COMPARATIVE GROWTH AND LEAF NUTRITION OF SELECTED ROSELLE (*Hibiscus sabdariffa)* GENOTYPES IN NEW JERSEY

By

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ABSTRACT OF THE THESIS

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In an age of rapid technological advances it is deeply concerning that every person does not have access to the clean food and water they need for basic human development, leaving many with lasting developmental problems. Feeding the world has been the aim of many aid organizations, governments and charities and although advances have been made in increasing the basic caloric intake, access to fruit, vegetables and pulses to ensure adequate nutrition. Traditional, local and indigenous vegetables have become increasingly popular as people look to decrease their ecological impact while increasing access to nutritious food. Smallholder farmers and family farms have an opportunity to meet the increasing demand for indigenous vegetables while increasing income and rural development. African indigenous vegetables such as roselle (*Hibiscus sabdariffa*) have the potential to create income for farmers, while providing a source of nutritious vegetables for themselves and their families. The objective of this study was to determine the yield and nutrition of three roselle genotypes in New Jersey. The genotypes chosen (African Green, Indian Red, Indian Variegated, and Thai Red) were chosen based on the regional demand for ethnic vegetables. African Green roselle yielded the highest dry weight, 81.89 grams, per plant harvested every two weeks over the growing season, followed by Indian Variegated (79.94g), Indian Red (74.23g) and Thai Red (55.70g). Indian Red yielded the highest when harvested every three weeks (100.41g) with Indian Variegated yielding a similar amount (91.94g) and African Green with the least (64.31g). In all varieties, roselle was found to have 2% of the daily-recommended dose of Calcium and Potassium. 230g of dried roselle leaves are required to meet the minimum calcium, iron and potassium needs of children 1-8 years old. Further information is needed in the impacts of leaf harvesting on calyx production as well as the development of an early blooming cultivar with increased nutrition. Overall, indigenous vegetables such as roselle can serve as a model for other specialty ethnic crops in their transition to commercial specialty crops. Empowering smallholder farmers with new technologies, such as improved seeds, and innovations in agriculture can facilitate the growth of high quality products and rural communities worldwide.

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

AIV – African Indigenous Vegetables

EU – European Union

FAO – Food and Agriculture Organization

GDP – Gross Domestic Product

GM – Genetically Modified

IFPRI – International Food Policy Research Institute

MDG – Millenium Development Goal

SDG – Sustainable Development Goal

SSA – sub-Saharan Africa

TMV – Tobacco Mosaic Virus

UN – United Nations

US – United States

USAID – United States Agency for International Development

WFP – World Food Program

INTRODUCTION

Agriculture must do more with less to continue to support a growing world population. Staple crops as well as fruits, pulses, and vegetables must yield more and become more nutritious to sustain the health and well-being of billions. Currently smallholder farmers are producing the majority of the world's food but continue to be among the most malnourished groups. Genetic modification, large-scale monocrop farming and fortification have all posed potential solutions but high costs and low availability have hindered their acceptance. Smallholder farmers need a solution allowing them to produce high value crops on small plots to capture local markets. Reaching markets and increasing profits depend on having access to credit, education and infrastructure to create successful businesses. One solution seems to be working in developing countries in sub-Saharan Africa and Southeast Asia is the growth of indigenous vegetables, which rely on local knowledge and demand to provide a market driven solution to smallholder income generation. Indigenous vegetables have higher nutritional value than western vegetables and seed stocks can be improved locally as they are in close proximity to the crop's centers of origin. Indigenous vegetables can be an essential tool in food and income generation to support rapidly growing populations in developing countries.

World Population Growth

By 2050 the world population will reach 9.8 Billion (UN, 2017). This growth will be most rapid in developing countries and regions currently struggling to meet food demand, Africa and Asia. Initially many scholars and professionals called for a doubling of food production of key crops such as maize, rice, wheat and soybean, which make up the majority of calories consumed (Ray et al., 2013). However, there are other means to meet the growing demand, including sustainable intensification, reducing food waste, and increasing food accessibility.

Sustainable intensification is the concept of maximizing the output of crop land currently under cultivation using sustainable methods rather than expanding the amount of crop land over all. Some methods for sustainable intensification are the adaptation and transfer of technologies that can improve yield in underperforming countries, which also happen to be those set to experience a large population increase (Tillman et al, 2011). Addressing food waste and accessibility in more developed countries could be a solution to food insecurity faced by low-income households. However, in where crop subsidization plays a large role in the types of crops grown, such as the United States, it is important to make the distinction between sufficient calories and nutritious, desirable food.

The term “Food security” was defined at the 1996 World Food Summit stating that “food security exists when all people at all times have both physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life” (FAO 1996). In 2000 the United Nations adopted the Millennium Development Goals outlined in “The Future We Want” (Resolution A/RES/66/288 from the Rio+20 Conference held in 2012) to set targets for countries to aim for in creating development plans. MDG Goal 1 "To eradicate extreme poverty and hunger" defined hunger by the proportion of the population who are undernourished and the prevalence of children under 5 that are underweight (UN 2000). The MDGs and other efforts led to an overall increase in the agriculture sector growth and decreased overall undernourishment of people in the developing world from 23.3% in 1990 to 12.9% in 2014 (UN 2015). The emphasis on level of hunger and weight in the MDGs overlooked the critical aspect of malnutrition and micronutrient deficiency, which had been quietly growing in developing countries.

In 2015 the United Nations Sustainable Development Goals (SDGs) replaced the MGDs, based on a more holistic understanding of successful development the 17 interconnected "Global Goals" were identified by the United Nations Member States in paragraph 54 United Nations Resolution A/RES/70/1 of 25 September 2015. The SDGs cover a broad range of sustainable development issues from environmental sustainability and ecosystem management to goals meant to steer cities and institutions toward a more sustainable future. SDG goal 2: Zero Hunger aimed at achieving food security and improved nutrition by promoting sustainable agriculture and improving productivity of smallholder farmers (UN, 2015). MDGs and efforts by many countries were able to improve access to basic caloric needs the way in which it was achieved, by focusing on the growth and productivity of staple crops (maize, rice, wheat, and soybeans) created malnutrition problems that the new SDGs aim to overcome by focusing on diverse diets and access to fruits and vegetables.

Malnutrition

Malnutrition refers to people whose diet does not provide adequate calories, protein, and micronutrients; or they are unable to utilize the food they eat due to illness or lack of safe water. When lacking essential vitamins and minerals children and adults can develop "hidden hunger" which are signs of malnutrition and hunger that are less visible (and harder to measure). The main categories are wasting, stunting and specific micronutrient deficiencies. Wasting is a low weight for height, resulting from a lack of macro- and micro-nutrients in infants and young children that can be reversed relatively quickly with optimal feeding (with few side effects). Stunting, defined as a failure to grow in stature as a result of inadequate nutrition over a longer period of time, is more prevalent in developing countries and more severe long-term effects such as retarded physical and cognitive growth. The main causes of malnutrition are low yields, poverty, conflict, environmental challenges, and population growth that hinder access to micronutrient rich food.

Malnutrition is prevalent in more developed countries in the form of obesity. Obesity is defined as a body mass index (BMI) of ≥ 30 kg/m^2. Obesity can cover up other nutritional deficiencies if people eating too many starches and grains and not enough fruits and vegetables. Approximately three billion people are either not eating enough or eating the wrong types of food, resulting in illnesses and health crises. A 2014 report found that 2.1 billion people were overweight and obese, 62% of them in developing countries (Ng et al., 2014). The diseases that develop because of obesity—diabetes, hypertension, hypercholesterolemia, cardiovascular disease, cancer, and stroke—will undoubtedly overwhelm already struggling health systems worldwide.

In more developed countries such as the United States, subsidization for grain crops means that family farms are more likely to grow grains to access the subsidized crop insurance. Among US adults, higher consumption of calories from subsidized food commodities was associated with a greater probability of some cardiometabolic risks (Siegel et al., 2016). Promotion of vegetable and fruit crops through farmer education and agricultural policies could potentially improve population health.

Going forward, food security must utilize sustainable technological advances to ensure that everyone has access to nutritious and desirable food. Focusing on smallholder and family farmers will be essential in combating food insecurity and stimulating rural development. Increased production of high value vegetable and fruit crops can provide income for farmers, nutritious food for low-income communities and economic benefits for countries.

In SSA one in four people are estimated to be undernourished, with 34% of children being 'stunted' by malnutrition (UNDP RBA 2012). The main crops in east Africa are limited to the staple crops of maize, rice, and root crops such as cassava , as well as intensive use of pastoral lands. The maize mixed cropping system covers over 40% of the area, followed by pastoral (14%), root crop (12%), and cereal-root crop mixed system (11%). Other major crops in the region include cassava, banana, and rice, and white teff in the Ethiopian highlands. In drier parts of East Africa, the mixed cropping system is based on millet; while in the humid regions mixed cropping systems are based on maize and cassava (Francis 1986). Significant progress has been made in increasing the yields of staple crops and encouraging production, the emerging threats of climate change, malnutrition and market needs make diversifying crop production either by mixed cropping or by crop rotations. By incorporating crops such as vegetables, either indigenous or imported, smallholder farmers can increase their income, and diversify their diets.

Although undernourishment in sub-Sharan Africa (SSA) has decreased from 33.2% in 1990 to 23.2% in 2014 the number of undernourished people has increased (due to population growth) (UN 2015). The nutritional condition of any population depends on the consumption of fruits and vegetables (van der Lans et al. 2012). In eastern Africa where the disease burden of the population is very high, complications from non-communicable diseases can be clear indications of inadequate intake of fruits and vegetables (WHO 2015) .About 400 g of fruits and vegetables are recommended for consumption per person per day by the World Health Organization (WHO 2003). The emphasis on level of hunger and weight has overlooked the critical aspect of malnutrition and micronutrient deficiency, which had been quietly growing in developing countries. Attention has been on the potential of smallholder farmers of SSA to increase yield as a potential solution to the food shortage in SSA, however with increased cultivation comes increased human labor needs, and humans do not work well when malnourished or under an extreme disease burden.

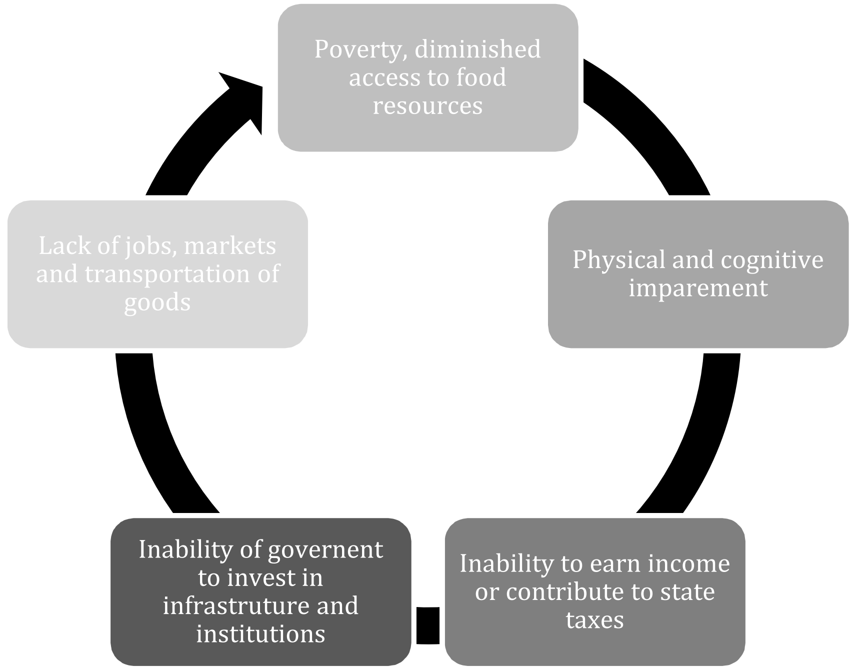


Figure 1 . The cycle of poverty, food insecurity, malnutrition, and the lack of economic growth and development

Poverty, poor nutrition, as well as a lack of economic development and good governance are interconnected barriers to development in east Africa. As seen in so many other aspects of development, the cycle shown in Figure 1 (above) is what Jeffery Sachs describes as a 'poverty trap'. Sachs describes the poverty trap as self-reinforcing mechanism which causes poverty to persist from one generation to the next if nothing is done to break the cycle (Sachs 2015). The main factor contributing to the poverty trap are environmental degradation, corrupt governance, limited access to capital, poor education a heavy disease burden, lack of healthcare and conflict. In SSA specifically smallholder farmers face lack of infrastructure to transport goods to market (contributing to high post-harvest losses), lack of access to capital (restricting the amount of inputs that can be purchased), lack of education (primary education and specialized agriculture education), high disease burden (decreasing the number of farm helpers they can access during harvest). In SSA the share of the African population living in extreme poverty has declined from 56% in 1990 to 43% in 2012, however the number of people who are poor has risen due to population growth (280 million in 1990 to 330 million in 2012) (Beegle et al. 2016). Since poverty greatly affects rural smallholder farmer's ability to produce higher yields, breaking the poverty and subsequent malnutrition cycle can give countries in SSA the boost needed to stimulate development in the region.

To overcome the food storage over $35 billion is spent by SSA on food imports every year. Although food is grown in the region $4 billion in losses are incurred each year due to transportation issues, spoilage, and other post-harvest losses (UN FAO 2009). It is very feasible to grow enough food to sustain the region with surplus but it is also imperative that the crops grown are nutritious or the region will be facing micro nutritional problems and potentially obesity in the future.

Sub-Saharan Africa:

Agriculture development in eastern Africa has been developing from subsistence style farms to small but productive farms specializing in staple crops. Aid programs focused on crop improvements, agroforestry and soil conservation, conservation agriculture, integrated pest management, horticulture, livestock and aquaculture have dramatically changed the way agriculture is conducted in eastern Africa. By early 2010, these projects had documented benefits for 10.39 million farmers and their families, and borne witness to improvements on approximately

12.75 million ha. Additionally, by increasing food outputs by sustainable intensification, crop yields rose on average by 2.13-fold (Pretty et al., 2011). However, emerging concerns such as dramatic population increases, climate change, and market dynamics pose new challenges for smallholder farmers, as well as the programs that aim to assist them in staying on their farms and contributing to the rural economy.

The population of eastern Africa is 140 million and growing at an average of 2.5% per year. With such high growth rates, urban areas will be growing not only due to migration, but more so because of the birth rates of the existing population, and expansion of the regional boundaries of what is considered an urban area (Tschirley et al. 2013; Cohen 2004). This increase in population comes with an urgent need for more resources, especially nutritious food and education to ensure that the increase in population is healthy and capable to live fulfilling lives, and therefore contribute to the countries continued development. With an increase in population and development comes an increase in the middle class, demanding different food products and services which the region will need to provide access to, in order to keep their development steady. Steady development will need to include funding, planning and developing all sectors of the economy, to ensure that each member of the population has access to education, health care, food, and clean water, which are basic human rights.

Food Security

In Sub-Saharan Africa (SSA) 80% of the farmland is managed by smallholders (FAO 2012). The average age of farmers is also about 60, despite the fact that 60 per cent of Africa's population is under 24 years of age (FAO, 2014). One of the keys to supporting smallholder farmers and consumers is with the creation of co-operative farmers groups. Through the creation of co-ops farmers can have access to education, credit and better access to markets. Some co-ops have each farmer contribute to a fund used for loans amongst the farmers. Loaning to others in the group creates higher instances of loan payback as they all know and trust each other. Through co-ops, farmers have better access to educational opportunities as it is easier to present information on farming practices, nutrition, and other services to groups of farmers rather than finding each one individually. When supplying large markets such as supermarkets, farmer's co-ops can harvest, process and ship at the same time, cutting down on individual expenses and benefitting all the farmers in the cop-op. These types of arrangements can be especially beneficial to women farmers who can receive the support they need to ensure their farms are productive to support their families.

Supermarkets are growing to serve the urban populations that prefer them to outdoor markets as they are perceived to have better quality, healthier and cheaper prices (Reardon et al. 2003). These supermarkets often buy from farmers directly and provide storage and steady payments for farmers with products that meet their standards. Also, as supermarkets have brand names to protect, they tend to be more careful in the use of pesticides and chemicals to deceive the consumer. Unfortunately, they can be detrimental to smallholder farmers who are not growing what the supermarket requires or are not in a convenient location for delivery to supermarkets. Another innovation would be using indigenous vegetables as fortificants in processed staple crops (ex: cassava flour, oatmeal, wheat flour, rice flour, or powdered supplement mixes). The processing and drying prolongs the storage life of the vegetables, allowing the farmer to sell them under optimal market conditions. This is increases availability of vegetables and profits for farmers.

Smallholder & Family Farms

Worldwide there are more than 570 million farms, more than 475 million farms are considered smallholder farms as they are less than 2 hectares in size and are characterized by their focus on family stability as they use mostly family labor for production and use part (or all) of their production for family consumption (FAO 2012). 500 million farms are considered family farms as they are owned and generally run by members of one family. In developing countries, small farms operate a greater share of farmland than smaller farms in the higher-income countries.

Comparing farms in more developed vs developing areas is difficult as the farming systems are at different stages of economic development. In developing countries, agriculture employs a larger percent of the population than in more developed countries. Agriculture is also crucial to economic growth. In 2014, it accounted for one-third of global gross-domestic product (GDP) (World Bank, 2015). Historically, as agriculture dependent economies develop new technologies less people are needed to farm, thus pushing more workers into the cities, which further drives development in services and industries. Major problems arise in countries whose populations are pushed out of agriculture by drought, natural disasters and conflict as the cities have not developed the jobs to employ everyone, resulting in slums and a strain on public services.

In least developed countries, the agriculture sector comprises around 23% of the GDP (Data.worldbank.org, 2018). In developing areas such as southeast Asia and Sub-Saharan Africa, about 70–80% of farms are smaller than 2 ha and operate about 30–40% of the land (Lowder et al., 2016). Growth in the agriculture sector is two to four times more effective in raising incomes among the poorest compared to other sectors (Townsend, 2015). The large percentage of people working in agriculture and related industries can make or break a developing economy depending on their supporting institutions, government assistance and economic conditions.

Unfortunately, smallholder farmers are not getting the support they need, of the 2.5 billion people in developing countries living directly from the agriculture sector, 1.5 billion live in smallholder household (FAO 2012). Investments in improved inputs (seed, fertilizer, and education) have allowed for increases in smallholder production in recent years however much of these gains have been to staple crops (maize, cassava, rice and wheat). Further investments into infrastructure, improved inputs, education, and crop development need to be made in order to meet the needs of growing populations.

By focusing on smallholder farmers, countries can boost their rural economies, raise the standards of living, and provide the economy with much needed stimuli such as capital, labor, and foreign exchange to finance and fuel growth in nonagricultural sectors (de Janvry and Sadoulet 2009). Focusing on high value crops such as fruit and vegetables, smallholder farmers could potentially increase their incomes and create value added jobs in their communities.

Family farms, specifically in the United States, tend to be bigger than smallholder farms as technological advances allow fewer people to work larger areas of land. Many family farms focus on staple crops as the government subsidies the growth by ensuring farmers receive an income even when crops under preform, the market price is low, or crops are ruined by a natural disaster. The Farm Bill dictates the programs and subsidies available for farmers in the United States and aims to reduce the risk involved in farming to ensure a stable income for farmers. However, the Farm Bill does not subsidize specialty crops such as fruit and vegetables to the extent that they support the growth of staple crops such as maize, soy and wheat. A study from Iowa State University found that increased fruit and vegetable production in the Midwestern region could boost farm sales by $882 million and retail sales as high as $3.31 billion along with creating on and off farm jobs (Swenson, 2010). Aligning policies, nutritional recommendations and the crop choices by farmers could potentially increase income, nutrition and stability for rural communities.

Smallholder and family farms have very different economic situations and resources available to them; however, farming comes with the same inherent risks as profits are dependent on weather and can be lost due to natural disasters. There are very prominent similarities to the hardships faced by farmers worldwide, mostly related to the riskiness of farming. Crop insurance is not always available to farmers to mitigate losses when a crop fails; this leads to a more conservative farming style that is resistant to unproven changes. Farmers generate income at harvest time, some farmers are fortunate to have several harvests per year. However, the income from harvests must last the family until the next harvest season, this poses problems if the family runs out of money and cannot access credit for more. The uncertainty, risk and hard labor of farming has not attracted the next generation of farmers. Currently, the average age of farmers worldwide is about 60 (FAO, 2014). Farmers need more government support in the form of subsidies, crop insurance, and healthcare to be able to meet growing demand without falling into bankruptcy. High value specialty crops can help to increase profit and reduce risk by allowing farmers to grow a diversity crops to meet local demands and spread out the risk of farming.

Ethnic Crops

Ethnic crops are those that are utilized within a specific national or cultural group. Ethnic crops can range from grains to vegetables but are usually ones that are native or naturalized to a specific region and have been maintained close to their center of origin. These crops are usually used in specific cultural dishes and have a great importance among different groups of people, sometimes utilizing different plant parts due to their traditional systems. Today, ethnic vegetables can be a great source of income for farmers in the United States and Europe catering to large ethnic populations, adventurous consumers, and specialty restaurants. These crops can allow ethnic populations to access traditional crops as well as create exciting new products to diversify and enrich people's diets.

African Indigenous Vegetables

AIVs have been proven to be high in vitamins and minerals (Yang 2009). Diets rich in micronutrients and antioxidants are strongly recommended to supplement medicinal therapy in fighting HIV/AIDS (Friis et al,2006). Although the AIVs have a very high potential to help solve malnutrition in SSA unfortunately in Nigeria, leafy vegetables are relatively available and affordable particularly during the rainy seasons but were found to be among the least consumed foods (Maziya-Dixon et al., 2004). In some areas the AIVs are seen as low income foods, however there is potential in making the crop trendy as well as promoting their health benefits. By focusing on growing AIVs along with staple crops the potential problem of micronutrient deficiencies can be avoided.

The growth of indigenous vegetables can easily be paired with sustainable intensification to increase of production (yield) per unit of inputs (fertilizer, seed, labor, land and others). Agro-ecological intensification tries to minimize the negative impacts agriculture can have on ecological system while utilizing natural systems to increase production. The main practices promoted by agro-ecological intensification are the use of natural mulching and intercropping, conserving soil and water resources, using integrated pest management, and using organic inputs. Agro-ecological intensification differs from ecological or sustainable intensification by the way it incorporates social and cultural perspectives and ideas into the system, as well as farmer education (Wezel et al. 2014). Agro-ecological intensification employs a systems based approach to address access to markets, value chains, and knowledge-sharing systems ensure the farmers are benefitting as much as the ecosystem.

Alternative approaches to feed the world while enriching a diet with more nutritious food ingredients should provide a greater focus and attention on horticulture and other non-staple crops. An effective approach should complement the crop enterprises of smallholder farmers by making nutritious crops more available and affordable, but not replacements to their current traditional staple crops upon which the family and farm income depend. Using diversity of crops can mitigate risk by contributing revenue streams over more than 1-2 time points (Weller, Wyk, & Simon, 2015). By the introduction of crop diversity, particularly those suited to the specific microenvironment in which they are grown, small-scale farmers could achieve additional revenue, provide work over a wider time period of the growing seasons, and also make such produce available to consume. By developing 'new', more nutritious, and better-adapted crops there is potential to address health concerns, the growth of local economies, and empowerment of impoverished communities. African indigenous vegetables (AIVs) such as roselle (*Hibiscus sabdariffa),* African Spiderplant *(Cleome gynandra),* Amaranth (*Amaranthus spp.)*, Moringa *(Moringa oleifera),* and others provide nutritious products which are eaten locally, highly profitable and desired locally and in eager markets around the world.

TABLE 1. The most popular African indigenous vegetables based on everyday use in Kenya and Zambia

Rank[1]	Common Name	Latin name	Plant part	Nutrient Content
1	Field Maize	*Zea mays*	kernel	Beta-carotene, ascorbic acid, magnesium, potassium[6]
2	Kale	*Brassica oleracea*	leaf	Protein, Iron, ascorbic acid, calcium, potassium[6]
3	Pumpkin Leaves	*Cucurbita maxima*	leaf, tuber	Fresh: calcium, protein, vitamin C. Dried: protein, iron[5]
4	Cowpea	*Vigna ungulculata*	seed pod	Fiber, thiamin, riboflavin, folate, copper, iron[6]
5	Ethiopian Mustard	*Brassica carinata*	leaf	Folic acid, ascorbic acid[3]
6	Amaranth	*Amaranthus spp.*	seed, leaf	calcium, iron, ascorbic acid[3], protein, vitamin A[5]
7	Roselle	*Hibiscus sabdariffa*	Leaf, calyx	Riboflavin, protein, anti-oxidants[3]
8	Jute Mallow	*Corchourus olitorius*	leaf	Beta-carotene, riboflavin, folic acid, ascorbic acid, calcium, iron[3]
9	Nightshade	*Solanum spp.*	berry, leaf	Beta-carotene, folic acid, ascorbic acid, alkaloids[3]
10	Spider Plant	*Cleome gynandra*	seed pod, leaf	ascorbic acid, beta-carotene, folic acid, calcium[3,5]
11	Okra	*Abelmoschus esculentus*	Calyx, leaf	Riboflavin, folic acid, ascorbic acid, calcium, anti-oxidant[3]
12	Moringa	*Moringa olifera*	leaf	beta-carotene, vitamin E, riboflavin, iron,

				folic acid, extremely high in ascorbic acid[3]
13	African Eggplant	*Solanum aethiopicum*	Fruit, leaf	Beta-carotene, ascorbic acid, calcium, iron, alkaloids[3]

Sources: 1. Simon et al. Rutgers, 2. CRS, 2016, 3. Lin et al, 2009, 4. Fasakin, 2004, 5. Mingochi and Luchen, 1997, 6. USDA Nutrient Database, 2018.

AIVs have the potential to address many concerns such as: nutritional concerns, gender equality, interest of foreign markets, increase the economic power of farmers and rural communities, and importantly are crops that are culturally accepted across sub-Sahara Africa. AIVs are easy to grow, and adapted to poor soil conditions, often where the poorer farmers are located. AIVs are great sources of high-quality nutrition (Abukutsa 2007). They are easily accessible, inexpensive, and contain minerals and vitamins in levels exceeding those found in most exotic vegetables (See Table 2), as well as often producing a higher number of harvest per year as a result in part of being better adapted to local conditions. The AIVs are native or naturalized vegetables that have been consumed in African diets for many generations (Smith 2007). The top desired AIVs in two project locations are illustrated in Table 1 (See Table 1 from Malawi and Table 2 from Zambia). The most desirable AIVs are hard to obtain if not grown in a home garden, and therefore show great potential in urban populations that traditionally consumed AIVs but lack access in urban areas. The combination of the highly nutritious, desirability and potential income for smallholder farmers makes AIVs a good investment for development organizations aiming to reduce disease burdens, malnutrition and inequality.

Table 1 | **Annual income analysis based on 1/4 acre (0.1ha) of vegetables**

Category	Vegetables	Number of harvests per year	Annual production cost (US$)	Annual gross earning (US$)	Annual profitability (US$)
AIV	Amaranth (*Amaranthus* spp.)	8	1,142	5,714	4,571
	Cowpeas (*Vigna unguiculate*)	7	1,306	3,733	2,426
	Nightshade (*Solanum* spp.)	5	1,633	4,666	3,033
Exotic vegetables	Kales	4	1,440	3,200	1,760
	Spinach	3	1,400	2,800	1,400
	Cabbages	3	1,440	2,400	960

Source: Mumbi *et al.* (2006).

Table 2. Annual income analysis on 1/4 acre of exotic versus indigenous vegetables.

The AIVs have seen marked expansion in production, marketing, and consumption in recent years potentially due to increased consumer awareness about their health and nutritional benefits (Schippers 2000). High marketing returns have motivated commercialization of AIVs by small-scale farmers, who produce and supply them either individually or collectively in groups (Ngugi et al. 2007). Currently, most food retail outlets in east Africa sell some AIV products, and AIV availability and diversity in high-valued retail outlets such as supermarkets have further induced their consumption in urban areas (Ngugi et al. 2007). Changes in lifestyle and availability of cooling-storage facilities have also boosted their consumption levels in urban dwellers (Ruel et al. 2005). Moreover, ethnic background, cultural preferences, inter-marriages, and urbanization are important cultural interactions for enhancing AIV consumption among people from different ethnic origins (Kimiywe et al. 2007). By expanding the growth of AIVs by smallholders in the eastern Africa region can increase the income of farmers while supporting the consumption of nutritious vegetables for the rural and urban populations.

Regional Constraints

Agricultural systems in eastern Africa have significant vulnerabilities to climate, environmental conditions, and global markets. Agriculture in some of the eastern African countries constitutes around 30% of that country's GDP, making their economies reliant on global agriculture prices. Agriculture itself is reliant on rainfall, as much of the region does not have irrigation systems. The overall tropical conditions in some areas of the regions have characteristics that make farming difficult (high temperatures and sandy soils with low moisture retention) as well as a high plant and human disease burden. Low rainfall and civil unrest is a statistically significant driver of urbanization (Barrios et al., 2006 and Annez et al, 2010). Stagnant urban growth also leads to movement back to rural areas (Potts 2012). This human movement and the underlying environmental conditions of the region make agriculture a hard sector to predict and rely upon for developing countries.

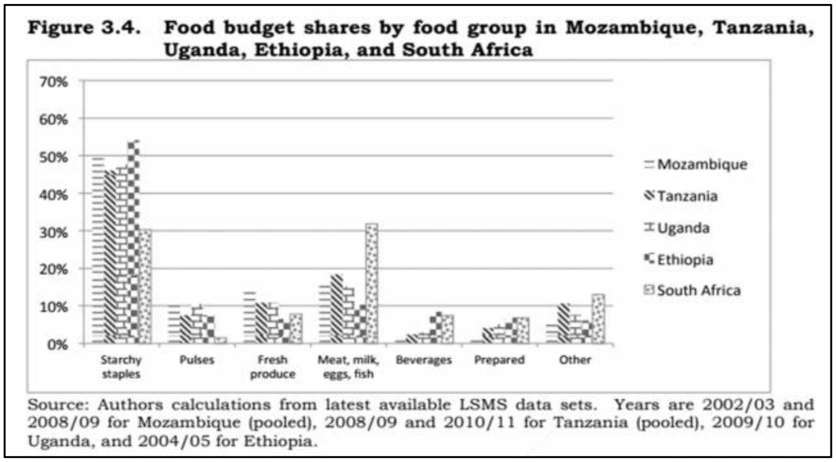


Figure 2 Food Budget by Country. Source: Tschirely et al.

Increases in overall population eastern Africa have seen a dramatic increase in the number of people considered middle class, from 27% in 1980 to 35% in 2010, comparable with the middle class population in India. Ncube *et al*. (2011) use a broad definition of middle class including $2–20 a day in purchasing power parity (PPP) terms, and divide it into 3 categories; from $2-4 per capita consumption per day is 'vulnerable middle', this is the largest group who are just out of poverty and have the potential to slip back; $4–10 is the 'lower middle' class, and $10–20 is the 'upper middle' class. A growing middle class changes the eating patterns of a country, notably by demanding more processed foods, meat products, and vegetables compared to the starch-based diet of those persons in the poorest classes. The lesser developed countries in east Africa compared to more developed South Africa consume more starchy staples and pulses (beans) than people in South Africa (Figure 2). Typical diets of people in developed countries consist of more meat, animal products, processed food and beverages than diet of low income countries.

Another regional concern is the impacts of climate change upon agriculture. The Intergovernmental Panel on Climate Change (IPCC) suggested in their 2014 report that the global community, in its adaptation efforts in regards to climate change, may need to consider "...altering the systems and structures, economic and social relations, and beliefs and behaviors that contribute to climate change and social vulnerability." Meaning that not only will agriculture have to adapt to changing conditions, but the systems that caused climate change in the first place (unsustainable use of fossil fuels) will have to change as well. This could be a burden to developing countries who will not have the same advantages as developed countries had in the unlimited use of energy to grow, but could come as an interesting advantage, in terms of requiring east African states to utilize new technologies that produce energy at a lower cost and in a more sustainable manner.

East Africa's agriculture, long under developed and undernourished, is on the brink of becoming a major source of food for the world's growing population. With issues such as nutrient deficiencies (Sanchez & Swaminathan, 2005), technology and crop varieties being addressed (Street, 2003), the next questions will be whether countries will adopt practices to minimize climate change impacts, protect their natural resources, and meet the nutritional needs of their people (Smith, 2007). As the development of agriculture in eastern Africa gains momentum, intensive industrial systems are looking more feasible, although this system has led to major advances in combating hunger and providing staple foods to millions, it has not been able to provide all the requisite minerals and vitamins necessary for a diversified and healthy diet (Ikerd, 2015). Food production in the region needs to compensate for inherent environmental constraints while striving to meet the nutritional needs of the growing population and middle class.

Roselle

Roselle is an under-utilized crop in United States. Roselle is primarily grown for its calyx in Florida, California, Louisiana, and Kentucky (Mohamed et al, 2012). Few growers also harvest the leaves for selling at ethnic specialty grocery stores. There is great potential for the growth and sale of ethnic crops in the eastern United States due to the large ethnic populations in major cities (Govindasamy et al., 2006). Ethnic populations including Chinese, Asian Indian, Mexican and Puerto Rican were willing to pay more for ethnic vegetables, thus identifying a market possibility for commercial growers (Govindasamy et al., 2010). Ethnic crops such as roselle, although labor intensive in production, have the ability to create income for specialty crop growers near large ethnic populations.

Ethnic vegetables, like roselle, tend to be new to commercial cultivation. The risk of planting a non-uniform and untested crop can be too great a risk for some farmers. However, with the help of universities and extension officers the crops can be adapted and potentially bred to become adapted to the new climates and growing conditions.

Agriculture is a major contributor to the national economies in east Africa and is dominated by smallholders who contribute up to 90% of agricultural production (Salami et al. 2010; Wiggins and Keats 2013). Agriculture alone accounts for 21–42% of the national gross domestic products (FAO 2013). Smallholder farmers are small-scale farmers managing areas from less than one acre to 10 acres. They are characterized by their focus on family stability, as they use mostly family labor for production and use part (or all) of their production for family consumption (FAO 2012). The majority of smallholders live in South Asia and sub-Saharan Africa (SSA) and produce up to 80 percent of the food supply in those regions. Of 2.5 billion people in poor countries living directly from the agriculture sector, 1.5 billion live in smallholder household (FAO 2012). In SSA 80% of the farmland is managed by smallholders (FAO 2012). Investments in improved inputs (seed, fertilizer, and education) have allowed for increases in smallholder production in recent years, however much of these gains have been to staple crops (maize, cassava, rice and wheat). Further investments into infrastructure, improved inputs, education, and crop development are needed, in order to meet the micronutrient demand of the population of SSA. By focusing on smallholder farmers, east African countries can boost their rural economies, and raise their standards of living.

ROSELLE DESCRIPTION

Hibiscus sabdariffa var. *ruber* (common name roselle) is an annual, autogamous, dicotyledonous herbaceous subshrub reaching 2.4m tall (Boulanger 1984). The leaves are alternate and simple in young plants and the upper leaves of older plants with the lower leaves being deeply 3, 5 or 7 lobed. *Ruber* has red stems, and yellow or buff flowers with a rose or maroon eye. When the flowers are done blooming the calyx enlarges becoming fleshy, crisp and juicy with a taste similar to a cranberry. Inside the calyx is a 5 valved capsule containing 3-4 seeds in each capsule which dehisces when mature. Roselle has low water demand and can be grown in arid and semi-arid regions on poor soils which are correlated with the location of low income impoverished farmers.

Hibiscus sabdariffa L. is in the Malvaceae (Mallow) family and has two non-fixed varieties (*sabdariffa* and *altissima*) (Berhaut 1967). *H. sabdariffa* var. *altissima* (Wester) is a sparsely branched annual (reaching 4.8 m high) grown for its fiber in India, the East Indies, Nigeria and tropical America for its jute-like fiber. This variety has red or green, non-fleshy calyces and is not used for food, only fiber. *H. sabdariffa* var. *sabdariffa* has 4 races that breed true to seed: *bhagalpuriensi, intermedius, albus*, and *ruber. Bhagalpuriensi* has green and red streaked inedible calyces. *Intermedius and albus* have yellow-green edible calyces and also produce fiber. The race *ruber* has edible leaves and calyces (used in jams, jellies, candies, teas, beverages and other food and medicine products) (Villani, 2013).

The roselle is naturalized to India, Malaysia, Africa, West Indies, and Central America however its origin is not known with certainty (possibly Sudan or India).

However there is evidence of its domestication at the head waters of the River Niger and Western Sudan 6500 years ago (Murdock, 1995). It is also widely distributed in the Tropics and Subtropics of both hemispheres (Fasoyiro, 2005). Seeds were also brought to the Americas by slaves from Africa as a food source (Crane 1949). Roselle is used in ayurvedic medicine and in traditional Chinese medicine as a treatment of hypertension, pyrexia and liver damage (Odigie 2003). The leaves are also traditionally eaten as vegetables in Sub-Saharan Africa (Zhen 2016).

Roselle has a variety of different common names, some referring to the whole plant, leaves, fiber or calyx. Some of the common English names are Jamaican sorrel, red sorrel, Indian sorrel, rozelle, rozelle hemp, natal sorrel and rosella (Mohamed et al., 2012). See Table 3 for a list of the most common names used in each country. Vernacular names include rozelle, jelly okra, lemon bush and Florida cranberry (Small, 1997). The major commercially grown varieties from China, Thailand, Mexico and Africa – primarily Sudan, Senegal and Mali (Plotto et al., 2004).

TABLE 3. Common Names of Roselle (*Hibiscua sabdariffa*)

COUNTRY	LANGUAGE	NAME
Australia	Australian English	Rosella
Brazil	Portuguese	Vinafreira, azedinha, caruru azedo, quiabo azedo, quiabo d'angola, quiabo Rosado, quiabo roxo
China	Chinese (Mandarin)	luo shen hua (洛神花)
Egypt	Arabic	Karkade[1]
France	French	l'oiselle[1], oseille de Guinée[2]
Ghana		Sobolo
India	Tegulu	Gongura
Iran	Farsi	Chaye-Torosh
Jamaica	English	Jamaican sorrel, sorrel, saril
Japan	Japanese	Rozeri-sô[2]
Kenya	Swahili	Ufuta, Ufuta dume[2]
Mali	Bambara	Dâ[1]
Mexico		Flor de Jamaica
Myanmar	Burmese	chin baung ywet
Namibia		Omulete
Nigeria	Yoruba	Isapa
		Zoborodo
Niger		Bissap
Pakistan	Urdu	Sabdriqa/lalambari
Senegal	Wolof	Bissap[1]
Sierra Leone		Sawa Sawa
Thailand	Thai	grà jíap. Kraceīyb (กระเจี๊ยบ)
United States	English	Roselle, Jamaica sorrel, Guinea sorrel, red sorrel, Karkadé, sour-sour, sorrel[2]
Zambia	Chewa	Lumanda
	Ngoni	Limanda

Table 3. Common names for roselle (*Hibiscus sabdariffa*). Sources: 1. Plotto et al., 2004. 2. (Quattrocchi, 2016

Growth and Harvest

Roselle requires a monthly rainfall from 130-250mm in the first three to four months of growth. Dry weather desirable in the latter months of growth and can increase the quality of calyces and aid in post-harvest drying. Roselle is highly sensitive to changes in day length, known as photoperiodism. This photoperiodism means care should be taken in the timing of planting as plants exposed to short day/long night cycles will switch from vegetative to reproductive growth, no matter their age.

Planting is usually done at the beginning of the rainy season to utilize the natural rainfall. Seeds are usually planted 2.5 cm deep, 60 cm-1 m between rows and 45-60 cm between plants in a row, this larger spacing increases calyx size (Mohamed et al., 2012). Sowing is done by hand or using a modern grain drill that can be adjusted to the seeds small size. When planting for fiber roselle is planted close to produce long stem with little foliage. Plants are thinned and harvested by hand.

The calyces are harvested in late November/December, usually 3 weeks after flowering, and are timed according to the ripeness of the seeds. Flowers are diurnal and last only one day. After the flowers fall off the calyx swells and produces seeds inside. The calyces are harvested before the seed pod has dried and opened as this makes them more susceptible to sun cracking, diseases and a loss of quality. Calyx production per plant ranges from 1.5 kg in California, to 2 kg in Puerto Rica, to 7.5 kg in South Florida. Harvesting methods differ by country, the two main methods are; removing the whole plant and removing the calyces are later, or harvesting the calyces using clippers as they ripen. After harvesting the inner seed pods are removed from the out calyx by hand or using a sharp metal tool. For fiber, the entire plant is harvested at flowering time then the fiber is stripped from the wood. Leaves can be harvested throughout the growing season and the plant will still produce calyces at the end of the season.

Care should be taken after harvesting the calyx to ensure it is not exposed to dirt, the ground or contaminated surfaces to reduce spoilage and disease. Drying of the calyx can be done using different methods, the most effective ones utilize mesh or screens to increase air circulation and reduce sun baking and disease. The drying ratio of fresh to dry is 10:1.1, meaning for every 100 pounds of fresh calyx, 11 pounds of dried product is produced. The quality of calyx is determined by color, texture, and flavor. Low cost drying methods can greatly impact the quality of the calyces, preferred methods are expensive hot air dyers or less costly solar drying tunnels.

Diseases that affect roselle include fungi, viruses, bacteria, nematodes and some insect pests. Damage from insects is rare but mealy bugs, leafhoppers, and cotton strainers can impact the plants (Plotto et al, 2004). The fungi that are found on roselle are as follows; *Aecidium garckeanum, A. hibiscisurattense, Alternaria macrospora, Cercospora abelmoschi, C. malaysensis, Corynespora cassiicola, Cylindrocladium scoparium, Diplodia hibiscina, Fusarium decemcellulare, F. sarcochroum, F. solani, F. vasinfectum, Guignardia hibisci-sabdariffae, Irenopsis molleriana, Leveillula taurica, Microsphaera euphorbiae, Phoma sabdariffae, Phymatotrichum omnivorum, Phytophthora parasitica, Ph. terretris, Pythium* *perniciosum, Rhizocotonia solani, Sclerotinia fuckeliana, S. sclerotiorum,* and *Sclerotium rolfsii* (Duke, 1983). Young roselle should be monitored for powdery mildew as it can cause growth defects in later stages of growth.

Roselle is also susceptible to several viruses including; leaf curl, cotton leaf curl, tobacco mosaic virus, and two members of the *Tobamovirus* family Hibiscus Latent Fort Pierce Virus and Hibiscus Latent Singapore Virus. Hibiscus latent Fort Pierce virus (HLFPV) was described for the first time in Fort Pierce, Florida, USA, on *Hibiscus rosa-sinesis* plants showing diffuse chlorotic spots, ringspots and chlorotic mottle (Adams et al., 2006). HLFPV has since been reported in Japan, Brazil, Indonesia, Thailand, and Italy (Gao et al., 2016 and Nerva et al., 2018). Roselle is also affected by root-knot nematodes: *Meloidogyne arenaria, M. incognita acrita* and *M. javanica* (Duke, 1983). Insect pests that attack roselle are: *Anomis erosa, Chaetocnema* spp.*, Cosmophila erosa, Dysdercus cingulatus, D. poecilus, Drosicha townsendi, Nistora gemella, Phenacoccus hirsutus, Pseudococcus filamentosus* and *Tectocoris diophthalmus* (Duke, 1983). For the best results roselle should be monitored throughout the growing season and any weeds, diseased plants and drought should be dealt with as soon as possible.

Uses and nutrition

Calyx

Today roselle is used in drinks, wine, beverages, jams, jellies, coloring, and flavoring ingredients in Europe, Africa, Asia, and the Americas (Duke, 1985). It is produced commercially in China, India, Sudan, Uganda, Indonesia, Malaysia, Mexico and now the United States in Florida, California, Louisiana, and Kentucky. (Mohamed et al, 2012). The tea is popular for its health benefits and unique taste.

A considerable amount of research has been done on the nutrition (see Table 4) and active phytochemical profile of the calyx and popular hibiscus tea. Recent research has analyzed the therapeutic potential of roselle, the antioxidant, hypotensive and antiatherosclerotic effects decrease oxidative stress, antherosclerosis, lipid profile and blood pressure (Guardiola and Mach, 2014). The phytochemical profile is an important aspect consider when analyzing and breeding roselle cultivars.

TABLE 4. Nutrition of roselle calyx

Nutrient	Value (100g)
Water	99.58g
Ash	0.42g
Calcium	8mg
Iron	0.08mg
Magnesium	3mg
Phosphorus	1mg
Potassium	20mg
Sodium	4mg
Zinc	0.04mg
Manganese	0.477mg
Niacin	0.04mg
Folate (total)	1ug
Choline (total)	0.4mg

Source: *Nutrient Data Laboratory, ARS, USDA* **National Food and Nutrient Analysis Program Wave 18f**, 2014 Beltsville MD

Leaves

Very little research has been conducted on the growth, nutrition or yield of the roselle leaves as they are mostly grown in household gardens, not in commercial cultivation. Most research on roselle focuses on the popular calyx with some exception for India where the leaves are eaten in some popular regional dishes.

The leaves are a very important vegetable in India (Andhra, Karala, Karnataka, Assam and other what?), and valued for their iron content. They are used in a wide variety of pickled dishes, dals and curries, particularly goat and mutton curries, but also with chicken and pork. The leaves are also used in Africa, particularly Senegal, where they are used in a recipe with fish and rice.

Nutritional data on roselle leaves is difficult to determine as there is not very much data, there likely are significant differences between the different cultivars grown throughout the tropics (see Table 5) and the collected data does not originate from a controlled comparative study using same nutritional analytical techniques, growing conditions and more. The phytochemical compounds found in roselle leaves include polyphenols neochlorogenic acid, chlorogenic acid, cryptochlorogenic acid, quercetin, kaempferol and their glycosides were identified together with 5-(hydroxymethyl)furfural (Zhen et al., 2015). The *in vitro* anti-oxidant level varied by cultivar from 17.5 to 152.5 ± 18.8 μmol Trolox/g as expressed in their varied coloration (Zhen et al., 2015). Roselle leaf extract showed potential anti-inflammatory activity in when applied to RAW 264.7 cells as it reduced the lipidpolysaccharide-induced nitric oxide production (Zhen et al., 2015).

The compound 5-(Hydroxymethyl)furfural (5-HMF) was found in roselle leaves and was identified as a potential biomarker for assessing the quality of dried roselle leaves (Zhen et al., 2015). 5-HMF is usually formed when dehydration happens in acid environment or high temperature, and is commonly found in food with sugar under drying or baking (Roman-Leshkov et al., 2006). The levels of 5-HMF varied by cultivar and was potentially impacted by the effectiveness of drying methods (Zhen et al., 2015).

An analysis of the nutritional and secondary metabolites of Zambian roselle harvested at immature, mature and senescent leaf stages determined that raw, mature leaves had the best nutritional content (Siziya, 2017). The raw, mature roselle leaves from the ZM 5738 genotype used in the study had; 78.73% moisture, 13.33% ash, 13.63% protein, 6% fat, 25.73% fiber, 41.30% carbohydrates, 1.66% alkaloids, 1.94mg/g oxalates, 141.25 mg/kg flavonoids, and 252.30 mg/kg vitamin C (Siziya, 2017). The cooking method of roselle leaves also has an impact on the nutritional content, with raw preserving most of the available nutrients but water blanching reduced anti-nutritional factors such as alkaloids and oxalates along with water-soluble vitamins (Siziya, 2017).

TABLE 5. Nutrition of roselle (*Hibiscus sabdariffa)* leaves

Nutrient	Nutrient Composition (100g)[1]	Nutrient Composition (100g)[2]
Moisture	85.6g	85.6%
Energy	57Kcal	43Kcal
Protein	1.7g	3.3g
Fat	0.1g	0.3g
Carbohydrate	12.4g	9.2g
Ash	0.2g	1.6g
Vitamin A, RE	133ug	
Vitamin A, RAE	66.5ug	
Beta-carotene	797ug	4135mg
Thiamine	0.01mg	0.17mg
Vitamin C	44mg	54mg
Calcium	9mg	93mg
Fiber		1.6g
Phosphorus		93mg
Iron		4.8mg
Riboflavin		0.45mg
Niacin		1.2mg

Sources:

1. ASEAN FCT, 2000
2. Duke and Atchley, 1984

Other Plant Parts

The stem, seeds and flowers are also utilized in some regions. The stem of the kenaf, or fiber producing cultivars are used in producing bast fiber which is turned into bags and other finished goods. In Africa, the seeds can be roasted as a coffee substitute and ground into protein powder (Plotto et al., 2004). The seeds are also pressed for their oil in China. The flowers are edible and occasionally used in cocktails and teas as heat and carbonated liquids can make them “bloom” or open while submerged in the beverage.

OBJECTIVES

This research was initiated to address the lack of data on the yield of roselle as a conventional crop. Different genotypes were used to identify differences in regional genotypes. The genotypes were also tested for differences in micronutrients over the harvesting period to determine differences.

MATERIALS AND METHODS

Four roselle cultivars (Africa Green (AG), Indian Red (IR), Indian Variegated (IV), and Thai Red (TR)) were grown over the 2017 and 2018 field season in New Brunswick, New Jersey (see Figure 3). Seeds were acquired from; AG (Nigeria), IR (www.seedsofindia.com), IV (sport from IR seeds), TR (Baker Creek Heirloom Seeds, www.rareseeds.com). The African green (sometimes called 'white') genotype has green leaves, stems, veins and calyces (Figure 4). Indian red has red petioles, stems leaf veins and calyces with green leaf tissue (see Figure 5). Indian variegated has red and green striped stems, leaf veins, and calyces with green leaves and red petioles (see Figure 6). The Thai red genotype is primarily used for calyx harvesting and has red calyces, veins, and stems with leathery dark green leaves (see Figure 7).

Plants were started from seed in a standard greenhouse flat filled with Pro-Mix® brand BX general-purpose professional growing medium soil. Seedling trays were grown under greenhouse conditions (12 hour light cycles) for approximately 6 weeks before being planted in the field. Plants were then transplanted into the field in a randomized complete block design by hand. Plants were sown in black plastic mulch with drip irrigation and grown for another 6 weeks until harvesting began (See Figure 8). In 2017, the seedlings required 6 weeks of greenhouse production, then hibiscus was transplanted into the field for an additional 7 weeks until harvested. In 2018: the seedlings required 5 weeks of greenhouse production, then hibiscus was transplanted into the field for an additional 5 weeks until harvested.

The roselle was grown in a mix of Nixon Loam and Sassafras soils at Rutgers Horticultural Research Farm #3. Drip irrigation with black plastic mulch was used to ensure even watering and weed control. The roselle was planted in a randomized complete block design to control for variations in soil types and wetness. Each section was planted with 45 cm between plants, 1 meter between rows, and with unharvested end plants to reduce edge effects. A combination of herbicides and hand weeding was used to control weeds between rows.

Roselle was harvested by removing the branch tips (See Figure 6). After the initial removal of the apical meristem subsequent branches were harvested if they exceeded 11 cm in length (from the main branch). Branch tips were then placed in paper bags, fresh weights were obtained. Plant samples were dried in an electric plant drier at 50C for 4 days or until dry. Samples were then weighed for dry mass and stored. The dried samples were ground to 20 mesh or 0.85 mm sieve size. The samples were analyzed at the Pennsylvania State University Agricultural Analytical Services Lab using the standard acid digestion and ICP analysis protocol (Huang and Schulte, 1985).

Data was analyzed using Microsoft 2010 Excel (with the add-in XLSTAT by Addinsoft) and SAS University Edition (SAS Institute Inc., 2018). The repeated measures ANOVA test and Tukey's Post-hoc analysis were conducted on the harvest data collected over the 2017 and 2018 growing seasons. Repeated measures ANOVA and Tukey's honestly significant difference post-hoc analysis both chosen to accommodate missing data points due to mold, missing samples and diseased plants. Statistically significant data was determined by a p-value threshold of 0.05.

Figure 3. Roselle genotypes from left to right; African Green (AG), Indian Red (IR), Indian Variegated (IV), and Thai Red (TR).

Figure 4. African Green genotype produces a green calyx (right) along with green leaves, stems and branch tips (left).

Figure 5. Indian Red genotype has a red calyx (right) with red stems, red petioles and leaf veins (left).

Figure 6. Indian Variegated genotype has a variegated calyx (right) with variegated stems, red petioles and green leaf veins (left).

Figure 7. Thai Red genotype has a red calyx (right), dark narrow leaves, and red stems (left).

Figure 8. Roselle seedlings being started in the greenhouse and after transplanting into the field with black plastic mulch and drip irrigation installed.

Figure 9. Roselle branch tip, from right to left; African Green, Indian Red, and Indian Variegated. Each bundle is from an individual plant.

2017 GROWING SEASON

In the 2017 growing season planting was delayed due to rainy conditions. Therefore, planting was done 6 weeks after the plants were sown in the greenhouse. The roselle plants were harvested beginning at 7 weeks after transplanting into the field. The African green, Indian Red and Indian Variegated genotypes were grown. Diseases present were fusarium, powdery mildew and edema, all appearing at the end of the season. Branch tips were harvested by hand every two and three weeks. Fresh weights, dry weights, height and tip numbers were collected.

Leaf Yield

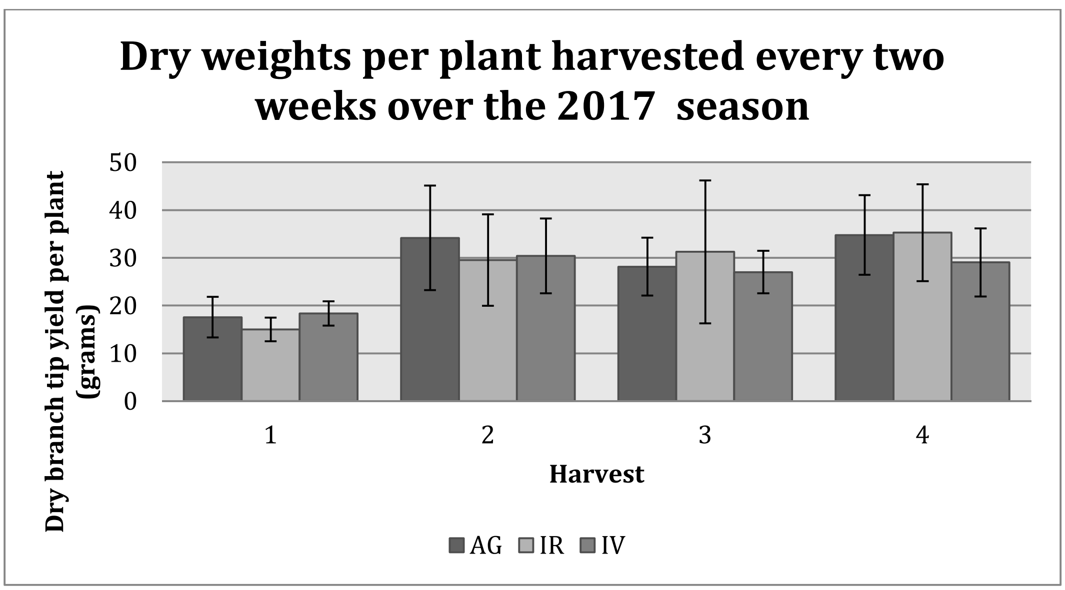


Figure 10. Dry leaf yield per plant means from the African Green, Indian Red, and Indian variegated cultivars harvested every 2 weeks for 8 weeks with ± 1 Standard deviation. Plants were grown 6 weeks in the greenhouse and 7 weeks in the field until harvest weeks

TABLE 6. Means with standard deviations, repeated measures ANOVA, and Tukey's honestly significant difference results for dry branch tips per plant harvested every two weeks over the 2017 season

Genotype	HARVEST 1	HARVEST 2	HARVEST 3	HARVEST 4	SUM
AG	17.57	34.18	28.16	34.77	114.67
SD	4.25	10.93	6.07	8.33	
IR	14.98	29.53	31.24	35.26	111.01
SD	2.48	9.57	14.99	10.13	
IV	18.34	30.38	27.01	29.06	104.80
SD	2.55	7.84	4.47	7.13	
ANOVA type 3: Solution for Fixed Effects					
Effect	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	14.6989	0.5861	35	25.08	<.0001
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%:					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
GENOTYPE-AG vs GENOTYPE-IV	10.100	4.709	2.454	0.000	Yes
GENOTYPE-AG vs GENOTYPE-IR	1.360	0.634	2.454	0.803	No
GENOTYPE-IR vs GENOTYPE-IV	8.740	4.075	2.454	0.001	Yes
Tukey's d critical value:			3.47		

The 2017 two-week harvest when analyzed alone resulted in a p-value of <0.0001 indicating a highly significant difference between the means of the African Green (AG), Indian Red (IR) and Indian Variegated (IV) genotypes. Tukey's HSD post-hoc analysis determined that the IV genotype was significantly different from both the AG and IR (see Table 6). Based on the per plant averages, IV started the season with slightly higher yields than the other two genotypes but fell slightly behind in the later harvests. (see Figure 10).

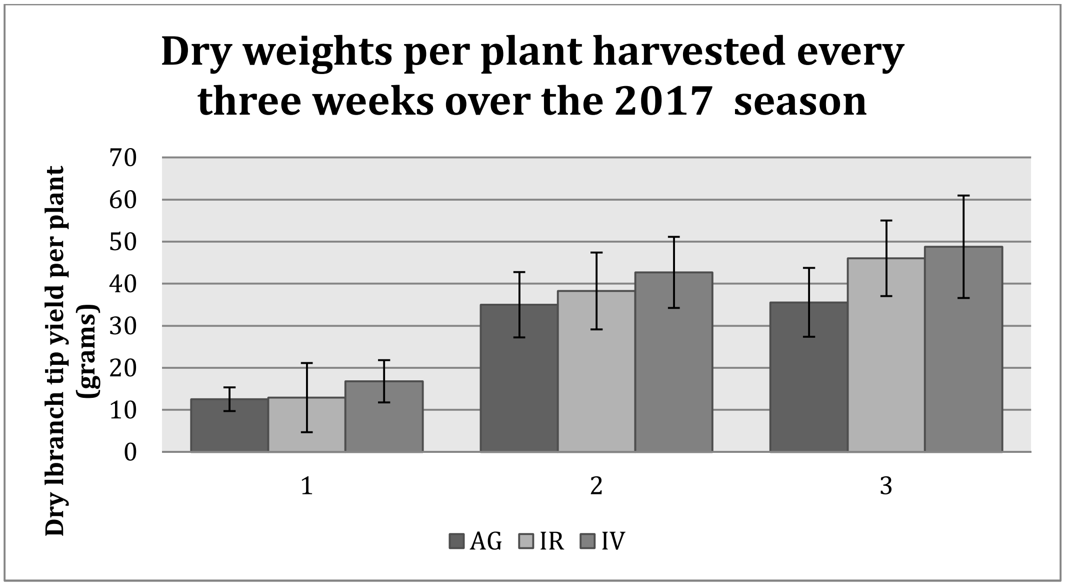


Figure 11. Dry leaf yield per plant means from the African Green, Indian Red, and Indian variegated cultivars harvested every 2 weeks for 8 weeks with ± 1 Standard deviation. Plants were grown 6 weeks in the greenhouse and 7 weeks in the field until harvest weeks

Table 9. Means with standard deviations, repeated measures ANOVA, and Tukey's honestly significant difference results for dry branch tips per plant harvested every three weeks over the 2017 season

Genotype	HARVEST 1	HARVEST 2	HARVEST 3	SUM	
AG	12.54	35.01	35.54	83.10	
SD	2.84	7.78	8.19		
IR	12.92	38.27	46.06	97.26	
SD	8.20	9.15	8.99		
IV	16.82	42.73	48.76	108.30	
SD	5.03	8.45	12.18		
ANOVA type 3: Solution for Fixed Effects					
Effect	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Intercept	14.99	0.67	52.00	22.36	<.0001
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%:					

Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
GENOTYPE-IV vs GENOTYPE-AG	8.07	2.43	2.42	0.05	Yes
GENOTYPE-IV vs GENOTYPE-IR	2.74	0.82	2.42	0.69	No
GENOTYPE-IR vs GENOTYPE-AG	5.33	1.60	2.42	0.25	No
Tukey's d critical value:			3.42		

Harvests conducted at three-week intervals were analyzed using the same methods as the two-week intervals. In the 2017 three-week interval harvest the results from the repeated measures ANOVA suggest significant difference between the genotypes (see Table 9). The post-hoc analysis determined that there was a significant difference between the AG and IV genotypes. The average yield per plant of AG are lower than both IR and IV with IV yielding the most (see Figure 11).

Nutrition

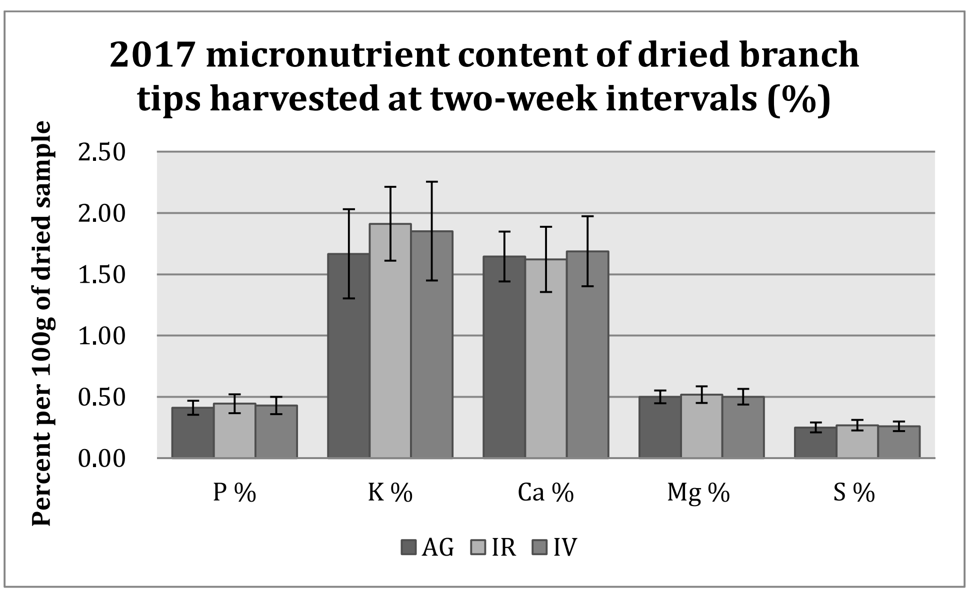


Figure 12. 2017 average micronutrient content of dried branch tips harvested at two-week intervals with ±1 standard deviation (AG n=10, IR n=12, IV n=12)

TABLE 10. 2017 micronutrient content of dried branch tips harvested at two-week intervals of the African green, Indian red, and Indian variegated genotypes

GENOTYPE	P %	SD	K %	SD	Ca %	SD	Mg %	SD	S %	SD
AG	0.41	0.06	1.67	0.36	1.65	0.20	0.50	0.05	0.25	0.04
IR	0.44	0.08	1.91	0.30	1.62	0.27	0.52	0.07	0.27	0.04
IV	0.43	0.07	1.85	0.40	1.69	0.28	0.50	0.06	0.26	0.04

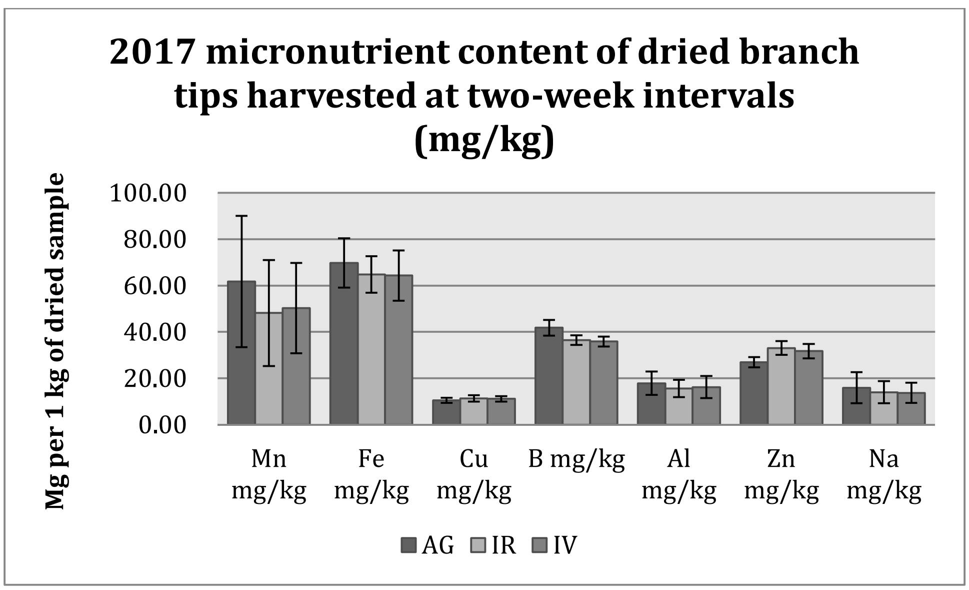


Figure 13. 2017 average micronutrient content of dried branch tips harvested at two-week intervals (mg/kg) with ± 1 standard deviation (AG n=10, IR n=12, IV n=12).

TABLE 11. 2017 micronutrient content of dried branch tips harvested at two-week intervals (mg/kg)

GENOTYPE	Mn mg/kg	SD	Fe mg/kg	SD	Cu mg/kg	SD	B mg/kg	SD	Al mg/kg	SD	Zn mg/kg	SD	Na mg/kg	SD
AG	61.76	28.29	69.73	10.61	10.53	1.10	41.79	3.36	17.87	5.06	26.93	2.15	15.94	6.66
IR	48.17	22.83	64.79	7.89	11.31	1.40	36.49	2.12	15.61	3.67	33.07	2.98	13.99	4.74
IV	50.30	19.50	64.35	10.83	11.16	1.18	35.89	2.15	16.23	4.73	31.71	3.10	13.69	4.36

The micronutrient content in the African green, Indian red, and Indian variegated genotypes were very similar. The sample sizes were too small to compare with an analysis of variance (AG n=10, IR n=12, IV n=12). However, the genotypes grown have similar micronutrient contents based on the similar means and low standard deviations (see Tables 10 & 11). The only mineral with higher deviation within and between genotypes is manganese (Mn) (see Figure 13).

2018 GROWING SEASON

In the 2018 growing season, seedlings were grown for 5 weeks in a climate controlled greenhouse before transplanting to the field. The roselle plants were harvested after 5 weeks of field growth. The African green, Indian Red, Indian Variegated, and Thai Red genotypes were grown. Diseases present were powdery mildew, Tobacco Mosaic Virus (TMV), and edema. Powdery mildew was present on seedlings and persisted over the growing season. Branch tips were harvested by hand every two and three weeks. Fresh weights, dry weights, height and tip numbers were collected.

Leaf yield

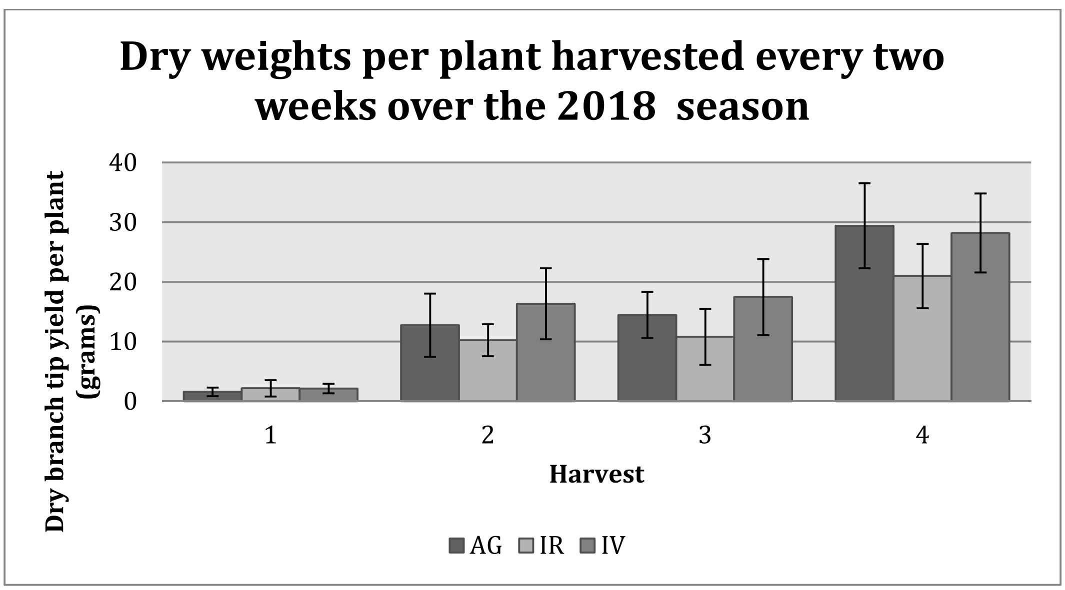


Figure 14. Dry leaf yield per plant means from the African Green, Indian Red, and Indian variegated cultivars harvested every 2 weeks for 8 weeks with ± 1 Standard deviation. Plants were grown 5 weeks in the greenhouse and 5 weeks in the field until harvest weeks began. Results were analyzed with repeated measures ANOVA (n=9, p=<0.0001)

Table 12. Means with standard deviations, repeated measures ANOVA, and Tukey's honestly significant difference results for dry branch tips per plant harvested every two weeks over the 2018 season

Genotype	HARVEST 1	HARVEST 2	HARVEST 3	HARVEST 4	SUM
AG	1.59	12.77	14.47	20.29	49.12
SD	0.72	5.30	3.85	6.80	
IR	2.18	10.24	10.80	14.24	37.46
SD	1.36	2.70	4.67	6.82	
IV	2.14	16.34	17.48	19.13	55.09
SD	0.81	5.93	6.37	5.56	
Solution for Fixed Effects					
Effect	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Intercept	1.79	0.20	24.00	9.09	<.0001
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%:					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
GENOTYPE-IV vs GENOTYPE-IR	2.71	1.49	2.51	0.31	No
GENOTYPE-IV vs GENOTYPE-AG	0.98	0.54	2.51	0.85	No
GENOTYPE-AG vs GENOTYPE-IR	1.73	0.95	2.51	0.61	No
Tukey's d critical value:			3.55		

During the 2018 growing season the AG, IR, IV, and TR genotypes were significantly different according to a repeated measures ANOVA with a p-value of <0.0001. However, the Tukey's HSD post-hoc analysis did not identify any differences between the genotypes (see Table 12). The average dry weight yield per plant shows the IR genotype with a lower yield than AG and IV (see Figure 14).

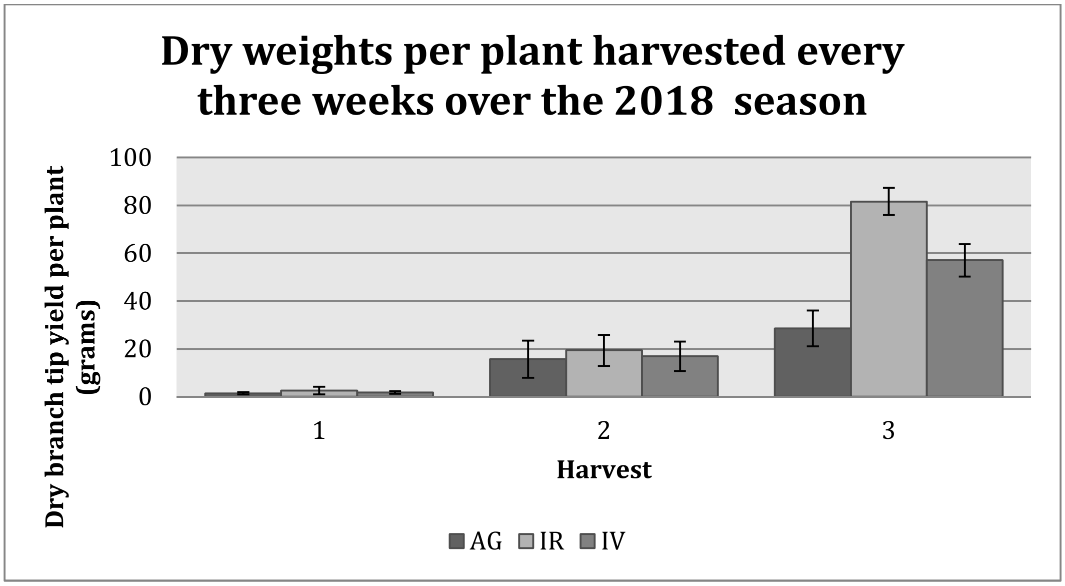


Figure 15. Dry leaf yield per plant means from the African Green, Indian Red, and Indian variegated cultivars harvested every 2 weeks for 8 weeks with ± 1 Standard deviation. Plants were grown 5 weeks in the greenhouse and 5 weeks in the field until harvest weeks

Table 13. Means with standard deviations, repeated measures ANOVA, and Tukey's honestly significant difference results for dry branch tips per plant harvested every three weeks over the 2018 season

Genotype	HARVEST 1	HARVEST 2	HARVEST 3	SUM	
AG	1.37	15.62	28.53	45.52	
SD	0.46	7.77	7.51		
IR	2.58	19.37	81.63	103.57	
SD	1.64	6.46	5.70		
IV	1.71	16.87	57.00	75.58	
SD	0.52	6.21	6.74		
ANOVA type 3: Solution for Fixed Effects					
Effect	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Intercept	1.47	0.28	20.00	5.26	<.0001
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%:					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
GENOTYPE-IR vs GENOTYPE-AG	1.38	0.29	2.55	0.95	No
GENOTYPE-IR vs GENOTYPE-IV	0.07	0.02	2.55	1.00	No
GENOTYPE-IV vs	1.31	0.28	2.55	0.96	No

GENOTYPE-AG	
Tukey's d critical value:	3.61

In the 2018 three-week interval the p-value is <0.0001, however the post-hoc analysis determines there is no difference between the genotypes (see Table 13). The average yield from all genotypes was very low the first week with IR yielding the highest as the season progressed (see Figure 15).

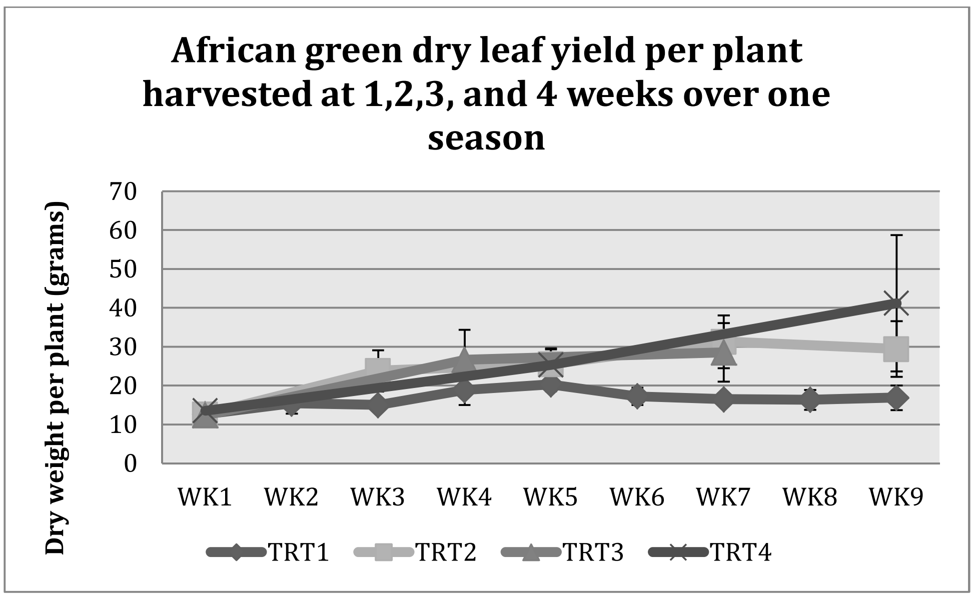


Figure 16. African green harvest timing study harvested every week, two weeks, three weeks and four weeks. Graph shows means with ±1 standard deviation (n=9).

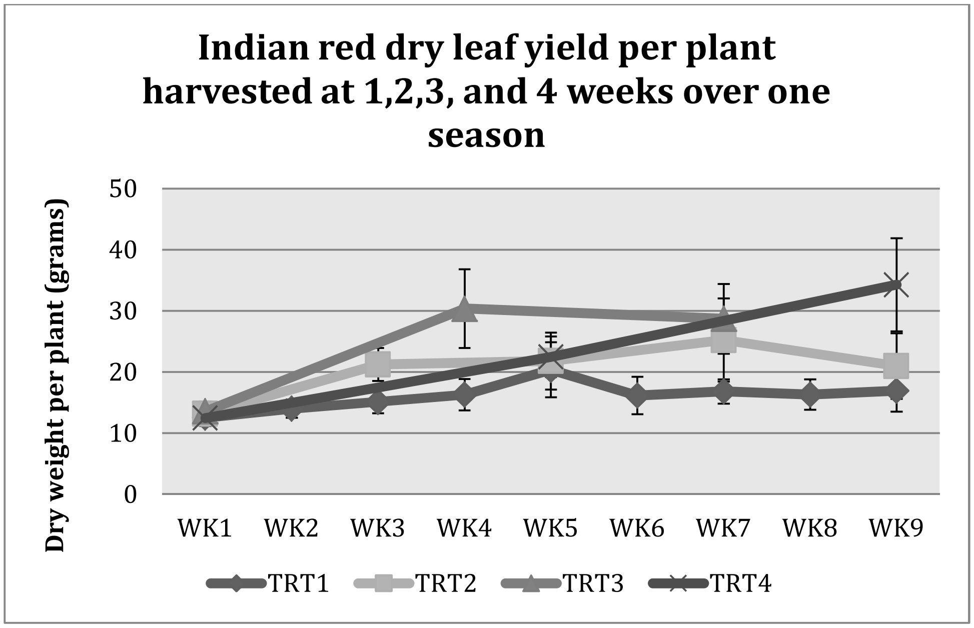


Figure 17. Indian red harvest timing study harvested every week, two weeks, three weeks and four weeks. Graph shows means with ±1 standard deviation (n=9).

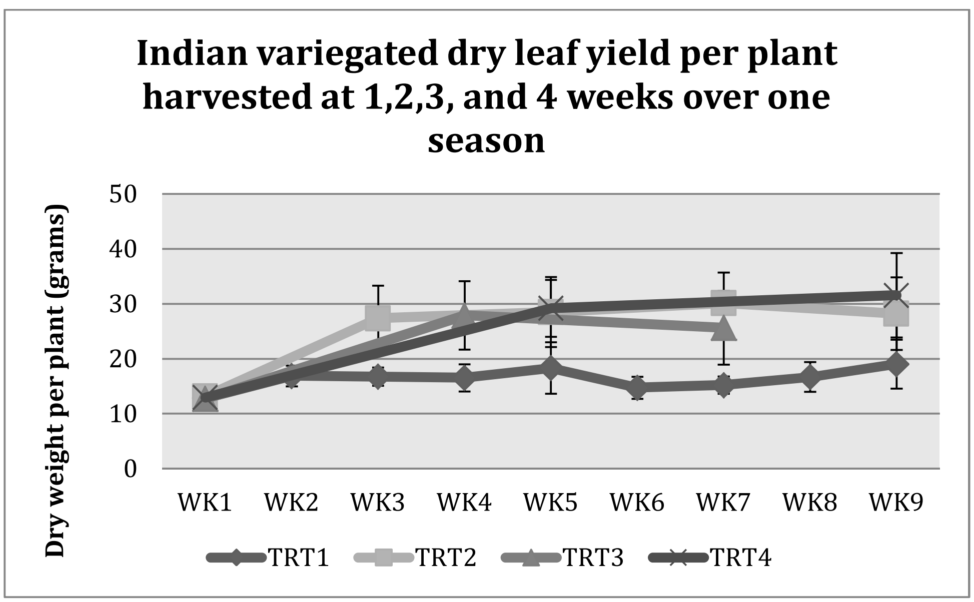


Figure 18. Indian variegated harvest timing study harvested every week, two weeks, three weeks and four weeks. Graph shows means with ±1 standard deviation (n=9).

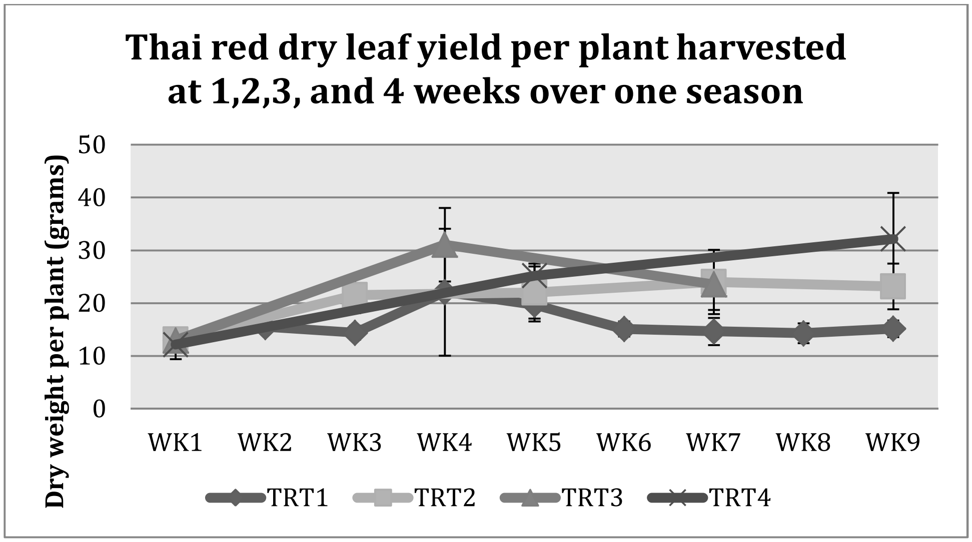


Figure 19. Thai red harvest timing study harvested every week, two weeks, three weeks and four weeks. Graph shows means with ±1 standard deviation (n=9).

TABLE 14. Total yield per plant for each treatment (1 week harvest, 2 week, 3 week , and 4 week).

	TOTAL DRY WEIGHT TIP YIELD PER PLANT (GRAMS)			
GENOTYPE	1 WEEK	2 WEEK	3 WEEK	4 WEEK
AG	148.9776	122.5238	67.515	79.98667
IR	144.6421	102.4478	72.67389	69.28014
IV	146.8444	127.2888	66.21696	73.66222
TR	143.8871	103.8144	67.6175	69.55444

Preliminary data from one growing season showing the differences of 1, 2, 3 and 4 week harvest intervals on yield show higher yields with one-week interval harvesting (Table 14). Although roselle is indeterminate frequent harvesting may cause smaller but more numerous branch tips as axillary buds take over for apical meristems. Figures 16-19 show the dry branch tip yields of AG, IR, IV and TR over one growing season. Although further research needs to be conducted to determine the highest yielding harvest regime some insights can be drawn from this early data. The one-week harvest did not allow for significant regrowth between harvesting and kept the plants at a very short height. However, longer harvest intervals allowed for larger, but fewer branch tips. Depending on preferred leaf size and quantity, different harvest regimes can be implemented with similar results seen among the four genotypes.

Nutrition

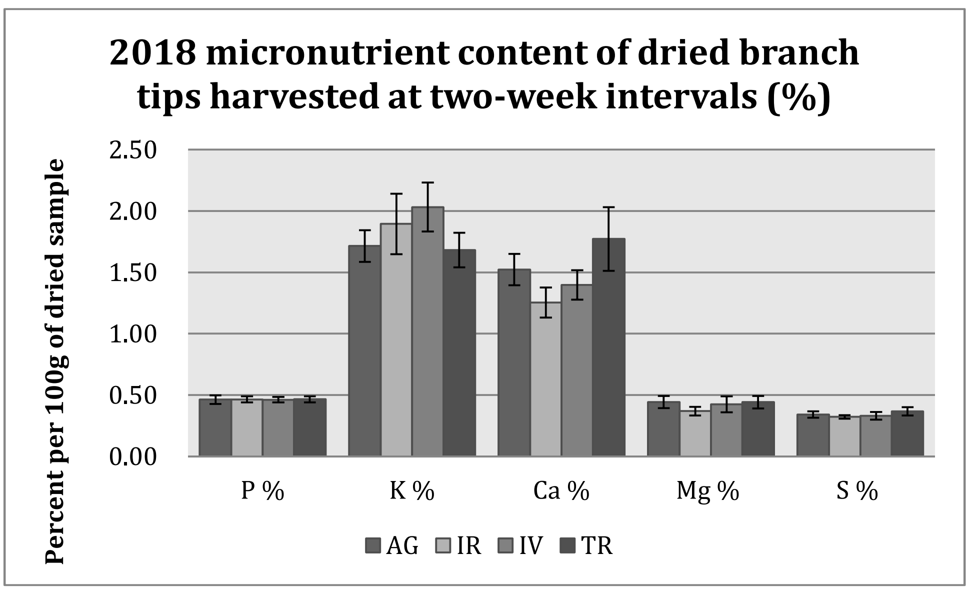


Figure 20.Dried branch tip average micronutrient content from the 2018 growing season in percent per 100g of leaves with ± standard deviation

TABLE 14. Average died branch tip micronutrient content from AG, IR, IV and TR over the 2018 growing season with standard deviations in percent per 100g of sample										
GENOTYPE	P %	SD	K %	SD	Ca %	SD	Mg %	SD	S %	SD
AG	0.46	0.03	1.72	0.13	1.52	0.13	0.44	0.05	0.34	0.03
IR	0.46	0.02	1.89	0.25	1.25	0.12	0.37	0.03	0.32	0.01
IV	0.46	0.02	2.03	0.20	1.40	0.12	0.42	0.07	0.33	0.03
TR	0.47	0.02	1.68	0.14	1.77	0.26	0.44	0.05	0.37	0.03

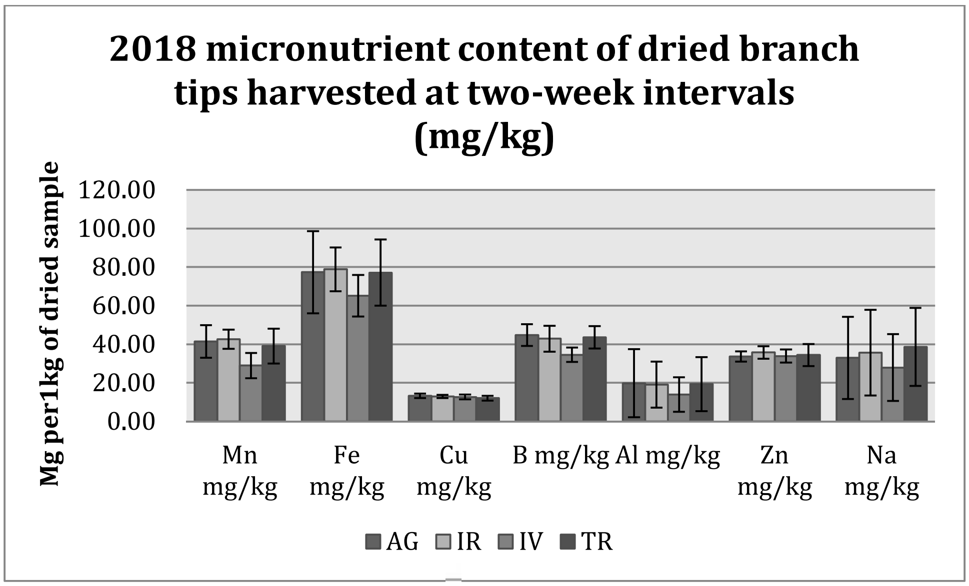


Figure 21. Dried branch tip average micronutrient content from the 2018 growing season in mg/kg of leaves with ±1 standard deviation

TABLE 15. Average died branch tip micronutrient content from AG, IR, IV and TR over the 2018 growing season with standard deviations in mg/kg of sample													
Mn mg/kg	SD	Fe mg/kg	SD	Cu mg/kg	SD	B mg/kg	SD	Al mg/kg	SD	Zn mg/kg	SD	Na mg/kg	SD
41.46	8.47	77.39	21.30	13.28	1.12	44.72	5.64	19.78	17.63	33.67	2.64	32.95	21.27
42.60	4.92	78.84	11.35	12.94	0.84	42.86	6.75	19.06	11.97	35.77	3.21	35.65	22.28
28.94	6.50	65.11	10.73	12.61	1.25	34.50	3.74	13.94	8.93	33.86	3.41	27.88	17.29
39.05	9.07	77.13	17.14	12.05	1.21	43.64	5.78	19.34	13.99	34.40	5.75	38.57	20.20

The micronutrient content in the African green, Indian red, and Indian variegated genotypes were very similar over the 2018 season. The sample sizes were too small to compare with an analysis of variance (AG n=12, IR n=11, IV n=11). However, the genotypes grown have similar micronutrient contents based on the similar means and low standard deviations (see Tables 14 & 15). The minerals with higher deviation within and between genotypes are calcium (Ca) and potassium (K) (see Figure 16).

2017 AND 2018 COMPARISONS

In the 2017 and 2018 growing seasons can be compared using the two-week harvest data as the they were harvested and planted in a similar manner at the same location in New Jersey. Plants were sown in the greenhouse and transplanted into the field at 6 weeks (2017) and 5 weeks (2018). The roselle plants were harvested beginning at 7 weeks (2017) and 5 weeks (2018) after transplanting into the field. The African green, Indian Red and Indian Variegated genotypes were grown. Branch tips were harvested by hand every two-weeks by hand. Fresh weights, dry weights, height and tip numbers were collected.

Leaf yield

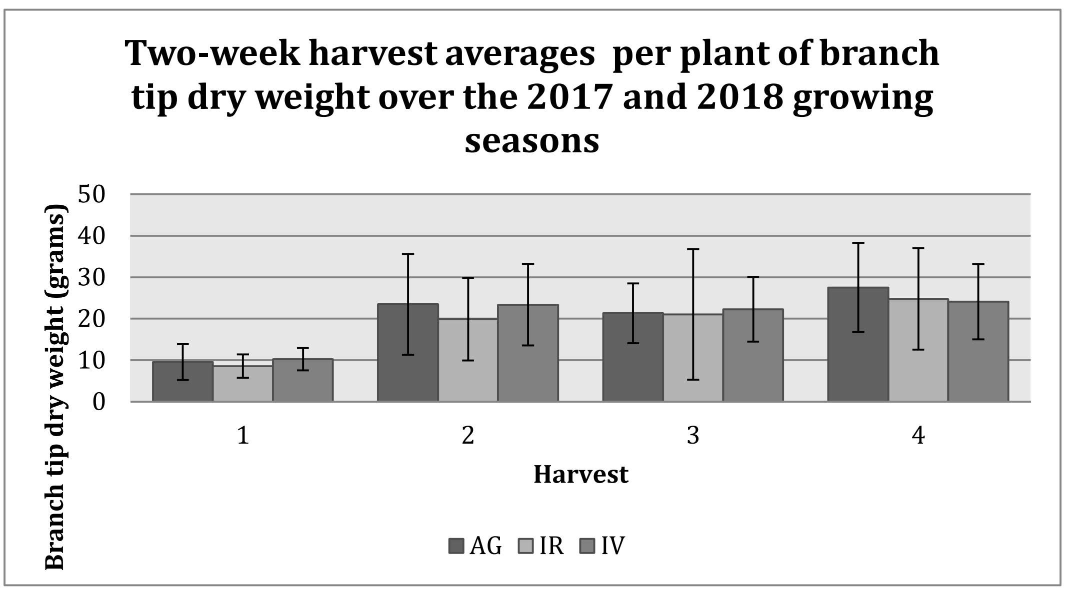


Figure 22. Dry leaf yield per plant means from the African Green, Indian Red, and Indian variegated cultivars harvested every 2 weeks for 8 weeks with ± 1 Standard deviation. Plants were grown approximately 6 weeks in the greenhouse and 6 weeks in the field until harvesting began.

Table 16. Means with standard deviations, repeated measures ANOVA, and Tukey's honestly significant difference results for dry branch tips per plant harvested every two weeks averaged from the 2017 and 2018 season

Genotype	Harvest				
	1	2	3	4	
AG	9.58	23.48	21.31	27.53	
SD	4.31	12.15	7.19	10.75	
IR	8.58	19.89	21.02	24.75	
SD	2.83	9.94	15.70	12.21	
IV	10.24	23.36	22.25	24.09	
SD	2.68	9.83	7.79	9.04	
Solution for Fixed Effects					
Effect	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Intercept	8.0846	0.8739	60	9.25	<.0001
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%:					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
GENOTYPE-AG vs GENOTYPE-IV	5.050	1.912	2.405	0.144	No
GENOTYPE-AG vs GENOTYPE-IR	3.191	1.208	2.405	0.453	No
GENOTYPE-IR vs GENOTYPE-IV	1.858	0.704	2.405	0.762	No
Tukey's d critical value:			3.402		

The two-week interval harvests from 2017 and 2018 were analyzed with a repeated measures analysis of variance (ANOVA) test and a Tukey's honestly significant difference (HSD) post-hoc analysis to determine the statistically significant differences between the means. A p-value threshold of 0.05 was used to determine the significance of the results at the 95% confidence threshold.

Results for the two-week interval harvests over the 2017 and 2018 growing seasons when averaged together have a significant difference between the means based on a repeated measures ANOVA test (see Table 16). However, the Tukey's HSD post-hoc analysis shows no significance between the genotypes. Based on the means and small standard deviations the genotypes had very similar average dry branch tip yields per plant (see Figure 18).

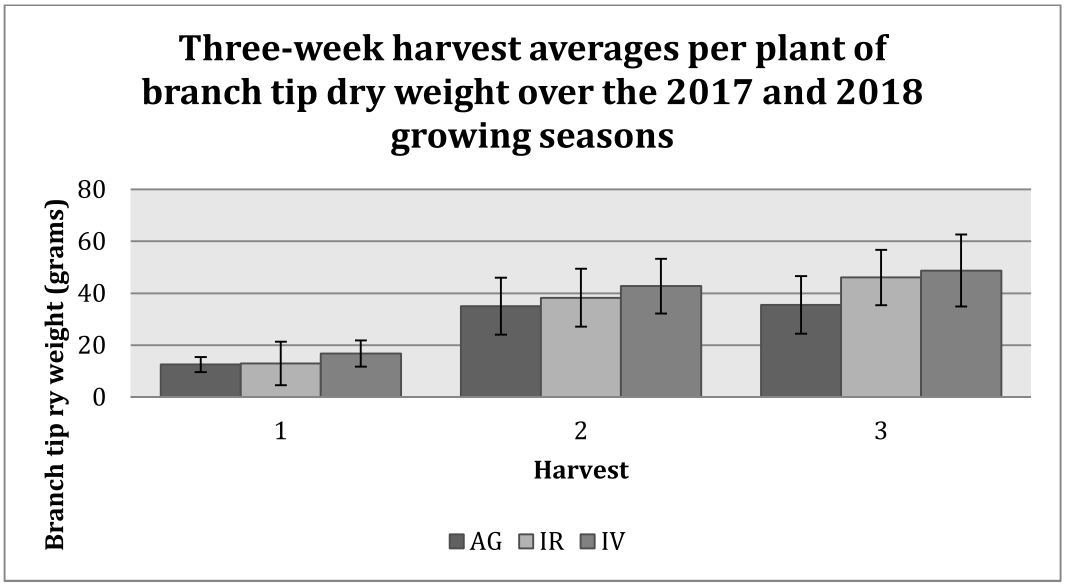


Figure 23. Dry leaf yield per plant means from the African Green, Indian Red, and Indian variegated cultivars harvested every 3 weeks for 9 weeks with ± 1 Standard deviation. Plants were grown approximately 6 weeks in the greenhouse and 6 weeks in the field until harvesting began

Table 17. Means with standard deviations, repeated measures ANOVA, and Tukey's honestly significant difference results for dry branch tips per plant harvested every three weeks averaged from the 2017 and 2018 season

Genotype	Harvest				
	1	2	3		
AG	12.54	35.01	35.54		
SD	2.88	10.99	11.12		
IR	12.92	38.27	46.06		
SD	8.36	11.20	10.65		
IV	16.82	42.73	48.76		
SD	5.06	10.49	13.92		
Repeated Measures ANOVA: Solution for Fixed Effects					
Effect	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**

Intercept	8.08	0.87	60.00	9.25	<.0001
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%:					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
GENOTYPE-IV vs GENOTYPE-AG	4.99	1.78	2.39	0.18	No
GENOTYPE-IV vs GENOTYPE-IR	3.13	1.12	2.39	0.50	No
GENOTYPE-IR vs GENOTYPE-AG	1.85	0.66	2.39	0.79	No
Tukey's d critical value:			3.39		

The 2017 and 2018 three-week interval harvests combined, show a significant difference between the genotypes in the ANOVA analysis but not in the Tukey's HSD post-hoc (see Table 17). IV had the highest combined averages from the three-week interval harvests, followed by IR with AG being the lowest yielding (see Figure 19).

Dry branch tip yields per genotype show AG producing the most during two-week interval harvests and IR yielding the most in the three-week interval harvest, but both only by slight margins over the other two varieties (see Table 17). Overall, AG, IR, and IV are comparable in yields over two-and three-week interval yielding a similar seasonal profit.

TABLE 18. Average dry weight total yield per plant over the growing season (grams)

GENOTYPE	Two-week interval harvest 2017	Two-week interval harvest 2018	Two-week interval harvests averaged	Three-week interval harvest 2017	Three-week interval harvest 2018	Three-week interval harvests averaged
African Green	114.67	49.12	81.895	83.1	45.51	64.305

Indian Red	111.01	37.46	74.235	97.26	103.57	100.415
Indian Variegated	104.79	55.09	79.94	108.3	75.58	91.94

Total yield per plant over the 2018 growing season had higher averages than the 2017 growing season (see Table 18). African green genotype yielded the highest in combined averages from 2017 and 2018 when harvested at two-week intervals. Indian red had the highest yield in the three-week interval harvest in the combined 2017 and 2018 seasons.

Nutrition

TABLE 19. Micronutrient content per 100g of dried leaves for four roselle genotypes harvested at two-week intervals

	AG	SD	IR	SD	IV	SD
P %	0.439	0.052	0.454	0.056	0.445	0.054
K %	1.693	0.257	1.903	0.269	1.942	0.324
Ca %	1.578	0.174	1.438	0.277	1.542	0.260
Mg %	0.469	0.058	0.444	0.093	0.463	0.074
S %	0.300	0.057	0.295	0.042	0.295	0.050
Mn mg/kg	50.684	22.081	45.387	16.365	39.622	17.908
Fe mg/kg	73.908	17.350	71.816	11.946	64.729	10.530
Cu mg/kg	12.028	1.770	12.127	1.401	11.886	1.396
B mg/kg	43.391	4.872	39.675	5.873	35.193	3.059
Al mg/kg	18.915	13.218	17.337	8.820	15.084	7.067
Zn mg/kg	30.603	4.175	34.419	3.324	32.783	3.366
Na mg/kg	25.219	18.193	24.819	19.232	20.790	14.291

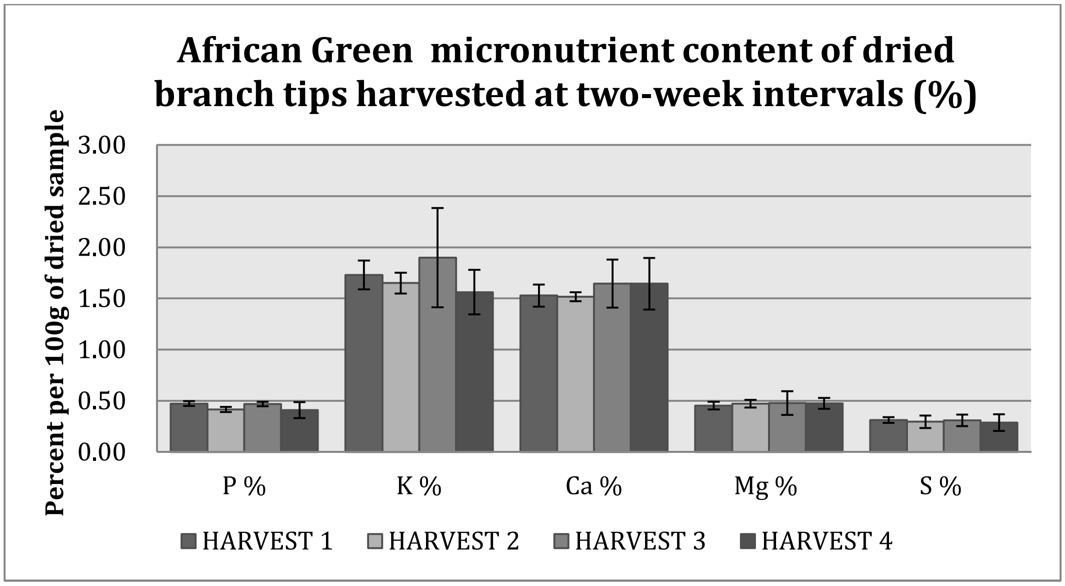


Figure 24. Content of leaf tissue Phosphorus, Potassium, Calcium, Magnesium, and Sulfur per 100g dried leaf sample. Samples are from 2-week harvests averaged over two growing seasons are shown with ±1 Standard deviation. MANOVA results indicate significant differences between the genotypes with a p-value of <0.0001 (n=22).

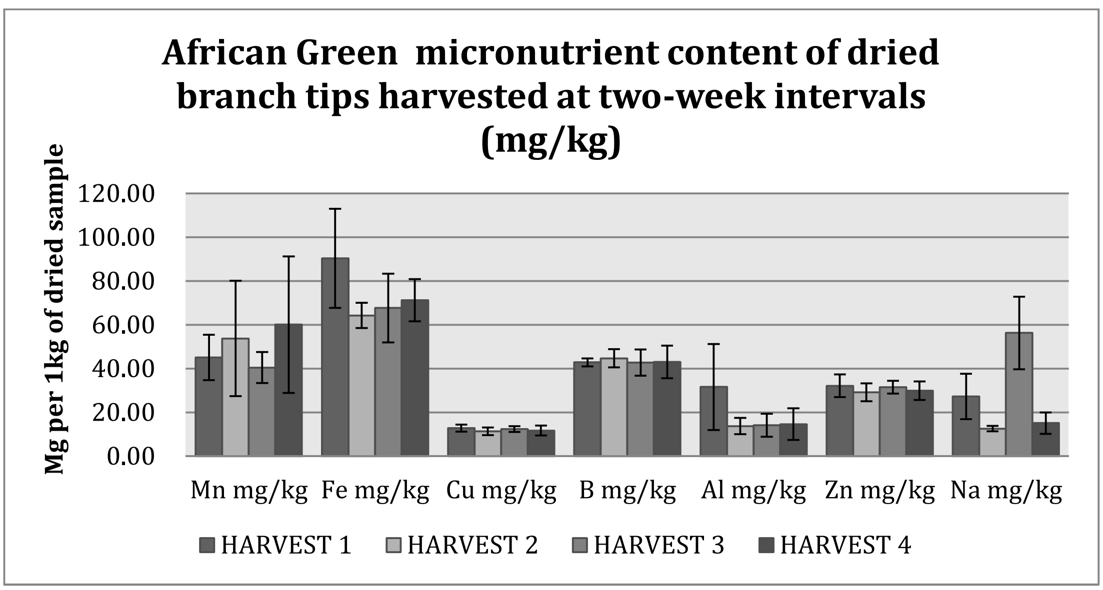


Figure 25. . Micronutrient amounts per 100 g dried leaf sample. Samples are from 2-week harvests averaged over two growing seasons with ±1 Standard deviation. MANOVA results indicate significant differences between the genotypes with a p-value of <0.0001 (n=22).

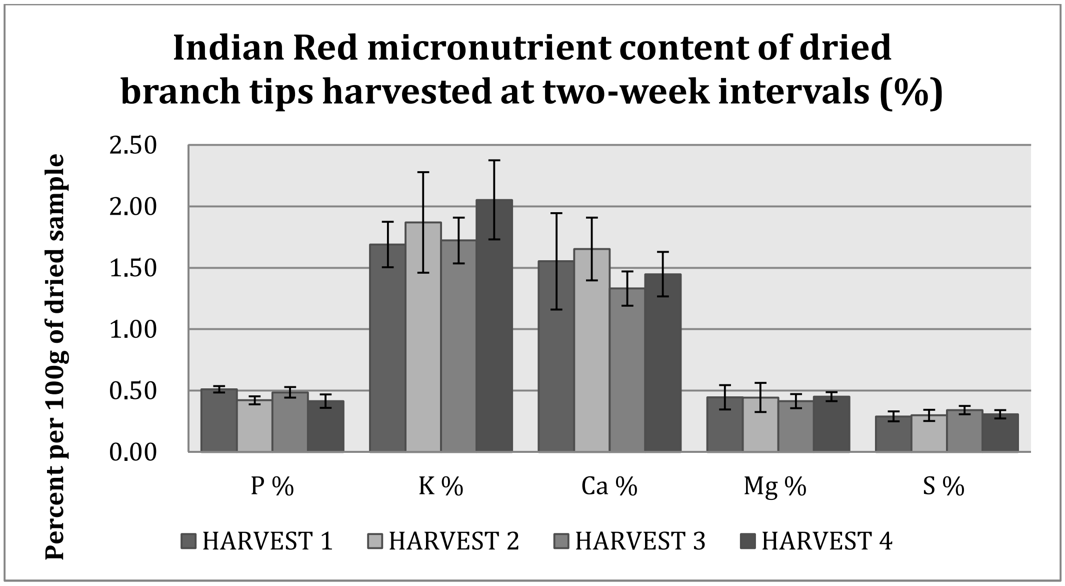


Figure 26. Percentages of Phosphorus, Potassium, Calcium, Magnesium, and Sulfur per 100g dried leaf sample. Samples are from 2-week harvests averaged over two growing seasons are shown with ±1 Standard deviation. MANOVA results indicate significant differences be between the genotypes with a p-value of <0.0001 (n=22).

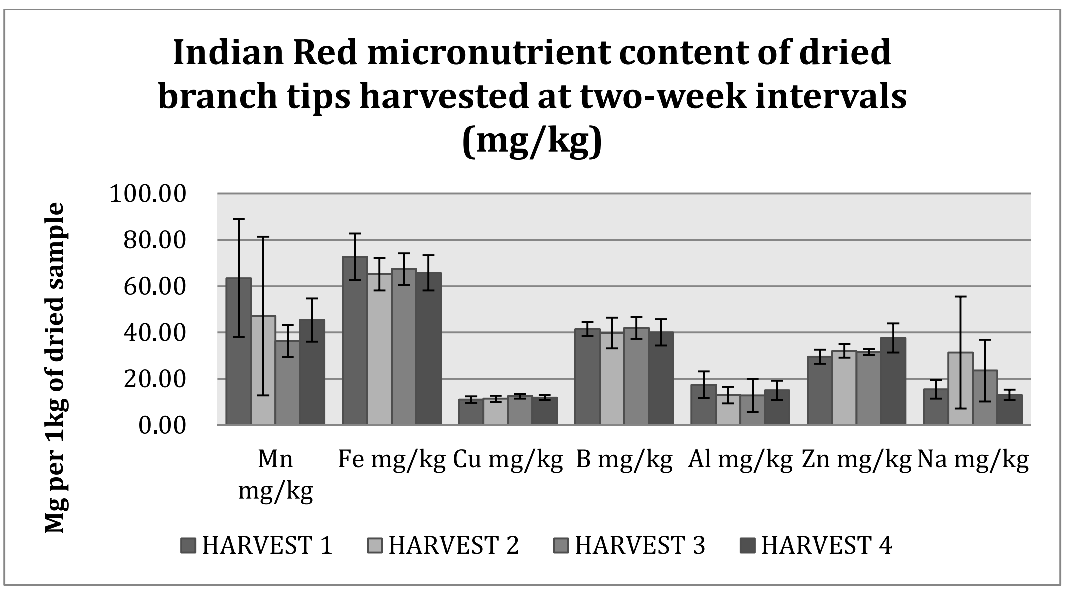


Figure 27. Micronutrient amounts per 100 g dried leaf sample. Samples are from 2-week harvests averaged over two growing seasons with ±1 Standard deviation. MANOVA results indicate significant differences between the genotypes with a p-value of <0.0001 (n=22).

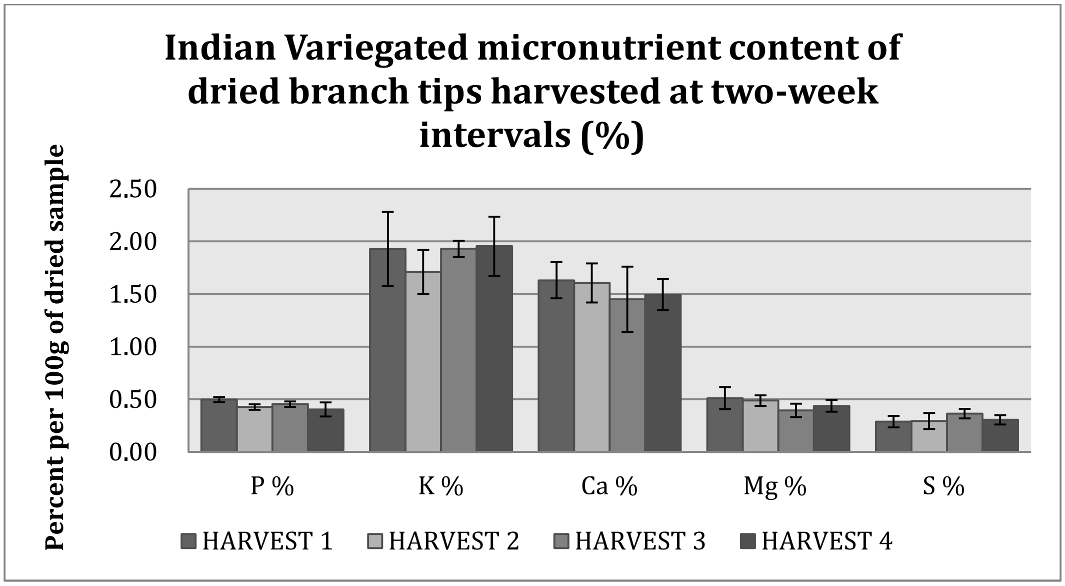


Figure 28. Phosphorus, Potassium, Calcium, Magnesium, and Sulfur per 100g dried leaf sample as illustrated as % of dry weight. Samples are from 2-week harvests averaged over two growing seasons are shown with ±1 Standard deviation. MANOVA results indicate significant differences between the genotypes with a p-value of <0.0001 (n=22).

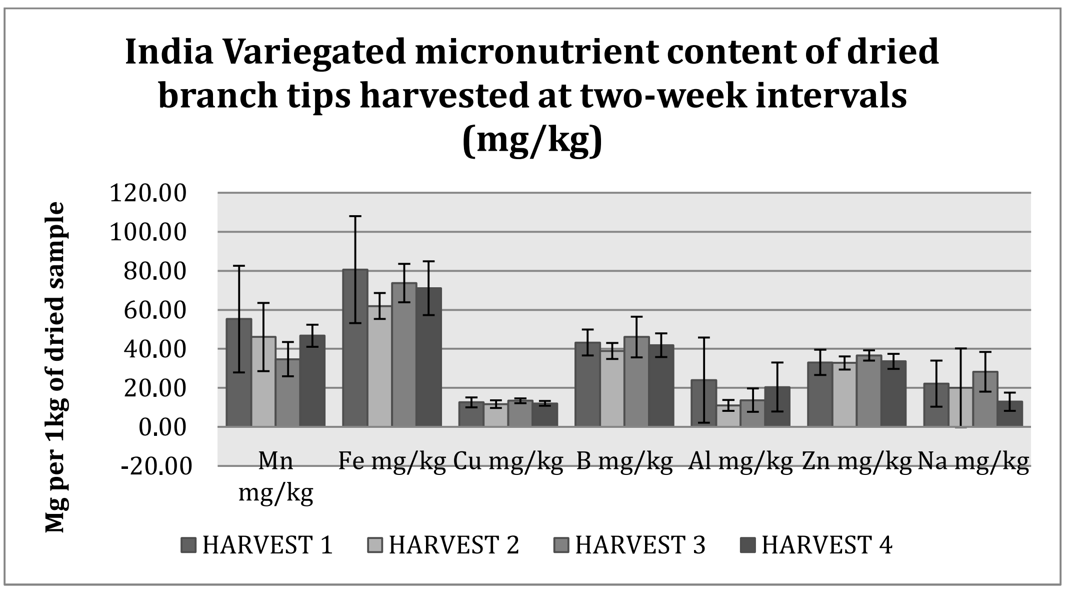


Figure 29. Micronutrient amounts per 100 g dried leaf sample. Samples are from 2-week harvests averaged over two growing seasons with ±1 Standard deviation. MANOVA results indicate significant differences between the genotypes with a p-value of <0.0001 (n=22).

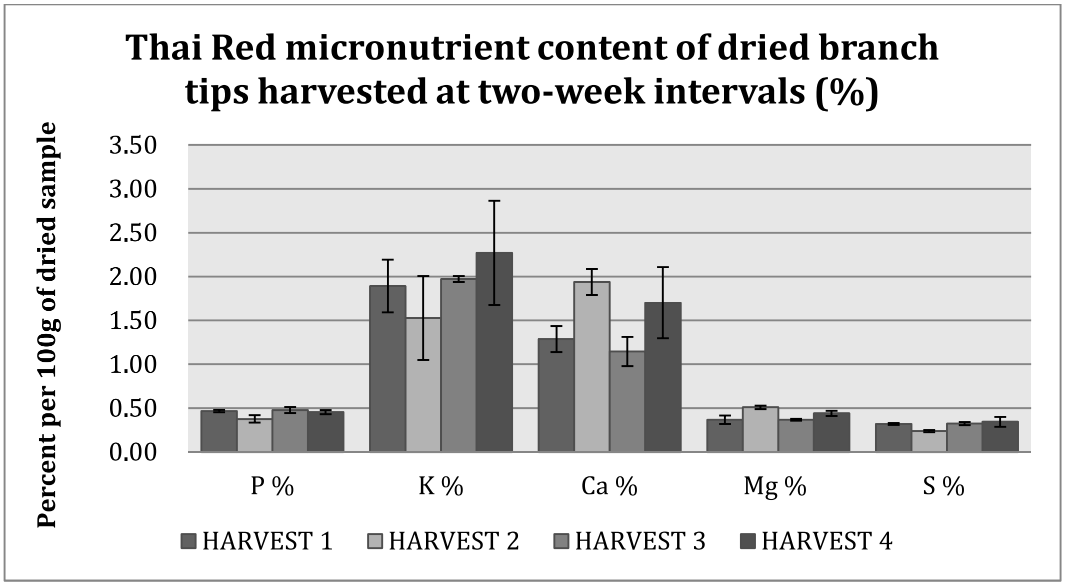


Figure 30. Percentages of Phosphorus, Potassium, Calcium, Magnesium, and Sulfur per 100g dried leaf sample. Samples are from 2-week harvests averaged over two growing seasons are shown with ±1 Standard deviation. MANOVA results indicate significant differences between the genotypes with a p-value of <0.0001 (n=22). Based on one season of data.

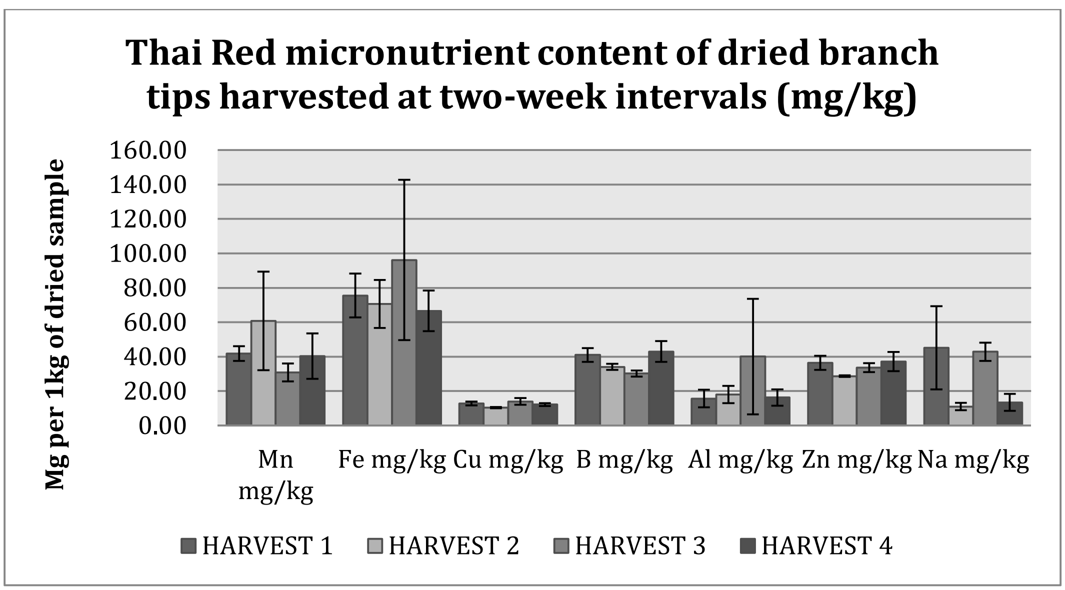


Figure 31. Micronutrient amounts per 100 g dried leaf sample. Samples are from 2-week harvests averaged over two growing seasons with ±1 Standard deviation. MANOVA results indicate significant differences between the genotypes with a p-value of <0.0001 (n=22). Based on one season of data.

Results from the micronutrient analysis of roselle genotypes were analyzed using the Multivariate analysis of variance (MANOVA). All genotypes showed a significant difference between the nutrients found in each harvest with p-values of <0.0001. The mineral content in the African Green (AG) genotype ere very similar across all harvests (Figure 21). However, AG showed higher iron content in the first week of harvesting and higher sodium in harvest number 3 (Figure 20). The Indian Red (IR) genotype also showed very similar levels in the mineral analysis (Figure 24). IR, however, had slightly higher iron and magnesium in the first harvest and higher sodium in harvests 2 and 3 (Figure 25). Indian Variegated (IV) also has little variation among minerals over the 4 harvest times (Figure 26). IV has a similar pattern to AG and IR in that the first harvest had higher iron and magnesium content and harvest 3 had higher sodium. IV also had higher variation with aluminum content among the harvests.

Micronutrient content of minerals and trace mineral were very similar among the three genotypes (Table 15). Roselle provides substantial levels of calcium and iron compared to daily needs. However, variations within the genotypes resulted in large standard deviations.

Data from one growing season for the Thai Red genotype shows similar micronutrient levels (Figures 28 and 29). However, TR seems to have higher variation between the harvests and does not show the higher iron or magnesium in the first harvest as the other genotypes.

Small samples sizes and large variations within genotypes have possibly led to a deceptively low p-value the MANOVA analysis. Future work should utilize large samples of several genotypes from the same region to determine the nutrition of roselle specific to certain areas. Plant breeders should consider the metabolites such as antioxidants as well as nutrient content of roselle when breeding more homogenous cultivars.

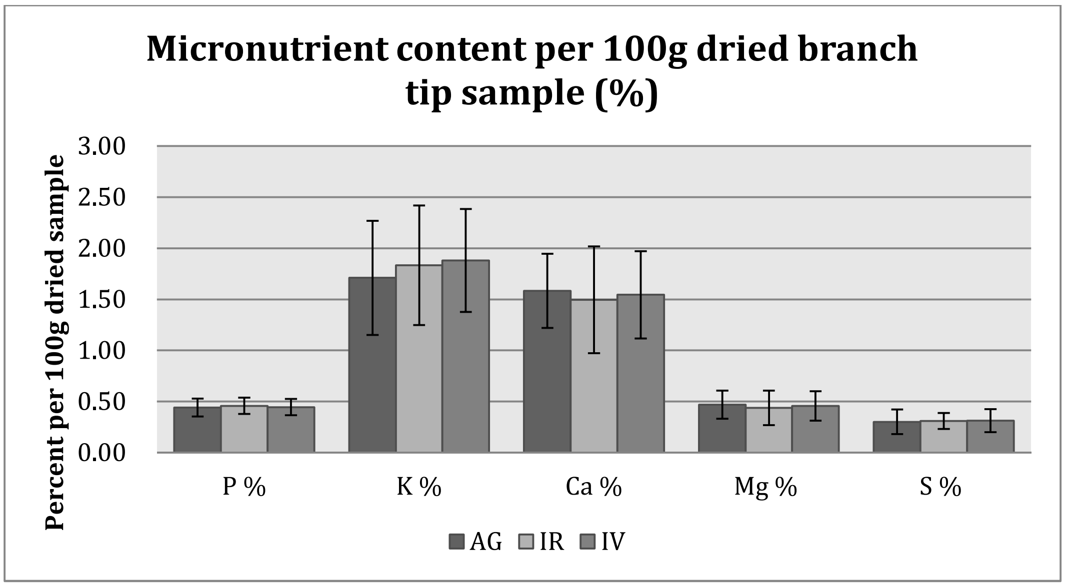


Figure 32. Percentage of Phosphorus, Potassium, Calcium, Magnesium and Sulfer per 100g dried leaf sample. Samples means from 2-week harvests averaged over two growing seasons. (n=66)

TABLE 20. ANCOVA and post-hoc analysis of phosphorus content per 100g of dried roselle sample from two growing seasons (n=66)

P %					
Type III Sum of Squares analysis (P %):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
GENOTYPE	2	0.026	0.013	5.062	**0.009**
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
IV vs AG	0.140	3.043	2.401	**0.009**	Yes
IV vs IR	0.058	2.171	2.401	0.084	No

IR vs AG	0.082	3.100	2.401	**0.008**	Yes
Tukey's d critical value:			3.396		

TABLE 21. ANCOVA and post-hoc analysis of potassium content per 100g of dried roselle sample from two growing seasons (n=66)

K %					
	Type III Sum of Squares analysis (K %):				
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	0.643	0.321	4.093	**0.021**
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
IV vs AG	0.663	2.612	2.401	**0.030**	Yes
IV vs IR	0.246	1.678	2.401	0.222	No
IR vs AG	0.417	2.846	2.401	**0.016**	Yes
	Tukey's d critical value:		3.396		

TABLE 22. ANCOVA analysis of sulfur content per 100g of dried roselle sample from two growing seasons (n=66)

S %					
	Type III Sum of Squares analysis (S %):				
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	0.000	0.000	0.021	0.979

TABLE 23. ANCOVA and post-hoc analysis of calcium content per 100g of dried roselle sample from two growing seasons (n=66)

Ca %					
	Type III Sum of Squares analysis (Ca %):				
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	0.517	0.258	4.756	**0.012**
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
AG vs IV	0.494	7.029	2.401	**< 0.0001**	Yes
AG vs IR	0.369	5.253	2.401	**<**	Yes

				0.0001	
IR vs IV	0.125	1.776	2.401	0.186	No
	Tukey's d critical value:		3.396		

TABLE 24. ANCOVA analysis of magnesium content per 100g of dried roselle sample from two growing seasons (n=66)

Mg %					
Type III Sum of Squares analysis (Mg %):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	0.007	0.003	0.585	0.560

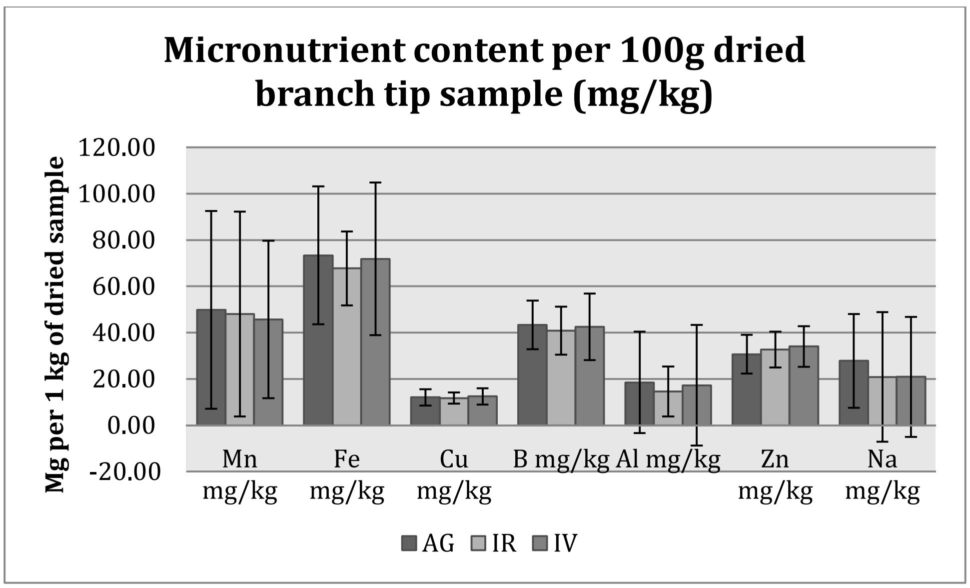


Figure 33. Micronutrient content in mg/kg of manganese, iron, copper, boron, aluminum, zinc, and sodium. Samples means from 2-week harvests averaged over two growing seasons. (n=66)

TABLE 25. ANCOVA analysis of manganese content per 100g of dried roselle sample from two growing seasons (n=66)

Mn mg/kg					
Type III Sum of Squares analysis (Mn mg/kg):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	1081.559	540.780	1.516	0.228

TABLE 26. ANCOVA analysis of iron content per 100g of dried roselle sample

from two growing seasons (n=66)

Fe mg/kg					
Type III Sum of Squares analysis (Fe mg/kg):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	291.125	145.562	0.822	0.444

TABLE 27. ANCOVA analysis of copper content per 100g of dried roselle sample from two growing seasons (n=66)

Cu mg/kg					
Type III Sum of Squares analysis (Cu mg/kg):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	1.413	0.707	0.299	0.743

TABLE 28. ANCOVA and post-hoc analysis of boron content per 100g of dried roselle sample from two growing seasons (n=66)

B mg/kg					
Type III Sum of Squares analysis (B mg/kg):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	222.928	111.464	5.003	**0.010**
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
AG vs IV	13.452	3.148	2.401	**0.007**	Yes
AG vs IR	6.343	2.571	2.401	**0.033**	Yes
IR vs IV	7.109	2.882	2.401	**0.015**	Yes
Tukey's d critical value:			3.396		

TABLE 29. ANCOVA and post-hoc analysis of aluminum content per 100g of dried roselle sample from two growing seasons (n=66)

Al mg/kg					
Type III Sum of Squares analysis (Al mg/kg):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	672.503	336.251	3.911	**0.025**
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant

IV vs AG	23.449	2.793	2.401	**0.019**	Yes
IV vs IR	11.388	2.350	2.401	0.056	No
IR vs AG	12.062	2.489	2.401	**0.041**	Yes
Tukey's d critical value:			3.396		

TABLE 30. ANCOVA and post-hoc analysis of zinc content per 100g of dried roselle sample from two growing seasons (n=66)

Zn mg/kg					
Type III Sum of Squares analysis (Zn mg/kg):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	114.675	57.338	4.252	**0.019**
Tukey (HSD) / Analysis of the differences between the categories with a confidence interval of 95%					
Contrast	Difference	Standardized difference	Critical value	Pr > Diff	Significant
IR vs AG	3.805	1.983	2.401	0.125	No
IR vs IV	1.647	0.858	2.401	0.669	No
IV vs AG	2.159	0.649	2.401	0.793	No
Tukey's d critical value:			3.396		

TABLE 31. ANCOVA analysis of sodium content per 100g of dried roselle sample from two growing seasons (n=66)

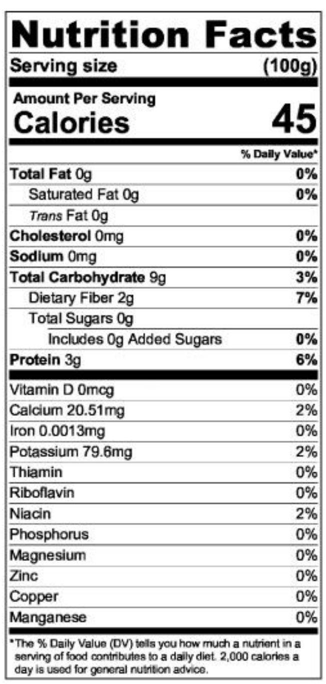
Na mg/kg					
Type III Sum of Squares analysis (Na mg/kg):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
VAR	2	116.236	58.118	0.190	0.828

TABLE 32. Amount of roselle needed to meet Recommended Dietary Allowances (RDAs)

Nutrient	Age	mg/day	African Green	Indian Red	Indian Variegated	Thai Red
Ca	1-3 years	700	44.35 g	48.67 g	45.38 g	46.13 g
Ca	4-8 years	1,000	63.36 g	69.53 g	64.83 g	65.89 g
Fe	1-3 years	7	9.47 g	9.74 g	10.81 g	9.07 g
Fe	4-8 years	10	13.53 g	13.92 g	15.45 g	12.95 g

K	1-3 years	3,000	177.17 g	157.65	154.51 g	156.65 g
K	4-8 years	3,800	224.42 g	199.69 g	195.71 g	198.41 g

Nutritional data was combined from the 2 week harvests from two growing seasons to analyze the average nutritional content in each genotype. The genotypes were analyzed for 12 micronutrients and compared by each to see their variance. There were significant differences in phosphorus levels between the genotypes with AG being significantly lower than IR and IV. AG was also significantly lower in potassium than IR and IV. AG was also significantly higher than IR and IV in calcium and aluminum. All of the genotypes were significantly different from each other in boron levels according the post-hoc analysis. For zinc the ANCOVA indicated a variance, however the post-hoc analysis did not identify which means were different.

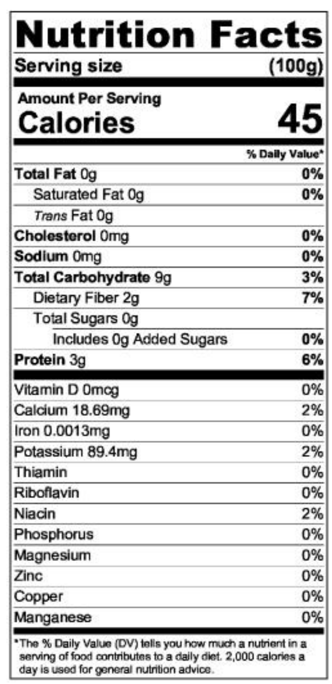


Nutrition Facts

Serving size	(100g)
Amount Per Serving Calories	45
	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 0mg	0%
Total Carbohydrate 9g	3%
Dietary Fiber 2g	7%
Total Sugars 0g	
Includes 0g Added Sugars	0%
Protein 3g	6%
Vitamin D 0mcg	0%
Calcium 20.51mg	2%
Iron 0.0013mg	0%
Potassium 79.6mg	2%
Thiamin	0%
Riboflavin	0%
Niacin	2%
Phosphorus	0%
Magnesium	0%
Zinc	0%
Copper	0%
Manganese	0%

*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Figure 35. Nutrient facts for African Green



Nutrition Facts

Serving size	(100g)
Amount Per Serving Calories	45
	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 0mg	0%
Total Carbohydrate 9g	3%
Dietary Fiber 2g	7%
Total Sugars 0g	
Includes 0g Added Sugars	0%
Protein 3g	6%
Vitamin D 0mcg	0%
Calcium 18.69mg	2%
Iron 0.0013mg	0%
Potassium 89.4mg	2%
Thiamin	0%
Riboflavin	0%
Niacin	2%
Phosphorus	0%
Magnesium	0%
Zinc	0%
Copper	0%
Manganese	0%

*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Figure 34. Nutrient facts for Indian Red

Nutrition Facts

Serving size	(100g)
Amount Per Serving	
Calories	**45**
	% Daily Value*
Total Fat 0g	**0%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 0mg	**0%**
Total Carbohydrate 9g	**3%**
Dietary Fiber 2g	**7%**
Total Sugars 0g	
Includes 0g Added Sugars	**0%**
Protein 3g	**6%**
Vitamin D 0mcg	0%
Calcium 20.05mg	2%
Iron 0.0011mg	0%
Potassium 91.3mg	2%
Thiamin	0%
Riboflavin	0%
Niacin	2%
Phosphorus	0%
Magnesium	0%
Zinc	0%
Copper	0%
Manganese	0%

*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Figure 36. Nutrient facts for Indian variegated

Nutrition Facts

Serving size	(100g)
Amount Per Serving	
Calories	**45**
	% Daily Value*
Total Fat 0g	**0%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 0mg	**0%**
Total Carbohydrate 9g	**3%**
Dietary Fiber 2g	**7%**
Total Sugars 0g	
Includes 0g Added Sugars	**0%**
Protein 3g	**6%**
Vitamin D 0mcg	0%
Calcium 19.73mg	2%
Iron 0.0014mg	0%
Potassium 90mg	2%
Thiamin	0%
Riboflavin	0%
Niacin	2%
Phosphorus	0%
Magnesium	0%
Zinc	0%
Copper	0%
Manganese	0%

*The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Figure 37. Nutrient facts for Thai red

Income

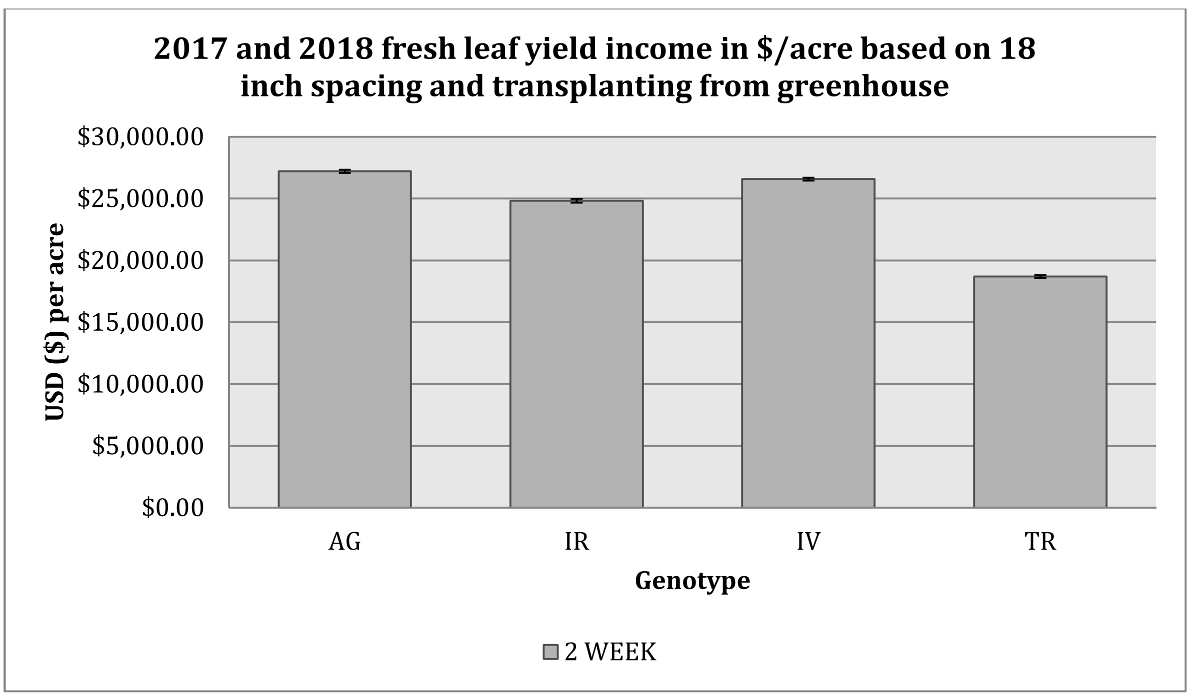


Figure 38. Fresh leaf yield means from the African Green (AG), Indian Red (IR), Indian Variegated (IV), and Thai Red (TR) genotypes harvested every 2 weeks for 8 weeks with ± 1 Standard deviation. Data was calculated assuming $2/pound and 9,680 plants per acre. Results from ANOVA p-value 0.001

TABLE 33. Potential income for roselle genotypes at two-week harvest intervals

GENOTYPE	AVERAGE TIPS/PLANT				AVERGAE TIP WEIGHT (FRESH WEIGHTS IN GRAMS)				GRAMS / PLANT	POUND /ACRE	INCOME /ACRE ($2/POUND)
	1	2	3	4	1	2	3	4			
AG	8.48	22.50	35.03	42.60	8.93	7.00	5.15	5.25	637.51	13604.93	27209.86
IR	7.24	17.86	30.55	36.82	9.25	8.10	5.60	5.40	581.60	12411.79	24823.58
IV	7.19	16.99	25.19	28.13	11.41	9.35	7.33	7.01	622.69	13288.68	26577.37
TR	7.69	20.19	33.24	37.07	7.61	6.10	4.30	3.05	437.92	9345.50	18691.01

Potential income for growing roselle, assuming ideal conditions and an ample market, should be about $25,000 at $2/pound (see Table 33). Price per pound varies depending on markets, with direct to consumer prices around $4/pound and wholesale prices $2/pound. The genotypes used in this research responded differently to the various harvest regimes and therefore will vary in yield and income depending on harvest conditions, weather, and disease burden.

DISCUSSION

Diseases

Discrepancies between the ANVOA and Tukey's analysis are potentially caused by small sample sizes due to disease, mold and missing data. Diseases observed included powdery mildew, fusarium wilt, and tobacco mosaic virus (TMV). Powdery mildew (as seen in Figure 13), caused detrimental symptoms on some plants while it caused others to have a shortening of internodes and a 'witches broom' effect (a mass of stems growing from a similar point) which caused a decrease in yield. Fusarium wilt, Figure 14, caused several plants to split open along the stem and produce a jelly-like substance. Tobacco mosaic virus (TMV) was also found in one plant sample possibly from pests in the greenhouse prior to transplanting. All diseases were identified by Rutgers Plant Diagnostic Laboratory.

Other problems encountered were edema and incorrect genotypes included in seeds. Edema was observed on all genotypes with AG and TR being the most affected. Edema, or oedema, was possibly due to the overwatering of the plants, causing bumps on the epidermis of the stems and petioles. As the season progressed the bumps caused by edema would rupture, leading to possible increased risk of disease. During the 2018 season several plants matured into the kenaf variety of roselle and had to be removed from the study.

TABLE 34. Diseases observed on roselle (*Hibiscus sabdariffa*) over two growing seasons in New Brunswick, New Jersey

DISEASE	YEAR	GENOTYPES	SYMPTOMS	OBSERVATIONS
Fusarium spp.	2017	IR	Stem split, stem oozing	Infected plants had stem split and continue to grow to 15cm wide (see Figure 41)
Tobacco Mosaic Virus	2018	IR	No visible symptoms	Possibly from vectors in the greenhouse
Edema	2017-2018	TR, AG	Bumps on stem and petioles	Due to overwatering (see Figure 39)
Powdery Mildew	2017-2018	AG, IR, IV, TR	Mildew on upper leaf surface	Appeared late in the season in 2017. 2018 plants were aflicted from seedlings through harvest, with some plants developing 'witch's brooming' (see Figure 40)

Figure 39. Edema bumps and lesions possibly from over watering. Shown on African Green and Thai Red.

Figure 40. Powdery mildew on leaf surface (left) and causing a 'witch's broom' effect (right).

Figure 41. Fusarium spp. causing lesions and stem splitting

Recommendations

Considering the similar yield and profitability of the genotypes in this study, consumer surveys should be conducted to determine the most desirable, and therefore marketable, of the genotypes. Next steps should include breeding roselle for increased and uniform yields. As the growing season in New Jersey is too short for proper calyx production, breeding should focus on plants with early flowering in order to maximize farmer profits by having leaf and calyx producing plants.

Future studies should determine the impacts of leaf harvesting on the calyx production in order to determine the best harvest regime. Given the unique flavor and health benefits of roselle potential use as a microgreen and in vertical farming should be explored.

Trends in Agriculture Development

Eastern Africa has been making steady progress towards achieving long-term sustainable economic growth, however in striving to meet goals that are several years old. Politicians and experts should continue looking ahead toward the future of development. Technology and innovation should not be viewed as daunting and inaccessible but as an opportunity for developing countries to 'jump' ahead in development and begin to compete with the more developed countries. Traditionally, development has been seen as path blazed by strong economies starting with the United Kingdom during the industrial revolution in the late 1700s. This process usually included a steady progression from agrarian to industrialized economies mainly based on services and manufacturing. However with the technological revolution as some call it, comparing it to the industrial revolution, developing countries have been given the opportunity to 'jump' several steps in the path to development, called leapfrogging. A classic example of this was the use of cell phones in China and India. The adoption of cell phones happened very quickly, completely bypassing the need for telephone poles, telephone wires, communications centers and training their population in an obsolete technology (Sauter and Watson, 2008). This helped countries and development agencies avoid investing in expensive and outdated technology, however this should be taken into consideration in the future.

The downside to rapid innovation is the necessity for basic infrastructure and needs to be met before new technology can be utilized. Without the necessary basic infrastructure and human capacity requirements, for example, roads, communications, health and education, then countries will not be able to compete or use new technologies in development. Innovation and mechanization will also change the landscape of jobs available in developing countries. They cannot rely on foreign companies to bring investments and industry to utilize the cheap labor conditions when they can automate the process at home at a lower price. To prepare their population for technological innovations and jobs in the future, leaders in eastern Africa should be a focus on things that cannot be automated, including people skills, critical thinking and effective use of technology. Investing in human capacity can help to reduce the dependence on aid by replacing the skilled technical experts, which have been borrowed from other countries to help run projects, with locally trained experts. These locally trained experts could and should have an intimate knowledge of how systems currently work and can reduce some of the trial and error seen when foreign 'experts' do not understand the people they are trying to help.

Building human capacity will help attract outside investments. Investments in the education, health, well-being and infrastructure can help build industry from within and promote foreign direct investments (FDIs). Along with good governance, policies to protect workers and provide stable, long term employment can help the overall development in a selected country. Combined with technologies such as high-speed internet and blockchain technology, foreign aid, official development assistance, and government taxes can be tracked in a responsible way, creating transparency for donors, experts and citizens to track funds and combat corruption (Niforos, 2017). The focus on youth education and investment in job training can be beneficial in the long term, not only enticing foreign investment in industry but by enabling youth to develop entrepreneurship skills and create their own innovative ideas to solve regional problems.

The growth of informal sector jobs in both developed and developing countries is not a trend to be overlooked. The rise of companies such as uber, alibaba, amazon that increases access to informal jobs can provide casual employment or home production opportunities can change the face of employment. Informal sector jobs can play an important role in developing economies by providing jobs to those who cannot work in a traditional environment. The informal sector in Zambia contributes 20% to the overall economy and mostly employs women and youth (ILO 2016). However, informal jobs are often associated with low wages and lack of benefits. Combined with governmental policies on universal healthcare and a livable minimum wage, informal sector jobs could provide a great opportunity for growth in developing countries (Bacchetta et al., 2009). Consideration should be made in regards to the benefit informal sector jobs can have on smallholder farmers specializing in labor intensive vegetables and value-added processing. As larger farms become more common, an increase in smallholder farmers specializing in organic or niche crops selling directly to consumers could greatly benefit rural development as well as combat malnutrition.

CONCLUSION

Growing roselle as an ultra-niche crop in New Jersey has the potential to become a profitable endeavor. The genotypes grown in this study preformed very similar under the different harvesting regimes. When selecting a variety to grow, consideration of the local market and demand is essential in achieving the potential profits of approximately $20,000 per acre. Care should be taken in monitoring the roselle for diseases as they can greatly reduce the yield and quality of the leaves. Future breeding programs should focus on meeting the demands of consumers in terms of taste, traditional uses and preferred texture. The variation within genotypes in this study provide a great potential to choose the beneficial traits such as disease resistance, increased yields and nutrient content.

Roselle and other African indigenous vegetables have the potential to combat widespread malnutrition and micronutrient deficiencies in the US and abroad. Careful plant breeding can utilize the variation between genotypes like the African, Indian and Thai ones used in this study to create more homogenous crops in terms of yield and nutritional content. Roselle already has a promising nutritional profile that can be enhanced with selective breeding. Further research into the variations of nutritional content over the growing season in roselle and other indigenous vegetables can lend insights into changes in human health as well as better harvesting methods.

Investments in innovation, infrastructure, and industry are one of the keys for linking rural economies to urban markets, and could be the key to breaking the nutrition and poverty trap faced by eastern African smallholder farmers. In the 1980's the Green Revolution helped to increase the agricultural output in Asia through improved seed, improved irrigation and farmer education campaigns, however several factors rarely mentioned played a large role in setting the stage: extensive transportation, low cost fertilizer and international agriculture research institutions (Otsuka et al. 2011). In order for smallholder farmers to benefit from a similar rapid growth in agriculture output, there needs to be an increase in infrastructure to allow farmers to maximize their yields and profit from their land. Infrastructure plays a large role in allowing farmers to take their goods to market when prices are optimal, and not when everyone else is harvesting and overloading the market with goods. Infrastructure such as roads, transportation, cold storage, and energy allow farmers to bring ore low cost inputs on to the farm as well as easily reach urban markets with their products. Although the same inputs and methods used in South Asia during the Green Revolution may not work directly, investments in innovation by east African governments in the form of agriculture research stations, they can adapt crops and technology to their specific regions.

Widespread adoption of the growth of AIVs by smallholder farmers have been limited by weak institutions, restricted access to markets and credits, inadequate infrastructure and constrained growth. The challenge is now to spread effective processes and lessons to many more millions of typically small farmers and pastoralists across the region. Common lessons for scaling up and spreading information include the value of increasing the access of farmers to new technologies and practices, social networks that connect individuals with farmers groups and aid groups, improvement in farmer education, the engagement of the private sector, a focus on micro finance, and the inclusion of women's groups. By increasing governmental spending on universal health care, and education and training programs to support smallholder farmers, people in the informal sectors and those wishing to become entrepreneurs by utilizing new technologies, east African governments can diversify their economies, increase wealth and continue overall development.

Indigenous vegetables have the potential to not only transform smallholder farming production in terms of profitability and sustainability but for local research institutions to develop new crops. As indigenous vegetables tend to be new crops for small markets large seed companies, especially international ones, tend to avoid their development. Focusing on local growth, utilization and development can benefit developing countries' economies while providing an easily modified crop in the event of major pest outbreak or climate trend. By addressing smallholder farmer constrains of access to markets, inputs, and credit using local resources countries will have a chance to develop their own systems in the absence of outside assistance. A movement towards basic nutritional autonomy can alleviate pressure for food aid, and allow countries to decide if GM technology might be right for them in the future. Using locally developed and grown vegetables for fortifying food can also stimulate rural development and value added business to grow along with smallholder farmers.

APPENDICES

Appendix I: Plant Disease Clinic Results

RUTGERS
New Jersey Agricultural
Experiment Station

Plant Diagnostic Laboratory
New Jersey Agricultural Experiment Station
Rutgers, The State University of New Jersey
PO Box 550
Milltown, NJ 08850

Lab Sample Number: D29766 **Received:** 8/24/2018

Submitter Sample ID: **Replied:** 8/27/2018

Host Plant: Hibiscus sabdariffa

Cultivar:

Submitted by: **Contact:** Mara Sanders **Phone:**

Organization: Dept. of Plant Biology & Pathology **Fax:**

Address: 59 Dudley Road Foran Hall

City: New Brunswick **State:** NJ **Zip:** 08901

County: RUTGERS RESEARCH **Cell / Email:**

Symptom(s): abnormal growth

Recommendation:

This sample tested positive for tobacco mosaic virus. Special tests for impatiens necrotic spot, tomato spotted wilt, and cucumber mosaic virus group were negative. Virus infected plants should be culled.

Powdery mildew was also identified on this plant. Severe powdery mildew can cause leaves to spot, scorch and drop, or deform young leaves in the manner we observe on this sample. In most cases, the disease has little impact on overall plant health. Powdery mildew is favored by warm conditions, shade, poor air circulation, and high relative humidity. Powdery mildew is easily controlled with applications of a thiophanate-methyl or sterol-inhibiting fungicide. Make applications to the plant when the disease appears. Be sure to follow label specifications and get good coverage. Remove badly damaged and fallen leaves. Maintain or improve plant vigor with fertilization and irrigation in times of drought.

Diagnostician: RJB

Check out Rutgers Plant Diagnostic Laboratory's blog for timely updates on plant diseases and insect pests.

plant-pest-advisory.rutgers.edu

WORKS CITED

Abukutsa OMO (2007) The diversity of cultivated African leafy vegetables in three communities in western Kenya. Afr J Food Agric Nutr Dev 7(3):1–15

Adkins S, Kamenova I, Chiemsombat P, Baker C, Lewandowski D (2006) Tobamoviruses from hibiscus in Florida and beyond. Acta Hortic 277:65–70

American Diabetes Association. (2018). 2. Classification and diagnosis of diabetes: standards of medical care in diabetes—2018. *Diabetes Care*, *41*(Supplement 1), S13-S27.

Bacchetta, M., Ernst, E., & Bustamante, J. P. (2009). Globalization and informal jobs in developing countries. Geneva: International Labour Organization.

Barrett, C. B. (2008). Smallholder market participation: Concepts and evidence from eastern and southern Africa. *Food policy*, *33*(4), 299-317.

Beegle, Kathleen; Christiaensen, Luc; Dabalen, Andrew; Gaddis, Isis. 2016. Poverty in a Rising Africa. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/22575 License: CC BY 3.0 IGO.

Catholic Relief Services (CRS). (2016). Assessment on Availability of African Indigenous Leafy Vegetables in Malawi and Zambia. United States Agency for International Development. https://www.crs.org/sites/default/files/tools-research/assessment_on_availability_of_ailvs_in_malawi_and_zambia.pdf [accessed 30 Dec 2017).

Data.worldbank.org. (2018). Agriculture, forestry, and fishing, value added (% of GDP). Data. [online] Available at: https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=XL [Accessed 10 Sept. 2018].

Duke, J. A., & Atchley, A. A. (1984). Proximate analysis. *The handbook of plant science in agriculture. CRC Press, Inc., Boca Raton, FL*, 145-149.

de Janvry, A., and E. Sadoulet. 2009. "Agricultural Growth and Poverty Reduction: Additional Evidence." World Bank Research Observer 25 (1): 1–20

FAO, Declaration on world food security. World Food Summit. 1996: Rome.

FAO. 2012. "Enduring farms: climate change, smallholders and traditional farming communities". United Nation, Food and Agriculture Organization. Online:

http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/Factsheet_SMALLHOLDERS.pdf [accessed 29 Dec 2017].

FAO. 2013b. *FAO statistical yearbook 2013*. United Nations Food and Agriculture Organization (FAO), Rome, Italy.

FAO. (2014). Contribution to the 2014 United Nations Economic and Social Council (ECOSOC) Integration Segment.

Fasakin, K. (2004). Proximate composition of bungu (Ceratotheca sesamoides Endl.) leaves and seeds. Biokemistri 16(2):88–92.

Francis, C. A. 1986. *Multiple cropping systems*. Macmillan Publishing Company, New York.

Gao R, Niu S, Dai W, Kitajima E, Wong SM (2016) Hibiscus latent Fort Pierce virus in Brazil and synthesis of its biologically active full-length cDNA clone. Virus Genes 52:754–757

Govindasamy, R., Van Vranken, R., Sciarappa, W., Ayeni, A., Puduri, V.S., Pappas, K., Simon, J.E., Mangan, F., Lamberts, M. and McAvoy, G., 2010. Ethnic crop opportunities for growers on the east coast: A demand assessment. J. Extension, 48.

Huang, Chao-Yong Luh and E.E. Schulte. 1985. Digestion of Plant Tissue for Analysis by ICP Emission Spectroscopy. Commun. in Soil Sci. Plant Anal., 16(9), 943-958.

Ikerd, J. (2015). The Failure of Modern industrial agriculture. *Dollars & Sense*, (April), 11–13.

International Labor Organization (ILO). (2016). Zambia Decent Work Country Programme 2013- 2016. URL:http://www.ilo.org/wcmsp5/groups/public/---africa/---ro-addis_ababa/---ilo-lusaka/documents/genericdocument/wcms_445938.pdf [accessed 15 December 2017]

Kimiywe J, Waudo J, Mbithe D, Maundu P (2007) Utilization and medicinal value of indigenous leafy vegetables consumed in urban and peri-urban Nairobi. Afr J Food Agric Nutr Dev 7(4):1–15

Lin LJ, Hsiao YY, Kuo CG. 2009. Discovering indigenous treasures: Promising indigenous vegetables from around the world. AVRDC – The World Vegetable Center Publication No. 09-720. AVRDC – The World Vegetable Center, Shanhua, Taiwan. 317 p. http://203.64.245.61/e-book/ebook1.htm

Lowder, S. K., Skoet, J., & Raney, T. (2016). The number, size, and distribution of farms, smallholder farms, and family farms worldwide. World Development, 87, 16-29.

Mingochi, D. S., & Luchen, S. W. S. (1997). Traditional vegetables in Zambia: Genetic resources, cultivation and uses. Promoting the Conservation and Use of Underutilized and Neglected Crops (IPGRI). http://www.bioversityinternational.org/fileadmin/bioversity/publications/Web_version/500/ch20.htm

Mumbi, K., Karanja, N., Njenga, M., Kamore, M., Achieng, C., Ngeli, P., 2006, Investigative Market Research: Viable Market Opportunities and Threats for Urban and Peri-Urban Farmers, Farm Concern International, Urban Harvest and International Potato Centre, Nairobi.

Ncube M, Lufumpa CL, Kayizzi-Mugerwa S. 2011. *The Middle of the Pyramid: Dynamics of the Middle Class in Africa*. Market Brief, African Development Bank, April.

Nerva, L., Vallino, M., Turina, M., & Ciuffo, M. (2018). Identification and characterization of Hibiscus latent Fort Pierce virus in Italy. *Journal of Plant Pathology*, *100*(1), 145-145.

Ng, M., Fleming, T., Robinson, M., Thomson, B., Graetz, N., Margono, C., Mullany, E.C., Biryukov, S., Abbafati, C., Abera, S.F. and Abraham, J.P., (2014). Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. The lancet, 384(9945), pp.766-781.

Ngugi, I. K., Gitau, R., & Nyoro, J. (2007). Access to high value markets by smallholder farmers of African indigenous vegetables in Kenya. *Regoverning Markets Innovative Practice Series, IIED, London*.

Plotto, A., Mazaud, F., Röttger, A., & Steffel, K. (2004). Hibiscus: post-production management for improved market access. *Food and Agriculture Organization of the UN,(FAO)*.

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *International journal of agricultural sustainability*, *9*(1), 5-24.

Quattrocchi, U. (2016). *CRC world dictionary of medicinal and poisonous plants: common names, scientific names, eponyms, synonyms, and etymology (5 Volume Set)*. CRC press.

Ray, D. K., Mueller, N. D., West, P. C., & Foley, J. A. (2013). Yield trends are insufficient to double global crop production by 2050. PloS one, 8(6), e66428.

Roman-Leshkov, Y., Chheda, J. N., & Dumesic, J. A. (2006). Phase modifiers promote efficient production of hydroxymethylfurfural from fructose. Science, 312(5782), 1933–1937

Ruel MT, Minot N, Smith L (2005) Patterns and determinants of fruit and vegetable consumption in sub-Saharan Africa: a multicounty comparison. FAO/WHO workshop on fruit and vegetable for health, 1 -3 September 2004. Kobe, Japan.

SAS Institute Inc. 2018. SAS® University Edition Quick Start Guide for Students with Visual Impairments. Cary, NC: SAS Institute Inc

Salami, A., A. B. Kamara, and Z. Brixiova. 2010. Smallholder agriculture in east Africa: Trends, constraints and opportunities. Working Papers Series No. 105. African Development Bank, Tunis, Tunisia.

Sanchez, P. A., & Swaminathan, M. S. (2005). Hunger in Africa: The link between unhealthy people and unhealthy soils. *Lancet*, *365*(9457), 442–444.

Sachs, J. D. (2015). The age of sustainable development. Columbia University Press.

Sauter, R., & Watson, J. (2008). Technology Leapfrogging: A Review of the Evidence A report for DFID. Sussex Energy Group SPRU (Science and Technology Policy Research), University of Sussex.

Senyolo, G. M., Wale, E., & Ortmann, G. F. (2014). Consumers' Willingness-To-Pay for underutilized vegetable crops: The case of African leafy vegetables in South Africa. *J Hum Ecol*, *47*(3), 219-227.

Siegel KR, McKeever Bullard K, Imperatore G, et al. Association of Higher Consumption of Foods Derived From Subsidized Commodities With Adverse Cardiometabolic Risk Among US Adults. JAMA Intern Med. 2016;176(8):1124–1132. doi:10.1001/jamainternmed.2016.2410

Siziya, I. (2017). CHANGES IN SECONDARY METABOLITE AND MACRONUTRIENT CONTENT ASSOCIATED WITH MATURITY AND PROCESSING METHODS IN SELECTED ROSELLE (Hibiscus sabdariffa) GENOTYPES. (Master's thesis). University of Zambia

Simon, J. and R. Govindasamy. 2008. Market intelligence study for bissap (*Hibiscus sabdariffa*) products from Senegal in the USA. Project highlighted findings with Market channel distribution chain. USAID-Economic Growth Programme, IQC No. 685-1-06-00005-00 Task Order No. 685-1-01-00005-

00; IRG (International Resources Group) and J.E. Austin Associates, Virginia. February 07, 2008. 8pp.

Simon, J. and R. Govindasamy. 2007. Market intelligence study for bissap (*Hibiscus sabdariffa*) products from Senegal in the USA. Project highlighted findings. USAID-Economic Growth Programme, IQC No. 685-1-06-00005-00 Task Order No. 685-1-01-00005-00; IRG (International Resources Group) and J.E. Austin Associates, Virginia. December 04, 2007. 38pp.

Simon, J., Weller,S., Hoffman, D., Govindasamy, R., Dinssa F., Nyabinda, N., Odendo, M., Ndinya C., Byrnes D., Morin, X., Merchant, E., Wu, Q., Yaninek, S., Gohole, L. 2018. Improving Nutrition and Income Generation with African Indigenous Vegetables: Selected Lessons Learned. [PowerPoint slides]. Source: https://horticulture.ucdavis.edu/sites/g/files/dgvnsk1816/files/extension_material_files/simon-african-indigenous-vegetables-lessons-nutrition-2018%20%282%29.pdf [date accessed 20 Sept 2018].

Smith. (2007). Volume 7 No . 3 2007 AFRICAN LEAFY VEGETABLES : THEIR ROLE IN THE WORLD HEALTH ORGANIZATION ' S GLOBAL FRUIT AND VEGETABLES INITIATIVE, *7*(3), 1–17.

Sparks, D. L., & Barnett, S. T. (2010). The informal sector in Sub-Saharan Africa: out of the shadows to foster sustainable employment and equity?. *The International Business & Economics Research Journal*, *9*(5), 1.

Street, K. (2003). MSSD DISCUSSION PAPER NO . 53 SUCCESSES IN AFRICAN AGRICULTURE : RESULTS OF AN EXPERT SURVEY Eleni Z . Gabre-Madhin and Steven Haggblade Markets and Structural Studies Division International Food Policy Research Institute. *Framework*, (53).

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences, 108(50), 20260-20264.

Townsend, R. (2015). Ending poverty and hunger by 2030: an agenda for the global food system. Washington, DC: World Bank Group.

Tschirley, D. L., Haggblade, S., & Reardon, T. A. (Eds.). (2013). *Africa's Emerging Food System Transformation*. Global Center for Food Systems Innovation, Michigan State University.

Tschirley, D, Reardon, T, Dolislager, M, and Snyder, J (2015), The Rise of a Middle Class in East and Southern Africa: Implications for Food System Transformation. J. Int. Dev., 27, 628–646. doi: 10.1002/jid.3107.

United Nations Department of Economic and Social Affairs (2014). World Urbanization Prospects: The 2014 Revision.

United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision, Key Findings and Advance Tables. Working Paper No. ESA/P/WP/248.

United Nations, The Millennium Development Goals Report. 2015. New York.

United Nations, United Nations Millennium Development. 2000, United Nations: New York.

United Nations Development Programme, Regional Bureau for Africa. (2012). The Nutrition Challenge for Sub-Saharan Africa. Retrieved from: http://undp.org

U.S. Department of Health and Human Services and U.S. Department of Agriculture. 2015–2020 Dietary Guidelines for Americans. 8th Edition. December 2015. Available at http://health.gov/dietaryguidelines/2015/guidelines/

Wiggins, S., and S. Keats. 2013. *Leaping and learning: linking smallholders to markets in Africa*.
Agriculture for Impact, Imperial College and Overseas Development Institute, London.

World Health Organization. 2013. WHO Fruit and Vegetable Promotion Initiative – report of the meeting, Geneva, 25–27 August 2003. url: http://www.who.int/dietphysicalactivity/publications/f&v_promotion_initiative_report.pdf?ua=1 [access 30 Dec 2017]

Van der Lans C, Snoek H, de Boer F, Elings A (2012) *Vegetable chains in Kenya: production and consumption of vegetables in the Nairobi metropolis.* Wageningen UR Centre for Development Innovation Rapport GTB-1130, Wageningen, The Netherlands. (http://edepot.wur.nl/216710).

XLSTAT 2018: Data Analysis and Statistical Solution for Microsoft Excel. Addinsoft, Paris, France (2018)