THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF BIOLOGY

AN ANALYSIS OF THE EVOLUTIONARY ADVANTAGES OF NATIVE SPECIES IN THE ARID AND SEMI-ARID LANDSCAPES OF NORTHERN KENYA

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ABSTRACT

Climate change is rapidly transforming the planet, causing severe alterations to soil, landscapes, wildlife, weather patterns, and air quality that can critically disrupt ecosystems. Environments that have been getting hotter and drier due to climate change are at risk of becoming uninhabitable by native wildlife species. By studying plants in Kenya's arid and semi-arid landscapes, patterns of adaptations occurring in plants in response to the changing environment can be directly observed. Knowledge of adaptations can be used to provide aid to local Kenyan farmers to improve yield and productivity. Northern areas of Kenya were the primary focus of this study, specifically Marsabit, Samburu, and Turkana. This study used images of arid and semi-arid landscapes to gather a list of species that were further studied to gain information about the mechanisms that have allowed the species to inhabit the deteriorating area. Six model species were identified and analyzed: *Vachellia tortilis, Vachellia abyssinica, Salvadora persica, Sansevieria erythraeae, Balanites rotundifolia*, and *Prosopis juliflora*.

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Chapter 1

Introduction

Scientists predict that the Earth we once knew is heading toward a destructive, unforgiving future if climate change is not addressed and acted on now. Climate change is a relatively new concept that has arisen in the past two-hundred years, primarily due to anthropogenic or human causes. The changes humans have made to Earth's atmosphere have been gradual throughout human existence but have built up with time. The main contributor to climate change is the use of fossil fuels as energy. Fossil fuels started to be widely used during the Industrial Revolution in the 1750s. Burning fossil fuels releases carbon dioxide into the atmosphere since they are slowly formed from decaying organisms (Hardy, 2003). Carbon dioxide and other greenhouse gases in the atmosphere trap infrared radiation and therefore heat into the atmosphere below, increasing surface and ocean temperatures (Zandalinas et al., 2021). Since the start of the Industrial Revolution, levels of atmospheric carbon have increased by about thirty-three percent, and Earth's climate has increased by about two degrees Fahrenheit (Hardy, 2003). These unprecedented changes impact wildlife and the environment in ways humans could not have predicted.

However, the warming of the Earth is not all that needs to be worried about. There are numerous other effects of climate change, including loss of sea ice, acceleration of sea levels rising, long and intense heat waves, drought, longer wildfire seasons, uneven precipitation patterns, increase in natural disasters, changes to soil and microbiomes, and a decrease in freshwater availability (Jackson, 2023). These problems will lead to a completely different landscape across the globe, with an overall loss of land and changes in land usage. This impacts where humans will be able to survive and where they will be able to farm. With the growing human population more enormous than ever, there is less and less livable land and arable land to use. In addition, other species will lose their natural habitats and, therefore, shelter and food. It is predicted that by 2050, 15 to 37 percent of species alive today will become extinct due to climate change (Thomas et al., 2004).

In order to save ourselves and our planet, action must be taken to return atmospheric carbon dioxide levels to pre-Industrial Revolution levels.

1.1 Effects of Climate Change on Plants

The effects of climate change on animals and the environment have been extensively studied in recent years, but information on plants is less substantial. The focus on plant species has primarily been on how to engineer crops to withstand climate change, while wild-type species are left to fend for themselves. It is crucial to have crops that are able to endure climate change so humans have enough food to support the growing population, but the effects of wild-type species loss can also be detrimental. Global warming decreases the fitness of wild-type plant species, forcing them to adapt or migrate to avoid extinction in their natural habitats.

Even though more research is needed, there are known effects to plant growth and behavior due to climate change. Research on how carbon dioxide levels directly affect plants is inconsistent amongst plant species, so most studies focus on increases in temperature and differences in weather patterns (Craufurd & Wheeler, 2009). Since plants have a narrow optimal working temperature range, changes in seed development and germination, vegetative development, and thermomorphogenic responses can be recorded (Lippmann et al., 2019). Germination and seed dormancy rely heavily on temperature and can even be affected by a change of less than one degree Celsius (Lippmann et al., 2019). Whether or not a seed germinates or continues to stay in a state of dormancy is then heavily dependent on the temperature of its environment. Warmer temperatures are associated with earlier germination but can be inhibited by hormones released in response to high-stress temperatures, so adaptability to one's changing climate is crucial (Lippmann et al., 2019).

Climate change can also have vast effects on a plant's vegetative development. For example, global warming has extended the growing season but has decreased the duration of vegetative development (Lippmann et al., 2019). Plants have limited energy that can be used at one time, so compartmentalizing energy into what process(es) are needed the most can take away from growth during the developmental stage. For example, an increase of just one degree Celsius for wheat plants decreases yields by about five to eight percent (Craufurd & Wheeler, 2009). Even though wheat is used as a cultivated crop, the trend can be applied to various plant species.

Lastly, thermomorphogenic responses to climate change can be used to determine a plant's adaptation to climate change. All plants do not utilize thermomorphogenic responses, but they are still an efficient indicator of adaptation. For example, global warming induces cell elongation and leaf hyponasty resulting in a more open plant structure (Lippmann et al., 2019). This allows for increased ventilation and transpiration in order to cool the plant's leaves in response to higher temperatures (Lippmann et al., 2019). However, this response adds to the decreased vegetative development phenomenon associated with climate change. These environmental pressures push species to adapt or else risk extinction.

1.2 Adaptation Mechanisms

Natural selection and evolution are constantly working in all living organisms to aid species' abilities to adapt to changing environments and lifestyles. Most species combat climate change by moving or shifting their developmental timelines (Hoffmann & Sgro, 2011). However, plants have more difficulty moving than other organisms to transverse land since they rely on seed dispersal by external forces such as wind patterns or animal consumption and travel, making evolutionary adaption more critical (Hoffmann & Sgro, 2011). If plants capitalize on the increased carbon dioxide levels and growing seasons, they have an increased chance of survival. A high degree of plasticity is necessary in order for plants to adapt to their rapidly changing environment. Plasticity refers to the degree of pressure the organism feels from the environment to adjust (Hoffmann & Sgro, 2011). In addition, natural selection requires a large population size to ensure genetic variation is present, which selection needs to act on.

Adaptation can occur through a number of different methods. Adaptations can arise through natural selection, mutation, gene flow, or genetic drift. Natural selection acts on genetic diversity already present in a population. During reproduction, traits given to offspring are chosen due to advantages given to the parents during their lifetime. Over time, advantageous characteristics will increase in a population. Mutations occur in populations at random and are highly probable but mostly deleted. Mutations that are deemed to be evolutionarily beneficial to a species tend to increase in a population due to natural selection. Gene flow occurs when two populations of the same species reproduce together. Even though genetic variation is inevitably lost due to the admixture of the two populations, hybridization can prove advantageous in changing environments and facilitating new adaptations (Hoffmann & Sgro, 2011). Genetic drift is similar to natural selection in that it changes gene frequency in populations; however, genetic drift is entirely random.

1.3 Biogeography of Arid and Semi-Arid Landscapes

Sub-Saharan Africa has been severely affected by climate change, which has caused drastic changes in the natural landscape and biodiversity. Eighty-three percent of land in Kenya is arid and semi-arid land (ASAL), used for agriculture and livestock production (Macharia et al., 2012). Pastoralists and smallholder farmers, or family farmers, rely on these areas for their livelihood. These individuals depend on natural resources available to them in the region(s) they choose to utilize, so changes to the natural landscape and weather patterns can be detrimental to a population’s food production (Kalele et al., 2021). In addition, these farmers often do not use technology or modern farming practices, making adaptations to the effects of climate change more difficult.

ASALs in Kenya have seen increased occurrences of changing weather patterns and land degradation in recent years, which has proven difficult to adapt. Climate change's impact on the natural landscape has caused increased levels of poverty and food insecurity and decreased biodiversity and access to natural resources (Macharia et al., 2012). The main concern is water scarcity for agriculture in the sub-Saharan regions (Speranza et al., 2010). This problem has caused much of the land to become dry and uninhabitable by the once native species of the area. The average temperature in Africa is expected to rise by three to four degrees Celsius in the next 100 years (Bryan et al., 2013). Therefore, research on how to transform the land or species that can thrive in the harsh, stressed environment is imperative to maintain the landscape and hopefully retain the once prosperous agricultural area. Kenya has sustained around a 52 percent poverty rate due to the inability of the environment and its dependents to adapt to climate change (Bryan et al., 2013). By providing resources to smallholder farmers and pastoralists on how to combat changes to their crops and other natural resources, a means to combat climate change can be achieved. With agriculture being a leading source of income in Kenya, 73 percent of the Kenyan labor force, educating farmers and experts on native species and plant adaptation patterns can aid in the success of local farmers (Bryan et al., 2013). With the help of new technologies and partnerships with local experts and farmers, assessing native species growth patterns can potentially increase yield and profitability for local farmers.

Chapter 2

Materials and Methods

PlantVillage is a global non-profit organization that aims to combat climate change's adverse effects using AI, satellite technology, mobile phones, and drones to increase yield and profitability for local Kenyan farmers. In collaboration with PlantVillage, Penn State has established an innovation lab that utilizes developing technologies to address crises emerging in local farms, called the *Feed the Future Innovation Lab for Current and Emerging Threats to Crops* (CETC IL). These technologies employ the aid of local farmers and farmers hired to mentor and train local farmers, also known as extension workers, to identify and track diseases that affect crops. With proper education and preparation provided through PlantVillage, local Kenyans can adapt their farming practices to thrive in changing climates. Local farmers are employed to identify crop conditions, natural species presence, weed spread, symptoms of crop disease, and pest presence in their region to warn farmers of crises like the recent locust crisis. Utilizing drones, satellites, and expert and user submissions, images are analyzed in the innovation lab to create AI algorithms that diagnose species types and diseases on crops. In collaboration with an AI assistant named *Nuru*, the Swahili word for light, and mobile spectrophotometry, information on plants and diseases can then be coded and used to identify and diagnose plants with a single photo taken on the app. Special teams of experts, designated as Dream Teams, are given smartphones with AI technology that are able to identify crop species and any diseases that may be present. The program enables these teams to train local and extension farmers to use the app and employ methods to identify diseases in their crops.

The CETC IL project that was the focus of this research was on ASALs across Kenya. The project aims to create an AI algorithm that identifies the amount of live vegetation available for smallholder farmers and pastoralists to gain information about areas that can sustain their livelihood. To determine wild-type species in ASALs, an area of interest was first determined. Three regions in northern Kenya were chosen, as depicted in Figure 1. These counties were

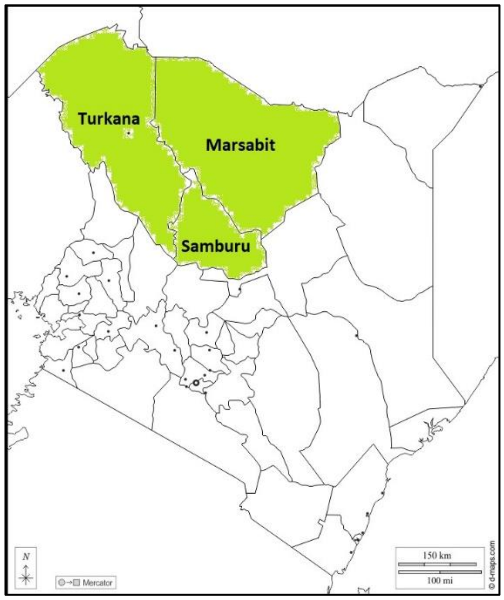

Figure 1: The location of the study sites located in Northern Kenya
Turkana, Marsabit, and Samburu, highlighted green, are counties of Kenya located in Sub-Saharan Africa.

selected as they all include large ASALs that have been the focus of previous studies conducted by PlantVillage and CETC IL. Through satellite technology and hand-taken photos, images of various landscapes were taken by local agriculturalists and scientists in the area and uploaded to be annotated for live vegetation presence. Then, an AI algorithm could be created to give local farmers an estimate of live vegetation in a chosen area of interest. This technology allows local pastoralists and farmers to determine if an area is able to sustain them and their livestock. The images used to create the AI algorithm were utilized to identify species for this thesis.

2.1 Identifying Plant Species

Plant species were chosen based on their prevalence throughout ASALs. Species found extensively throughout the annotation phase of AI development were isolated and sent to a group of individuals specializing in ASAL regions for PlantVillage. Six species were definitively identified as model species from which to gain the needed information.

Figure 2: *Vachellia tortilis* found in Marsabit, Kenya

The coordinates for this location are 2.57146, 37.62809. The image was taken on November 30, 2022.

Figure 3: ***Vachellia abyssinica*** **found in Marsabit, Kenya**

The coordinates for this location are 2.51262, 37.56085. The image was taken on November 9, 2022.

Figure 4: Salvadora persica found in Turkana, Kenya

The coordinates for this location are 3.14873, 35.6798. This image was taken on December 16, 2022.

Figure 5: Sansevieria erythraeae found in Samburu, Kenya

The coordinates for this location are 0.87126, 37.0118. This image was taken on December 12, 2022.

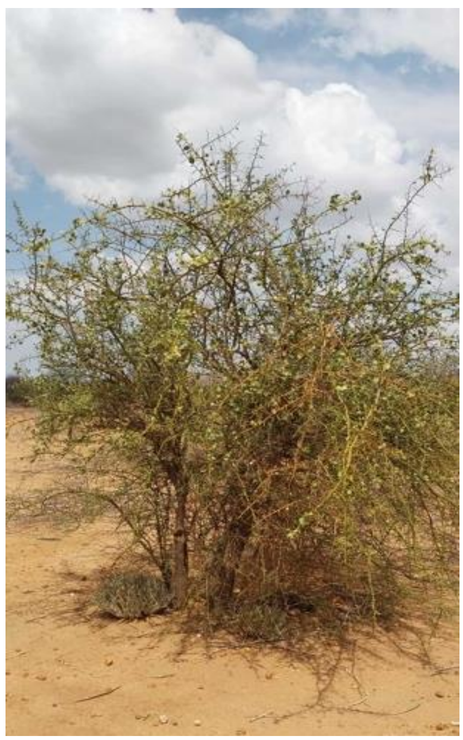

Figure 6: Balanites rotundifolia found in Turkana, Kenya

The coordinates for this location are 2.15748, 35.4438. This image was taken on December 14, 2022.

Figure 7: Prosopis juliflora found in Turkana, Kenya

The coordinates for this location are 2.15778, 35.45567. This image was taken on December 14. 2022.

2.2 Identifying Plant Adaptations

After identification, the plant species were researched to find what traits have allowed them to flourish in the increasingly harsh environment. Characteristics that gave the plant the ability to withstand drought, high salinity, water, and temperature stress were the main focus of interest.

Chapter 3

Results

3.1 *Vachellia tortilis*

Vachellia tortilis is an essential species native to Africa and the Middle East that has shown the ability to exist in harsh ASALs. It has been extensively studied for its stress-tolerant characteristics. In addition, it is a woody tree species that has gained copious attention for its regeneration effects on soil and has therefore been studied expansively. *Vachellia tortilis* grow to around 20 meters and are used for animal grazing, fuel wood, charcoal, and construction material, making it a widely used species in Kenya and neighboring countries (Kennenni & Maarel, 1990). Established as a notable species, it is vital to understand the adaptations the species has acquired that have allowed it to persist in increasingly harsher environments. The adaptations discussed in this paper will be the root system, hydraulic lift, energy conservation techniques, and the symbiotic relationship with rhizobia.

Vachellia tortilis has an expansive root system that maximizes water and nutrient absorption. The tree has deep vertical tap roots as well as an extensive system that reaches laterally (Ludwig et al., 2003). The deep tap roots allow the tree to reach far down into the soil around it to gain access to water during times when rainfall is minimal, and the topsoil may be dry. This gives them a competitive advantage compared to other plant species located nearby that compete for water and nutrients during times of drought. In addition, it has been discovered that *Vachellia tortilis* has the ability to perform hydraulic lift. Hydraulic lift is a process that involves moving water from deep in the soil using tap roots into the drier topsoil, so the horizontal, shallower roots can access water (Ludwig et al., 2003). This can severely aid the plant's survival due to the redistribution of water to its root system during drought when water is not plentiful. The roots are able to redistribute water from up to 10 meters down from the base of the tree, making this an advantageous adaptation (Ludwig et al., 2003). This ability not only aids the tree itself but can benefit species surrounding the tree that do not have deep root systems and cannot reach water on their own.

Many plants located in ASALs have the ability to conserve energy during times of stress to focus on necessary metabolic processes. *Vachellia tortilis* focuses on growth only when water is available and can control transpiration to reduce unnecessary water loss. For example, shoot extension and leaf growth only occur during rainfall or immediately after periods of rainfall when water is plentiful (Otieno et al., 2005). However, large trees are able to continue growing even during times of drought due to their large tap root (Otieno et al., 2005). When a plant is under a lot of stress, it has to use a lot of energy to compensate for any destruction or complications that occur, so minimizing metabolic processes during times of stress gives the plant a better chance of survival. The trees are also able to control transpiration, which is decreased during times of soil or atmospheric drought (Otieno et al., 2005). Transpiration allows leaves to release water vapor through their stomata to release excess heat and act as a form of temperature control. Usually, times of drought will be coupled with heat making it hard for plants to mechanistically determine between releasing heat and losing water. Still, Vachellia *tortilis* have shown that they are able to reduce water loss while maintaining an internal working temperature. This is partly due to the deep roots that supply a water source even during times of drought, therefore delaying the need to stop transpiration until it is absolutely necessary.

Lastly, the symbiotic relationship between *Vachellia tortilis* and rhizobia allows the plant to survive in harsh environments. Since rhizobia are able to fix nitrogen and give the plant a stable nitrogen source, the plant is, therefore, able to survive in acidic, saline, and dry soils (Assefa & Kleiner, 1998). Furthermore, nitrogen is an essential element in chlorophyll and other molecules in plants, so having a steady nitrogen source increases the plant's metabolic processes and allows them to optimize yield. In addition, this also gives the tree its soil regeneration properties due to the added nitrogen in the environment and the increased efficiency of the plant.

3.2 *Vachellia abyssinica*

Another member of the *Vachellia* genus, *Vachellia abyssinica*, is a woody tree native to Africa that has persisted in ASALs. The trees can grow up to 20 feet and are used for firewood, charcoal, animal grazing, and construction (Negash, 2010). The species is also known for its soil regeneration properties, similar to *Vachellia tortilis*. *Vachellia abyssinica* is competing with aggressive species such as *Eucalyptus*, but its environmental adaptations have allowed it to dominate over the invasive species. *Vachellia abyssinica* has developed multiple adaptions to withstand the harsh environment of ASALs, including its leaf characteristics and structure, growth strategy, and germination patterns that will be discussed in this section, in addition to other adaptations it shares with *Vachellia tortilis*.

The root system of *Vachellia abyssinica* allows for a competitive advantage in stressed environments. The root system is very similar to Vachellia tortilis, as it is comprised of deep vertical tap roots and an expansive horizontal root system that allows for hydraulic lift to be performed (Negash, 2010). Again, this process allows the plant to access not only shallow water and nutrients but water and nutrients trapped deep below the soil surface are able to, which can be absorbed or redistributed to shallower soil. The species also has a symbiotic relationship with rhizobia that has allowed it to gain soil regenerative properties and maximum growth opportunities (Negash, 2010).

The leaves of *Vachellia abyssinica* have also given them a competitive advantage in stressed environments. The leaves are pinnate and composed of many small leaflets that work well to conserve water (Negash, 2010). The leaflets are dropped when drought stress intensifies to add nutrients to the soil below, which can then be reabsorbed through the expansive root system and used again (Negash, 2010). This system allows the plant to rely on itself during times of low nutrients and water availability; combined with the hydraulic lift process, it can give the tree an enormous competitive advantage compared to other species.

The species utilizes a system similar to that of *Vachellia tortilis* that allows them to monitor growth around times of stress. Vachellia abyssinica is a fast-growing species during its early stages, which gives it its long, thick trunk and canopy leaf structure (Negash, 2010). However, growth slows when the tree matures, and a new approach is enacted. The tree's advance-retreat strategy allows for growth when moisture and temperature conditions are favorable and terminates growth when conditions are unfavorable (Negash, 2010). In addition, the tree can quickly transition from each phase to allow maximum growth under appropriate conditions.

Lastly, the species has developed germination to allow for the most effective strategy. Allowing seed dormancy to occur gives germination a higher chance of success, and mass germination is prevented (Negash, 2010). Dormancy gives the seeds a competitive advantage to germinate when environmental conditions are appropriate and allows for the seeds to have a higher chance of survival by not all germinating simultaneously. *Vachellia abyssinica* achieves dormancy through the presence of a hard and leathery outer seed coat that hardens as the seeds develop (Negash, 2010). This coat allows the seed to withstand extreme environmental pressures until conditions improve. This phenomenon has occurred because of severe environmental forces that have pushed the species to find a way to combat dehydration and other consequences of the changing habitat (Negash, 2010). The seeds are then unable to germinate until the coat is broken or the composition of the coat is changed.

3.3 *Salvadora persica*

Salvadora persica is a halophytic shrub that has developed to withstand harsh ASALs. *Salvadora persica* is native to Africa and the Middle East, which has pushed the species to adapt to high-saline climates and created a key model organism for studying environmental adaptations. The shrub can reach up to three meters in height with a diameter of up to one foot (Khatak et al., 2010). The plant is a facultative halophyte capable of growing under high saline conditions, making it a prime candidate of interest (Rangani et al., 2018). Salvadora persica has acquired numerous adaptions to help it survive in ASALs, including its growth strategy, antioxidative defenses, osmotic adjustment mechanisms, and hormone regulations.

Like the two *Vachellia* species, *Salvadora persica* can regulate its growth patterns during times of stress to conserve energy. In order to combat stress, energy is compartmentalized for defensive strategies rather than for growth; however, there is a period of rapid recovery of growth following periods of stress (Rangani et al., 2018). This adaptation has benefited the species, allowing them to withstand periods of high stress while continuing to periodically grow and develop. This mechanism can be seen through a reduction in transpiration rates and decreases in leaf area during periods of drought (Rangani et al., 2018). Because of this growth strategy, the species is able to focus energy on protective and antioxidative mechanisms during times of drought.

In response to stress, *Salvadora persica* has developed highly refined antioxidative defenses and osmotic adjustment mechanisms. During periods of stress, reactive oxygen species (ROS) accumulate due to abnormalities in normal processes that can build up and cause toxic effects on the plant. The major contributor to ROS is photorespiration, which produces hydrogen peroxide and free radicals. Cellular redox levels are found to be maintained during times of stress in *Salvadora persica*, seen through the maintenance of ROS scavenging enzymes. (Rangani et al., 2018). The ROS scavenging enzymes are able to quench toxic ROS, avoiding the buildup of toxic compounds and protecting the species during times of stress. In addition, photosynthetic pigments decrease during drought to further aid in reducing ROS buildup by dissipating excess excitation energy; decreased rates of photosynthesis parallel this (Rangani et al., 2018). However, oxidative damage can still occur even with maintained levels of ROS scavenging enzymes. In addition, saline stress specifically imposes osmotic pressure and ion toxicity in plants. *Salvadora persica* has developed mechanisms for osmotic adjustment to combat any oxidative damage that does occur during stress. Soluble sugars and polyphenols accumulation caused by water deficits can aid in osmotic balance and further detoxification of ROS (Rangani et al., 2018). The sugars and polyphenols can be used to build osmoprotectants to protect the plant during times of stress. In addition, proline levels increase two-fold during times of salt stress (Rangani et al., 2018). Proline is an amino acid that plays a role in ROS scavenging and osmotic balance, so an increase during times of stress reveals the protective mechanism adapted by the organism.

Lastly, *Salvadora persica* utilizes phytohormones to aid in protection during times of stress. Abscisic acid and jasmonic acid increase under salt stress to assist in acclimation to the changing environment (Kumari & Parida, 2018). Abscisic acid aids in signaling stress by recognizing salinity conditions in the roots and providing signals to shoots. In turn, the plant will reduce its leaf area, decrease transpiration rates, and enact the synthesis of osmoprotectants and antioxidant enzymes (Kumari & Parida, 2018). Jasmonic acid aids in the signaling of defensive strategies during times of stress or pathogenic attack. In response, the plant will regulate ion transporters in the roots to aid in osmotic adjustments during stress (Kumari & Parida, 2018). Salvadora persica can also maintain salicylic acid levels, which help signal antioxidative defenses during stress (Kumari & Parida, 2018). The ability of the species to sustain normal or increased levels of hormones shows the plant has adapted to stressed ASALs.

3.4 *Sansevieria erythraeae*

The *Sansevieria* genus has adapted multiple strategies to combat stress. *Sansevieria erythraeae* has not been extensively studied, so the genus became the topic of interest in studying this species. There are approximately seventy distinct species in the genus of succulent plants native to the drier regions of Africa (Koller & Rost, 1988). The genus has high variability in its adaptations paralleled to the degree of stress the specific species endures, but there are some characteristics that are adapted broadly. *Sansevieria* has adapted a complex leaf structure and the crassulacean acid metabolism (CAM) pathway to maximize efficiency during times of stress.

Succulents are known for being well-adapted to areas of drought and salinity stress. *Sansevieria,* as a genus, has developed leaves directly in response to the stress it endures. Various leaf shapes are present throughout the genus, with more cylindrical leaves showing adaption to more stressed environments (Alfani, 1989). These cylindrical leaves have an internal parenchyma consisting of a three-dimensional network of living and non-living cells (Alfani, 1989). This network allows the plant to be better adapted to water-stress environments because of its ability to maintain water. Dead cells function as water storage to quickly receive water directly from vascular tissue from living cells nearby and slowly lose water (Alfani, 1989). This allows the plant to delegate less energy to water uptake and loss and to focus resources on other metabolic needs.

In addition, *Sansevieria* is able to utilize the CAM pathway to minimize photorespiration. As discussed previously, photorespiration increases ROS and oxidative stress, so adapting the CAM pathway allows the species to deter negative consequences. CAM is a variant of photosynthesis that involves carbon dioxide fixation to specialized cells at night, providing a constant source of carbon dioxide so photosynthesis can occur during the night to combat water and heat stress during the day (Alfani, 1989). Being able to perform photosynthesis at night allows the plant to bypass many consequences of photosynthesis/photorespiration under daytime conditions and enables the plant to perform photosynthesis to conserve maximal water.

3.5 *Balanites rotundifolia*

Balanites rotundifolia is not an extensively studied species, but there is information about the genus and its relative *Balanites aegyptiaca*. The species is one of Africa's most widespread native woody plant species and has incurred numerous adaptations (Sands, 2001). The plant has become well adapted to various soils with different moisture and salt content, showing its ability to readily adapt to its environment (Chothani & Vaghasiya, 2011). *Balanites rotundifolia* has developed an adaptive root structure, the ability to adapt to stress as a seedling, and oxidative defenses to combat stress.

As discussed previously, trees are likely to adopt root systems that allow them to maximize water efficiency due to drought conditions. To increase surface area and, therefore, absorption, more than two-thirds of the plant's biomass is located in the roots (Elfeel et al., 2007). Similar to the tap root and horizontal expansion of the roots of *Vachellia* species, *Balanites* developed a mechanism to enhance nutrient and water absorption. This adaptation occurs while the plant is a seedling; seedlings exposed to drought exhibit enhanced survival through increased root growth but reduced leaf growth and area (Khamis et al., 2019). This immediate reduction in growth parameters emphasizes the adaptions to water stress the species has developed.

The ability to combat oxidative stress due to environmental factors has been studied in the species *Balanites aegyptiaca.* It was found that the species is able to upregulate its defense system in times of drought. (Khamis et al., 2019). This was discovered by studying the natural oxidative stress marker, malondialdehyde, and tocopherol, or vitamin E. Malondialdehyde levels increased with drought, which reveals that it faces oxidative stress as levels and free radical presence increase in the plant (Khamis et al., 2019). However, the plant was able to combat oxidative stress, showing it has adapted mechanisms to relieve itself. Furthermore, tocopherol can combat photooxidation byproducts by acting as a free radical scavenger and can exceed the production of ROS production to save the plant from undergoing photooxidation in photosynthetic membranes (Khamis et al., 2019). This adaption allows the plant to focus energy away from combatting oxidative stress and instead on maintaining normal metabolic processes during times of stress.

3.6 *Prosopis juliflora*

Prosopis juliflora is a member of the Fabaceae, or legume, family, which is well adapted to hot and dry climates. More specifically, members of the family can persist in temperatures reaching 48 degrees Celsius and annual precipitation of only 150,750 mm (George et al., 2007). *Prosopis juliflora* is an invasive species native to the United States and Mexico, but nevertheless still provides insight into adaptations to combat stress in ASALs. The species is able to grow in extreme environments of different types while controlling soil erosion, stabilizing sand dunes, and improving soil fertility, making it a valuable species in areas in need of regeneration (Patnaik et al., 2017). The species can grow as trees reaching a maximum height of 20 meters, or as shrubs reaching a maximum height of three meters (Patnaik et al., 2017). The high variability of the species shows its ability to adapt to changing environments. This is achieved because the plant can undergo obligate outcrossing, meaning that the species cannot reproduce within its own species and must breed with other species, which increases species diversity (Hussain et al., 2021). Adaptations of *Prosopis juliflora* are studied through expressed sequence tag data that have found numerous proteins and enzymes that aid in stress defense.

Prosopis juliflora has various genes associated with different types of stress defenses. The most abundant group of proteins found were heat shock proteins which aid in drought stress (George et al., 2007). Heat stress proteins are produced in direct response to stressful conditions and act as molecular chaperones to assist in broad-spectrum defense against stress. The second most abundant protein identified was metallothionein, which aids in detoxifying metal ions and ROS to combat many stress conditions (George et al., 2007). This allows the species to exist in environments with high metal levels by accumulating heavy metals to aid in soil regeneration since most organisms do not possess mechanisms to withstand heavy metals. The species was also found to have high levels of lipid transfer proteins, which play a defensive role in many stressed environments (George et al., 2007). Lipid transfer proteins were found to be upregulated in response to salt, mannitol, and abscisic acid and can even induce chilling tolerance with overexpression (George et al., 2007). The proteins can transfer phospholipids between membranes, allowing them to have an expansive role in stress tolerance through different environments. Other genes were found that aid in drought, cold, pathogen, osmotic, and submergence stress showing the comprehensive defense system that species have evolved (George et al., 2007). The species has adapted to many extreme environments, highlighting its highly adaptable nature. Therefore, although it is an invasive species, *Prosopis juliflora* is an important model species in the study of adaptation.

Chapter 4

Discussion

Plants can adapt a wide variety of strategies to combat stress, and finding model organisms that can be studied to understand these mechanisms further can significantly aid in the preservation and regeneration of environments. ASAL regions in Africa are at risk of overgrazing and climate change that forces species to find ways to adapt or risk extinction. This research was conducted to gain a list of model species and their adaptations that have allowed them to pursue in the increasingly extreme environment. *Vachellia tortilis, Vachellia abyssinica, Salvadora persica*, *Sansevieria erythraeae, Balanites rotundifolia*, and *Prosopis juliflora* have provided necessary insight into some defensive adaptations that plants in ASAL regions of Africa have exhibited. *Vachellia tortilis* utilizes its root system, hydraulic lift, energy conservation techniques, and a symbiotic relationship with rhizobia to adapt to its environment. In addition to the techniques *Vachellia tortilis* uses to adapt to its environment, *Vachellia abyssinica* utilizes a unique leaf structure, growth strategy, and germination pattern. *Salvadora persica*, on the other hand, utilizes growth strategy, antioxidative defenses, osmotic adjustment mechanisms, and hormone regulations. *Sansevieria erythraeae* has adapted a complex leaf structure and the crassulacean acid metabolism (CAM) pathway to maximize efficiency during times of stress. *Balanites rotundifolia* developed an adaptive root structure, the ability to adapt to stress as a seedling, and oxidative defenses to combat stress. Lastly, *Prosopis juliflora* utilizes specialized proteins, including heat shock proteins, metallothioneins, and lipid transfer proteins, to aid in its adaption to changing environments. While the method to conserve water and resources differs between species, ensuring access to said resources during times of stress and resource deficit is consistent between the studied species, especially by means of hydraulic lift to extended depths, oxidation defenses, and growth patterns to capitalize on climactic changes.

While the study provided insight into adaptations that can be utilized, the goal of this study is to gain knowledge on the types of species able to withstand, thrive, and regenerate a fertile environment for local farmers. Using these adaptations, species with similar adaptions can be introduced into the environment, or research can be conducted to determine if these adaptations can be genetically induced in other native species. In addition, the techniques utilized in this study, in cooperation with the technology from PlantVillage, can be used to provide more insight into areas that can sustain smallholder farmers and pastoralists.

Earth is changing due to human advancements and the neglect of the environment that has since ensued. With growing awareness of the effects of industrial development globally, steps should be taken on a worldwide scale to combat and prevent the increasingly extreme environments that are being created. However, preventative measures can only provide future relief. With the projects being undertaken by PlantVillage, relief and aid can be provided to the people suffering the most from the effects of global warming now. In a rapidly changing agricultural climate where adaptations to resource scarcity determine the livelihood of millions of food providers, species, disease, and pest tracking through PlantVillage will become an increasingly valuable tool for local food providers globally. Studies such as this increase the community’s understanding of how these climactic changes affect their crop growth and their livestock’s food supplies during travel and migration. Combining the input of local and international experts with developments in agricultural tracking technologies, Kenyan farmers can plan crop species for planting in the next year, track native species growth for harvest and livestock support during migration, and be forewarned of diseases and climactic crises that may affect their crop yields.

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ACADEMIC VITA

Elizabeth Baron

EDUCATION

Pennsylvania State University | Class of 2023 **University Park, PA**
Schreyer Honors College
Eberly College of Science | Bachelor of Science in Biology

HONORS

- **Schreyer Honors College** 7/7 Semesters
- **Dean's List** 6/7 Semesters

COURSEWORK

Human Anatomy & Human Physiology, General Chemistry I & II with Labs, Organic Chemistry I & II with Lab, Microbiology, Sociobiology, Neurological Basis of Human Behavior, Human Pathophysiology, Plant Physiology

MEDICAL EXPERIENCE

Somerfield Health Center **Brentwood, TN**
Certified Nursing Assistant Clinicals *Oct 2018 – May 2019*

- Provided care to elderly residents twice a week for 2 hours in order to achieve 60 clinical hours
- Attended to the needs of 20 residents, including waking up, dressing, bathing, clothing, feeding, and comforting
- Worked a total of over 60 hours in the nursing home to be able to take the CNA licensing test. I passed both the written and skill portions of the test to receive my license in May 2019

RESEARCH EXPERIENCE

Plant Village **State College, PA**
Undergraduate Research Assistant *Sept 2022 – Present*

- Work 10 hours a week to train the Plant Village AI model to identify specific plants, diseases, insects, and landscapes depending on needs
- Annotate an average of 20 images per week with specific labels coordinating to plant characteristics or disease
- Review and collaborate with 15 other undergraduate students to ensure accurate and precise annotations while keeping protocols up to date

PROFESSIONAL EXPERIENCE

Blaze Pizza **Brentwood, TN**
Team Member *Oct 2017 – Present*

- Provide customer service by operating alongside 8+ team members to receive and make orders
- Working 5-8 hour shifts averaging sales of 70 pizzas per hour

- Prepare over 10 categories of inventory while opening the store, guaranteeing an operational day while achieving a positive, efficient, and successful work environment
- Learned 9 different positions throughout the store, including preparation, opening, and closing the restaurant, as well as overseeing the service line and dining room, making sure the store always ran smoothly

LEADERSHIP & INVOLVEMENT

Penn State Women's Ice Hockey Club — **University Park, PA**

- Active Member ` *Jan 2022 – Present*
- THON™ Primary Chair *May 2020 – May 2022*
- THON™ Dancer Feb 2023
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