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ABSTRACT

The prevalence of micronutrient deficiencies continues to remain alarmingly high in sub-Saharan Africa. One potential solution to undernutrition is to promote the consumption of African Indigenous Vegetables (AIVs) that are rich in vitamin A, iron, zinc and other health-promoting phytochemicals. However, due to limited advances in agronomic practices, seed development, available improved varieties, and access to these indigenous plants in the marketplace, work was needed to drive AIVs into the formal marketplace to meet consumer demand. This paper summarizes the research and activities of a diverse group of stakeholders and researchers who came together to improve research, management, production, distribution, and consumption of nutritious AIVs in Eastern

Africa. We hypothesized that good management techniques along the AIV value chain from seed to consumption would be essential to improving access and availability of AIVs for food and income insecurity. In parallel, we hypothesized that by increasing the supply of nutrient dense AIVs into the local markets, and by empowering women, who are the major decision makers on household diets, the sales of AIVs will increase the availability, accessibility and consumption of vegetables, conferring various micronutrients and health-relevant phytochemicals to both the farming and nonfarming consumer communities. Community needs were assessed to design, implement, and evaluate context-specific nutrition and production behavioral change communications (BCC) to increase AIV production and consumption. Nutrition interventions were administered to 500 households in both Kenya and Zambia. Production training was administered to 1563 farmers in Kenya and 1421 farmers in Zambia. Through the five-year project period, we monitored and evaluated training impact and improved germplasm on yield and sales and continued to improve outreach efforts to maximize results. At the end of a five-year period we observed an increase in sales, distribution centers, and consumer acceptance of AIVs. In addition, we quantified the nutritional and anti-nutritional aspects of major AIVs. In conclusion, the use of AIV as the focus of the study through a market-first science-driven model to improved access, availability, affordability, and consumption and increased income for farmers and other players along the AIV value chain.

INTRODUCTION

Even prior to the pandemic, poverty in sub-Saharan Africa (SSA) was increasing, rather than decreasing, and human development indicators were worsening (von Braun, 2020). A recent UNICEF report noted that there were an estimated 15 million cases of acute malnutrition in Western and Central Africa in 2020 (Balde and Sidhu, 2020). Undernutrition is particularly serious in the low-income strata of the population due to poor access to health care and nutritious foods (Hampwaye et al, 2017). In addition, 146 million children are underweight, a major risk factor for mortality for children under five years of age (Black et al., 2013; UNICEF, 2001a, 2001b). Most cases of undernutrition can be attributed to dysfunctional food systems that exacerbate food insecurity, food losses and food waste causing superficial food shortages (food deserts) in high production environments (Crush and Frayne, 2011; Rosin et al, 2012). Redesigning, conceptualizing and evaluating new approaches to strengthen the food ecosystem to improve both total energy (calories from macronutrients) and micronutrient under-nutrition, is needed to provide solutions to these complex challenges.

Addressing these nutritional challenges will not be easy because food demand continues to exceed supply. The deficiencies, particularly vitamin A, iron, zinc, and iodine, in commonly consumed, inexpensive, calorie-rich ultra-processed food further magnify the food insecurity problem suffered by 239 million people worldwide (FAO, 2010; Oyebode et al., 2014). A deficit in micronutrient-rich food is a troubling trend as the world has an abundance of food. The challenges faced to meet the demand for nutritious foods include lack of abundant and efficient food distribution systems in the developing world, seasonal availability of local food, continued population growth, lack of access to natural resources, and low crop production (FAO, 2002, 2007, 2010). There is also an increase in distribution, marketing and consumption of calorie-dense foods that lack adequate nutrition. Inadequate intake of iron and zinc is widespread in Sub-Saharan Africa (SSA), and half of all anemia cases were caused by dietary iron deficiency with anemia being most prevalent in adolescent girls, women of childbearing age and preschool children (Harika et al. 2017). Anemia may lead to learning disabilities, mental retardation, poor physical development and reduced ability to fight infectious diseases, ultimately leading to premature death and diminished stamina and work capacity and losses in the gross domestic product thus exerting a high economic burden on society (FAO, 2002, 2007, 2010). Coming up with new cost-effective, data-driven interventions to address these micronutrient deficiencies is desperately needed and supports the USAID nutrition plan (USAID, 2014).

Addressing nutritional deficiencies is part of a larger strategy to create food security and good health in SSA. In 1996, at the World Food Summit, a complex definition for food security was adopted: "Food security [is] a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (World Food Summit, 1996). Food security goes beyond sufficient calories and thus includes nutritious food such as fruit and vegetables that are essential for optimal health yet most of the world do not consume the recommended levels (WHO 2003, Hoffman et al., 2017, 2018, Oyebode et al., 2014). Increased fruit and vegetable consumption counter nutritional deficiencies of diets dominated by high energy (calorie-rich) foods that are poor in micronutrients such as the staple crops maize and rice (Oyebode et al., 2014).

There are important regional, local and intra-household dimensions of food security and improving food security requires context-specific understanding to improve productivity, health, and nutrition of the undernourished and micronutrient deficient in a community. Particular attention needs to be given to vulnerable populations such as children, youth, pregnant or nursing mothers, and those afflicted by communicable (HIV/AIDS) or non-communicable diseases (FAO, 2002). More important, poor nutrition and health are directly related to poor educational attainment and lower economic productivity, creating a vicious cycle of poverty and poor health outcomes (Ndiku et al., 2010). Education on healthy nutrition, good eating habits, food preparation and safe handling are among the effective strategies for overcoming malnutrition and chronic diet-related diseases such as obesity, diabetes, hypertension and cardiovascular diseases (FAO, 2007).

Interest in African Indigenous Vegetables (AIVs), such as amaranth (*Amaranthus* spp.), African nightshade (*Solanum scabrum, S. villosum),* spider plant (*Cleome gynandra L.),* African kale (*Brassica carinata),* jute mallow (*Corchorus olitorius L.*), cowpea (*Vigna unguiculata)* leaves and African eggplant (*S. aethiopicum),* are on a sharp steady increase in SSA as a result of increased awareness and education of their nutritional and overall health benefits, as well as improvements on traditional recipes (McBurney et al., 2004, Weller et al. 2015; Ochieng et al 2018). This interest has raised the demand for high-quality seeds and improved lines and cultivars by local farmers. Despite the development of several advanced lines, prior to this project, there had been only a few official releases of AIV varieties in Africa. The World Vegetable Center's (WorldVeg) Regional Center for Eastern and Southern Africa facilitated the release of seven new varieties of AIVs in Tanzania in 2011; however, training in efficient seed production, processing, quality, postharvest management, and management of locally produced seed was needed (João, 2010; Ndinya et al., 2020). Furthermore, there were and still are, major obstacles within the value chain that must be addressed to improve seed and fresh produce of AIV availability, shelf-life and postharvest handling and quality. These obstacles may be addressed through targeted training and education on agricultural practices, using participatory, hands-on approaches that seek gender equity in participation. Such trainings need to reach women growers and provide technical assistance to communities on improved agronomic practices, harvesting, postharvest and proper storage. Through these training the use of AIVs to provide an immediate economic and nutritional opportunity for households could be emphasized.

It is important to address the gender disparity in terms of labor allocation and household decision making in SSA where growing horticulture crops and cooking vegetables is done largely by women (Hamilton, 2004; Fischer et al, 2020). Additionally, the majority of small vendors in local markets are women (Ochieng et al., 2019; Fischer et al, 2020). When women have an income, they gain more power in household decision-making and are likely to devote income to household needs and educational investments (Dolan and Sorby, 2003). Women are primarily responsible for providing and preparing nutritious food to their families; thus, they hold the decision-making powers on whether the family will consume nutritious vegetables or not (FAO, 2001). Therefore, it is essential to engage the women in the target communities when designing intervention programs.

Besides the market, economic, and agronomic dimension to AIVs, it was essential to scientifically qualify and quantify the nutritional and anti-nutritional elements of key AIVs. AIVs are rich in pro-vitamin A and vitamin C, several mineral micronutrients, as well as health-promoting phytochemicals with antioxidant, antibiotic and anticancer properties and other nutraceuticals (Weinberger and Lumpkin, 2007; Yang and Keding, 2009). These AIVs are assumed to offer excellent health benefits and are thought to be a practical and a sustainable intervention tool to address malnutrition related problems, especially in women and children (Juliani et al, 2009a, 2009b; Lin et al., 2009; Shindano and Chitundu, 2009; Ochieng et al, 2017). However, there is a significant gap in our knowledge between actual and potential benefits from indigenous vegetable production that can vary by growing conditions and the genetics of the specific AIV, as well as post-harvest management practices, preservation, and preparation (Coppin et al., 2013, 2014; Ayua et al., 2016, 2017). There is a need to recognize that all AIVs are not the same, with species and varietal differences in nutritional and phytochemical composition, as well potential anti-nutritive factors, which in turn affect flavor and cooking qualities, and consequently consumption behavior. Therefore, a need exists to characterize the nutrient composition of AIVs according to differences in variety, post-harvest practice, and preparation, to understand better how they can best contribute to increased consumption for improved nutrition and health (Tenkouano, 2011).

This paper reports on efforts made to improve food security and nutrition through AIVs. The goal of this Horticultural Innovation Nutrition Research Program was to improve the production and increase consumption of AIVs in communities and to assess AIVs impact on nutrition, income and health outcomes of people at risk for malnutrition (Figure 1). To achieve this goal, the project had five major objectives including: (1) Improved African Indigenous Vegetable Germplasm; (2) Increased Demand for AIVs in the Formal Marketplace; (3) Training of Farmers in Best Practices; (4) Culinary Training and Improved Vegetable-Based Recipes; and (5) Identification and Quantification of Nutrient and Anti-nutrient Qualities of AIVs.

We hypothesized that good management techniques along the AIV value chain from seed to consumption would be essential to improve access and availability of AIVs for food and income insecurity, and sale, as well as health and dietary diversity. These factors address issues of access, availability, affordability, and consumption for growers and non-growers.

We hypothesized that good management techniques along the AIV value chain from seed to consumption would be essential to improving access and availability of AIVs for food and income insecurity. In parallel, we hypothesized that by increasing the supply of nutrient dense AIVs into the local markets, and by empowering women, who are the major decision makers on household diets, the sales of AIVs will increase the availability, accessibility and consumption of vegetables, conferring various micronutrients and health-relevant phytochemicals to both the farming and nonfarming consumer communities. We also hypothesize that science can drive grower, buyer and consumer demand. The ability to effectively communicate to families and those making food purchasing decisions the health and nutritional benefits will be as strategic as improvements and strengthening of the actors in the AIV value chain.

METHODS

This Horticultural Innovation Nutrition Research Program project was built upon two prior USAID funded initiatives conducted in Kenya and Tanzania (led by Purdue University in concert with Rutgers, and in Zambia (led by Rutgers in concert with Purdue). These earlier projects conducted market evaluation studies with growers and consumers to identify their relation and knowledge of AIVs; their understandings of AIV production practices and which foods would be preferred if available and accessible. Results of those studies informed us that (i) AIVs were well recognized and in many cases the preferred vegetables of choice, but were perceived to be often unavailable or not easily accessible and/or expensive; (ii) with less time for traditional food preparation traditional AIVs recipes took longer time to prepare in the kitchen; (iii) many viewed these plants not as crops to cultivate but to collect during the rainy seasons as they grow naturally; (iv) serious gaps along the value chain were noted that limited the growth of this sector. Importantly, the surveys included questions asking for the relative rank order of AIVs by interest and preference to consume if available (Arumugan et al., 2020; Govindasamy 2020a, 2020b). The relative rank order of each AIV was not the same from each survey conducted in different regions, yet several AIVs ranked the highest and we used that market oriented and consumer demand as criteria to select those plant species that were common across all surveys (e.g. Amaranth, Nightshades, Spider Plant, and then added into that list hibiscus (roselle), moringa, mustard and other AIV leafy greens as the specific AIVs to focus in this current five-year study. This current project was executed by a multinational interdisciplinary team from Kenya, Tanzania and Zambia, consisting of AMPATH, KALRO, WorldVeg, AgriSmart, Hantambo Womens Group, Tumaini Children Center, Mirror of Hope, and the institutions of higher education including Rutgers, The State University of New Jersey, Purdue University and the University of Zambia. Through extension services, this project trained, facilitated, and mentored a significant number of farmers (1563 in Kenya and 1421 in Zambia) in partnership with private sector and government agencies. These allowed for human capacity growth and the sustainable institutionalization of new production, marketing, and regulations. In addition, this project worked with several universities where students were educated and trained in various aspects of AIVs, agribusiness, and applied research approaches to further develop future leaders within each host country. Below are some of the specific methods and activities that contributed to the program implementation as aligned with each of the five objectives.

There were five program objectives for the AIV project and the specific methods and activities that contributed to the program implementation as aligned with each of the five objectives are described below.

Methods for Improved African Indigenous Vegetable Germplasm. AIV variety trials were conducted on amaranth, hibiscus (roselle), African nightshades, spider plant, Ethiopian mustard in Kenya, Zambia, and at the WorldVeg in Tanzania (Byrnes et al, 2020, Mataa et al., 2020, Somers et al. 2020, Yuan et al. 2020a, 2020b, Zorde et al. 2020). Additional studies were conducted on hibiscus, moringa and sweet potato leaves in Zambia (Chirwa-Moonga et al. 2020; Mataa et al. 2020) and the US (Sanders et al. 2020). Additionally, participatory-based research was used to train farmers to select AIV seeds by quality to enhance the impact of the improved germplasm. Trainings occurred during field days. In Kenya, field days were conducted for varietal evaluation at Turbo and KALRO Alupe (Busia) between 2015 and 2018 with 48 farmers attending each field day (Ndinya et al. 2020a, 2020b). Farmer groups selected farmer representatives to attend the participatory trials. The trial design was a randomized complete block design (RCBD) replicated three times. Data were collected on maturity periods, leaf yields, seed yields and nutrient contents. In addition to agronomic traits, lines were evaluated by farmers based on marketability. During the participatory trial, farmers evaluated varieties based on six participatory agreed criteria: Maturity period, number of branches, leaf color, leaf size, pest and disease incidences, establishment and vigor, marketability and leaf yield on a 5-point hedonic scale and overall ranking. Descriptive analysis: mean scores and sum of ranks were used in the analysis. Out of the lines preferred by farmers, two lines each were picked from each of African nightshade, spider plant and amaranth for testing in the national performance trials overseen by KEPHIS (Kenya Plant Health Inspectorate Service).

The selected lines were tested for Distinctiveness, Uniformity and Stability (DUS).

A major aspect of this project was selection, breeding, and evaluation of amaranth for improved iron content. This was conducted using vegetable amaranth entries sourced from WorldVeg and a Rutgers University advanced breeding line that is iron-rich (RUAM24). All field experiments were arranged in a randomized complete block design (RCBD) with three replications.

USA site: Field experiments in NJ were conducted at Snyder Research and Extension Farm in Pittstown, NJ in 2013 and 2015. The soil at this site is characterized as a silt loam. Seedlings used for field trials in Pittstown, NJ were grown for four weeks in 72-cell trays with growing mix (Fafard Grow Mix 2; Sun Gro Horticulture, Agawam, MA) under greenhouse conditions at the Rutgers University Research Greenhouses in New Brunswick, NJ until transplanted in raised beds with 0.032 mm black plastic mulch with drip irrigation applied as needed. Granular 5N–17.5P–50.2K was applied 29 March 2013 at 746 $kg \cdot ha^{-1}$, 46N–0P–0K was applied 28 May 2013 at 224 $kg \cdot ha^{-1}$, and soluble 10N–13.1P–16.6K was applied at transplanting 6 June 2013 at 2.3 $g \cdot L^{-1}$ at approximately 0.12 L per plant. Granular 12N–17.5P–50.2K–10S–1Zn was applied 3 April 2015 at 313 $kg \cdot ha^{-1}$, 46N–0P–0K was applied 27 April 2015 at 224 $kg \cdot ha^{-1}$, and soluble 10N–22.7P–8.3K was applied at transplanting 17 June 2015 at 4.0 $g \cdot L^{-1}$ at approximately 0.12 L per plant.

Tanzania site: Field experiments in Arusha, Tanzania were carried out on-station at WorldVeg in 2016 and 2017. The site is characterized by well-drained clay loam soil with pH 6.4. Seedlings in Arusha, Tanzania were grown in 72-cell trays with sterilized media composed of forest soil/compost, manure, sand, and rice husks in a ratio of 3:2:1:1 by mass. Furrow irrigation was applied as needed. 20N–4.4P–8.3K fertilizer was applied to beds in Arusha at 200 $kg \cdot ha^{-1}$ prior to transplanting on 7 August 2014. Urea (46N-0P-0K) was applied 3 weeks after transplanting at 120 $kg \cdot ha^{-1}$. The first field trial at the Tanzanian site was conducted between December 2015 and March 2016, and the second trial between May and September 2017. Plants were lyophilized during the first trial and oven-dried at 40°C for the second trial.

Kenya site: The experiments in the Turbo region outside of Eldoret, Kenya were carried out during three distinct cultivation periods in 2017. The soil at this site was found to have an average pH of 5.7, CEC of 14.2 meq/100g, and 4.34% OM. Drip irrigation was applied as needed. We built a "chimney solar dryer" that was used to dry plant materials for shipment to Rutgers University. The first season of cultivation at the Kenyan site at Turbo was conducted during the hottest and driest period Kenya experiences annually. Seeds were sown November 17, 2016, transplanted January 12, 2017, and harvested February 15, 2017. Five grams of granular 17:17:17 fertilizer was applied to each plant at time of transplanting. The second field season at the Kenyan site was conducted during highest annual precipitation period with more moderate temperatures. Seeds were sown April 20, 2017, transplanted June 19, 2017, and harvested July 11, 2017. Five grams of granular 17:17:17 fertilizer was applied at time of transplanting. The third field season at the Kenyan site was conducted following the cooler period, when the average temperature increases to a moderate level with moderate precipitation from 50-100mm of rain per month on average. Seeds were sown September 9, 2017, transplanted to the field October 18, 2017, and harvested November 24, 2017.

Elemental analysis*:* Elemental micronutrient analysis was conducted on foliar subsamples of the dried yields from each line by inductively coupled plasma mass spectrophotometry at Penn State Agricultural Analytical Services Laboratory, University Park, PA. The elemental analysis was performed on the marketable yield of the first harvest in each trial. The marketable yield is defined in this study as inclusive of leaves and stems with diameters comparable to the petiole of leaves that would commonly be consumed. In our mineral analysis studies, several original samples received from our African partners appeared to be unusually high in iron. The concentration of Fe found in plants for biologically relevant quantities is notably different than the amount of iron that would appear in tissue analyses due to contamination e.g. by small amounts of soil or rust. We observed several sets of tissues appeared to have been exposed to such sources of iron and as such were not used in data analyses. Several trials were removed from the data set when unusually high levels of iron came back in the analyses.

Additional field experiments occurred in Zambia. These field experiments were conducted on community and private smallholder farms (Hantambo Womens Association Womens Association and the Mitengo Womens Marketing Association) and at the field station of the University of Zambia (Mataa et al. 2020).

Methods for Increased Demand for AIVs in the Formal Marketplace. In 2016, value-chain assessments were done by interviewing farmers and value-chain intermediaries to understand bottlenecks in the AIV value-chain (n=300 in both Zambia and Kenya) (Ochieng et al., 2019; Lohr, 2010).

Furthermore, in Kenya, 11 collection centers were established for farmers to aggregate their sales and meet the minimum sales threshold required by distributors for the formal marketplace. In addition, we provided 290 farmers with sack garden training in Eldoret. Each farmer was provided 10 sack gardens and taught how to create and maintain sack gardens through local training in sack construction, soil media and soil preparation, nutrient and watering and in preparing the seeds/seedlings and caring of the plants. Incorporating lessons learned, this sack garden model was then transferred, to a pilot program in Kibera, a division of Nairobi, where 32 women were trained. This program was implemented in partnership with a Mirror of Hope, an NGO partner (Brindisi et al., 2020).

Program staff visited the formal and informal markets as well as the growers after project was established to track sales and prices of AIVs. Growers were trained in record keeping, agri-business (tracking all input costs of production through sales and transportation to market) and sales were self-reported by grower groups. Sales were periodically crosschecked with buyers.

Methods for Training of Farmers in Best Practices. In Kenya, 70 groups with 1,563 farmers (501 men and 1,062 women) were trained in AIV production, raised bed technologies, sack gardening, better vegetable management technologies, harvesting, and postharvest methods (installation of 2 chimney solar dryers and 2 zero-energy cooling chambers) and vegetable preparation for marketing. In addition, demonstration plots were established for 39 farmer groups. These demonstration plots provided technical assistance, mentorship, and seed provision. To expand the program impact, we trained the lead farmers on production of the production of leafy vegetables and seeds to allow them to work with farmers outside our treatment area. We provided each participant with a training manual, using a series of modules developed by AMPATH, KALRO and University of Eldoret in concert with the teams at Purdue University and Rutgers University so they can independently spread the message on how to improve AIV production and reasons to consume AIVs. We also distributed seed kits containing amaranth, nightshade and spider plant for continuity of production of these nutritious vegetables. Seeds were from the WorldVeg, Arusha, Tanzania.

In Zambia, 1,421 farmers were trained on various agricultural methods best practices such as pest management, disease management, soil fertility, irrigation, water management, climate management and adaptation, marketing and distribution, post-harvest handling and storage, and value-added processing. As was accomplished also in Kenya, a subset of 372 farmers were trained in AIV production and completed additional training on raised bed technologies, better vegetable management technologies, water management, harvesting, and postharvest methods, quality control, pest management, vegetable preparation for marketing, sales, record-keeping and growing AIVs to meet market expectations and requirements. Here too, participants were required to participate in a series of training modules developed by AgriSmart in concert with the teams at Purdue University and Rutgers University. This further strengthened several women's groups (Hantambo and Mitengo Women's Groups) and other producer groups who embraced these AIVs as commercial crops and plant products.

Demonstration plots were established for farmer groups in both Lusaka and Eastern provinces. These demonstration plots provided technical assistance, mentorship, and seed through the annual hosting of field days and grower discussions.

A new Regional Horticulture Centre was piloted by University of Zambia (UNZA) and AgriSmart on the UNZA campus. This center was to serve as a training center and point of transferring technologies to small-scale farmers and students. In partnership, we utilized this regional center to conduct field studies focused on production, post-harvest and nutritional studies that engaged both faculty and students (Mataa et al. 2020). Prior to our partnership and intervention, there was no center and the field experiment station lacked most facilities needed to conduct applied research. Via this intervention and collaboration, a fenced area was constructed to protect from animal grazing and human traffic, and an irrigation system was purchased and installed, and a CoolBot, ShadeBot, and Evaporative Cooler (zero-energy coolers) were built for student and faculty use. To institutionalize these introduced technologies, each was incorporated into the practical course curriculum for both undergraduate and graduate students in the departments of Plant Science and Food Science & Nutrition at the University of Zambia (UNZA). Faculty and students now have access to these technologies for hands-on practical experience in research and applications that build upon the foundational sciences taught in class. In addition, during this project period, the Department of Plant Science at UNZA developed a new undergraduate degree program specializing in Horticultural Science, which will be an important avenue to continue pushing the AIVs agenda. The development and use of these new facilities to serve as an actual 'regional training center' will now take further commitment by its own institution, external supporters and champions to see it develop. There is a significant need for such a horticultural training center in Zambia and southern Africa.

Methods for Culinary Training and Improved Vegetable-Based Recipes. In Zambia and Kenya, to assess household consumption and health, a baseline survey (n=500 in both countries) was employed in 2016 (FAO, 2011, 2015; Lohr, 2010; Swindale and Bilinsky, 2006). This survey contained 4 themes relative to AIV consumption to inform the design of culturally relevant and need-based nutrition interventions: consumption quantities, frequencies, and varieties of AIVs, and knowledge gaps. Furthermore, the program implemented focus group discussions (n=20 per country) to identify barriers to and facilitators for consumption of AIVs, which informed a package of subsequent interventions. The first was implemented at the household level. Enumerators visited 250 households in both Kenya and Zambia to discuss a pamphlet that included nutritional benefits of AIVs, suggested cooking methods and recipes. The second was administered at the community level. The 250 households were divided into groups (11 in Kenya and 13 in Zambia) based on the geographical location for the BCC intervention. In order to increase engagement with both male and female heads of households, families were invited to participate. To ensure program implementation was consistent between study settings, a member from the KALRO team (Eldoret, Kenya) visited Hantambo in Zambia to train the Hantambo team members on the delivery of the BCC intervention. Several research projects examined the production and consumption behavior, nutrition and health trainings, gender impact, and marketing of AIVs (Arumugan et al. 2020; Govindasamy et al. 2020a; Mvungi et al. 2020; Ochieng et al. 2019; Odendo et al. 2020; Wayua et al. 2020).

Methods for Identification and Quantification of Nutrient and Anti-nutrient Qualities of AIVs. In order to identify and quantify the nutrient and antinutrient qualities of AIVs, the following activities were implemented. A genotype by environment study was conducted in Kenya, Zambia, Tanzania, and the United States to access the quantity of iron found in several varieties of amaranth (Byrnes et al., 2017). Additional, phytochemistry and nutritional intensive research studies were conducted on hibiscus, spider plant, and nightshade using a wide array of analytical instrumentation and technologies including HPLC/Mass-Spec at Rutgers University (Sanders et al., 2020; Yuan et al. 2020a, 2020b; AOCS, 2011). Specific to the study of hibiscus, the genotypes

(African Green, Indian Red, Indian Variegated, and Thai Red) were chosen based on the regional demand for ethnic vegetables in the Northeast United States. Field production trials were conducted in New Jersey at the Rutgers Experimental field stations in 2017 and 2018 (Sanders et al., 2020). These studies documented the nutrient richness of the AIVs and focused on food safety, relative to possible anti-nutritive factors. Guided by the germplasm and varietal nutritional composition in-country, local data were generated to better provide a foundation as to the real nutritional benefit of each AIV studied (Wang et al, 2005).

RESULTS AND DISCUSSION

In this project, we used AIVs as the driving force of a market-first science driven participatory model. The following results and discussion are categorized according to each of the five program objectives.

Improved African Indigenous Vegetable Germplasm. Table 1 provides an overview of the AIV varieties released during this project. In addition, there are other varieties being prepared for release. Figure 2 provides an overview of the iron content in the iron-rich amaranth variety currently pending official/government release to the market. Subsequent studies also found that some of these released and experimental AIV variety lines had higher or comparable nutritional quality to those found in the market (Dinssa et al., 2020), even when grown under adverse conditions such as sack gardens in an urban informal settlement (Brindisi et al., 2020). These improved AIV germplasm lines will have a long-term impact on household food and nutrition security, and farmer livelihood due to the improved nutritional content and vegetable yield as new improved varieties. In addition, the diverse varieties released from different crops and within the same crop will have long-term positive impact on the environment by diversifying farming systems and ensuring high-yield performing, nutrient-rich AIVs that growers and the markets demand.

The results of these activities led to the selection and release of improved varieties during the project life (Dinssa et al. 2020; Ndinya et al. 2020a, Ndinya et al. 2020b). Moreover, the variety trial activities generated improved germplasm that were used in various basic and applied studies during the project, and for use in future breeding programs by national agricultural systems and private seed or breeding companies, as well as in basic and applied research programs of higher learning institutions and advanced research centers (Byrnes et al. 2020, Dinssa et al., 2020, Ndinya et al. 2020a). Using much of the identical genetic materials across different environmental ecological zones and countries permitted us to examine the robustness of such varieties in order to provide reliable and consistent recommendations on their adaptation and resilience to different weather and climatic patterns and challenges relative to wind, heat, drought, flash flooding, soil types and more.

Increased Demand for AIVs in the Formal Marketplace. With formal markets in Kenya and Zambia focusing sales on exotic vegetables, AIVs have continued to carry the stigma of being an inferior food for the poor, a perception that is currently changing due to increased awareness and demand for healthy foods (|Ochieng et al, 2018). With the expansion of AIVs into the formal market, restaurants, hotels, and grocery stores are reviving the cultural heritage of these abandoned crops. Greater awareness of their nutritional impact, their health benefits and modern ways of preparing such traditional foods will drive demand and consumption and expand farmer revenue as demand for AIVs influences supply and price. Additionally, it may impact how farmers utilize their agricultural space, allocating more land to AIVs relative to cereal crops such as maize and sorghum and even compared to introduced traditional European vegetables.

In Kenya, the sack garden intervention in Eldoret and Nairobi improved the availability of vegetables in densely populated urban areas with the generation of modest sales from surplus AIV production. In addition, AMPATH reported the sales data for 55 farmers groups with a total of 1,191 beneficiaries. Table 2 provides an overview of the sales in Year e4 and Year 5 of the project. During year 5, these farmers produced 1,802,036 bundles of AIVs with 518,572 consumed by the farmers and their families, and 1,283,464 bundles of AIVs sold in the market. The total revenue of the bundles sold in Kenya was calculated to be $376,142USD where a bundle weighed approximately 0.5 kgs and was sold for an average of 25 shillings per bundle**.** Compared to Year 4 reporting this is a 77% increase in revenue and a 63% increase in the number of bundles consumed. In addition to market expansion, between Year 4 and Year 5 farmers increased the total hectares being farmed by 213% (total of 16.9 hectares in Year 4 compared to 52.96 hectares in Year 5)**.** In addition, farmers also expanded their total number of harvest days by 7.6% (354 harvest days in Year 4 to 381 harvest days in Year 5). These numbers are likely under-reporting the sales data for Year 5, as they calculate sales only for the period from October 2018-June 2019 as opposed to October 2018 - October 2019.

With the focus on the introduction of AIVs coupled to with training in Zambia, AIV sales were expanded within the formal market sectors (grocery stores, hotels, and wholesale markets) over the project period (8 in 2018 to 11 in 2019). In Zambia, the Hantambo Women's Group reported $95,628.63 in sales from 11 grocery stores for the first quarter of 2019 (January - March) with an estimated annual sale of $382,514.51 (Table 3). This is a 14% increase compared to Year 4 sales (reported $336,000). In part, an increase in sales data can be attributed to a 37% increase in grocery store outlets (8 outlets in Year 4 compared to 11 in Year 5). This growth in sales can be partially attributed to the expansion of retail space within the two supermarkets and increased demand of the vegetables. The initial space allocated for AIV sales was relatively small (50 cm wide and 3 shelves high); however, over the project period the allocated retail space expanded (1 meter wide and 3 - 4 shelves high). In addition, one of the supermarkets displayed the AIVs on wooden islands at the front door where clients enter. This demonstrates an increase of confidence in the value of the products as well as higher consumption of AIVs. Entrance into formal supermarkets was noteworthy as the quality and safety issues are of real concern to the buyers. In addition, the smallholder growers needed to demonstrate their reliability to provide the quantity, specificity of produce and scheduling and packaging of the product to meet supermarket requirements. This process is quite rigorous and took considerable time, effort, and trainings for AIV growers to meet the demand and expectations of quality by the formal supermarket-purchasing department. Marketing the AIVs through targeted education that highlights the benefits of each of the different AIV varieties may continue to drive an increase in sales.

Training of Farmers in Best Practices. A cohort of farmers in Kenya and Zambia were trained on improved agronomic practices. This training led to an increase in yield and sales of AIVs. As a direct result of this project, farmers in our study design expanded the hectares dedicated to growing AIVs (Table 2) and learned how to optimize the number of harvest days throughout the year and increase yields. Improved agronomic practices, such as pest management and improved germplasm further increased overall AIVs production by farmers contributing to an increase in sales and revenue for farmers. The training materials used in Zambia were created by AgriSmart in concert with Rutgers, and then later incorporated into a Stichting Nederlandse Vrijwilligers (SNV) Netherlands development organizations' book used by other USAID projects focused on Train-the-Trainer.

The increase in AIV production, acreage, and sales over the project period were significant. Given that our project is the only major multinational project promoting and providing technical assistance on AIVs, and including these as a focus for commercialization, we conclude that these successes were a direct result of our Horticulture Innovation Lab sponsored project. We also note that the above numbers reflecting income generation, as well as increased home consumption by the AIV growers, are under-reported. A summary of the current practices (Govindasamy et al, 2020a, 2020b) and training impact follows below.

Pest Management: This project provided a basis for developing pest management strategies for managing AIV pests in a sustainable manner. This involved determining the common insects found on AIVs and quantifying the yield impact due to specific insect pests (Figure 3) (Yaninek and Deletre 2019). We then evaluated the efficacy of a range of locally available pest management options and developed pest management best practices for AIVs in general, and for amaranth, African nightshade and spider plant in particular. This information was delivered in the form of factsheets in English and French for accessibility to users (Yaninek et al 2019a – 2019h).

Seed Production and Saving: In Kenya and Zambia, farmers were trained on seed production and storage. This allowed farmers to save seeds from their best performing varieties minimizing expenditure on seed every planting season (Ndinya et al, 2020b, Mvungi et al., 2020). For example, 3 women's groups in western Kenya that our project trained are now producing KEPHIS approved and certified AIV seeds for sale to other farmer groups and individual farms. This has become a new enterprise for making money based upon the production, seed collection, storage, and savings and selling of new and improved AIVs to strengthen the local seed supply chain.

Water-use Efficiency*:* Kenya and Zambia have two rainy seasons and two dry seasons. During the dry seasons, water management is essential for AIVs high yield production. Thus, farmers were trained in water management strategies in order to meet water demands during the dry seasons. In Kenya, a group of farmers were trained to use moneymaker water pumps to draw water from a borehole and water collection systems. In Zambia, a selected group of farmers were trained on water collection systems and using pumps (gas/petrol or solar powered) and gravity-fed water tanks to operate drip irrigation systems. The result was an increase in the number of growers being able to grow and sell their AIV produce over the dry season. Access to water during periods of water stress facilitates the production and marketing of fresh produce over a longer time-period, creating higher prices for fresh AIVs during dry seasons and creates more cash in farmers pockets throughout the year.

Postharvest technologies: In Kenya, farmers were introduced to and trained on postharvest technologies such as the ShadeBot and Zero Energy Cooling Chambers. The use of these technologies improved postharvest handling and shelf life of not only AIVs, but also other local fresh vegetables and fruits. This in turn reduced postharvest losses and increased farmer's income.

In Zambia, processing and preservation of AIVs improved as a result of installation of solar dryers at the community level. Postharvest loss of AIVs can be significantly reduced as observed during and after the promotion of ShadeBot and CoolBot technologies at UNZA and community level. Growers also used the ShadeBot locally on their own farms and adopted technologies to preserve the quality of the harvested product. ShadeBot technology using low-cost local materials created awareness of the importance of shade on highly perishable crops both at the farm, during transport and when produce is displayed in the open vegetable market.

Culinary Training and Improved Vegetable-Based Recipes. Consumption variety and frequency patterns suggest that a majority of the survey respondents consume a monotonous diet of cereal grains, a low variety of dark leafy vegetables, and legumes. This monotonous diet can result in micronutrient deficiencies due to the lack of essential vitamins and minerals found in a diverse diet; particularly due to the fact that a majority of these households eat a primarily meatless diet because of the high cost of animal products (milk, meat, eggs) (Ochieng et al 2018).

To improve diet quality, and as a direct response to training requested by community members in Kenya and Zambia, 250 households in each country participated in a series of culinary training that focused on improved recipes and nutritional information regarding AIVs. As a result, households learned how to prepare AIVs quickly preserving nutrients within the recipes and rehydrate dehydrated AIVs. These trainings informed households how to properly dehydrate, save, and store their AIVs when they are in plenty, then rehydrate and use them when they are scarce, and create new combinations of flavorings to diversify household recipes and decrease dietary monotony (Odendo et al., 2020). Continued work on best ways to prepare foods while preserving the maximum nutritional content is needed (Chirwa-Moonga et al 2020).

Identification and Quantification of Nutrient and Anti-nutrient Qualities of AIVs. The identification and quantification of nutrients and anti-nutrient qualities in AIVs, specifically in amaranth, African nightshades, roselle, spider plant, sweet potato leaves (Chirwa-Moonga et al. 2020) increase confidence for the health and safety of these vegetables, while also allowing farmers to effectively communicate their nutritional and health benefits. Additionally, this may identify new, value-added products that can be sold within the formal market.

Over the project period, many lessons were learned relative to the organization structure required to complete a multinational multiyear project as well as within each of the stated project objectives. The top lessons from this project are summarized as follows.

Overarching Lessons Learned:

1. Using a science-based, market driven model to promote AIV production and consumption was successful.
2. Participatory approaches result in a higher level of community acceptance, engagement and ownership.
3. AIV training empowered women, as they are champions of establishing home vegetable gardens.
4. It is important that collaborations among project partners requires that all players move at the similar pace to maintain quality control.
5. Program processes need to be iterative and optimize situations. This will allow the incorporation of new and additional local partners as needed throughout a project to provide additional expertise, regional coverage or simply make the project stronger. As an example, this project was completed with colleagues from International Centre of Insect Physiology and Ecology (ICIPE) who were invited to collaborate with the pest management team in Year 4.
6. Language, communication skills, and developing a shared lexicon are key since terms used may have different meanings across cultures in each country.

Improved African Indigenous Vegetable Germplasm

1. Improved AIV varieties can have a greater yield than previously used conventional varieties
2. Improved AIV varieties are readily accepted by farmers and consumers particularly when utilizing a participatory approach to selection that engages key stakeholders in decision-making.

Increased Demand for AIVs in the Formal Marketplace

1. Limited market for AIVs is a big challenge for farmers and linking farmers to markets would significantly stimulate production.
2. Improved connections between AIV producers and key market players have increased the availability of fresh AIVs to the public.
3. Sales tracking began in Year 3 and continued to Year 5, and more than $1,000,000 in sales of AIVs by the growers was recorded. This is a significant achievement and growers learned that market demand was far from being saturated.

Training of Farmers in Best Practices

1. Strengthening the capacity of farmer groups in various aspects of AIV production is key in the promotion of AIVs.
2. Money Maker pumps are eagerly accepted by farmers as an efficient means to provide water to AIV crops and improve production.
3. AIV production resulted in greater yields and profits to farmers and improved the ability of their families to buy other nutritional foods for dietary diversity. AIV production income encouraged some farmer groups to expand their operations into other secondary investment e.g. poultry farming, goat rearing and dairy cows.
4. Sack garden training resulted in increased availability of AIVs in slum areas and improved dietary diversity and income generation. A new sack design using

renewable and local materials is being evaluated.
5. Training on production, as well as postharvest handling and technologies, significantly reduced AIV wastage at farm, market and household levels.
6. Using practical sessions and demonstration plots during training enables farmer to grasp important concepts more easily.
7. Increased access to seed and production technologies are most important to improved AIV production.

Culinary Training and Improved Vegetable-Based Recipes

1. Improved recipes that reduce cooking time and improve taste increase the consumption of AIVs.
2. Community level BCC that engage the entire household are effective for disseminating information among household members and minimize the spread of misinformation.

Identification and Quantification of Nutrient and Anti-nutrient Qualities of AIVs

1. AIVs are nutrient rich.
2. Empowering farmers with information relative to the nutritional aspects of AIVs aids in the promotion of sales as this information serves as a value-added component.

In five years, the legacy and impact of this project are expected to continue. Examples of continued program impact occurred organically, such as increased demand for AIVs has been met with increased supply and sales, reshaping and strengthening the AIV supply chain for both consumers and producers. However, some of the impacts are dependent on external factors including: (i) further funding to provide continued focus in strengthening and making available improved varieties of AIVs, (ii) strengthening seed systems, (iii) improving the value chain from seed to product on consumer tables. This includes improvement of production systems, overcoming the noted yield gap experienced by many small holder farmers, incorporation of an integrated pest management system to increase yields and mitigate crop risk, (iv) installation of irrigation and/or water collection systems for extended growing season and/or year round production, (v) food safety practices, (vi) pre- and postharvest handling and processing, and (vii) continue to explore BCC approaches for continued engagement and increased consumption of nutrient-rich foods such as AIVs.

CONCLUSION

Traditional indigenous foods could play a central role in meeting food security needs. Despite the higher nutritional value and profitability of many AIVs, these indigenous foods are still considered neglected or underutilized plants and, in some areas, continue to suffer from perceptions of being ‘inferior foods’ or ‘weeds’ harvested and/or grown by women on the fringes of the farming systems. This incorrect notion needs to be replaced with the realization that these new crops can be mainstreamed in the formal and informal markets and are the preferred fresh produce by many in SSA. Our findings suggest that a continued focus on demonstrating and showcasing that these indigenous foods can provide the needed micronutrients and vitamins now lacking in the daily diets of so many in SSA, and can create a real source of income for women and youth, while strengthening food security in vulnerable regions and improve dietary diversity. These vegetables have significant economic opportunities to growers, food suppliers and providers of fresh and processed foods (e.g. biofortification of staple crops with AIVs) that may further reduce poverty, hunger, and malnutrition. While not the prime focus of our research, these indigenous crops are well adapted to local and regional conditions, appear to be climate resilient, provide unique opportunities to adapt and grow under changing and harsh environmental conditions and thus many are considered to exhibit tolerance to a wide range of abiotic stresses, from excessive heat and drought to flooding conditions. While we focus on African indigenous or traditional leafy vegetables in this work, similar arguments can be made for fruits and other botanicals in that these plants provide environmental and cultural sustainability (e.g. cultural heritage and asset) that can complement the economic potential in their development. In summary, these core technical needs are necessary to support the requisite foundation for sustainability, mobilize the private sector to establish aggregation and distribution centers, and influence public policies that support AIV production, distribution, and consumption.

Table 1: An illustrative example of new AIVs officially released in Kenya during this project (Ndinya et al., 2020)

African nightshade: ● Line Ex-Hai released under commercial name 'KKAyaro' ● Line BG16 released under commercial name 'KKBIGI'
Amaranth: ● Line Ex-Zim released under commercial name 'KKMrambi' ● Lines AM 38 released under commercial name 'KKLivokoyi'
Spider plant: ● Line PS –approved by KEPHIS and now to be named ● Line ML-SF29 – approved by KEPHIS and now to be named

Table 2: Sales of AIVs in Kenya between Year 4 (October 2017-October 2018) and Year 5 (October 2018-June 2019). $ = US dollars. Bundles weighed on average 0.5 kg

Kenya	Size of land (Ha)	Average harvesting frequency (days)	Total bundles consumed	Total bundles sold	Total income for all production sold in ($)	Total income if all bundles were sold in Dollars ($)	Metric tons
Year 4	16.90	354.00	318286	891715	$212,893.70	$292,009.30	445.86
Year 5	52.96	381.00	5185	1283464	$376,142.30	$527,838.90	641.73
% Increase	213.37	7.63	62.93	43.93	76.68	80.76	43.93

Table 3: Sales of AIVs by retail outlets in Zambia between Year 4 (October 2017-October 2018) and Year 5 (October 2018-October 2019). Year 5 sales data for Zambia is an estimate extrapolated from data recorded the first quarter (January-March 2019).

Zambia	Number of Grocery Outlets	Annual sales data ($US)
Year 4	8	$336,000.00
Year 5	11	$382,514.52
% Increase	37	13.84

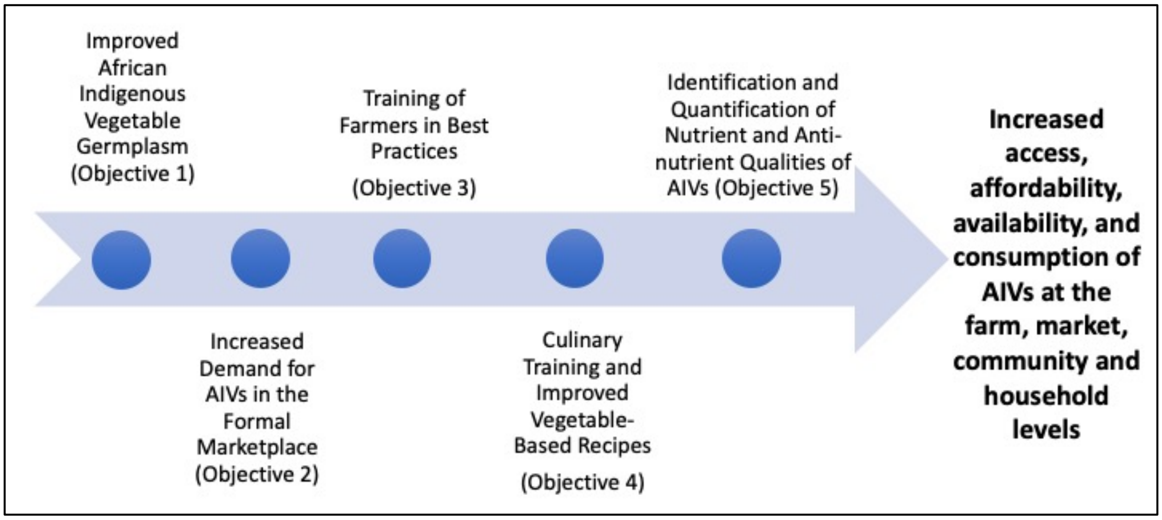

Figure 1: Coordinated program objectives building upon our Rutgers models of Access, Affordability, Availability and Adoption of African Indigenous Vegetables. Adoption in this context includes adoption by farmers and families to grow the AIVs for consumption and sales; and adoption by consumers (nonfarmers) that choose and select the purchase and consumption of AIVs in their local formal and informal markets.

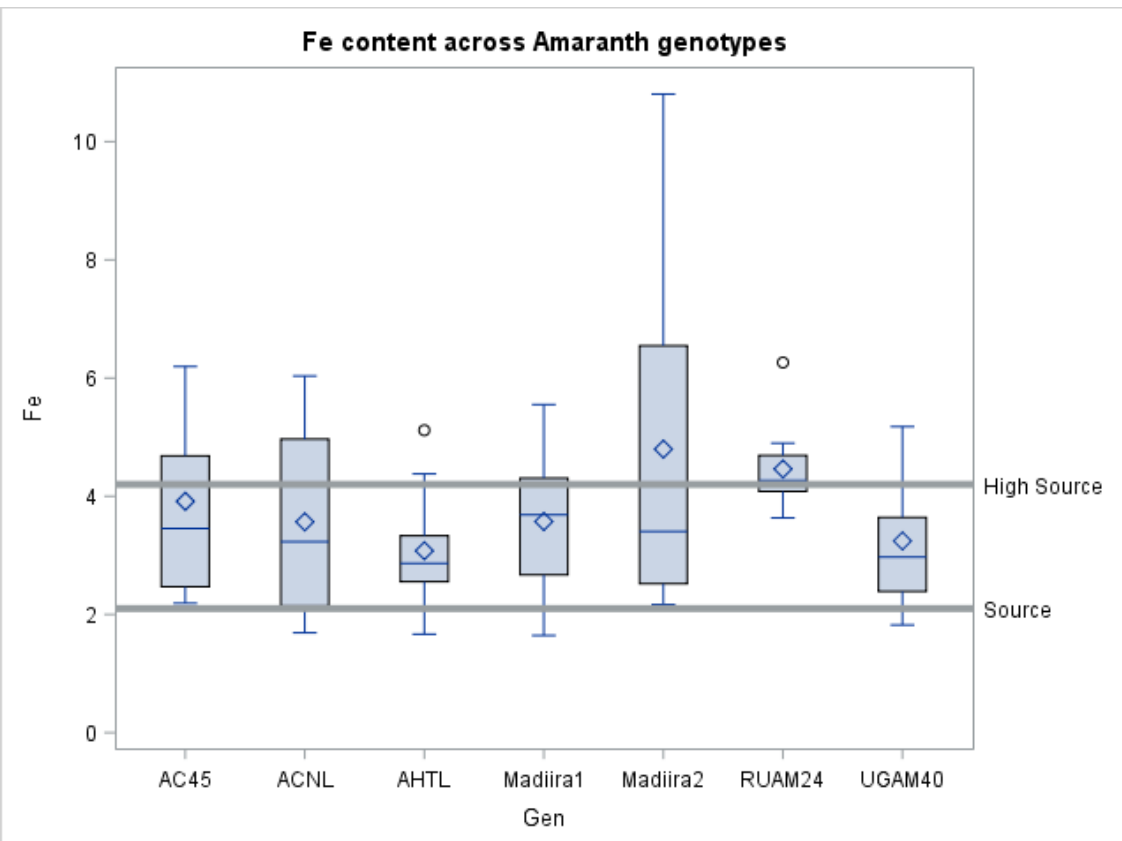

Figure 2: Mean Fe content of genetic entries within amaranth across multiple environments in Kenya, Tanzania, and USA. "High source" thresholds are defined as being the content necessary to provide at least 30% of the Nutrient Reference Value (NRV) per micronutrient if 100g is consumed: 4.2 mg/100g Fe, 90 mg/100g Mg, 300 mg/100g Ca, and 4.5 mg/100g Zn, by fresh weight basis (Codex Alimentarius, 1997). "Source" thresholds are defined as half the value of respective high source thresholds (Codex Alimentarius, 1997). The x-axis represents amaranth species: UG-AM-40 and AC45 (*Amaranthus sp.)*; Madiira 1, Madiira2, AC-NL (*A. cruentus*); AH-TL (*A. hypochondriacus)*; and RUAM 24 (*A. tricolor).*

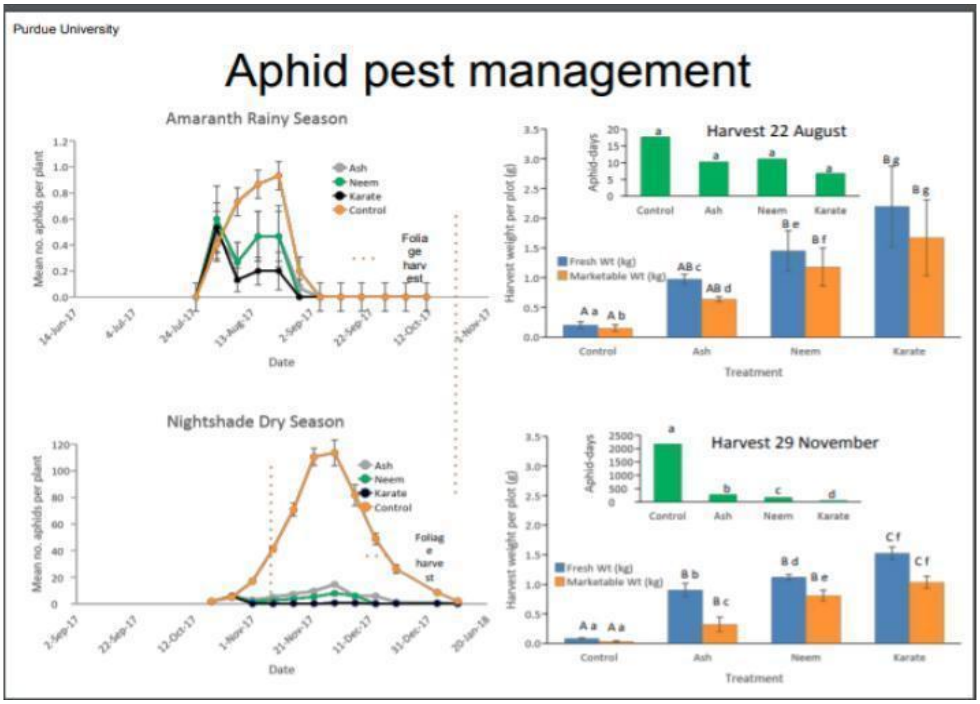

Figure 3. Aphid pest management in western Kenya.

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