International Journal of Research Studies in Science, Engineering and Technology
Volume 7, Issue 8, 2020, PP 31-38
ISSN 2349-476X

Impact of Climate Change on production and Diversity of Coffee (Coffea Arabica L) in Ethiopia

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ABSTRACT

Coffee belongs to the genus Coffea in the Rubiaceae family and mostly grown in the tropical and subtropical regions. As known Ethiopia is one of the birthplaces of coffee arabica (Coffea arabica L.) and gifted by diverse genetic reserves in the mountain rainforests of southwest and south east of the country. In most coffee producing part of the country, the production and diversity of arabica coffee are under serious threat, largely due to clime change, increasing population pressures, replacement of landraces by chat, a few high yielding and diseases resistant improved coffee varieties, subsequent deforestation and lan d degradation. The change in climate condition also disturbs rainfall amount, distribution, and changes in dynamics of crop diseases and pests, which cause reduction of agricultural production and diversity of arbic a coffee. The combined effects of this phenomenon have critical impacts on coffee genetic diversity and prod uction of arabica coffee. Based on different research findings were reviewed, different mechanism of agrono mic practices mightbe applicable to withstand the impact of climatic change on production and coffee genet ic diversity. The possible remedy might used to overcome the problems is use of shade trees and reforestation, genetic improvement, coffee Banana intercropping and other conservation practices are the critical ones.

Keywords: *Impact of Climate Change, Temperature, Rain fall, Pest infestation, Disease out break*

INTRODUCTION

Coffee belongs to the genus *Coffea* in the *Rubiaceae* family and mostly grown in the tropical and subtropical regions. The two main s pecies used in the production are, Arabica coffee (*Coffea arabica L.)* and Robusta coffee (*C. can ephora Pierre ex A. Froehne*r) although, the for mer is indisputably the most significant and pro viding approximately 70% of commercial produ ction (FAO, 2008; USDA, 2012). *Coffea* (*Eucoff ea*) and *Mascarocoffea* subdivided from genus *C offea* (Charrier and Berthaud 1985) and the form er economically the most important (Wellman, 1 961), which comprises more than 124 species (Davis et al., 2011). Is the only allopolyploid (2n = 4x = 44) coffee species and approximately abo ve 95% of arabica coffee is self fertile (Veddeler et al., 2008).

Coffee is one of the most important cultivated crops around the world. It is economically the second most exported commodity after crud e oil, and employs over100 million people world wide (Gray et al. 2013; Esquivel, P. and Jimenez , V.M., 2012). Global estimated production of a rabica coffee 170.56 millions of 60-kg bags and that of African country is estimated 18.67 millio ns of 60-kg bags; however, out of Global estima ted production C. arabica and Robusta coffee pr oduction share irrespective values of 100.29 mill ions of 60 kg bags and 70.27 millions of 60-kg bags (ICO, 2019). Ethiopian has the estimated to tal coffee production area of 764,863.16 ha and i ts production estimated around 8.2 millions of 6 0 kg bags while, the national average yield for arabica coffee is 647 kg/ha (CSA, 2018).

The production (yield) and the diversity of C.ara bica are strongly associated to climatic variabilit y, and thus strongly influenced by natural climat ic fluctuations (Camargo MBP, 2010). However, as reported by Esser, (2015) Climate change is affecting the world coffee cultivation, the destruction of natural coffee habitats coupled with changes in weather patterns can adversely affect coffee genetic resources and the livelihoods of millions of people in Ethiopia and elsewhere. This because of, coffee is growing in more than 70 countries across the tropics and the gross value of production of green coffee now exceeds US$16 billion, and its export value reached US$24 billion (FAO, 2015).

Even if, the market demand for coffee is still rising the climate change and emerging pest and diseases also posing important challenges to global coffee productivity (Bunn et al., 2015) and there has been dramatic forest loss (Moat et al., 2017). In addition, gene pool is under seriou s threat mainly because of deforestation of its natural habitat for timber and food crop production and replacement of landraces by a few high yielding and diseases resistant improved varieties (Yigzaw, 2005). Accordingly, the objective of this topic is to review impact of climatic change on production and diversity of arabica coffee.

Influence of Climate on Production and Genetic Diversity

As indicated by many findings climatic change is adversely affect coffee genetic diversity and production through time. Changes in climate also, affect biodiversity at the species and ecosystem level, and further changes in biodiversity are inevitable with further changes in climate (Secretariat of the Convention on Biological (Diversity, 2009). The productivity C. arabica is robustly associated with climatic variability, and thus strongly influenced by natural climatic fluctuations (Camargo, 2010). As stated by, Davis (2012) that the profoundly negative trend for the future distribution of indigenous C. arabica would be 65% reduction in the number of bio climatically suitable localities, and at worst (scenarios of almost 100% reduction, by the year 2080 under the influence of accelerated global climate change).

Climate change is predicted to increase mean te mperatures and change precipitation regimes as a result, traditional coffee growing regions may disappear and new regions may appear (Laderach et al., 2010). The relationships between the climatic parameters and coffee production are quite complex, because it affect the growth and development of the plants at different growth stages (Camargo, 2010).

In Ethiopia, JAR was as old as center for coffee collection and maintenance programs. Since, at Jimma-Melko & Gera coffee maintenance/conservation activity was started with national & CBD selection programs, whereas in other sites, the collection has been maintained in seven Ex-situ sites (Fekadu, 2008). Currently from 1996-2015, the collected accessions were reached around 6923 accessions (Desalegn and Wakuma, 2017). However, it was facing to genetic erosion because of Climate change (temperature rice), deforestation, crop replacement, disease etc.

Table1. *Summary of indigenous and exotic collections from 1996-2015/16 by JARC*

Type of Collection	Year of Collection	No. of Collected Accession (Original)	No. of Alive Accession	Number of Lost Accession (%)	Remark
National	1966-1990	1633	1431	12.37	Indigenous collection
CBD Resistant selection program	1973-1987	868	825	4.95	
Local Landrace Collection program	1994-2015	4232	3519	16.85	
Exotic Coffee Collection	1968-1984	190	78	58.95	Exotic collection
Total		**6923**	**5853**	**15.46**	

Source: *Desalegn and Wakuma, 2017*

Temperatures

Drought and unfavorable temperatures are the major climatic limitations for coffee production (Da Matta and Ramalho 2006). These limitations are expected to become increasingly important in several coffee growing regions due to the recognized changes in global climate and also because coffee cultivation has spread towards marginal lands, where water shortage and unfavorable temperatures constitute major constraints to coffee yield (Da Matta and Ramalho 2006; Kimemia, 2014). Because of Coffee will become increasingly stressed as the air temperature increases and soil moisture decreases (due to lack of rainfall), and vice versa. Jaramillo *et al* (2009) stated that even the smallest increases in temperature could cause extensive damage to coffee production.

The global warming caused by increase of greenhouse gas emissions (carbon dioxide and methane) in the atmosphere also causing wide changes in atmospheric events resulting to climate change. These include, shifting of optimal growing zones, changes in rainfall (amount and distribution), and changes in dynamics of crop diseases and pests, loss of agricultural land due to either rising sea levels and/or desertification (Kimemia, 2014). The combined effects of this phenomenon have critical impacts on coffee diversity and production.

Coffee arabica is indigenous to African regions characterized by abundantly distributed rainfall and atmospheric humidity frequently approaching saturation (Pinheiro et al., 2005). For this reason, coffee particularly C. arabica has categorized as a highly sensitive plant species to climatic change (Da Matta et al., 2019). Therefore, it is a highly environmentally dependent crop and an increase of a few degrees of average temperature and/or short periods of drought in coffee-growing regions can substantially decrease yields of quality coffees. Taking into account the global warming phenomena, severe reductions of adequate coffee growing areas are to be expected (Da Matta and Ramalho, 2006), thus sustainability of coffee productivity and quality may become more difficult to maintain.

Extreme temperatures, depending on their intensity, duration and speed of imposition, impair cell metabolic processes (e.g. photo synthesis), growth and survival of plants, as well as their economic exploitation (Da Matta and Ramalho, 2006). In fact, temperature may limit the successful economic exploitation of the coffee crop, in part because coffee growth is particularly affected by both high and low temperatures. The optimum mean annual temperature range for Arabica coffee is 18-21ºC (Da Matta and Ramalho, 2006) and Above 23ºC, development and ripening of fruits are accelerated, often leading to loss of quality (Camargo, 1985). Continuous exposure to temperatures as high as 30ºC could result in not only depressed growth but also in abnormalities such as yellowing of leaves and growth of tumors at the base of the stem (Da Matta and Ramalho, 2006). As indicated by Camargo, (2010) a relatively high temperature during blossoming, especially if associated with a prolonged dry season, may cause abortion of flowers. In addition, large variations in temperature also increase bean defects, modify bean biochemical composition and the final quality of the beverage (Carr, 2001; Silva et al., 2005).

Rainfall

Coffee requires suitable environmental condition. However, the average temperatures required for coffee Arabic range between 15 and 24°C, rain fall 2000 mm per annum and altitudes between 1000 and 2000 m above sea level. Robust coffee required average temperature range between 24 and 30°C, rainfall ~2,000 mm and altitudes of about 800 m above sea level (Killeen and Harper, 2016). Overall drought and unfavorable temperatures are the major climatic limitations for coffee production. These limitations are expected to become increasingly important in several coffee growing regions due to the recognized changes in global climate. Precipitation variability due to climate change results in increased irrigation water demand (Nelson et al. 2009).

Except coffee is require three months of dry season to be stay dormant, to triggering flower bud for coming cropping season. Howev er, it is more sensitive to climate variation, speci ficity during blossoming and fructification stage (Haggar and Schepp, 2011). Particularly, coffee flowering triggered by the first rainfall at the beginning of rain season, while if rain drops off or becomes too heavy, flowers and fruit may drop from the coffee tree (Läderach et al., 2010).

The unpredictable rains will make coffee to flower at various times throughout the year, making the farmers to harvest small quantities continuously (Jassogne et al., 2013). Sporadic rainfall results in random flowering, with flowers and berries at different stages of growth being on the same primary branch, flower drop and biennial bearing. The unpredictable rains will also affect coffee to flower at various times throughout the year, causing the farmers to harvest small quantities continuously. Increased drought and sunshine can induce the p remature ripening of the beans, with sufficient quality loss as well as the yield (Craparo ACW et al., 2015). This precipitation variability due to climate change results in increased irrigation water demand (Nelson et al. 2009). In addition, it affects the physiological activity of the Arabica plant causing a reduction in photosynthesis processes (Cheserek JJ et al., 2012).

Pest Infestation and Disease Outbreak

Climate variation is the most favorable for increase of coffee pest disease; the loss estimate globally is 13% of yield reduction (Agegnehu et al., 2015). Major disease that occurred because of climate variation during coffee growing will increase pest and disease prevalence, expanding the altitudinal range in which the fungal disease coffee rust and the coffee berry borer can survive (Läderach et al., 2010). For example, rising temperatures will increase infestation by the Coffee berry borer, particularly where coffee grows unshaded and the cropping is continuous throughout the year (Walyaro, 2010). Jaramillon et al. (2009) predicted that climate ch ange would worsen pest prevalence berry borer i n Eastern Africa. As Mendesil et al., (2003) also reported wide spread occurrence of the coffee berry borer in southwestern Ethiopia. Climate change increases need for fungicides and lead to resistance of certain pests and diseases on coffee (Gianessi and Williams, 2011). In the case study of Colombia and Ethiopia, an increase in rainfall and temperature threatens the coffee at an alarming rate, respectively and is more conducive, for pests and disease prevalence (Iscaro, 2014).

Loss of Suitable Land

The current areas coverage for growing of Arabica coffee may be replaced by other cash crop like Chat and food crops in the some parts of continents (Läderach et al., 2010). It is predicted that at the year 2050, 16% of the area suitable for growing of coffee can be reduced (Läderach et al., 2010). Many findings identified that because of climate change such as flood, land degradation, drought that can reduce the land suitability for coffee production (Läderach et al., 2010).

Ovalle-Rivera et al. (2015) estimated that the acreage with aptitude for growing C. arabica would be reduced for all producing countries by 2050, moving the optimal production from low altitude to areas with higher altitude. Läderach et al. (2010) and Davis et al. (2012) found similar results for Central America and Ethiopia. To meet future demand in 2050, 2.5 the area that is currently available for coffee production is required. Jassogne et al. (2013) stated the climate change mapping showed that the area suitability for C. arabica in Uganda would reduce drastically in the future. As Jassogne et al., 2013 indicates the average daily maximum and minimum temperature trends revealed an increase in temperature over the 50-year period. By 2050, it is predicted that global temperatures would increase by 2°C together with some increased seasonality of precipitation.

Laderach et al. (2011) pointed out in the case study, that coffee-producing zone in Nicaragua is currently at an altitude of elevation between 800 and 1400 masl; by 2050, the optimum elevation will increase to 1200 and 1600 masl. Additional case study in Uganda reveals if temperatures increase, areas suitable for coffee will be higher in the landscape and unfortunately, the areas that will become more suitable for coffee will compete with other crops or national nature reserves (Jassogne et al., 2013).

Increased Cost of Production

The occurrence of climate variation such as sporadic and low-intensity rains during growing phase coffee or flowering period, and towards the later-phases of flower bud development, is the main reasons for unsynchronized fruit ripening (DaMatta et al., 2008). Climate change also increasing atmospheric CO2 concentrations tend to increase the water use efficiency of C3 plants such as coffee and will tend to offset the increased evaporative demand (Schroth et al., 2009). This change makes coffee production to be under irrigated, thereby increasing pressure on scarce water resources (Kasterine et al., 2010). Harvesting often represents the majority of production costs, so if erratic flowering and ripening cycles require additional harvesting cycles, these changes could drastically and unsustainably raise costs (Läderach et al., 2010). All the above-mentioned will increase the cost of production, whereas more coffee may grow and need under irrigation (Bongase, 2017).

Reduce Coffee Production and Quality

Haggar and Schepp (2011) revealed the potential yield and quality of coffee is determined by both temperature and rainfall condition since both ability to interfere with the phonological growth of the crop. These impacts include, for example, disrupted flowering cycles and prolonged drought periods, which ultimate result in reduced coffee quantity and quality (Masters et al., 2009). Other climate variation such as soil water balance during different growth stages of the coffee crop, can affect the available soil water and decrease of the final yield (Camargo, 2010). The Arabica coffee is more sensitive to climate variation, specifically during blossoming and fructification stage (Haggar and Schepp, 2011). Especially, coffee flowering triggered by the first rainfall at the beginning of rain season, while if rain becomes too heavy, flowers and fruit may drop from the coffee tree (Läderach et al., 2010). The unpredictable rains will make coffee to flower at various times throughout the year, making the farmers to harvest small quantities continuously (Jassogne et al., 2013). This change will affect the crop physiology especially during the flowering and fruit filling stage (Ebisa et al., 2017).

Mitigation and Adaptation Strategies

Many scholars revealed climate variation is a phenomenon that will continue to cause severe or negative effect on yield throughout the world (Iscaro, 2014). To overcome this problem, mitigation of global warming involves taking actions to reduce greenhouse gas emissions to enhance sinks aimed at reducing the extent of global warming which is important (International Coffee Council, 2009). One of the limitations to understanding the impacts of climate variability on coffee production is the lack of having precise meteorological data at coffee growing areas which is important for the development of climate-based insurance (Haggar and Schepp, 2011). An ecosystem services payments scheme would be an ideal strategy synergizing the goals of emissions mitigation, biosphere preservation and poverty alleviation (Läderach et al., 2010). Improving new cultivars resistant to pests and diseases, more productive, well adapted to the local climatic and soil conditions, and have acceptable and desired quality for the market is very important. Ethiopia has a unique genetic diversity of cultivated, semi-wild and wild Arabica varieties with different types of disease resistance environmental adaptations and quality characteristics for future breeding coffee varieties opportunity that are adapted to the changed climate (Lossau, 2010 and Bongase, 2017).

Measures to adapt coffee cultivation to climate change also contribute to reducing CO2. Other environmental benefits include enhanced water storage, the regulation of local temperatures, and biodiversity conservation (Lossau, 2010). Changes in temperature and frequency of rains are associated positively and significantly with a higher probability to implement at least one adaptation strategy to climate change (Zuluaga et al., 2015). As climate change becomes increasingly severe, an assessment of coffee producers' ability and willingness to adapt would-be especially valuable to those hoping to create adaptation strategies and policies (Battiste et al., 2016). Good management practices that reduce soil erosion (e.g. cover crops and contour bunds) and increase water retention (mulching, shade) will further help farmers adapt to climate change and retain the more fertile topsoil (Jassogne et al., 2013). Scientists seem to agree that the best way to preserve A. coffee is with shade trees (Jaramillo et al., 2009). Shade trees planted near coffee plants have the ability to block out the sun's impact on the plants. They create lower temperature, reduce up to 4°C better suited for Arabica coffee plants.

Intercropping

Intercropping coffee with bananas potentially contributes to climate change adaptation through increasing the appropriate microclimate for coffee growing. The dual advantages of bananas include provision of shade, controlling stomata closure during extreme water deficit and reducing transpiration, which allows banana to remain highly hydrated under drought stress. Banana intercropping is more advantageous so that the banana plant competes less with the coffee plant for water than some other shade trees (GACSA, 2015). Banana shade reduces the air temperature in the coffee canopy by over 2°C. Coffee grown under banana shade generally produces heavier and larger cherries due to reduction of overbearing, and buffering against biennial fluctuations in coffee yields and the taste of processes product is therefore better, and farmers can earn a higher price (GACSA, 2015).

Other Conservation Practices

Mulching with different grass species and crop residues potentially provide both nutrients, soil moisture and reduce evaporation. Cover crops planting in similar manner also improve soil moisture availability, nutrient enhancement and serve as shade tree (Asten, et al., 2012). Rain harvesting is one of important mechanism to cope with water deficiency (drought season) thereby to apply as irrigation. Conserve all the rainy water by forking, digging terraces and mulching which also prevents soil erosion before coffee establishment (Youkhana A and, Idol T 2010).

Challenges and Future Prospects

The reduction of suitable land growth due to shifting of the area of adaptation recommended for coffee arabica varieties so far released is one of challenge for future breeding program. In addition, emerging abiotic stress, increased temperature, changes in dynamics of diseases and pests attacking, change in rainfall in terms of amount etc, due to prevailing climate change are among the major challenges of the breeding program (Benti, T, 2017).

As future Prospects As sited by, Abraham A. and Ebisa (2017), Coffee, (*Coffea arabica)* planting under shade is the most important for both quality improvement and maintaining sustainable production. The screening of coffee using molecular technique for adaptation of coffee plants to drought to get drought resistance trait. Further efforts on improvement activities on developing resistance variety are quite crucial to have sustainable and effective coffee production. Conservation of available coffee genetic diversity before the advance of deforestation, the identification and protection of more in-situ conservation site and systematic collection that cover all coffee growing areas of Ethiopia should continue to reduce loss of genetic diversity (Desalegn A. and Wakuma M, 2017). In general, climate change can be mitigated by integrating multidisciplinary approach to overcome impacts of climate change on arabica coffee.

Conclusion

Climate change has emerged in recent years as one of the most critical topics. It is predicted that rising temperatures and water shortages will negatively affect coffee production and genetic variability at lower elevations and vice versa. The already perceived and the future predicted impacts of climate change on coffee genetic diversity and production will not only be threat small-scale farmers but researchers and all actors involved in coffee industry including consumers. World population will rise to nine billion by 2050. In this scenario, coffee production is also likely to decrease globally, particularly in Africa. Coffee price varies inversely with production changing and generating the largest price increase. Only half the area will currently available for coffee production by 2050 G.C. 2.5-times of the current area will be needed to be meet the future demand. Reduced yields and increased prices were shown to reduce the coffee market by more than 5 million tons per year. Because of the above reason, many authors believe that the area with aptitude for growing coffee would be reduced by 16% by 2050, especially for coffee Arabica. Mitigation of global warming involves taking actions to reduce greenhouse gas emissions and to enhance sinks aimed at reducing the extent of global warming measures to adapt to coffee cultivation to climate change also contributing to reducing CO_2. Other environmental benefits include enhanced water storage, the regulation of local temperatures, and biodiversity conservation. Improved agronomy and sustainable management of resources including the use of drought and heat resistant varieties, irrigation, and shade cover are good first steps.

Many researchers concluded that the fluctuation of climate in the coffee growing area resulted in reduction in the yield and quality, increasing the outbreak of pest disease, increasing cost of production and reduced area of production. The consequence of the problem may make the coffee sector to have negative impact on the producers and consumers. Generally, further research will be focused on discovering climate change adaptation strategies feasible for smallholder producers for practically implement.

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Citation: *Abaynesh Asegid "Impact of Climate Change on production and Diversity of Coffee (Coffea Arabica L) in Ethiopia" International Journal of Research Studies in Science, Engineering and Technology, 7(8), 2020, pp. 31-38.*