmentally sustainable, and economically viable, in order to secure the continued sustainability of coffee production and to preserve the quality of coffee within the context of a shifting climate.

6. Recommendation

Although the effects of climate change on coffee quality and production have been examined, further research is required to create novel post-harvest processing methods, new coffee types, and effective pest and disease control measures. Furthermore, research ought to be done on how climate change affects the nutritional content of coffee as well as the socioeconomic effects on the communities that grow coffee. The objective is to create economically feasible, environmentally sound, and socially acceptable adaptation plans in order to preserve coffee quality and assure the sustainability of coffee production in the face of climate change. To do this, cooperation between academics, coffee growers, businesses, and legislators is required.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Aerts, R., et al. (2018). Global impacts of climate change on coffee farming. *Review of Agricultural, Food and Environmental Studies*, 99(3-4), 335-340.
- [2] Avelino, J., Cristancho, M., Georgiou, S., Imbach, P., Aguilar, L., Bornemann, G.,... & Läderach, P. (2015). Coffee rust crises in Colombia and Central America (2008-2013): impacts, plausible causes, and proposed solutions. *Food Security*, 7(2), 303-321.
- [3] Bertrand, B., Guyot, R., & Guiraud, J. P. (2018). Overview of recent advances and future prospects in coffee breeding. To achieve the sustainable cultivation of coffee (pp. 1-28). Burleigh: Dodds Science Publishing.
- [4] Bote, A. A., Kifle, M. H. & Tsegaye, W. A. (2019). Effects of climate variability and changes on coffee quality: a review. *Agricultural and Forest Meteorology*, 265, 1-12.
- [5] Bunn, C., derach, P., Rivera, O. O., Kirschke, D., Romero, J. J. & Vides, A. (2015). A bitter cup: Climate change profile of global production of Arabica and Robusta coffee. *Climatic Change*, 129(1-2), 89-101.
- [6] DaMatta, F. M. (2004). Ecophysiological constraints on the production of shaded and unshaded coffee: a review. *Field Crops Research*, 86(2-3), 99-114.
- [7] DaMatta, F. M., and Cunha, R. L., Antunes, W. C., Martins, S. C. V., Sanglard, L. M. V. P. & Loureiro, M. E. (2010). Impact of climate change on crop physiology and food quality. *Food Research International*, 43(7), 1814-1823.
- [8] Farah A (2012). Coffee constituents. In *Coffee: Emerging Health Effects and Disease Prevention* (pp. 1-26). John Wiley & Sons.
- [9] ICO. (2021). Coffee Market Report. Retrieved from [<https://www.ico.org/documents/cy2020-21/cmr-0321-e.pdf>]
- [10] Illy, A., & Viani, R. (2005). Espresso coffee: Science and quality. Academic Press.
- [11] Jaramillo, J., Muchugu, E., Vega, F. E., Davis, A., & Borgemeister, C. (2011). Coffee and climate change. *Conservation Biology*, 25(6), 1117-1125.
- [12] Jaramillo, J., Setamou, M., Muchugu, E., Chabi-Olaye, A., & Jaramillo, A. (2011). Impact of climate change on coffee production *Climatic Change*, 109(1-2), 267-280.
- [13] Jaramillo, J., Muchugu, E., Vega, F. E., Davis, A., & Borgemeister, C. (2009). Some like it hot: The influence and implications of climate change on coffee berry borers (*Hypothenemus hampei*) and Coffee Production in East Africa. *PLoS ONE*, 4(8), e6807.
- [14] Kleinwächter, M., Selmar, D., & Buedenbender, L. (2017). Climate change might affect coffee taste: the impact of expected shifts in growing areas on sensory profiles and implications for coffee value chains. *PLoS One*, 12(12), e0187835.
- [15] Martins, L. D., Vieira, H. D., and DaMatta, F. M. (2014). Elevated CO₂ concentration alters the chemical and sensory profiles of coffee beans. *Food Chemistry*, 145, 398-404.
- [16] Mehari, Z. H., Asfaw, Z., & Gebrehiwot, K. (2019). Impacts of Climate Change on Coffee (*Coffea arabica* L.) Diseases and their management: A review. *International Journal of Agronomy*, 2019, 1-13.
- [17] Oliveira, L. S., Queiroz, V. T., Araújo, A. M., & Gomes, J. P. (2018). The impact of processing methods on the sensory quality of coffee. *Journal of Food Quality*, 2018, 1-10.
- [18] Ovalle-Rivera, O., Läderach, P., Bunn, C., Obersteiner, M., Schroth, G., & Castro, N. (2015). A survey of the potential impacts of climate change on coffee production and land use in Mesoamerica. *Climatic Change*, 129(1-2), 131-142.
- [19] Rodrigues, W. P., Martins, M. Q., Fortunato, A. S., Rodrigues, A. P., Semedo, J. N., Simões-Costa, M. C.,... & Pais, I. P. (2019). Improving coffee through biotechnology: Current status and prospects. In *Plant Biotechnology for the Sustainable Production of Energy and Co-Products* (pp. 329-350). Springer, Cham.
- [20] Schroth, G., et al. (2016). Towards a climate change adaptation strategy for coffee communities and ecosystems in Sierra Madre de Chiapas, Mexico. *Mitigation and Adaptation Strategies for Global Change*, 21(8), 1261-1277.
- [21] Schroth, G., Läderach, P., Dempewolf, J., Philpott, S., Haggard, J., Eakin, H.,... & Martinez-Valle, A. (2020). Towards a climate smart coffee agriculture: the case of Mesoamerica. *Climatic Change*, 158(1), 1-23.
- [22] Vaast, P., Bunn, C., Jassogne, L., Van Asten, P., & Läderach, P. (2016). Current understanding and research priorities in coffee agroforestry systems. In *Agroforestry for Sustainable Agriculture* (pp. 169-193). Springer, Cham.