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# Climate Hazards and the Changing World of Coffee Pests and Diseases in Sub-Saharan Africa

**B. A. Ogundeji[1*], M. A. Olalekan-Adeniran[1], O. A. Orimogunje[1], S. O. Awoyemi[2], B. A. Yekini[3], G. A. Adewoye[1] and I. A. Bankole[2]**

*[1]Cocoa Research Institute of Nigeria, P.M.B.5244, Ibadan, Nigeria.*
*[2]Federal College of Agriculture, Akure, Nigeria.*
*[3]Federal College of Agriculture, Ishiagu, Ebonyi State, Nigeria.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. Author BAO designed the study. Authors BAO and MAO wrote the first draft of the manuscript. Authors OAO, SOA, BAY, GAA and IAB managed the final draft. All authors read and approved the final manuscript.*

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## ABSTRACT

Coffee has over the years remained of great importance to the global economy. Although the crop originated from Africa, its production is presently dominated by Brazil and Vietnam, which now respectively account for 34 and 13% of global production. Ethiopia and Uganda which are at the fore-front of production within sub-Saharan Africa account for 62% of the region's coffee output. Out of the many species of coffee that exist, *C. arabica* (Arabica coffee) and *C. canephora* (Robusta coffee) are of outstanding economic importance. While the former does well on high altitudes (1000-2000 m above sea level), average temperature ranges of between 15 and 24°C, and 2000 mm rainfall per annum, the latter, which can thrive under hotter, drier conditions can be grown on altitudes of about 800 m above sea level. Generally speaking, optimal coffee-growing conditions include cool to warm tropical climates, rich soils, and few pests or diseases. Each of the grown species however does well under specific environmental conditions. The constantly increasing environmental temperatures, coupled with accompanying variations in weather conditions, have

**Corresponding author: E-mail: tundeji1@gmail.com;*

some direct debilitating effects on coffee production and quality. Pests and pathogens, being able to tolerate a wide range of temperature, have the capabilities to proliferate and negatively influence the crop's yield, quality and production cost. In view of the the highlighted problems, some mitigation strategies have been developed by researchers to limit the extent of damage caused by global warming on coffee production in the region. Chief among these include genetic improvement/development of resistant cultivars, reforestation (planting under shade), high-density planting/irrigation, integrated pest management, improved access to climate information and reduction of green house gas emissions. These, among others would enhance the quantity and quality of coffee produced and consequently boost the region's economy.

*Keywords: Coffee; Sub-Saharan Africa; pests; diseases; climate; mitigation.*

## 1. INTRODUCTION

The coffee tree belongs to the Rubiaceae family and genus *Coffea.* The genus *Coffea* is native to tropical Africa (specifically having its origin in Ethiopia and Sudan), Madagascar, the Comoros, Mauritius and Réunion in the Indian Ocean [1]. Seeds (beans) of coffee berries are roasted and brewed to prepare coffee drink. They are a major cash crop and an important export product, accounting for over 50% of some developing nations' foreign exchange earnings [2].

Coffee is one of the legal internationally traded commodities of many countries following petroleum oil. Consumers from all around purchase and enjoy it in their daily activities [3]. In addition, Davis, et al. [4] identified during their study, that coffee is the second most transacted goods in the world, with Brazil being the leading producer and exporter, followed by Vietnam and Colombia [5].

Although more than 80 coffee species have been identified worldwide, over 60 tropical and subtropical countries produce and export coffee, being for some of them the main agricultural export commodity [6]. While over 100 million people derive their livelihood from coffee globally [7]. The global coffee production depends economically on only two species, *Coffea arabica* (which is higher yielding and native to Ethiopia, Sudan and parts of Kenya) and *C. canephora,* which is native to western and central sub-Saharan Africa [8,9]. Arabica or highland coffee (*C. arabica*) accounts for 60–80% of the world coffee production and *C. canephora* widely referred to as Robusta coffee accounts for the rest. Coffee is the leading global beverage after water and its trade exceeds US$ 10 billion worldwide [3,10].

Although coffee originated from Africa, its production outside the continent had significantly increased over the years with the largest producers (Brazil and Vietnam) now accounting for 34% and 13% of world production, respectively). In terms of acreage, coffee production in Vietnam ranks 5th in the world. Africa produces only 11% of the world's coffee on 19% of its area. Ethiopia and Uganda which dominate the region's coffee production, together account for 62% of sub-Saharan Africa's coffee output. Ivory Coast is West Africa's largest producer, and the third largest in sub-Saharan Africa [11,12,13].

Except for Ethiopia which consumes 40% of its coffee production, large producers export nearly all their coffee. In Uganda and Ethiopia, coffee constitutes 21% of the export value of agricultural products. In the Cote d'Ivoire, coffee exports only make up 1.5% of agricultural trade; here cocoa has taken the place of coffee. Coffee cultivation is often tainted in controversy as farmers increasingly abandon traditional shade-coffee in favor of sun cultivation, a more industrial approach. While full sun causes bushes to produce more berries and speeds up berry ripening, it requires the clearing of forests, larger volumes of water, higher inputs of fertilizers and pesticides, and it decreases biodiversity [14].

Coffee is grown mostly in sub-Saharan African countries by smallholder farmers as a cash crop, while the production system employs millions of people in the region. Most of the countries export coffee, which contributes significantly to national foreign exchange earnings [15,16].

## 2. ENVIRONMENTAL REQUIREMENTS OF COFFEE

Coffee is a tropical plant which grows between the latitudes of 25ºN and 25ºS but requires very specific environmental conditions for commercial cultivation. Sequence of weather events like temperature, rainfall, sunlight, wind and soils are

all important to coffee production, but requirements vary according to the varieties grown. The crop is a perennial crop that can grow under both humid lowlands and tropical humid/sub-humid highlands. Arabica coffee does best at higher altitudes and is often grown in hilly areas. Average temperature required for coffee Arabica ranges between 15 and 24ºC (59 and 75ºF), rainfall, 2000 mm per annum and altitudes between 1000 and 2000m above sea level [16].

Ideal climatic conditions for Arabica coffee include, a dry period of three months (to stress trees in order for them to flower well, but not too long of a dry spell, or trees will become weak), a good soaking to initiate flowering (but not continuous rain, as this will affect the fruit set), not too high a temperature (which can cause a range of physiological problems, including flower abortion), regular rainfall throughout the berry development stage, a drier period coming up to harvest and a dry period around harvest to facilitate picking and sun drying (this would be the ideal situation, but is not the case for all coffee production countries) [17].

Alteration in precipitation patterns, temperature, storms, strong winds and other extreme weather events directly impact coffee quality and productivity levels. Above the required moderate temperatures, fruit development and ripening in Arabica coffee accelerate. Faster ripening might not sound bad, but it actually degrades coffee bean quality. Continuous exposure to temperatures up to and just over 30ºC can severely damage coffee plants, stunting growth, yellowing leaves, even spawning stem tumors. These potentially damaging hydro-meteorological events or phenomena are called Climate Hazards [11,17].

Robusta coffee which can take hotter, drier conditions but does not tolerate temperatures much below 15ºC, as Arabica can for short periods, require average temperature range between 24 and 30ºC (75–86ºF), rainfall 2,000 mm per year and can be grown between sea level and altitudes of about 800 m above sea level [18].Heavy rain is needed in the beginning of the season when the fruit is developing and less, later in the season as it ripens [19].

In general, coffee needs an annual rainfall of 1500 to 3000 mm, Arabica needing less than other species. Optimal coffee-growing conditions include cool to warm tropical climates, rich soils, and few pests or diseases. If earth's climate continues to warm over the coming decades, obstacles to coffee cultivation will multiply. The pattern of rainy and dry periods is important for growth, budding and flowering. Rainfall requirements depend on the retention properties of the soil, atmospheric humidity and cloud cover, as well as cultivation practices. All coffee needs good drainage, but it can grow on soils of different depths, pH and mineral contents, given suitable applications of fertilizer [19].

Because of the importance of coffee to the rural economies of so many tropical countries, the latest IPCC report explored the potential impacts of a warming climate on coffee production in the Americas and Africa. The scientists forecast varying impacts in different Brazilian states: in Parana, a 10% reduction in suitable growing area; in Minas Gerais and Sao Paulo (the main coffee-growing States), a drop in suitable cropland from 70–75% to 20–25% of total land area; in Goias, coffee production would no longer be possible. Newly suitable areas would emerge in Santa Catarina and Rio Grande do Sul, but these new areas would only partly offset losses elsewhere. Across the Atlantic, Kenyan coffee production could also face serious setbacks, with minimum altitude rising from 3,300 to 4,600 feet above sea level. Kenya could lose suitable cultivation lands in its eastern and (especially) western highlands.

## 3. LIFE CYCLE OF COFFEE

Of great importance is the general life cycle of a coffee tree and its berries. Coffee trees take approximately three years to mature and produce good quality fruit. The trees usually start out as seedlings in a tree farm, and once they have reached a certain height, are transferred to a coffee plantation. Each year, the coffee tree starts to flower after a period of rainfall followed by a dry spell. The flowering is a physiological response to water limitation. After the tree flowers, it takes approximately 6-9 months for the coffee berries to mature. The berries first start out as green, then become red as they mature. Not every tree matures uniformly, and therefore hand picking the berries is sometimes preferred in order to sort the ripe from unripe coffee berries. This ensures the highest quality of coffee. The coffee berry is the whole fruit, but that is not what we roast and grind to get our coffee. The coffee fruit has a skin, pulp, and

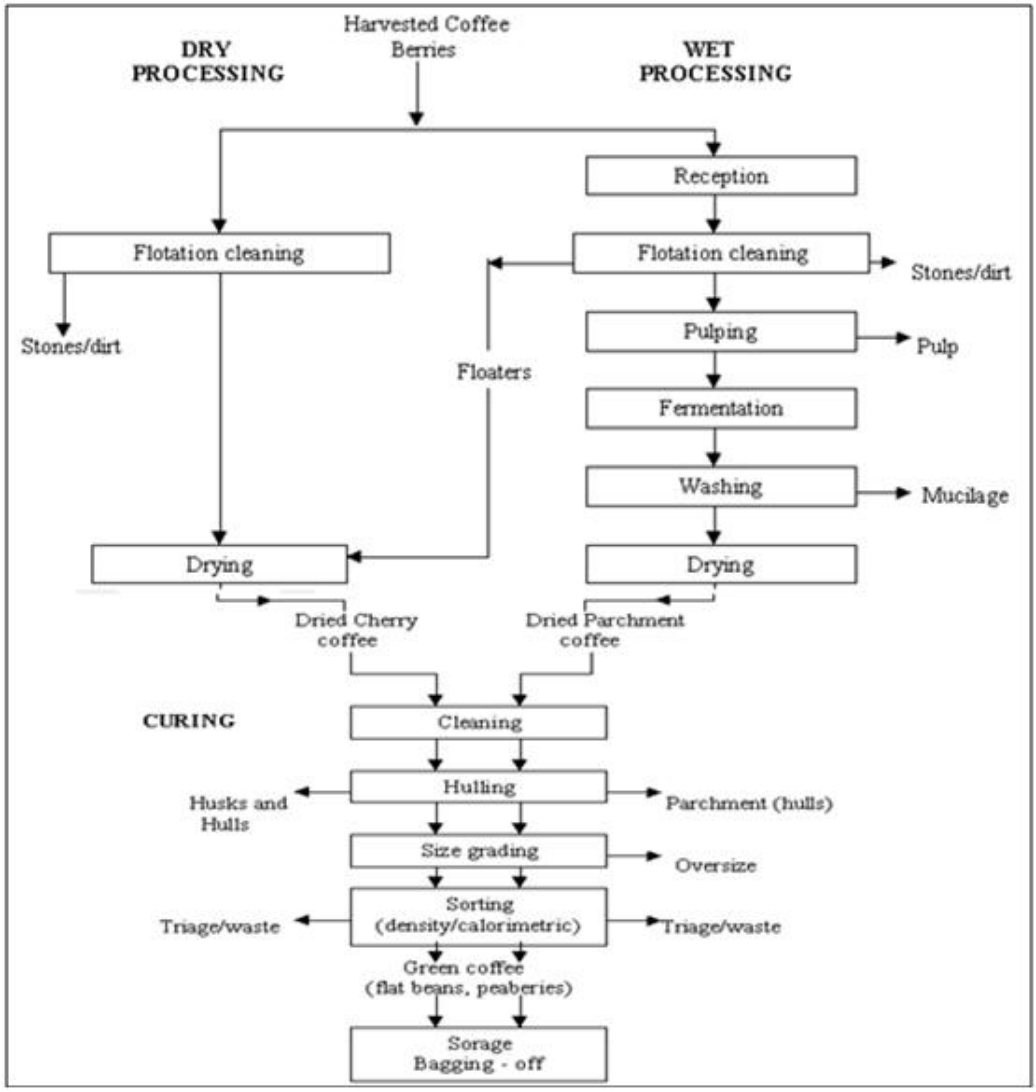


**Fig. 1. Stages of wet and dry processing of coffee**

parchment that cover the seed of the coffee. Inside the fruit are two seeds, which is what we make our coffee out of. After the coffee berries are picked, the outer skin and pulp is removed with a machine called a depulper. The seeds are then placed in a tub of water to ferment and remove any excess skin and pulp. Once the seeds have undergone fermentation, the coffee is washed and then put out under the sun to dry, where the beans are rotated frequently to ensure even drying of each seed/bean. After this, the beans are ready to be exported as it is or roasted (Fig. 1) [15].

From the life cycle of coffee trees and the processing of the coffee beans, it is evident that environmental temperature, humidity, rainfall and sunshine are important in all parts of coffee growing, harvesting, and processing. For example, coffee berries are also sensitive to sunlight, and often have shade trees planted in order to provide the required amount of sunlight to reach the berries. These environmental factors also affect the pests and diseases that can destroy coffee crops [20,21].

## 4. COFFEE PESTS AND DISEASES

As the case is with some other perennial crops, coffee plant's health, nutrition, growth/development, yield, as well as physical and chemical product qualities are negatively affected by a wide range of insects, pests, and diseases. Major insect pests affecting coffee

plant include black twig borer and coffee berry borer. The former causes wilting and yellowing of foliage, often at the end of twigs and branches, while the latter makes small holes on red cherries and forms a brown or grey deposit on top of the hole, and eventually resulting in fruit dropping from plants [22].

Most prominent diseases of coffee include *Cercospora* leaf spot (brown eye spot, berry blotch), coffee berry disease (CBD) and coffee leaf rust (CLR) caused by *Cercospora coffeicola, Colletotrichum kahawae* and *Hemileia vastatrix respectively*. Others include coffee wilt disease (CWD), grey leaf rust (GLR), root rot disease (RRD) and coffee canker. These are caused by *Fusarium xylarioides/ Gibberella xylarioides/ Carbuncularia xylarioides, Hemileia coffeicola, Rosellinia bunodes/ Roselliniu pepo/ Phellinus lamoensis/ Leptopows lignosus, Ceratocystis fimbriata respectively.* All the fungal diseases result in the foliage loss, blockage of sap supply, ratting of fruits, etc., but the mode of action of each of the fungi and periodic symptoms may slightly vary [21]. *C. coffeicola* causes brown spots on the crop's foliage which enlarge and develop gray-white center and a red-brown margin. Lesions may also be surrounded by a yellow halo or may have a burned appearance if lesions are very numerous; infected leaves may drop from plant prematurely; lesions on green berries are brown and sunken and may have a purplish halo; infected red berries may have large black sunken areas. CBD infected berries develop some dark sunken lesions, resulting in massive droppings or mummification of the fruits. This disease can destroy up to 80% of the crop. Symptoms developed on coffee plants infected with CLR include small, pale yellow spots on upper leaf surfaces followed by powdery orange-yellow lesions on the undersides of leaves. Symptoms commonly develop on lower leaves of plant first and then spread; infected leaves drop from the plant and twigs and branches become defoliated [11].

Bacterial blight disease, caused by a bacterium, *Pseudomonas syringae* also affects coffee production. Evident symptoms include *water*-soaked spots on leaves which dry out and become brown and necrotic with yellow halos; necrosis of shoot tips which spreads rapidly down branches; leaves turn black and die off but remain attached to tree [11].

Coffee ringspot virus is the only viral disease causing necrotic ring spot and paling along the coffee leaves. This virus completely destructs the physical quality of berries by making a depression [22].

Prominent among other known parasites of Arabica coffee are nematodes. Robusta coffee varieties are resistant to some extent to the pest. This implies that symptoms produced by nematode attacks do not significantly affect the yield and/or quality of the variety. Root lesion and root-knot nematodes (*Pratylenchus* spp. and *Meloidogyne* spp. respectively) generally dwell in soil or roots of plant, suck the sap, cause lesions or open wounds (thereby providing sites for infection by fungi and bacteria), weaken the plant, prevent nutrient absorption even in fertilizer application, and thus reduce the yield and quality of beans by up to 40%. Research findings have revealed that inter-specific grafting of *C. arabica* with rootstock from *C. robusta* is a significant approach to protect the tree roots from root knot nematodes [23].

Occurrence and intensity of pests and diseases largely depends upon the kind of coffee production system. Highly diverse coffee-based agroforestry system is the habitat for many plant friendly birds and ants important in bio-control of coffee berry borer (*Hypothenemus hampei*). Additionally, shade prevents the various diseases like coffee berry disease (*Colletotrichum kahawae*), coffee blight (*Phoma costarricencis*), coffee brown eye spot disease (*Cercospora coffeicola*), coffee rust, and die-back from becoming epidemic by providing and modification of microclimatic conditions and host physiological changes. On the opposite side, diverse agro-ecosystems may play a conductive role in the eruption of American leaf spot disease (*Mycena citricolor*), white thread blight (*Corticium koleroga*), pink disease (*Erythricium salmonicolor*), and infection diseases. This explains why increase in environmental temperature does not only enhance the ability of many plant pathogens to cause disease, it also helps their spread into new geographic areas, where they will come into contact with new potential hosts [23].

Pathogen's survival in the absence of a host can also be affected by temperature and RH. Although the increase in temperatures predicted in the tropics will be relatively small compared with that predicted for temperate climates, the strongest consequences of global warming are expected to be observed in the tropics, because tropical species have a narrow temperature

growth range and are therefore relatively sensitive to changes in temperature. These species are also currently living very close to their optimal temperature conditions [24].

Pathogens that have evolved at higher latitudes may be able to tolerate a wider range of temperatures. These pathogens usually live in climates cooler than their physiological optima; therefore, warming is expected to enhance their fitness and the risk of epidemics of the diseases with which they are associated [25].

Based on the large amount of literature on the subjects, the coffee berry borer (CBB) and the coffee leaf rust are the two most important and most threatening to the health of coffee trees. They have been the most thoroughly studied so far. Shade in general, seems to be a good way to combat pests that negatively affect coffee plants. Scientists are trying to discover and investigate coffee cultivars that are resistant to these pests and diseases. This is most likely the best way to combat the effects of climate change and its subsequent worsening of pests/disease infestations. In general, more shade seems to be ideal conditions to prevent pests from invading coffee trees. Trees that provide shade above the coffee tree are good at keeping air temperatures moderate and shielding the plants from direct sunlight. Climate change will not be kind to coffee growth and development but may be kinder to the pests and diseases that feed and grow on the coffee [26].

While there is clear evidence that climate change is altering the distribution of coffee pests and diseases, the full effects are difficult to predict. Changes in temperature, moisture and atmospheric gases are capable of altering the interactions between the crop's pests, their natural enemies and hosts. Changes in land cover, such as deforestation or desertification, can make remaining plants and animals increasingly vulnerable to pests and diseases. While new pests and diseases have regularly emerged throughout history, climate change is now throwing any number of unknowns into the equation [27].

## 5. CLIMATE CHANGE AND COFFEE PRODUCTION

Climate change is one of the worst problems that the world is facing, and will result in incredible situations unless adaptation and mitigation measures are taken. The most frightening negative impacts of climate change on coffee productivity in sub-Saharan Africa have been identified as being severe and needs extra efforts to prepare for the future in order to maintain sustainable and productive coffee [28]. Global warming, deforestation, diseases and pests are contributing to the decline, and scientists warn that without conservation, monitoring and seed preservation measures, one of the world's most popular drinks could become a thing of the past [29].

Just as is the case with many other crops, the changing climate has been observed as a major threat to coffee production in sub-Saharan Africa and across the globe. The Climate Institute through a recent report commissioned by Fairtrade declared that without strong actions to reduce carbon emissions, climate change is projected to cut the global area suitable for coffee production by as much as 50% by 2050 [30]. A new modeling study, which agrees with this assertion, estimated how climate change will alter conditions such as temperature and precipitation that coffee beans grow in. Researchers first obtained the locations now used for growing the world's two most dominant coffee species—Arabica and Robusta. Then, they used climate models to project the future climates of the crop's growing areas in 2050 and how these climates would affect coffee growth. In a future in which humans make only modest progress to reduce carbon dioxide emissions, the world's total land area with climates suitable for coffee growing will fall by 50%. Major coffee-producing nations are especially vulnerable. Near the equator, Robusta may at least partially displace Arabica, the latter of which is susceptible to high temperatures. But Robusta, which is more vulnerable to fluctuating temperatures, could suffer somewhat greater global overall losses [31]. This indicates that the livelihoods of the 25 million coffee growers globally are under threat. This all adds up to increasingly insecure incomes for smallholder farmer communities, and resulting pressures on factors including diet, health, and access to education [31].

Coffee plants are quite sensitive to changes in microclimate, as coffee quality is strongly affected by temperature increases since, for optimum growth and taste, a temperature of about 18–21ºC is required, while the exposure to temperatures of 23ºC or higher can in most cases accelerate ripening of fruits and negatively affect the quality of the product [4]. Most times,

the climate change is felt through changing weather such as when the rainy season does not start when it is forecasted to rain, dry season lasts longer than usual, rains too much and cause flood, temperature becomes much colder or hotter than usual [32]. This climatic variability has always been the main factor responsible for the reduction of coffee yields in the world and determines the future coffee production status in the coffee producer's countries.

Most hitherto coffee production areas have become unsuitable due to climatic variations [33, 34]. Overall, influence of weather variations on coffee producing countries are predicted to be negative. Some countries would lose area suitability while others would gain from variation in weather elements. Coffee producing areas such as America, Africa, Asia and Oceania would however maintain some suitability for growing Arabica coffee [35,36].

Although, reduction of land suitable for coffee production may influence the world coffee market and increase the price of coffee [37], yet, farmers of the crop who are mainly involved in its small scale production (with over 20 million coffee farming families equivalent to more than 100 million people), at the long-run become indebted due to their reduced ability to invest in production [38]. However, as world population rises to about nine billion by 2050 coffee production is also likely to decrease globally, particularly in Africa and generate the largest price rises [12].

More variable climatic regimes are reducing crop yields, in some cases due to drought, and in others as a result of more humid conditions, which allow pests like the coffee berry borer and diseases like coffee leaf rust to proliferate [39]. Climatic factors such as solar radiation and relative humidity influence many physiological processes of the coffee tree, but are not generally thought to play an important role as thermal and rainfall conditions in defining potential yield or ecological limitations for this crop [40].

Identified global coffee production and trades have subsequently been brought under high risk because of declining forests spp.; water contamination, diminishing biodiversity to persistently uncertain revenues and makes currently an imperfect market in action [41]. The influence of this climate variation makes the farmers to be indebted, reduce ability to invest in production and reduce their income generation [39].

### 5.1 Climate Change and Incidence of Coffee Pests and Diseases

A warming climate could exacerbate pests. A 2011 study reported that the coffee berry borer, *Hypothenemus hampei*, appeared to be thriving under warming conditions. The pest, which probably originated from Central Africa, had spread to all coffee-producing regions in the world except China and Nepal. The authors reported that berry borer damage to coffee beans was already causing losses of more than $500 million per year [35].

Changes in the altitudinal range of the coffee berry borer have recently been observed in Uganda and on the slopes of Mt. Kilimanjaro in Tanzania (where it is now found at elevations 300 meters higher than those at which the insect was present ten years ago). Every 1–2ºC increase could lead to an increased number of generations, dispersion and damage by the coffee berry borer; whereas a rise in temperature of 2ºC and above could lead to shifts in altitudinal and latitudinal distribution of the pest. Only two years later, there are strong indications that these changes are already occurring [42].

In addition to insect pests, coffee is also vulnerable to fungal infections called *rust.* Rising temperatures and extreme rainfall have been blamed for a severe outbreak of coffee rust in Central America. Unlike outbreaks in the 1970s and 1980s, which remained confined to lower (warmer) altitudes, the wave of coffee rust that started in 2011 quickly spread to high altitudes, affecting more than half of the region's coffee farming land, and putting some 350,000 residents out of work [30].

Although Robusta coffee can tolerate higher temperatures and is more resistant to some pests and diseases, yet, it is affected by climate extremes. This may be one reason why the percentage of global coffee production of Robusta has risen from 20 to 40% since 1980. The overall result of the negative impacts of extreme weather conditions is a reduction in coffee quantity and quality, and increasing production costs due to the need for additional inputs or labor [11]. In an apparent agreement with these findings, Haggar and Schepp [43] revealed that the potential yield and quality of coffee is determined by both temperature and rainfall conditions. Both have the ability to interfere with the phonological growth of the crop. These impacts include, for example, disrupted

flowering cycles and prolonged drought periods, which ultimately result in reduced coffee quantity and quality [30].

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. As climate conditions become critical, the livelihoods of millions of farmers in sub-Saharan Africa are at risk and production capacity is jeopardized. Other potential contributors to this predicted downfall are pests and diseases [44]. Sub-Saharan Africa suffers from some serious environmental problems, including deforestation, soil erosion, desertification, wetland degradation and insect infestation.

### 5.2 Climate Change and Coffee Yield and Quality

The productions of both species of coffee are largely dependent on the climate to achieve high yields; temperature and rainfall conditions are considered to be important factors in defining potential coffee yield. Both factors interfere in the performance of the crop, and consequently in productivity and quality [45]. According to Killeen and Harper [17] many scientific justifications predicted coffee sectors are likely affected due to climate variation over the next forty years. They also reveal that coffee production area changed due to weather extremes where most suitable area becomes unsuitable because of climate variation [30]. Higher altitudes are projected to become more suitable for coffee while lower altitudes are projected to become less suitable.

Research findings have revealed the potential yield and quality of coffee are determined by both temperature and rainfall condition, thereby indicating the ability of both parameters 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 [13]. 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 [40]. The Arabica coffee is more sensitive to climate variation, specifically during blossoming and fructification stage [43]. Especially, coffee flowering triggered by the first rain fall at the beginning of rain season, meanwhile if rain drops off or becomes too heavy, flowers and fruit may drop from the coffee tree [38]. The unpredictable rains will make coffee to flower at various times throughout the year, making the farmers to harvest small quantities continuously. This change will affect the crop physiology especially during the flowering and fruit filling stage [46].

Future climate change is expected to increase climate-induced risk, especially by more frequent extreme events (drought, floods, and high temperature waves) and changed rainfall patterns and variability [31].

### 5.3 Climate Change and Variation in Coffee Biodiversity

Observed changes in climate have already adversely affected biodiversity at the species and ecosystem level, and further changes in biodiversity are inevitable with further changes in climate [47]. Davis [48] stated that the profoundly negative trend for the future distribution of indigenous Arabica coffee 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). In the study, a 90% reduction in area suitable for in situ conservation of coffee genetic resources was projected for the year 2080. Climate change is predicted to increase mean temperatures and change precipitation regimes and as a result, traditional coffee growing regions may disappear and new regions may appear [38]. 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 [40].

## 6. CLIMATE CHANGE MITIGATION STRATEGIES FOR IMPROVED COFFEE PRODUCTIVITY IN SUB-SAHARAN AFRICA

The purpose of climate change mitigation in sub-Saharan Africa is to set in motion measures to limit the extent of damage caused by global warming on coffee production in the region. It is possible to withstand the negative impacts of climate change by different adaptation and mitigation practices. Therefore, coordinated efforts at all levels of policy making are urgently needed to strengthen the sub- Saharan Africa's

ability to adapt to the likely deteriorating impacts of climate change, and indeed to help mitigate future problems.

In order to reduce the environmental impact and ensure the economic and social wellbeing of coffee farming communities in sub-Saharan Africa, there is need to define climate variables for monitoring in producer areas to determine the actual nature of climate variability and its impact on coffee productivity and quality. In order to achieve the goal of stabilization of atmospheric climatic conditions, a number of mitigation strategies that has been identified include:

- Genetic Improvement
- Reforestation through planting under shade
- High-density planting, vegetated soils and irrigation
- Use of integrated pest management
- Improved access to climate information
- Reducing Green House Gas Emissions

**Genetic Improvement:** Genetic breeding based on selective breeding aims to contribute to the long-term sustainability of coffee cultivation in lands potentially affected by climate change. Also, research on varieties that demand less water and on developing varieties that could cope with higher temperatures is equally important. In the context of the improvement of crop varieties, developing environmentally friendly, stable, increased resistance to heat shock and drought variety in coffee production has become necessary to withstand climate change challenges even due to their complex traits. According to Nzeyimana, et al. [48]. Some of the important traits that show resistance to drought include water-extraction efficiency, water-use efficiency (WUE), hydraulic conductance, osmotic and elastic adjustments, and modulation of leaf area. Most of these traits are complex and their control and molecular basis is not well understood. CIAT [49] found out that root characteristics and growth play a crucial role in maintaining the water supply to the plant, and drought adapted plants are often characterized by deep and vigorous root systems.

**Reforestation through planting under shade**- Shade helps to protect the coffee trees from extreme winds and dryness. Coffee plants grown in the shade suffer less from environmental stresses resulted from climate change. The ambient air temperature is uniform within the coffee trees making it cooler in the early parts of the day and warmer in the evening. The coolness, due to shading in the day reduces transpiration both from the leaves and the roots. It yields coffee with higher biochemical and physiological potential for carbon fixation and produce larger and heavier beans with better taste quality than coffee plants grown in full sun light. Shade trees may also be used for erosion control on steep slopes [50].

**High-density planting, vegetated soils and irrigation** aimed at maintaining and/or increasing organic matter and soil water-retention capacity, thereby enhancing the viability of cultivation under adverse climatic conditions.

**Use of integrated pest management**- Pests and diseases of coffee pose a danger to coffee production and can affect farmer livelihoods of the entire sub-Saharan African countries. Jaramillo, et al. [51] predicted shrinkage in coffee-growing areas in most of Kenya, Uganda and Rwanda due to the prevalence of the coffee berry borer caused by increases in temperature, and expansion of suitable area in Tanzania and Ethiopia by 2050. Also, making wider use of integrated pest and pathogen management and developing and using varieties resistant to pests and diseases are strategies to mitigate the proliferation of pests and diseases.

**Access to climate information**- One particularly useful initiative that is rapidly gaining momentum in SSA aims to bring weather information to farmers in a format that is understandable and useful for them in making timely farm-level decisions. Early warning is the provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazard to take action to avoid and/or mitigate their risk and prepare for effective response.

**Reducing GHG emissions-** Main cause of the climate change is from forest clearance and degradation associated with agricultural expansion through agricultural intensification, the burning of coal, oil, natural gas and mineralization of organic matter; these lead to increase in the carbon dioxide ($CO_2$) content of the atmosphere. Carbon dioxide ($CO_2$) and methane (CH4) are the most greenhouse gases that influence global climate through emissions. Mitigation of global warming involves taking actions to reduce greenhouse gas emissions and to enhance plans aimed at reducing the extent of global warming measures to adapt to coffee

cultivation to climate change also contributing to reducing $CO_2$ [52].

## 7. CONCLUSION AND RECOMMENDATION

Coffee plant is of economic importance to many countries within and outside Africa. The crop is however very sensitive to prevailing weather conditions across the globe. Marked increase in environmental temperatures beyond the required optimal levels badly affects coffee productivity and quality. In the same vein, increasingly warm climatic conditions often enhance the proliferation of coffee pests and diseases in sub-Saharan Africa. This as a result impacts negatively on the crop's production in the region. It is therefore pertinent to devise practicable mitigation strategies (including the encouragement of farmers to raise the crop under shade) to enhance production of quality coffee and thus, significantly boost the region's economy.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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