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Ethiopia, Plants

Breeding Climate Resilient Coffee Cultivars in Ethiopia

Ethiopia is considered one of the oldest independent countries and is home to a population of over 128 million people ("Ethiopia population (live)"). Located in the Horn of Africa, the modern nation of Ethiopia is considered to have been created by Emperor Menelik II through his effort to consolidate land through the conquest of neighboring kingdoms in the late 19th century (Greenfield, Richard David.). Today, the country is a rapidly developing country that is dealing with intense climate change disturbances. Most importantly climate change has impacted the region's agriculture with a projected to reduce yields of the wheat staple crop by 33% (Simane, Belay). Additionally coffee is important to the region for being one of the major exports and a crop that is threatened by climate change. Studies project that by 2030, there will be a significant decrease of 25% in annual yield due to increased climate variability ("Climate Change and Coffee Production in Ethiopia."). To mitigate this problem, Ethiopia needs to embark on the creation of a national coffee breeding research agenda consisting of both a modern plant breeding program and a pre-breeding program to create climate resilient coffee cultivars.

Addis Ababa serves as the capital of Ethiopia and is located in the central region of the country, and translates to "New Flower" (Crummey, Donald Edward). The government is a federal republic with a bicameral parliamentary democracy, the Ethiopian Federal Parliamentary Assembly consists of two legislative chambers, the lower house being the House of Peoples' Representatives consisting of 547 members, and the upper house being the House of Federation consisting of 112 members ("The Federal Government of Ethiopia."). Members of the House of Peoples' Representatives are elected for five year terms with single-seat constituencies while members of the House of Federation are elected by State Councils with five year terms ("The Federal Government of Ethiopia.","Ethiopia: Freedom in the World 2022 Country Report."). Ethiopian citizens elect representatives to parliament to create laws (*Central Intelligence Agency*). The current prime minister of Ethiopia is Abiy Ahmed and the president is Sahle-Work Zewde (McKenna, Amy,"Sahle-Work Zewde").

The economy of Ethiopia is primarily centered on agriculture and other sectors such as industry and services have only been slightly increasing ("Country Profile – Ethiopia"). The major exports of Ethiopia are coffee (27%), gold (18%), and oil seeds (9%). Ethiopia is the largest African coffee producer and it has been seen as where coffee was discovered in the eponym Kaffa region ("Country Profile – Ethiopia"). Coffee is the largest export and is responsible for a third of the agricultural exports ("Country Profile – Ethiopia"). Many of these goods went to the United Arab Emirates (18%), United States (14%), and Somalia (9%) ("Ethiopia - Market Overview."). The agriculture in Ethiopia has stretched 385,950 square km ("Agricultural Land (Sq. Km) - Ethiopia.") over the land, that is 34.2% ("Agricultural Land (Sq. Km) - Ethiopia.") of the total land area. The average farm size in the United States is 445 acres ("Farms and Land in Farms 2021 Summary") that is 180.085 hectares compared to Ethiopia where the average size is 0.95 hectares per household (IHSN). Women and children are responsible for fetching water over long distances and sometimes even taking up to half a day ("Country Profile – Ethiopia"). Many of the land owners are male and there are just a handful are women because they do not equally get access to farm plots. 75 percent of the labor on the farms and 70 percent in the household chores are managed by the women. Furthermore, women have less access to extension services and agriculture inputs including irrigation ("Country Profile – Ethiopia").

The typical family size in Ethiopia is 4.6 members with nearly half of the population being under 15 years of age (Ethiopian Statistical Service). The average home is made out of wood and mud, this causes many problems with leaking roofs and a decrease in cleanliness.The homes are very small including the average range of only one to two rooms per house. Averaging about 70 percent of homes are total replacements with the living conditions they are faced with (“Ethiopia.”). The members of the household are also dealt with unhealthy sanitation living areas. More than 43% have to use open pits or pit latrines without slabs and 38% are left without a use of a toilet facility (“Ethiopia.”). Additionally, 57% of Ethiopians population has access to safe drinking water that is significantly higher in the rural areas. Ranging around 5 million of the population of Addis Ababa live in overpopulated settlements. This area has a deficiency of sanitation that causes more health and safety risks in the region (“Ethiopia.”). Many of these families live on a plant-based diet consisting of grains, root and tuber groups that are made into bread, kocho, and kolo. The second food group the regions utilizes pulses and legumes that are known as peas. These are used to prepare stews such as lentil stew and pea-flour stew. Stews can also be prepared from a variety of meat (beef, fish, chicken). These families grow their own foods through the smallholder farms that produce 90 to 95 per cent of the region's agriculture output (“Ethiopia.” IFAD). The diets in Ethiopia are based around a low-fat diet because originally in Ethiopia refrigerators were not accessible therefore in order for shelflife of food to stay, special techniques were developed to preserve the food (“*The Blue Nile”*).

Ethiopians have an average income of 1,020 USD, Ethiopia considered one of the poorest countries (“Ethiopia: Country Data and Statistics). Agriculture is 68 percent of the employment share followed by trade (Page et al.). Children in Ethiopia have had a significant increase towards primary education with a net enrolment of 88.7 percent in the 2021-2022 school year. Although this increase is good for the region, many of the children do not progress with only 33.1 percent of children making it to secondary school. The teaching in the region is also a major challenge with 90 percent of 10 year olds not knowing how to read or understand a simple text-based sentence (“Learning and development!”). With health facilities, there are approximately 1600 health care posts and 3335 health centers and 156 hospitals in the region (“Healthcare”). These health facilities lack water quality and only about 32% have access to clean water. From the decrease in the quality, 17% of children die associated with diarrhea in which remains the third leading cause of under-five mortality attributed to poor water, sanitation and hygiene. Many of the families in Ethiopia face the challenge with finding sanitation in water quality. 43% of the population does not have access to an improved water source and 28% practice open defecation (“Ethiopia | Water, sanitation and Hygiene (WASH)”).

Ethiopia's decline in available water that has been caused by the abnormal rainfall patterns, and distribution along the land. Climate change has been a factor in the decline of annual precipitation within the country and has exacerbated food scarcity challenges within many regions. Significant flooding in many regions has occurred when areas receive significant amounts of rainfall over very short periods of time. This issue is burdened by the lack of climate-proofed water infrastructure. (“Climate change is real!”). Families in the region are suffering with greater variability and extreme weather events, this is affecting 85 percent of farmers who are dependent on rain-fed agriculture (“Ethiopia.” Global Climate Change). Climate change has already had a major impact upon the coffee industry with deforestation and loss in crops and area. As climate change continues, many of the suitable areas for coffee production will no longer be suitable in the upcoming future (“Building a climate resilient coffee economy for Ethiopia”).

Coffea arabica faces many challenges in relation to climate change (Montagnon et al.). The global trade of coffee depends upon two species: Arabica coffee (*Coffea arabica*) that makes up 60%, and robusta coffee (*Coffea canephora*) with 40% (Bilen, Christine). *Coffea arabica* is believed to have originated in the highlands of southern Ethiopia and the region is considered the center of diversity for the species. The center of genetic diversity within a crop species is the location where a plant species exhibits the highest degree of genetic variation ("Center of diversity"). Wild *Coffea arabica* populations and local landrace cultivars are adapted into their climate conditions and management uses (Casañas et al. Within this region might contain genes of interest for plant breeders such as disease resistance or climate resilience. The World Coffee Research predicts that global research into coffee research and development will require an additional investment of $452 million annually over the next decade to meet the challenges to the industry in areas such as coffee cultivar development ("Ensuring the Future of Coffee."). To maintain the economic viability of the coffee industry in Ethiopia, the country needs critical investment in its current coffee breeding programs managed by the Ethiopian Institute of Agricultural Research (EIAR) for the development of both pureline and hybrid *Coffea arabica* cultivars ("Ethiopia Mobilizes Investment to Build Modern National Coffee Breeding Program." (Benti, Tadesse.) Solutions to these daunting problems in the coffee industry will require significant government investment and support. I propose that the government of Ethiopia increases EIAR's budget through the annual appropriations process, to reinvigorate the current coffee plant breeding program and the creation of a new coffee pre-breeding program.

As Ethiopia's governmental agricultural research service, EIAR has demonstrated success in the creation of new and improved coffee cultivars, but lacks the investment needed to ramp up plant breeding capacity and develop coffee cultivars more quickly for widespread deployment to farmers. Plant breeding is a critical endeavor to develop new plant cultivars through the process of crossing the best performing cultivars with one another to combine desirable traits together which outperform both of the parents and other cultivars currently available in a single metric or over multiple metrics. The first step to a successful breeding program is the characterization of the current germplasm available to a plant breeder. Characterization entails the process in which cultivars are trialed over multiple years and locations, and where measurements of traits of interest are taken. The plant breeder can then narrow down which cultivars would be of the greatest use to use as foundational parents within a breeding program. It takes around 15-20 years to create a new coffee cultivar (Wilder, Ashlen.). Due to the long generation time for coffee plants to mature to the life stage where they are old enough to fruit (SanMax, Isabelle Mani.). Shortening the time that it takes for plant breeders to produce high performing coffee cultivars is critical in adapting the coffee industry in the face of a rapidly changing environment.

There are two types of coffee cultivar development strategies currently being utilized, which include pure line cultivar development and hybrid cultivar development. Pure line cultivar development is when two parental cultivars are crossed and then the resulting progeny are inbred through the process of self-pollination. Inbreeding is when individual plants are pollinated with their own pollen over multiple generations, which results in plants that are homozygous, their progeny that are identical to the parental line ("Inbreeding."). Inbreeding over multiple generations reduces heterozygosity until the line reaches homozygosity. Heterozygosity is when an individual has two different alleles at a locus, while homozygosity is when an individual possesses two identical alleles from both of the parents (Singh, Asheesh). Once a line reaches homozygosity, the resulting progeny are phenotypically and genetically the same which allows farmers to plant seeds that result in uniform progeny. A plant's phenotype are simply traits that are measurements of the plant's physical attributes which can be physically seen and are determined in part by their interaction with their environment ("Phenotypically Definition"). Currently, *Coffea arabica* is primarily propagated by seeds which results in variable plant quality ((PDF) Coffee (Coffea Arabica L.)). If farmers are able to switch to using cultivars that are clonally propagated or

grafted, the use of hybrid cultivars becomes feasible. Clonal propagation will help farmers with creating identical copies of the cultivar ("What Is Clonal Propagation?"). Hybrid cultivar development is when two inbred parents are crossed together which result in progeny that exhibit heterosis which surpasses the qualities of both original parents (Anderson, Gretchen). Both cultivar types are important to invest in to address the needs of various farmer preferences.

Additionally, for long-term resilience there is a need to develop a *Coffea arabica* pre-breeding program to introduce climate resilient traits from wild undomesticated *Coffea* species into domesticated germplasm (Volk, Gayle). Pre-breeding is the process of identifying desirable traits for new offspring to improve the cultivar. The Crop Trust defines the goals of pre-breeding as "to isolate desired genetic traits (e.g. disease resistance) from unadapted material like CWR [crop wild relatives] and introduce them into breeding lines that are more readily crossable with modern, elite varieties." ("Pre-Breeding."). To create resilient coffee cultivars, we need to identify the best wild crop relatives to use from the 125 *Coffea* species known to exist. These wild species could be reservoirs for genes of interest to improve *Coffea arabica* breeding (Petruzzello, Melissa.). Wild crop relatives are known to have been adapted through natural selection to survive adverse conditions such as dryness, wetness, high temperatures, and poor soils ("Home."). If we are able to stack these resistant traits together into current *Coffea arabica* germplasm, then these new cultivars will be able to withstand the negative impacts of climate change. *Coffea arabica* is derived from two ancestral species *Coffea eugenioides* and *Coffea canephora*. Plant breeders should first look to these species to identify what genes would be of importance to incorporate into *Coffea arabica*. The limited gene pool within *Coffea arabica* caused by the genetic bottleneck during domestication is a major hurdle to crop improvement. The creation of a pre-breeding program would widen the genetic diversity available within *Coffea arabica* that plant breeders can select from.

Ethiopia has been directly impacted by ongoing impacts of climate change which are expected to worsen throughout the 21st century. The country is one of the largest arabica coffee producers in the world and the center of origin for the species *Coffea arabica*. With the increase of annual temperatures and erratic weather patterns, many important coffee producing areas currently suitable for coffee production may soon be unable to profitably produce coffee without significant investment in the creation of resilient coffee cultivars. These challenges can be mitigated through greater investment in the expansion of plant breeding capacity within Ethiopia's current coffee breeding programs and the creation of a pre-breeding program to introduce climate resilient traits into current coffee breeding germplasm. New cultivars developed from these programs have the possibility of helping farmers withstand the impacts of climate change while ensuring a stable source of income for their families. If Ethiopia is expected to continue leading the world in arabica coffee production, it will need to implement significant steps to withstand the harsh impacts of climate change and allow coffee producers to achieve economic mobility.

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