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COMBATING CLIMATE CHANGE IMPACTS IN TEA AND COFFEE FARMING IN EAST AFRICA: THEORETICAL PERSPECTIVE

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ABSTRACT

Global warming has become one of the major challenges in maintaining global food security. Climate change triggered by global warming poses a major threat to agricultural systems globally and in East Africa in particular. This phenomenon is characterized by emergence of pests and diseases, extreme weather events, such as prolonged drought, high intensity rains, hailstones and frosts, which are becoming more frequent thus, impacting negatively agricultural productivity including rain-fed tea cultivation. East Africa countries are predominantly an agriculturally based economy, with the tea and coffee sector playing key role as a cash crop. In the recent years, however, the countries have witnessed unstable trends in tea and coffee production associated with climate driven stresses. Toward mitigation and adaptation of climate change, multiple approaches for impact assessment, intensity prediction and adaptation have been advanced in the East Africa countries tea sub-sector. This review described simulation models combined with high resolution climate change scenarios required to quantify the relative importance of the climate change on tea and coffee production. In addition, both biodiversity and ecosystem-based approaches were also described as a part of an overall adaptation strategy to mitigate adverse effects of climate change on tea and coffee in the East Africa countries and gaps highlighted for urgent investigations.

Climate variability and change have adversely affected agriculture sector and the situation is expected to worsen in the future. The paper found out that climate variability and change affect agricultural production but effects differ across crops. It was found that temperature has a negative effect on tea and coffee revenues but a positive one on tea, while rainfall has a negative effect on coffee. The paper found out that tea relies on stable temperatures and consistent rainfall patterns and any excess would negatively affect production. Temperature has a greater impact on crop production than rainfall. Climate change will adversely affect agriculture in 2020, 2030 and 2040 with greater effects in the tea sector. Therefore, rethinking the likely harmful effects of rising temperatures and increasing rainfall uncertainty should be a priority in East Africa. Driven by competitive pressure, global production has consolidated among fewer origins: more than 70% of supply is now sourced from five countries. African production has dropped by 18% since 1990 and only Ethiopia and Uganda figure in the top 10 global ranking. African origins must consider how to improve productivity to remain competitive in global markets, but they also need to consider value addition to earn a higher share of what they produce. Implementing adaptation measures at national, county and farm levels as well as putting in place policies that prevent destruction of the natural environment will assist to address the challenges posed by climate variability and change.

Climate change is projected to increase median temperature by 1.4–5.5°C and median precipitation by −2% to 20% by the end of the 21st century. However, large levels of uncertainty exist with temporal and spatial variability of rainfall events. The impact of climate change on crop yields in the region is largely negative. Among the grain crops, wheat is reported as the most vulnerable crop, for which up to 72% of the current yield is projected to decline. Thus, as climate change puts both Arabica and Robusta coffee bean production at risk, it affects the supply of coffee. When we consider the increasing amount of coffee consumption in America and the decreasing availability of coffee beans around the world, a shortage will be inevitable; these developments will have far-reaching implications for farmer incomes and livelihoods, rural-to-urban migration, and international coffee prices and demand. If we don't start acting to mitigate, or, in some cases, acknowledge climate change, it may soon be time to bid farewell to America's coffee habit. However, a recent study in Scientific Reports *has already offered cocoa as a more climate-resilient crop to serve as an alternative to coffee plants as coffee production declines.*

Keywords: *Climate change, Tea farming, Coffee farming, East Africa*

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INTRODUCTION

Climate change has become internationally recognized a serious problem. Its impacts have been well acknowledged on global scale in a range of different sectors. Among the different sectors agriculture is being one of them (Jayne et al., 2015). The impact of climate variations in all coffee producing countries is predicted to be negative and even though within a country it would vary a lot. The world-wide concern is the pace at which climate change is taking place and threats caused to the world flora and fauna diversity. If the changes are taking place at the present pace, many species are likely to become extinct due to their inability to adapt to the rapidly changing environment. Climate variability and change is the most important factor that causes year to-year uncertainty in crop productivity in general especially rainfed plantation crops like tea. Change in local climate is due to changes associated with large-scale features like the changes in the interactions between land, atmosphere and oceanic changes, and also changes in local land use and land cover changes. However, the observed rainfall trends show reduction in land rainfall during southwest monsoon season over India (Ramesh & Goswami, 2007) as well as tea growing regions (Raj Kumar *et al.,* 2012). However, model projections to date have not provided any conclusive evidence of the patterns of trends (Ramesh & Goswami, 2014) and inter-annual variation in terms of intensity, frequency and distribution of extreme ecological events that is expected in the near future (IPCC, 2007).

The impact of local change in climate further hampers global crop productivity and thus affects the food security. Recent simulation models developed have the effect of region-specific crop production (Horie et al., 1995; Matthews et al., 1995; Rosenzweig et al., 1995), which predict global climate change that may have either positive or negative influence on crop production. However, these modelling studies pointed out the need for further studies in order to evolve and improve our understanding of environmental effects on crop production. Specifically, further research is required to quantify the interactive effects of CO_2, air temperature and other environmental variables on crop production.

The geographical location of the main East African tea areas across and close to the equator allows for year-round plucking, and therefore a continued supply of fresh teas. Climate change is putting coffee production and their livelihood of coffee farmers and their families around the world at risk. According to Will Battle, author of According to Fuglie and Rada (2013) climate variability in terms of uncertain rain or delayed monsoon, flood, droughts and changing temperature will have measure impact on coffee production. Therefore, planning and implementing the mitigation and adaption strategies in a systematic manner would help to overcome the future challenges. Coffee is the second largest traded commodity in the world next to petroleum products and is among the most valuable legally traded commodity from the developing world (FAO, 2014).

There is great potential in particular in the countries close to the equator, which produce tea throughout the year appealing to cash-conscious buyers who may be put off by the financial constraint that comes with holding large stocks of seasonal teas from the traditional northern hemisphere Asian producers. African producers have become the number one supplier for several of the main black tea importing markets including Pakistan, Egypt and the United Kingdom. Kenyan tea is also growing from a small base to gradually claim a more significant share of the Russian and USA markets (Ramirez & Jarvis, 2010).

Although Africa's tea is grown first as an export crop, domestic consumption has been fostered and is growing steadily. [1]Kenya has experienced spectacular increases with consumption more than doubling over the past ten years and growing threefold in Uganda during the same period. In 2017, African tea producers together retained 67,000 tonnes for their domestic consumption, which represent 10 percent of their teas. This compares to 9 percent retained for domestic consumption in Sri Lanka and in Argentina, whilst China retains 86 percent and India 81 percent for their home market tea drinkers (Raj Kumar & Mohan Kumar, 2010).

Human activity is driving significant changes in global and regional climate systems through enhanced greenhouse effects (Intergovernmental Panel on Climate Change, 2014). Global climate models predict that these changes will alter both mean climate parameters and the frequency and magnitude of extreme meteorological events that may include heat waves, severe storm events and drought (Semenov and Halford, 2009). Such changes may have significant destabilizing effects, decoupling existing relationships between species, altering species distributions and challenging current management regimes. Understanding and predicting the impacts of climate change on agricultural ecosystem processes is thus critical.

Coffee is one of the most popular beverages on the planet, with an estimated three billion cups consumed every day. The coffee world is largely split in two: consuming countries, which tend to be the most economically developed, and producing countries, found geographically near the equator and which are (in many cases) also the least developed economies in the world. Coffee has proven to be one of the most important crops in the world due to the sheer magnitude of its trade. In fact, a study from the Royal Botanic Gardens performed by Davis et al. (2012) explains that coffee is the second most traded good in the world. The most traded good is oil. From 2009 to 2010, coffee exports totaled about US$15.4 billion. During those years, 93.4 million bags of coffee were shipped throughout the world (Paramaguru, 2012). Over 100 million people depend upon coffee production for their livelihood (Paramaguru, 2012).

If climate change continues as predicted, coffee production and trade will face difficult situations. The International Coffee Organization says climate change will lead to large reductions in coffee production. They predict that the biggest declines will occur in Africa and South America (Jaramillo et al., 2011). They predict this will affect coffee prices and force them to rise even more. Ramirez-Villegas et al. (2012) say that to protect coffee and coffee prices, greenhouse gases must be limited and reduced. Possible ways to limit greenhouse gases include a reduction in deforestation and better crop management (Ramirez-Villegas et al., 2012).

Impact of Climate Change on Tea Production

With climate change, it is expected that the main tea growing areas will experience an increase in the length of dry seasons per year, warmer temperatures and/or extreme rainfall intensity (Wijeratne, 1996; Trejo-Calzada and O'Connell, 2005; Eitzinger et al., 2011). Climate data collected at KALRO-TRI for over 58 years, indicate an annual temperature rise of 0.016°C per year while annual rainfall decreased by 4.82 mm per year over the same period (Cheserek et al., 2015). This has led to continued increase in soil water deficit (SWD) over time. On an annual basis, a large SWD, especially in January, February and March is reported leading to significant oscillations in tea production annually (Bore, 2008).

Considering the established positive influence of temperature on tea production, it is imperative to conduct the economics of supplying water to tea fields during drought to reap from the enterprise (Cheserek et al., 2015). The irrigation or fertigation possibilities in tea had been documented in earlier experiments conducted in Sri Lanka (Wijeratne et al., 2007), India (Panda et al., 2003) and East Africa (Carr, 1972, 2010a,b). Timing of irrigation in tea fields has also been determined with inherent benefits (Carr, 1972; Othieno, 1978). This paves way for simulations into the projected temperature scenarios to reveal the potential yield levels. The divide between the cooler and already warm places could also support regional specific temperature thresholds for the crop hence support breeding activities for site specific cultivars with better heat stress tolerance.

Recent works were driven principally by the emergence of improved cultivars which had poor rooting system hence subject to water stress problems. Relations between young grafted teas with water stress had been done (Bore et al., 2010). How plants recover from drought event has also been determined (Muoki et al., 2012) as well as response of composite tea to progressive drought (Bore et al., 2010). A remarkable breakthrough in tea plant and drought relations was established revealing the threshold moisture content below which tea plant succumbs (Cheruiyot et al., 2008). Deeper understanding of the relationships could be achieved via controlled carbon dioxide (CO_2) enrichment experiments such as Free Air Carbon Enrichment (FACE). There is need for development of cultivars which are not only tolerant to heat stress but equally adaptable to higher CO_2 levels in the atmosphere (Wijeratne et al., 2007). A significant increase in concentrations of total catechins, other polyphenols and amino acids have been reported elsewhere with elevated carbon dioxide, while caffeine levels decrease (Li et al., 2017). Studies on carbon enrichment in tea cultivars grown in Kenya have, however, not been quantified though clear increase in temperature as CO_2 rises has been established.

Impact of climate change on coffee production

In many coffee producing countries like Brazil and Vietnam coffee is grown under open condition, without any shade coupled with intense cultivation practices aiming at higher productivity. The terrain of coffee areas in these countries is highly amenable for mechanization of farm operations which bring in efficiency. While in India, coffee has been grown under two tier shade in a more sustainable way for centuries. Coffee is cultivated in undulating terrains of varying gradations, which gives less chance for mechanization. Thus, indirectly coffee provides daily employment to the native inhabitants of hilly region. Coffee has been introduced to India during 1600 AD and remained as a garden plant for nearly two centuries and later during 18th century commercial plantations were established. The plantations were raised in virgin jungles of the Western Ghats after selectively felling the undesirable trees by retaining desired number of jungle trees. Even when the Robusta, low land coffee was introduced into the 19th century, the importance of providing the natural shaded conditions was taken care of. Thus, the strong

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foundation was laid for sustainability of coffee industry and subsequently, India became the one of the few countries in the world to grow all of its coffee under natural shade canopy (Anonymous, 2014).

Climate disturbance have led to fluctuation in yields in almost all the coffee growing countries. Global warming is expected to result in the actual shifts on where and how coffee would be produced. Dr. Peter Baker of CAB international is of the opinion that if there is a 3^{o}C increase in temperature by the end of this century, the lower altitude limit for growing good quality Arabica coffee may go up by 15 feet per year. This may affect millions of producers as well as the all participants in the value chain of industry end user, the coffee consumer. It is predicted that both arabica and Robusta coffee growers would be affected. Raising temperature is expected to make some areas less suitable or completely unsuitable for coffee cultivation, incidence of pests and disease may increase and quality may suffer. Growers may have to depend more on irrigation, putting pressure on water resources. Overall, the production cost is expected to increase. Increase in temperature will force coffee to ripen faster than normal, impacting the inherent quality. Low grown arabica from tropical areas with higher temperatures mostly less quality in the cup compared to the same coffee grown at higher altitudes. The beans are softer and may well be larger but, lack the quality. Increase in temperature coupled with low rainfall or erratic distribution will affect flowering and fruit set. The International Coffee Organization (ICO) consider that it would be the most important; particularly considering the large number of small holder coffee farms whose capacity to implement means and methods to mitigate climate change affect may be low (Raghuramulu, 2019).

The 2007 report from the Intergovernmental Panel on Climate Change (IPCC) says climate change will lead to a loss of suitable environments for coffee growth in Latin America and the Caribbean (Ramirez-Villegas et al., 2012). It says climate change will lead to an increase in the coffee berry borer, the main insect threat to coffee. Ramirez-Villegas et al. (2012) reveal that in addition to the increased insect threat, diseases also could hurt coffee production in Colombia. Coffee leaf rust, known as Hemileia vastatrix, would hurt a large portion of coffee plants in South America.

Statement of the Problem

Coffee and tea farmers across East Africa face a bleak future, amid a biting drought that is expected to take its toll of the cash crops and reverse the gains from 2016. Rapid changes in the climatic conditions have becoming more evident with increasing degree of its intensity and extremities. Direct effects of these changes are felt by agriculture industries especially those which are utilizing environmental of a certain area and its human interaction such as the tea and coffee cultivation industry in East Africa.

Data from the East African Tea Traders Association shows that prices of tea at the Mombasa auction rose this past week to $2.5 (Ksh250) per kilogram, from $2.4 (Ksh240) recorded the previous week. In Rwanda, revenue from tea, the second largest export crop after coffee dropped to $52.7 million last year, from significantly down from $62.2 million in 2015, as quantities produced remained flat while the quality of green leaf was low. Tea growing areas experienced low rains from June-August. Low prices also contributed to the fall in revenue. Tea sold for an average $2.53 per kg in 2016, compared with 2.90 per kg in 2015. Rwanda plans to increase the area under tea to 38,000 hectares from 25,308 hectare currently, and the average yields to nine tonnes per hectare for fresh leaves from 6.7 metric tonnes. There are also plans to increase the quantity of fertilizers used.

Despite the myriad climate change related activities taking place at both the regional and national levels, a number of challenges and needs remain in regard to understanding the climate change impacts, vulnerabilities, and adaptation options in sectors such as water resources, forests, and energy. Additional needs include improving seasonal forecasts, developing approaches and tools for vulnerability and adaptation assessment, and devising methodologies and tools for climate change monitoring, detection, and attribution. It also will be necessary to strengthen planners' and policy-makers' awareness and understanding of climate change impacts and vulnerabilities to facilitate mainstreaming of vulnerability and adaptation considerations into general development and sectoral plans, policies, and processes. At the regional level, it is also necessary to better understand the interactions between migration, resource distribution and use, and climate change so that initiatives can reflect changing distributions of vulnerabilities. Moreover, there is a need to better leverage existing frameworks to enable collaboration and coordination in addressing both non-climate and climate stresses that affect transboundary ecosystems and promoting their effective management. As regional mechanisms are dependent upon the quality of engagement by individual nations, this may necessitate the creation of incentives that not only encourage active participation, but also enforcement of agreed measures. Addressing these needs at both regional and national levels will be essential for enabling successful regional response to climate change impacts in support of both regional and national climate-resilient development.

A more specific case is the drought induced by the La Niña weather phenomenon leading into the last quarter of last year delayed the flowering of coffee bushes. Depressed short rains in Kenya will significantly impact production, according to the National Drought Management Authority's Early Warning Bulletin for December 2016. Last year, coffee production in Kenya stood at 47,000 tonnes, up from 45,000 tonnes in 2015, according to AFFA. Farmers made \$218.4 million compared with \$208.9 million the previous year. This year, stakeholders project production to decline to between 40,000 tonnes and 43,000 tonnes. In Burundi, data from the Coffee Regulatory Authority (Arfic) shows that production declined from 18,000 tonnes in 2015 to 12,000 tonnes last year.

Changing weather patterns in Eastern Africa are increasingly being felt within agricultural systems not only by policy levels abut also small farmers. In Kenya, there is a particular concern over tea – a critically important sector for the economy, but which is also highly sensitive to climate change. Given its economic importance, tea in Kenya is facing challenges under climate change threats, raising concerns over the long run it viability. Already tea producers are facing reduced and erratic rainfalls, higher rate of hail or frost episodes as well as increasing temperatures that heavily affect yields and productivity levels. Over 500,000 smallholder tea producers are facing increased uncertainty about future livelihood. The Kenyan government has acknowledged climate change as a real threat to the county's development agenda and has formulated a framework for intervention.

Agriculture has always been deeply dependent on the weather, with farmers needing a steady mixture of sun, warmth, and rains in order to reliably produce the food that all of humanity depends on for survival. Now, these once predictable growing cycles are at risk from climate change, and tea and coffee farmers in East Africa are on the front lines. Climate change has resulted in the start date of tea buds and leaves plucking period to have become significantly earlier in spring. The risk of frost damage and economic loss, caused by frost, decreased significantly in the period of spring tea production. The economic losses caused by daytime rainfall decreased significantly in spring tea and coffee production. This study has provided essential evidence that climate change has already had a significant impact on tea and coffee plant output.

LITERATURE REVIEW

Climate change-induced, warming land and sea surface temperatures are projected to cause more frequent and intense hurricanes and tropical storms that inundate coastal areas (IPCC, 2001). These same extreme weather events can lead to

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decreased precipitation in interior regions, causing increased drought and desertification, subsequently threatening food security. Threats to food security can then lead to widespread migration of human settlements in order to seek better agricultural land, more available water resources, and escape increased exposure to malaria and other diseases. The impacts of climate change also have the potential to disrupt and potentially reverse progress made in improving the socioeconomic well-being of East Africans such as infrastructure development, sustainable agriculture, and tourism.

East African Agriculture

Agriculture is a major contributor to the national economies in East African region. Agriculture in the East African countries is dominated by smallholders who contribute up to 90% of agricultural production (Salami et al. 2010; Wiggins and Keats 2013). Agriculture accounts for 43 percent of the surveyed nations' annual gross domestic product (GDP), on average, although the precise proportions vary considerably from country to country. For example, agriculture in Burundi, DRC, Ethiopia, Sudan, and Tanzania accounts for more than 50 percent of GDP while in Eritrea, Kenya, and Madagascar it accounts for less than 30 percent. Kenya's low percentage is due to structural transformation toward a less agriculture-based economy.

Despite these differences, farming in all the surveyed nations is dominated by smallholders reliant on rainfall. These farmers face the challenges of land degradation, poor soil fertility management, and continuous cropping. Sluggish growth in agricultural productivity translates into slow overall growth and generally low per capita income levels. Meanwhile, population growth in these 10 East African countries is among the highest in the world, which threatens to worsen already severe food insecurity.

Projections for East African countries show that the temperature will increase between 1.3°C and 2.1°C (with greater or lesser local variation depending on the model) by 2050. Precipitation either will increase or remain the same, on average, across the region. Local precipitation may diverge from this average, however. One model predicts an increase of over 100 millimeters of rainfall per year over half of East Africa and a rainfall decrease in small areas of western DRC and southern Madagascar. Another model predicts significant rainfall decreases for large parts of DRC, Ethiopia, and Madagascar. Moreover, some analysts suggest that even these models' projections of average rainfall increase or stability are too optimistic. Instead, they argue East Africa will be much drier overall in the future, particularly during the "long rains" period of March to June.

According to FAO (2013b) in the six countries examined, agriculture accounts for 21–42% of the national gross domestic products (FAO 2013b). Currently, of all the crops grown in SSA, a cereal-legume mixed cropping pattern is the dominant system that includes maize, millet, sorghum, and wheat (Van Duivenbooden *et al.,* 2000). Other major crops in the region include cassava, banana, and rice. In drier parts of East Africa, the mixed crop-ping system is based on millet; while in the humid regions mixed cropping systems are based on maize and cassava (Francis, 1986). Coffee, tea, cotton, tobacco, and sugarcane are the major cash crops in most of the countries in SSA.

Agriculture sector and climate change

It is now widely accepted that the climate is changing all over the world. The global mean temperature increased by 0.6° C in the last century, and the 1990s were particularly hot years (IPCC, 2001). Moreover, there is growing scientific evidence that this warming of the world's climate is due to the greenhouse gases (GHGs) that have built up in the atmosphere, especially in the last century. East Africa is also showing signs of climate change. For example, in Uganda an analysis of the temperature records shows a sustained warming particularly over the southern parts of the country with the minimum temperature rising faster than the maximum temperature. With a rate of 0.3° C, the southwest is the fastest warming region of Uganda (GoU, 2002). The disappearance of the

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snow caps on Mount Kilimanjaro and the Ruwenzori peaks provides strong evidence of the warming trend in East Africa.

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Climate change will have critical impacts on the economies of the region and threatens to reverse the gains of sustainable development in Africa (Madzwamuse, 2011). "The speed of the current climate change is faster than most of the past events, making it more difficult for human societies and the natural world to adapt" (The Royal Society & National Academy of Sciences, 2014). By 2020, according to the IPCC 2007, between 75 and 250 million people are projected to be exposed to increased water stress due to climate change. Climate-change impacts are expected to exacerbate poverty in most developing countries and create new poverty pockets in countries with increasing inequality, in both developed and developing countries (IPCC, 2014). Hence, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. In fact, Climate change is an additional stressor for a continent that is already struggling with food insecurity, high poverty levels, and a HIV/Aids pandemic (Madzwamuse, 2011). Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition (IPCC, 2007).

History of East African tea industry goes back to the year the 1890s where like in many other teas growing countries, British planters started experimenting tea in one of their African colonies, Malawi. This was successful experimentation, and also it was regarded as one of the safer moves for British, due to the fertile growing conditions and also the region was expected to remain as a British colony for many years to come. On the other hand, they had begun to lose their profits from other colonies like Sri Lanka, due to some crop diseases spread around the country. From Malawi, it started to expand into other countries like Kenya, Tanzania, Rwanda, Burundi, and Zimbabwe as well. The CTC (cut, tear, Curl) technique of tea manufacturing was introduced to the East African countries by the year of the 1930s, and this was a real turning point of the East African tea industry. The reason was that world demand for smaller tea particles was at a rising trend due to the solid brew resulted by smaller tea particles. Hence with the CTC type tea production, the East African countries were able to produce much smaller tea particles, and this technique was ideal to bring out the original strong flavors of east African tea. It was an excellent ingredient for the production of tea bags as well. Soon, the teas produced in the area were met with a demand from all over the world especially from the European region as an essential ingredient of the English breakfast tea. Many of these countries started to get their independence starting around 1060's, and from there the tea industry was under the custody of local authorities. Some countries like Uganda and Tanzania followed nationalization strategy and faced many other political issues and as a result of today facing a declining trend.

The East African tea industry has achieved an overall growth since its inception, and it is important to notice that there have been two auction centers to sell the product of the region. The Mombasa tea auction being the main auction center was initiated in 1965 in Nairobi at a tiny scale, however, had to shift into Mombasa by 1969 with the expansion of trade. The Mombasa tea auction currently sells the offerings from Kenya, Uganda, Tanzania, Rwanda, Burundi, Democratic Republic of Congo, Malawi, Madagascar, Zambia, and Zimbabwe. This is now the only auction center in the world trading teas from more than one country. The Malawi auction center, on the other hand, was initiated in the 1970s in Limbe, Malawi. The most common tea in East Africa is Black Tea.

Regional studies have shown that climate change will affect climatic suitability for Arabica coffee within current regions of production (Ovalle-Rivera *et al.,* 2015). In fact, coffee in general requires very specific growing conditions that determine the growing area, yield and quality. Coffee is particularly sensitive to changes in seasonal temperatures and precipitation. In the regional, the optimum temperature ranges between 15°C and 24°C; precipitation between 1500 mm and 2000 mm per annum and is typically cultivated at altitudes between 1000 and 2000 m a.s.l. (Killeen and Harper, 2016). The growth of Arabica coffee declines significantly if the daytime temperature is below 18° C (Alemu and Dufera, 2017) or exceeds 23° C (DaMatta, 2004). Indeed, if temperature and precipitation are not ideal at the flowering season (are too cold or too wet), many difficulties may be encountered (Bittenbender & Smith, 2008).

Any increase in temperature and changes in precipitation patterns will decrease yield, reduce quality and increase pest and disease pressure (Ovalle-Rivera et al., 2015). The Arabica coffee variety is susceptible to disease due to its highly sensitivity (Naveen et al.,2010). It is worth noting that increased temperature doesn't make the plants more sensitive to pests and diseases but rather makes the occurrence of pests and diseases more common, which then impact the plant. The higher temperatures make the coffee more susceptible to disease, and favor pests such as leaf miners, stem borers and certain nematodes, which multiply more rapidly under these conditions (GIZ, 2011). Thus, temperatures above 25°C affect the plant's photosynthesis process and spur the development of diseases such as coffee leaf rust (CLR) and fruit blight. Low temperatures, below 15°C, spur coffee berry disease (CBD) (Ngabitsinze et al., 2011). Therefore, an increase in temperature and changes in precipitation patterns will tend to decrease yield, reduce quality and increase pest and disease pressure (Ovalle-Rivera et al., 2015) if no counteractive management practices are implemented, like irrigation. Furthermore, according to the Fifth Assessment Report by the IPCC Working Group II, highland Arabica coffee producing areas are at risk to see an increase in the coffee berry borer (Hypothenemus hampei) through warming temperatures.

In fact, the continent of Africa is warmer than it was 100 years ago (Hulme et al., 2001). In East Africa, climates suitable for Arabica coffee are predicted to shift from 400–2000 m a.s.l. to 800– 2500 m a.s.l. making little change in suitability of the areas in

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Ethiopia, Kenya, Rwanda, and Burundi that currently grow Arabica (Ovalle-Rivera et al., 2015). Coffee supply chains are likely to experience significant disruption due to climate change over the next forty years (Killeen and Harper, 2016). By 2050s, it is predicted that global temperatures would increase by 2°C together with some increased seasonality of precipitation. These changes would reduce climatic suitability 10 for Arabica coffee at low elevations and increase suitability of higher areas. The net effect is that coffee farming will tend to move uphill (Ovalle-Rivera et al.,2015).

Increasingly, the research community has turned their interest on the effect of climate change on the agricultural sector. Climate change has emerged as the most prominent of the global environment issues and there is a need to evaluate its impact on agriculture (Naveen et al., 2010). The concern over the potential effects of long-term climatic change on agriculture has motivated a substantial body of research over the past decade. In fact, "climate is the primary determinant of agricultural productivity" (Res et al., 1998). Thus, there is widespread interest in the impacts of climate change on agriculture in Sub-Saharan Africa (Schlenker and Lobell, 2010) even if robust analyses of coffee and climate change at the regional scale have until now been lacking (Craparo et al., 2015).

Tea being a rain fed crop requires certain soil and air temperature as well as moisture condition for its growth. It is apprehended that increased temperature and decreased rainfall pattern observed in this region are undoubtedly going to affect the above conditions posing a threat to the sustainability of tea crop. Tea cultivation though depends on the natural precipitation, are now-a-days being complemented by irrigation because of increased rainless periods leading to drought like situation (Fig 1-8e). Both excess and shortage of water affect growth of tea bushes. Tea bush need adequate and well distributed rainfall, but heavy and erratic rainfall is responsible for damage to tea plantation in terms of soil erosion (Fig 1-8d), lack of growth due to less sunshine hours and different types of diseases, besides flooding. Heavy rain washes away the top soil converting cultivable lands to barren or unproductive. Loss of soil fertility leads to reduction in water holding capacity of soil, exposure of root systems and reduction in microbial activities due to loss of organic matter. In undulating or hilly areas, particularly the Darjeeling hills, high soil erosion, landslides and depletion of inherent soil fertility is expected in coming years, if the present trends are continued.

With regards to the rapidly transforming climate conditions, the agriculture and forestry industries are among those, which are directly affected. Agricultural crops are grown and harvested seasonally in a specific period of climatic condition to obtain the optimum of desired harvest quantity and quality. Some of the crops require certain temperature ranges as well as certain intensity of solar radiation, which directly affect harvest quality and yield. In these industries, tea and wine grape cultivation are among those, which are very sensitive towards changes in the climatic condition whereas changes in the climatic region will directly affect the quality of the cultivated products. Based on Intergovernmental Panel on Climate Change (IPCC) (2007), climate change is expected to manifest itself in the increases of mean temperature, altered precipitation patterns, greater frequency of extremes, and increased climatic variability. Although wine grapes as well as crops are not very crucial to human survival, the extraordinary sensitivity of the vine towards climate makes the industry a strong early-warning system for problems that all food crops may confront as climates continue to change (Jones & Webb, 2010). This is also true for the tea industry, as changes in the climate occurring in the surrounding area of tea bushes directly influence the quality of the picked leaves during harvest. Similarly with wine grape cultivation, tea is sensitive to climate changes with potential effects on its yield, quality and economic viability as it is directly connected with the market. Climate change effect towards the cultivation of tea in general can be categorized into two types, which are: 1) Average temperature increase (warming of the climate) and 2) Increasing occurrences of extreme weather events.

Climate Change in East Africa

The East Africa region is comprised of the countries of Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, South Sudan, Tanzania, and Uganda. The countries of the region are already subject to climate variability and extremes including droughts and floods, which in some cases have had severe economic and social implications. Climate models predict that the region is likely to experience both near-term alterations in climate such as warmer temperatures, changes in the frequency and intensity of extreme events, and decreased precipitation, as well as long-term shifts such as sea level rise. Projected climate change impacts are likely to add to the toll of current climate variability and extremes, increasing the vulnerability of communities that depend upon natural resources for their well-being and livelihoods, and resulting in significant consequences for key development areas. In recognition of this, at the national level, activities have been initiated to identify adaptation priorities. However, a deeper understanding of climate change impacts, vulnerabilities, and adaptation options is required to action these priorities and to inform the integration of climate considerations into development and sectoral strategies and plans. At the regional level, research initiatives to strengthen capacity to generate, disseminate, and use climate data and information has been a significant emphasis. As initiatives proliferate throughout the region, coordination will become increasingly important.

Climate change is projected to increase temperature and precipitation variability in East Africa. Temperature in Africa is projected to rise faster than the rest of the world, which could exceed 2°C by mid - 21st century and 4°C by the end of 21st century (Niang et al. 2014). Country-specific median projected change in temperature and precipitation for the 2090s (2080s for Rwanda). The projection for Rwanda was obtained from Cole (2011) and the rest were obtained from United Nations Development Programme (UNDP) Climate Change Country Profiles (McSweeney et al. 2010a,b,c,d,e,f,g,h). Report for Rwanda represents an ensemble of 19 Global Circulation Models (GCMs) while UNDP studies comprise of an ensemble of 15 GCMs under three climate scenarios (B1: Rapid economic growth; focus on sustainability and environmental health; population growth peaks in 2050 and declines after; prevalent nonfossil fuel energy source use; relatively low increase in GHG emissions, A1B: Rapid economic growth and global economic development with balanced use of fossil fuels and nonfossil energy sources; population growth peaks in 2050 and declines after; moderate increases in GHG emissions, and A2: Economic development is regionally divided; global population continually grows; consistent fossil fuel use; relatively higher increase in GHG emissions).

Climate change also threatens some of the large protected areas (including ones that protect migratory species) that have been designated to conserve much of Africa's magnificent biodiversity. It is expected that vegetation will migrate or move in order to utilize suitable habitats requirements (i.e., water and nutrient availability); however, this may mean that in some locations the geographical range of suitable habitats will shift outside the protected area boundaries. In addition, weather extremes can also affect biodiversity in more complex ways. For example, in African elephants (Loxodonta africana), breeding is year-round, but dominant males' mate in the wet season and subordinate males breed in the dry season. Subsequently, a change in the intensity or duration of the rainy versus drought seasons could change relative breeding rates and, hence, genetic structures in these populations (Poole, 1989; Rubenstein, 1992). Strategies for future designations of protected areas in East Africa need to be developed that include projections of future climate change and corresponding changes in the geographic range of plant and animal species to ensure adequate protection.

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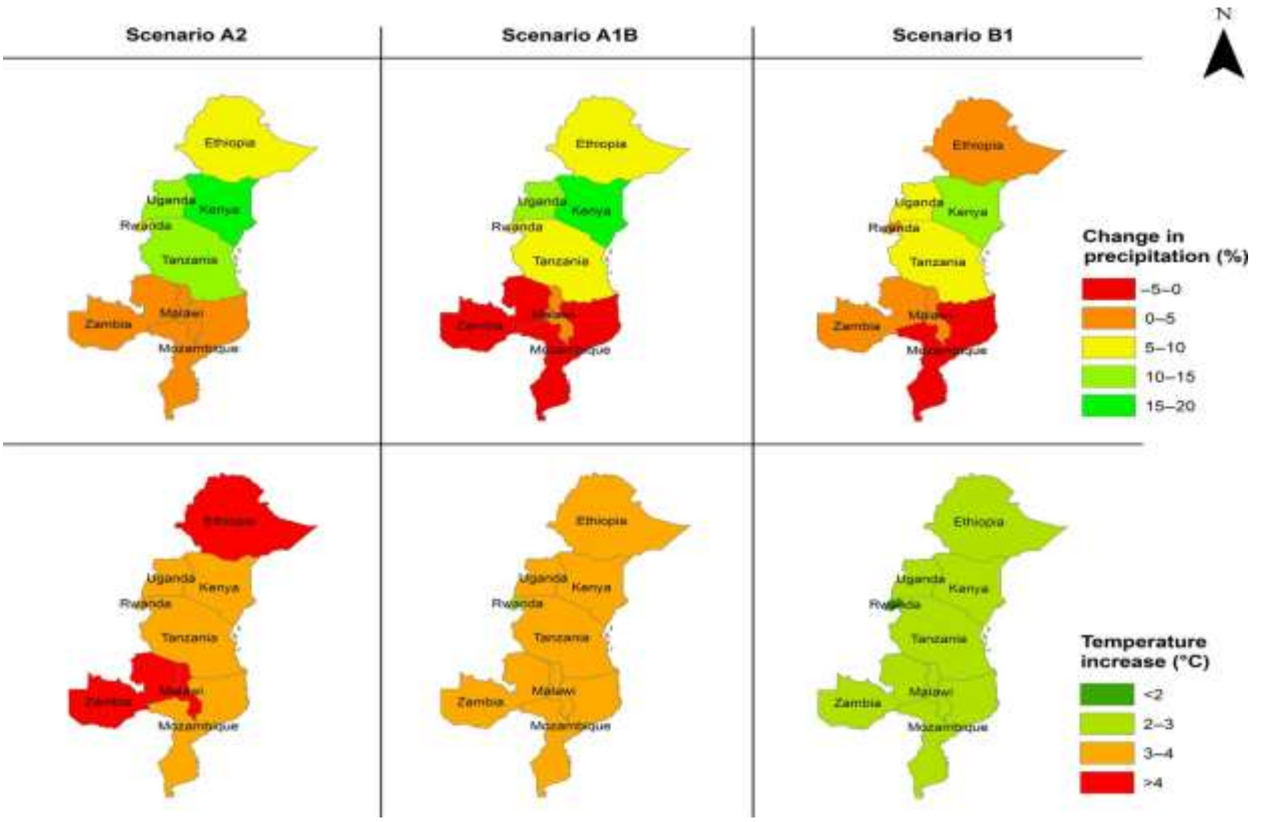

Figure 1: *Median projected temperature and precipitation change in East Africa for 2090s (2080s for Rwanda). Temperature and precipitation projections are from an ensemble of 19 GCMs for Rwanda and 15 GCMs for the rest of the countries under B1, A1B and A2 emission scenarios (McSweeney et al. 2010a,b,c,d,e,f,g,h; Cole 2011).*

Key players of tea and coffee industry in East Africa

Kenya: Kenya is predominantly an agriculturally based economy. Tea was reportedly introduced in the country by the Caine brothers who imported dark-leafed "Manipuri" hybrid seeds from Assam in 1904 and 1905 to establish a plantation at Limuru, Central Kenya (Matheson, 1950). In 1912, Chinary (var. sinensis) seeds were imported from Sri-Lanka to establish a plantation of tea with high quality and yield (Matheson, 1950). Planting expanded rapidly from 1924 following advice on the use of quality seeds from the light-colored leaf Assam or Manipuri types for drought resistance (Greenway, 1945). In the year 2018, Kenya produced 493 million Kg earning the country over Kshs. 140 billion in foreign exchange. This represents about 26% of the total export earnings, and about 4% gross domestic product (GDP) (Wachira, 2002; Kamunya et al., 2012; Azapagic et al., 2016). The country has more than 232,742 hectares of tea (International Tea Committee, 2018) spread in 18 counties and due to the low level of mechanization involved in cultivation, it offers direct and/or indirect employment to over 10% of the population. Further, because the industry is largely rural based, it contributes to both the local rural economies and reduces rural-urban migration (Wachira, 2002). Sustainability of the industry is thus crucial to the country's socio-economic well-being and development. Being a rainfed plantation crop in Kenya, tea depends greatly on weather for optimal growth. The plant is grown in high altitude areas East and West of the Great Rift Valley, between 1400 and 2700 m amsl, where rainfall ranges between 1800 and 2500 mm annually. Evidence suggests a negative impact of global warming on production and quality of tea, especially with regards to temperature rise, unpredictable rainfall trends and increasing frequency of extreme weather events such as hail storms, drought and frost (Boehm et al., 2016; Ahmed et al., 2018, 2019). Studies have documented that stress, especially drought, account for 14–20% loss in yield and 6–19% plant mortality (Ng'etich et al., 2001; Cheruiyot et al., 2007). Multiple environmental parameters are known to impact tea quality, although the directionality and magnitude is not clear likely due to variations in various factors such as cultivar, environment and management conditions (Ahmed et al., 2019). Under such circumstances, tea production is vulnerable to the predicted climate change effects and, subsequently, greater economic, social, and environmental problems. There is need for scientific and community-based adaptation and mitigation strategies. Adoption of multi-targeted approaches that seek to understand the complex physiological, biochemical and molecular regulatory networks associated with stress response will ensure sustainability of the tea sector. These necessitate intense research to improve tea production under diverse stress conditions.

Rwanda: Rwanda – the land of a thousand hills – is a small, densely populated, mountainous country at the heart of Africa. With a stable government and extensive development policies, the country is thriving. However, like many countries in Africa, it faces potentially large risks from climate change. What's different in Rwanda is that the country is already developing progressive climate policies and investing in climate change adaptation. Agriculture is a vital industry in Rwanda that employs 80% of the country's population and provides for a third of its Gross Domestic Product (GDP) as well as a large percentage of its foreign income through exports. The sector is dominated by tea and coffee production. By their very nature, tea and coffee crops are vulnerable to climate variability and change. They grow in subtropical to temperate, wet conditions, but the plants can be damaged by unseasonably heavy rains, or harmed by pests and diseases that spread in a changing climate. The Government of Rwanda has been banking on a major expansion of the country's tea and coffee-growing areas to drive future economic and social development. Does climate change put these plans at risk? The answer is yes, but there are many wise steps that government and industry leaders can take to protect crops from current climate variability and manage climate-related risks in the future. A new film ‘Adapting Rwanda: Growing Rwanda’s tea and coffee sectors in a changing climate’, by Hero productions and commissioned by CDKN and the Future Climate for Africa programme, documents some of the smart measures that farmers and estate managers can take to safeguard tea and coffee crops – and people’s livelihoods – in the short to medium term. The film presents a pragmatic approach to climate-proof tea and coffee sector plans from the early design stage, through implementation and project finance. The approach, developed by Paul Watkiss and the Tea and Coffee Climate Mainstreaming Project, in association with the Government of Rwanda, holds promise for Rwanda but also offers lessons to tea and coffee regions elsewhere in the world.

Uganda: An average temperature rises by 2.3 degrees Celsius by 2050 could potentially wipe out Uganda's most profitable tea producing areas, with severe losses in productivity already apparent by 2020. The multi-million-dollar Ugandan tea industry currently employs 60,000 small farmers and supports the livelihoods of up to half a million people. It is also known for producing the highest quality teas in the world. This means that the reduction in tea suitability for some areas will have a major impact on the country's economy. The Café direct Producers' Foundation, commissioners of the study together with the German Society for International Cooperation (GIZ), have therefore already met with farmer groups from Uganda and Kenya to discuss the implications of the new findings. The Producers' Foundation has also introduced more resilient tea varieties and helped with improving on-farm practices and encouraged the farmers to come up with their own, locally appropriate, adaptation and mitigation methods, such as reforest hillsides and protect water sources. This gives farmers an alternative source of income as well as food, and helps improve energy efficiency both on-farm and in tea processing factories. Creating an alternative income that is productive is also an important tool to reduce environmental degradation. Since suitability for tea production will be switched to higher altitudes with cooler climate, there is a theoretical risk that protected forests and nature areas will be cleared up to make space for the tea industry. A lucrative alternative source will thus help spread the risks associated with tea production. The farmers have noticed a change in the weather and rainfalls in the last few years, and now they have the science to understand the whole picture and the potential to take action.

Tanzania: Tea in Tanzania is mainly grown in five regions namely Mbeya, Iringa, Njombe, Kagera and Tanga. By controlling the prices of tea, the Tea Board of Tanzania (TBT) has been very successful in raising the tea production by focusing on supporting the small-scale farmers. Tea Board of Tanzania (TBT) is also organizing events, promotions and other marketing activities both in Tanzania and abroad to market the tea commodities produced by small farmers. Like other East African countries, Tanzania is also selling around 5,000 to 8,000 tonnes of tea at Mombasa tea auction every year. Another advantage that the Tea Board of Tanzania is doing to small-scale farmers in offering transport and warehouse storage facilities. Also, some tea processors like world known Unilever Tea have invested $8 million tea processing Plant in Mufindi, Tanzania.

Burundi: In Burundi, the first studies on the tea plant began at Gisozi Agricultural Research Centre (ISABU) in the province of Mwaro. In 1963, 1966 and 1969 the first state plantations known as "industrial blocks" were established in three tea production complexes: Teza, Rwegura and Tora respectively. Towards the end of the 1960s, the tea plant was popularized in village areas thanks to several projects financed by European donors, notably the European Investment Bank, the Caisse centrale de coopération économique (CCEE), the Agence française de développement, etc. (BM, 2008). Later, two other complexes were established in Ijenda and Buhoro in 1984 and 1992 respectively (FAO, 2016). State owned theiculture is therefore practiced in five complexes: Tora, Ijenda, Teza, Rwegura and Buhoro. Later, extensions in both state and village areas have been carried out and the increase in production has followed (Chart 1). In 2018, national production was 50,820 tonnes of green leaves (GL) on an area of 10,005 hectares. Nearly 80% of the theiculture is located on arable land in village areas with an average of 10 ares per farmer. Since 2010, more than 72% of the G L production comes from village areas.

The Tea Board of Burundi (OTB) is responsible for the management, control and regulation of the tea industry. The tea plant is a cash crop of vital importance to Burundi's economy. It is the second largest export crop after coffee, accounting for an average of 22.8% of the value of exports in 2017. It is the 2nd strategic sector for the country in terms of export earnings (Office Burundais des Recettes [OBR], 2017). Local leaders have come to a consensus, amongst themselves about the business principal which can drive improvements: quality starts at the farm level, and it can only be maintained through proper processing and storage.

South Sudan: South Sudan is a signatory to the Paris Climate Change agreement. The Ministry of Environment (MOE) and MAFS collaborated to create the 2015 Intended Nationally Determined Contribution (INDC) to the UN Framework Convention on Climate Change (Lamanna, 2019), and Working with UNEP, MOE delivered its National Adaptation Program of Actions (NAPA) in 2017. In addition, GRSS has drafted a disaster risk management policy, and prepared an environmental health policy. These programmes and policies can underpin the development of a sustainable and inclusive low-carbon and green economy that is resilient to climate change and integrate it in national strategies to eradicate poverty. Preparation of the Intended Nationally Determined Contribution is also critical. Effective implementation of these programmes and policies remains a challenge, due to the country's institutional and human capacity weaknesses.

METHODOLOGY

The paper reviewed published reports to collect the information regarding climate change on two specific cash crops in East Africa. Only information on tea and coffee was collected. Specially, the paper was based on the following objectives:

- Generate evidence of climate change impacts on tea and coffee production in the East Africa through a series of biophysical and socio-economic analyses;
- Provide policy support specific to climate change for tea as a template for a broader climate-smart agriculture development strategy and climate change policy more generally.

Because of the complexity of climate change and the multifaceted impacts, the paper followed an innovative approach based on the core principles:

- Demand-driven based on priority needs and feeding the project within the current programmes and initiatives on climate change,
- Evidence-based assessments (biophysical and socio-economic) of climate change impact.

Response of Tea and Coffee to Climate Change

Plant responses to stress are dynamic and complex. This is often manifested by its physiological and biochemical reactions, which can provide a basis for screening for and selection of individual varieties and germplasm resistant to stress factors. Such responses include stomatal closure, repression of cell growth and photosynthesis, accumulation of organic osmolytes, and activation of respiration (Muoki et al., 2012; Maritim et al., 2015). Several studies have reported the effects of stress on critical components present in tea and corresponding synthetic genes. The present section focuses on providing an overview of the physiological, biochemical and molecular mechanisms of stress response and tolerance in tea (Table 1). This will provide theoretical knowledge for development of climate-resilient tea cultivars as the parameters described can be used as stress index for screening and clonal selection.

Physiological Responses

Climate change induced stresses affect plant systems such as photosynthesis, respiration and water retaining capacity. Tea plants exhibit C_3 mechanism of photosynthesis, a key process affected by water deficits, via decreased CO_2 diffusion to the chloroplast leading to metabolic constraints (Tezara et al., 2002; De Costa et al., 2007; Pinheiro and Chaves, 2011). Relative impact of such limitations varies with the occurrence and intensity of stress. Rate of photosynthesis in tea increases up to an illuminance (photon flux density) of about 1000 μmol m^{-2} s^{-1} and then remains relatively constant (Smith et al., 1993), while the optimum leaf temperature for photosynthesis in tea is about 25–30°C (Smith et al., 1993; Mohotti and Lawlor, 2002; Barman et al., 2008). Under stress condition, the photosynthetic machinery of the tea plant are damaged, hence limiting the stomatal conductance of the leaves and eventually leading to a significant decline in net photosynthesis and respiration rate. Using drought resistant and susceptible tea cultivars, several studies have reported a significant difference in photosynthesis and respiration rate following reduction in soil moisture content (Netto et al., 2010; Lin et al., 2014; Maritim et al., 2015).

Tea has a critical xylem water potential value of −0.7 to −0.8 megapascal (MPa) in relation to potential SWD and saturation deficits of the air (Carr, 2010b). Previous studies have highlighted key physiological responses in relation to water deficit in tea (Cheruiyot et al., 2007; Maritim et al., 2015). Relative water content (RWC) is one of the most important measures of plant water status when plants are exposed to drought and heat stress. It reflects the degree of plants water status, retaining or regulation capacity (Anjum et al., 2011). RWC varies according to genotypes, with resistant genotypes maintaining higher RWC compared to susceptible ones (Maritim et al., 2015). Furthermore, a method for Short-time Withering Assessment of Probability for Drought Tolerance (SWAPDT) validated by targeted metabolomics for predicting the drought tolerance (DT) in tea was developed (Nyarukowa et al., 2016). The method relies on the percent RWC of tea leaves after 5 h under withering conditions. Based on metabolite profiles, drought tolerant tea cultivars differed from drought susceptible tea cultivars providing a basis for selection of new drought tolerant tea cultivars that may lead to improvement of crop productivity, amidst challenges imposed by drought due to climate change.

Biochemical Responses

As water is being removed from the cell, osmotic potential is reduced due to the effect of solute concentration (Yamada et al., 2005). However, if during the course of cellular water loss solutes are actively accumulated, osmotic potential would be reduced beyond the rate dictated by the mere effect of concentration. These involve the accumulation of organic compounds such as amino acids (e.g., proline), quaternary and other amines (e.g., glycinebetaine and polyamines) and a variety of sugars and sugar alcohols (e.g., mannitol, trehalose, and galactinol). Proline is widely studied because of its considerable role in stabilizing sub-cellular structures, scavenging free radicals, and buffering cellular redox potential under stress conditions (Ashraf and Foolad, 2007). In tea, proline accumulation under stress is significantly correlated with stress tolerance, and its concentration has been shown to be higher in stress-tolerant than in stress-sensitive plants (Chakraborty et al., 2002; Maritim et al., 2015). However, its use as a drought index is cultivar dependent. Nevertheless, stresses beyond tolerance levels will induce oxidative damage due to intensive production of reactive oxygen species (ROS) (Smirnoff, 1993). Glycinebetaine has also been reported to increase under stress condition (Maritim et al., 2015). Furthermore, tolerant cultivars have been reported to maintain higher polyphenol content at low SWC suggesting that cultivars with more stable polyphenols are more tolerant to water stress (Cheruiyot et al., 2007). Phenolic compounds can thus be useful indicators of DT in tea and will

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hasten the development of better-adapted cultivars to water-stress environments.

Genomic Responses

Rapid progress in molecular breeding in tea is attributable to advances in genomics technologies, especially DNA sequencing, leading to publication of two draft genomes (Xia et al., 2017; Wei et al., 2018). In Kenya, the approach has been integrated into tea improvement programs. Muoki et al. (2012) used subtracted cDNA libraries from irrigated and drought stressed plants of a tolerant cultivar to understand the molecular responses of tea to abiotic stresses, especially drought. With progressive drought, genes related to chaperones, cell rescue/defense and cellular transport categories exhibited an early up-regulation in tolerant as compared to the susceptible variety. Dysfunction of enzymes and proteins usually accompanies abiotic stresses. Plants induce the expression of chaperones to ensure protein stabilization and cellular homeostasis during stress (Wang et al., 2004). Maintenance of proteins in their functional conformations and prevention of aggregation of non-native proteins is particularly important for cell survival under stress (Muoki et al., 2012). Molecular chaperones function in the stabilization of proteins and membranes, and assist protein refolding under stress conditions (Wang et al., 2003). In addition, Maritim et al. (2016) reported a significant upregulation of drought-related genes such as heat shock proteins (HSP70), superoxide dismutase (SOD), gene catalase (CAT), ascorbate peroxidase (APX), calmodulin-like protein (Cam7) and galactinol synthase (Gols4) in drought tolerant as compared to drought sensitive tea cultivars. Further, three major enzymes, namely transferases, hydrolases and oxidoreductases are involved in flavonoid biosynthesis, alkaloid biosynthesis, ATPase family proteins related to abiotic/biotic stress response have been identified (Koech et al., 2019). However, plants have evolved various antioxidative systems to keep the levels of ROS under control (Mittler, 2002). ROS are capable of unrestricted oxidation of various cellular components and can damage cell membranes and macromolecules. Many abiotic stresses directly or indirectly affect the synthesis, concentration, metabolism, transport and storage of important carbohydrates in plants. Soluble sugars are known to act as potential signals interacting with light, nitrogen and abiotic stress to regulate plant growth and development (Cramer et al., 2011). Overall, the level of soluble sugars increases with progressive drought stress in tea, wherein drought tolerant cultivars maintained higher levels as compared to the susceptible cultivars (Damayanthi et al., 2010). This finding indicated the ability of the tolerant cultivars to withstand drought by osmotic adjustments. Data generated from these studies provide critical resource for development of markers that can be used for selection of climate resilient tea cultivars.

Breeding and Selection

Conventional Approach

Sustainability and profitability of the tea industry depends primarily on the availability of desired planting materials. Most of the genetic improvement and the substantial increase in tea yields realized this far is brought about by conventional breeding through selection for hybrid vigor, though the process has continued to evolve over the years. Tea breeding essentially consists of four phases; generation of genetic variability, selection of useful genotypes and comparative tests to demonstrate the superiority of the selected genotypes. A fourth phase that involves exposing pre-released and promising clones to multiple sites (genotype-environment interaction) for stability and adaptability is always the final phase in plant improvement programs (Wachira et al., 2002; Kamunya et al., 2010). It is worthwhile to note that TRI has developed over 1,000 improved cultivars, out of which 58 cultivars have been selected for consistent superiority in yield and quality and released for commercial exploitation. Fourteen of these clones are capable of yielding between 5,000 and 8,000 kg of made tea per hectare per year. These yield levels are some of the

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highest in the world and are in the magnitude of three times the average yields of unimproved tea.

Approaches involving intravarietal and interspecific hybridizations have also been tapped as means of introducing desirable traits (Kamunya et al., 2012). The approach is facilitated by the availability of diverse genetic collection, standardized vegetative propagation procedures, continuous germplasm enrichment through material transfers between research institutions and the comparatively low operational costs involved. A remarkable achievement of conventional breeding was the transition from pioneer seedling tea plantations to the adoption of modern high-yielding vegetatively propagated cultivars. This led to a drastic increase in tea production globally in the mid-20th century. The technique reduced the juvenile period to as short as 6 months from the protracted 3 years for seed raised tea plants (Wachira, 2000). Given the financial considerations associated with clonal teas, farmers are now uprooting and replacing the old and diverse seedling tea plantations with a few improved clones. As clones represent instantly fixed genotypes, the practice means over-reliance on a limited number of cultivars, implying that on-farm diversity is minimizing and the risks posed by co-evolving challenges associated with climate change is increasing. Another emanating problem is that most tea breeding programs rely heavily on a few clonal parents as donors of desired genes, thereby manifesting the potential danger of mono-cropping (Wachira, 2002). For instance, 67% of released varieties in Kenya share the same female parent, cultivar TRFK 6/8 which is susceptible to root knot nematodes.

As water resources for agriculture become more limiting, the need to develop drought tolerant cultivars is increasingly gaining importance. The ability of plants to tolerate changes in extremes of abiotic stress conditions is a complex and coordinated response, involving hundreds of genes. These responses are also affected by interactions between the different environmental factors and the developmental stage of the plant. Breeding involves genetic alteration or modification of organisms through natural or human-imposed mutations or crosses. This process has continued to evolve in tea over the years. A foundation in conventional breeding has contributed significantly to tea improvement. This involves the identification of stress tolerant parents intra- or interspecific hybridization, establishment of progeny trials (PTs), clonal field trials (CFTs), and clonal adaptability trials (CATs).

Attempts to improve stress tolerance in tea through conventional breeding programs have, however, met limited success, partially attributed to the robust breeding programs and improved crop husbandry (Kamunya et al., 2010, 2012). However, due to the lack of sufficient genetic information about genes that govern this complex trait and its component secondary traits, progress in tea improvement has been slow. Research has shown that DT varies considerably between tea cultivars (Ng'etich et al., 2001; Cheruiyot et al., 2008; Carr, 2010a, b; Kamunya et al., 2010), which further suggests the need for investigating the genetic architecture and adaptive responses of tea to drought. Limitations in conventional breeding coupled with advances in molecular breeding have unveiled a new era in tea breeding.

From Conventional to Molecular Breeding

Understanding the genetics of how organisms adapt to changing environment is crucial for the adaptability of a genotype (Chinnusamy and Zhu, 2009). Due to the limitations associated with conventional breeding approaches, other means of genetic improvement are being explored. Availability of molecular tools arising from the development of molecular markers manifested a significant advancement in crop improvement in the 1980s. Different marker systems such as randomly amplified polymorphic DNA (RAPD), restriction fragment length polymorphism (RFLP), amplified fragment length polymorphism (AFLP), sequence tagged sites (STS), single-strand conformation polymorphism (SSCP), inter simple sequence repeat (ISSR), simple sequence repeat

(SSR) or microsatellite, Diversity Arrays Technology (DArT) microarray and chloroplast DNA (cpDNA) have been developed and applied in tea breeding (Wachira et al., 2001; Mondal et al., 2004; Chen et al., 2007; Sharma et al., 2009; Wambulwa et al., 2016a, b, 2017; Koech et al., 2018, 2019). These markers have been applied in genetic studies relating to assessment of genetic diversity and germplasm characterization, genotype identification and fingerprinting, estimation of genetic distances between populations, assessment of mating systems, detection of quantitative trait loci (QTLs), and marker-assisted selection (MAS) in tea (Wachira et al., 1995, 1997; Paul et al., 1997; Hackett et al., 2000; Muoki et al., 2007; Kamunya et al., 2010; Koech et al., 2018, 2019).

Most attributes of agricultural importance frequently manipulated by plant breeders (e.g., size, shape, yield, quality, tolerance to abiotic, and sometimes biotic stresses) display a quantitative mode of inheritance and normally exhibit continuous variation (Collard et al., 2005). Continuous variation in a phenotype can be explained by the independent actions of many distinct genetic factors, each having small effects on the overall phenotype. Detection of QTL controlling complex traits followed by selection has become a common approach for selection in crop plants. QTLs or linkage mapping aims at identifying genomic regions that could be useful to analyze genetics of complex traits (Stapley et al., 2010). QTLs are typically mapped by crossing parental varieties contrasting for the trait of interest to generate a mapping population which are then scored for phenotypes and genotyped so as to identify the parts of the genome that improve the trait and the genome regions that influence component trait linked to the main trait. Once achieved, targeting of genomic regions for varietal improvement could be possible through MAS, thereby shortening the development and release of elite varieties for commercialization (Hackett et al., 2000; Kamunya et al., 2010). The approach is helpful in tea where conventional breeding technique takes over 20 years to develop an improved cultivar. Integration of molecular markers in breeding and clonal selection would also help in reducing the number of clones/seedlings for field testing (Kamunya et al., 2010).

The first genetic linkage maps for tea was constructed using RAPD and AFLP markers and covered 1349.7 cM with an average distance of 11.7 cM (Hackett et al., 2000). In addition, QTLs for yield, DT, quality traits [percent total polyphenols (%TP)], fermentability (FERM), theaflavins (TF), thearubigins (TR), and pubescence (PUB) has been reported (Kamunya et al., 2010). Here, bulk segregant analysis followed by complete genotyping identified 260 RAPD and AFLP informative markers. Of these, 100 markers showing 1:1 segregation, were used to generate a linkage map with 30 (19 maternal and 11 paternal) linkage groups spanning 1411.5 cM with mean interval of 14.1 cM between loci. On the basis of the map, QTL analysis was done on data over two sites. A total of 64 putative QTLs for various traits across different sites were detected. More recently, phenotypic data for two segregating tea populations was used to identify QTL influencing tea biochemical and drought stress traits based on a consensus genetic map constructed using the DArTseq platform (Koech et al., 2018). The map consisted of 15 linkage groups from the two populations comprised 261 F1 clonal progeny and spanned 1260.1 cM with a mean interval of 1.1 cM between markers. Both interval and multiple QTL mapping revealed a total of 47 putative QTL in the 15 LGs associated with tea quality and percent RWC at a significant genome-wide threshold. These markers contribute greatly to adoption of MAS for DT and tea quality improvement. However, positional cloning of genes controlling important traits in tree species is difficult (Stirling et al., 2001), partly due to the complexity of gene networks and interactions among or between genetic elements and the environment (Ribaut and Ragot, 2007). Such limitations can be overcome by adopting new approaches that exclude the need to map QTLs.

Future Prospects

Great progress has been made in assessment of the relationship between tea productivity and climate change. In order to anticipate the effects of climate change on tea and provide scientists with necessary knowledge and tools, multidisciplinary approaches should be embraced. The approaches outlined below are recommended:

- It would be important to quantify the long-term response of the tea plant to elevated CO_2 concentrations so as to understand the link between carbon supply and plant growth. The extensive use of artificial environments such as the free air CO_2 enrichment (FACE) technology can help examine the magnitude of elevated CO_2 on tea yield and quality at the level of the ecosystem.
- Invest in alternative breeding approaches such as mutation breeding for increased genetic variability. This should be followed by standardizing selection procedures which attempt to identify useful genotypes.
- Studies have shown that the response of plants to a combination of stresses is unique and cannot be directly extrapolated from the response of plant to each of the different stresses applied individually. Further, simultaneous occurrence of several stresses enhances the intensity of lethality to crop as compared to that imposed by a single stress. Nevertheless, little is known about the molecular mechanisms underlying the acclimation of tea to a combination of different stresses. Systems biology approach facilitates a multi-targeted approach for understanding complex molecular regulatory networks associated with stress adaptation and tolerance. The approach can help overcome limitations associated with morphological, biochemical and molecular adaptation of the plants to stress. Tolerance to a combination of different stress conditions, particularly those that mimic the field environment, should be the focus of future research programs aimed at developing improved varieties and plants with enhanced tolerance to naturally occurring environmental conditions.
- Establish multi-stakeholders' collaborations aimed at developing sustainable adaptation strategies for management of climate risks associated with climate change in the tea industry.

CONCLUSION AND RECOMMENDATION

The East African tea industry is having great potential for the future. However, the region has to overcome the challenges related to black tea production and production efficiencies. Further, when moving forward, it is a must to explore the possibilities for black tea value addition like iced tea in home countries as well, a large portion of the profit share remains with the ultimate packer or trader. The East Africa region has to focus on identifying changing trends in the consumer market instead of sticking to the age-old production and trading techniques. For instance, the demand for sustainable initiatives such as organic production and fair-trade production is rising all over the world, and this region has massive potential in capitalizing on these untapped areas.

Coffee production forms a strong base of food security and a source of livelihood to a large percentage of the rural people. Coffee production is largely dependent on climate conditions, making it vulnerable to climate variability. The reviewed reports indicate that coffee production affected by climate variability. The productivity of Arabica coffee is tightly linked to climatic variability. Temperature in particular is a very important driver in different phases of the life cycle. On the response of coffee production to rainfall and rainfall variability, the study findings indicate that: a general decrease in rainfall have no significant effects on the coffee production but its distribution matters. The rainfall decrease in months from December to February (flowering period for coffee) in the East Africa implies the coffee production decrease as the case of low coffee production in 2007. In terms of response of coffee yield to changes in temperature and temperature variability, the study found that changes in temperature and temperature variability have the significant effects on coffee yield. The changes in temperature have influenced expansion of coffee production. A decrease in mean and maximum temperatures implies the increase of coffee production in Maraba for the period (2002-2017), but the change in minimum temperature had no significant influence on coffee yield in the study area. An increase in mean and maximum temperatures implies the reduction of coffee production. These conditions increase climate risk and greatly compromise the economic viability of the coffee crop, making coffee farming less desirable. In some instances, this may have resulted to farmers uprooting coffee and adopting new crops that are better suited to new climate conditions or converting or which are under crop to other land uses other than farming. Although rainfall has been decreasing over the last sixteen years, overall, this study concludes that; the increase in coffee production in Maraba is strongly attributed to the decline of temperature and its variability. However, while the increase could be attributed to other factors, the trends of rainfall, temperature indicate that the study area is vulnerable to the impact of climate change and variability.

Global warming is predicted that rising temperatures and water shortages will negatively affect coffee production suitability at lower elevations and vice versa. The already perceived impacts of climate change on coffee production will not only be threat small scale farmers but also all actors involved in coffee industry. Therefore, it is possible to withstand the negative impacts of climate change by different adaptation and mitigation practices viz, shade use and reforestation, crop improvement, intercropping and other conservation practices. Comprehensive accomplishment of these practices helps to alleviate the impact of climate change on coffee.

Climate change impacts to rural farming communities can be reduced by distributing climate data regarding seasonal climate forecasts (based on short-term and long-term forecasts) to small farmers so that they can make more informed farming decision and adapt to the changing climate conditions. Some farmers have already started to use this information and are preparing themselves for dry conditions by planting drought-tolerant crops (Patt et al., 2005). Food production can be improved dramatically in dry areas when governments and/or organizations use climate forecasts and prepare accordingly by potentially distributing drought-tolerant seeds (Patt et al., 2005). Farmers can also take advantage of climate forecasts by planting less drought-tolerant and higher-yield, long season maize when wetter than usual growing seasons are forecast (Patt et al., 2005). While seasonal forecasts can be useful in some situations, it should be noted that they cannot be applied everywhere and that many times they do not consider multiple climate extremes, for example, they may forecast drought but not extreme rainfall. The aforementioned approaches are just a few of the many examples that governments, organizations, and communities need to consider in order to adapt to the challenges of subsistence food production and assure future food security (Patt et al., 2005; Ziervogel, 2004).

All sectors need to adopt and recognize the value and significance of healthy intact ecosystems. Sectors such as forestry, wetlands, tourism, agriculture, energy, infrastructure development (among others) need to:

- Offer tea and coffee capacity building and training for ecosystem-based adaptation, targeted at policy makers and practitioners at different levels;
- Ensure the coffee producers focus on policy of increasing both quantity and quality of coffee since it is one of the most sustainable way to enhance coffee production;
- For the Governments in EAC to continue promoting climate smart agriculture to improve

coffee production both yield and high quality, and to adapt to climate change focusing on small holder farmers that dominated the agriculture sector mainly coffee sector.

- For development partners to start investing in coffee extension focusing in the highly suitable region to avoid the loss of yield and good coffee quality in coming year

Sector specific recommendations included:

- **Financing:** Leverage resources and appropriate funding mechanisms for ecosystem-based approaches especially those that are trans-boundary in nature.
- **Agriculture:** Focus on systems that promote health of soil, water and agricultural ecosystems.
- **Water:** Employ integrated water resource management approach and protect ecosystems that naturally capture, filter, store and release water.
- **Transport:** New transport networks should not affect the ability of local people deal with climate change, for example by undermining ecosystem services.
- **Energy:** Mitigation responses and energy supply do not undermine ecosystem services or habitat loss.
- **Forestry:** promote responsible forest resource management that seeks to meet interests of the communities through ecosystem-based approaches.
- **Ecotourism:** seek to popularize the diversity of life, meet interests of the tourist without undue stress to the ecosystems.

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