Evaluating cultivars of 3 vegetable crops for inclusion in a food security systems

by

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Abstract

The important practices of Indigenous food sovereignty must be restored! Restoration of Indigenous foodways ensures the continuation of the historical lineage of heirloom seeds and preserves the cultural background that tribal nations carry. Citizens of tribal nations continue to face environmental conditions that create scarcity in heirloom vegetable production. Modern vegetable breeding, particularly hybridization, has been the key to improve yield, shelf life, pest resistance, and environmental durability. The purpose of this research is to understand and compare field production of heirloom and hybrid tomatoes (*Solanum lycopersicum)* 'Cherokee Purple' vs. 'Medusa', Anaheim- chili peppers (*Capsicum annuum)* 'Anaheim 118' vs. 'Charger' and Butternut squash (*Cucurbita moschata*). 'Neck Pumpkin' vs. 'Waltham' vs 'Avalon' vs. 'Paula'. In addition to yield, the shelf life and Brix sugar content of butternut squash was recorded

Limited irrigation was applied to the production plots to mimic the dry Arizona conditions of my home community. The Navajo Nation is the largest tribal nation in the United States and sprawls into northeastern Arizona, northwest New Mexico and southeast Utah. Water management is based in the central agencies of the Navajo Nation, where citizens face drought concerns yearly and farmers rely heavily on the monsoon season. However, this research was conducted at Kansas State University's Willow Lake Student Farm, where soil conditions are finer textured loam compared to the sandy soils of Arizona. Also, eastern Kansas experiences a much more abundant summer rainfall as compared to Arizona.

The observed yield data from the tomatoes and peppers showed no significant difference between heirloom and hybrid cultivar production. Although yield data from the squash

production concluded that the heirloom ‘Neck Pumpkin’ produced twice as much weight as the other cultivars, including open-pollinated ‘Waltham’ and hybrids ‘Avalon’ and ‘Paula’. ‘Neck Pumpkin’ also had the highest yield by count for 2021, but ‘Waltham’ had a slightly higher yield count but not significantly different from ‘Neck Pumpkin’ for 2022. Tomato mulch treatments showed no significant differences in yield, but field observations showed the benefits of mulch reducing weeds and retaining moisture when tomatoes and peppers experienced drought stress.

Additionally, the research can offer an informative background for Tribal Nations to encourage the continuation of heirloom production and tribal teachings. The project integrated tribal teachings from the outset and utilized the Three-Sisters demonstration. Seeds used for the Three-Sister Garden included Navajo and Pima Blue corn with Kentucky Blue beans and pitcher gourd, all planted in a circular pattern in the corners of the research plot. This demonstration illustrates the importance of companion planting and highlights the positive outcomes of practicing cultural teachings.

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Acknowledgements

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Chapter 1 - Compare open-pollinated and heirloom to hybrid cultivars (advantages and disadvantages), seed saving or purchases

Tomato is the second leading crop after potatoes, making it a lucrative market segment for farmers and businesses (Das et al., 2019). Tomato is a fruit with remarkable nutrients of vitamin C, carotenoids, and polyphenol contents; these diverse nutrients create a high demand from consumers. To meet demands, breeding programs aimed to identify specific characteristic traits to improve the quality and quantity of tomatoes (Das et al., 2019; Ronga et al., 2021). Breeding programs serve as the foundation of creating adapted features for vegetables to produce a good quality product for consumers and greater yield for growers. As a breeder, achieving desirable traits can be immensely gratifying, especially during harvest season (Das et al., 2019). Depending on the production scale, such outcomes can result in cost savings related to labor or costs or increased income through enhanced crop yield (Hoagland et al., 2015).

Referring back to scale, treated seeds are commonly utilized in commercial farming but may not be permissible in organic farming operations due to regulatory constraints (Hoagland et al., 2015; Healy et al., 2017). This is because organic farmers who use specific genotypes to resist disease and pests to increase yield cannot adequately succeed as other requirements include synthetic inputs during abiotic and biotic stresses (Ronga et al., 2021). Due to synthetic inputs in organic production, spraying synthetic pesticides or additional fertilizer is not in line with organic protocols. This may limit the use of newer hybrids and improved genotype seeds in organic fields. However, despite the types of inputs in both systems, research indicates a yield increase for tomato genotypes in both cropping systems (Ronga et al., 2021).

Understanding the significance of heirloom varieties is crucial, considering some varieties can date back 50 to 100 years or more (Kaiser & Ernst, 2017). Thus, losing the true heirloom seed can result in losing essential traits such as flavor, size, and in some cases, the cultural knowledge associated with planting, harvesting, preparation, and the assurance of future supply. Certain organic farmers prefer to use open-pollinated heirloom tomatoes instead of F1 hybrids because they prioritize preserving seed purity for the next growing season (Kaiser & Ernst, 2017). However, not all organic farmers prefer open-pollinated seeds, as some will use hybrids as a market niche, resistance to diseases, and good yields under unfavorable conditions (Renaud et al., 2014). In contrast, both heirloom and hybrid aim for good quality and quantity from a marketing perspective. Tomato research conducted by (Ronga et al., 2021) indicates going from heirlooms to hybrid, harvest index, and number of fruits produced were some of the main traits to attain marketable yields. Thus, to ensure marketable yields hybrid varieties have the advantage of obtaining higher amounts of fruit count and fruit weight in relation to yield. The cost of hybrids can vary from inexpensive to expensive depending on factors like taste, appeal, ripening characteristics, and the production scale.

Heirloom varieties of fresh produce and seeds are sold at a higher price but are less of a concern for consumers who value the diverse flavors and the heritage associated with heirlooms (Kaiser & Ernst, 2017; Lauterbach & Bantle, 2022). In contrast, hybrids are sold at a lower price because they have been bred to meet specific market demands, often at the expense of certain traits inherited from heirlooms. The cost differences between heirlooms and hybrids can be complex, considering the factors related to culture, society, economics, and nutritional domains. For example, heirloom rice varieties cultivated by Indigenous communities of the Cordillera Autonomous Region of the Philippines must compete with the market cost of rice (Bairagi et al., 2021). However, the two key themes that emerge as significant determinants of buyers’ willingness to pay a premium for heirloom varieties are household income and personal preference (Bairagi et al., 2021; Lauterbach & Bantle, 2022).

Buyers with higher incomes and those who strive for a healthy lifestyle will buy for quality. Both studies also found that married women who purchase groceries for the household are more likely to buy heirloom varieties (Bairagi et al., 2021; Lauterbach & Bantle, 2022). On the other hand, lower-income households and small-scale farmers may consider buying heirlooms. The choice is influenced by household size, the extent to which one desires to maintain seed purity, preference for selling at a local level, or the preservation of heritage practices within tribal communities (Bairagi et al., 2021; Duman et al., 2005). The price advantages and disadvantages of heirloom versus hybrid are difficult to understand because it is up to the buyers to determine why they prefer to spend or save money under certain circumstances.

Historically, as commercial cropping increased to large-scale fields, heirloom breeding strategies emerged as the next crop improvement phenomenon (Duman et al., 2005). Heirloom varieties declined drastically due to consistent breeding, and traits in heirlooms disappeared. A disadvantage of continuing heirloom production is needing a purpose to continue the lineage. For instance, heirloom seeds that are passed down for generations gradually become more vulnerable over time. The knowledge holder of these heirlooms, often grandparents, requires someone to pass the seeds to ensure their cultivation for future generations when they can no longer do so (Curry, 2019). The transfer of seed knowledge and practice carries culinary knowledge, health benefits, and cultural significance associated with heirloom varieties. However, some seed saver programs work to preserve heirloom seeds while also selling hybrid seeds. Nonetheless, hybrids are as important as heirloom varieties from a yield perspective in small-scale production, such as rural communities (Ronga et al., 2021). In these contexts, heirloom and hybrid production are vital in developing diverse agricultural landscapes in many food systems.

Cross-pollination of heirlooms by other varieties or hybrids from a neighboring field may lead to the incorporating specific genes that may disrupt genomes in heirlooms. From cross-pollination, the heirloom variety can lose essential traits that make it unique. Management techniques to avoid cross-pollination include buffer zones, and depending on what is grown and the operation scale, the spacing for a buffer zone varies (Coleman, 2012; Rebecka, 2020). The USDA organic regulations mandate a minimum buffer zone of 50 feet when commercial fields are next to organic crops (USDA's National Organic Program, 2023). However, more extensive separation is necessary for crops like corn, which can cross-pollination by wind, and squash, which insects pollinate. A minimum of 200 feet is often recommended for corn variety separation (Brittan, 2006; Thomison & Geyer, 2016).

Other buffer zones include windbreaks and diversion ditches. It is essential to notify their certifying agency if there are nearby commercial growers or unmanaged land to avoid airborne and waterborne contaminants (USDA National Organic Program, 2023). If growing an heirloom variety for their historical lineage, consider Organic System Planning becomes crucial. The planning involves considerations such as when to plant, strategies for using row covers, and setting harvest dates to maintain seed consistency (Coleman, 2012). Planning will allow space for avoiding cross-pollination and reduce the need for synthetic inputs.

In summary, growers face a critical decision when choosing between heirlooms, hybrids, or a combination in fields because they have advantages and disadvantages in a given system. Consequently, if staying with heirlooms, there will be limitations within the environment it grows in. The open-pollinated environment may have its challenges depending on neighboring growers. Commercial growers could apply synthetic inputs to their fields, and this can disrupt growing strategies. Disruptions to operations include cross-pollination and cross-contamination through wind and insects (Rebecka, 2020). However, for communities that face food system challenges, heirloom and hybrid varieties can play a vital role in mitigating challenges in their given system.

Chapter 2 - Food Security and food sovereignty comparison, cultural uses

(Loring, 2022) discussed the importance of food principles in a living system that works with rather than against ecological tendencies. Based on scale, living systems regarding food security have different goals: availability, access, and utilization (Gregory et al., 2005). An example of a system includes a community using energy input to build agriculture production and for the output to feed the community or to promote healthy living (Gregory et al., 2005). However, food security is not just about agricultural farming. It is about securing the land and the elements such as wild game (hunting and fishing) and wild edible plants (gathering) critical in maintaining or restoring food sovereignty (Mihesuah & Hoover, 2019; Phillips et al., 2014). Saving seeds, creating educational workshops promoting foraging edible plants, gardening, and cooking tribal foods with contemporary products are examples of securing foodways.

Tribes should decide freely to secure these elements toward self-determination and to make changes in their nation (Mihesuah & Hoover, 2019). Defining food security is challenging because households within communities face food insecurity on different levels, whether it be poor income or poor access to nutritional and affordable foods. Like many food systems, food insecurity creates barriers to achieving the goals of self-determination and sustainability. Unfortunately, other systems that create barriers to food access are politically, socially, economically, nutritionally, and physically driven (Sumsion et al., 2023).

It is important to note that during the eighteen and nineteenth centuries, Natives food supplies and soil health were destroyed using 'scorch-earth tactics' from U.S. soldiers by clearcutting forest land, killing large numbers of wild game (Bison) and domestic livestock, like sheep, and removing tribes from their ancestral homelands (Mihesuah & Hoover, 2019). Events like these, with historic allotment policies and broken treaties, placed Native tribes on smaller land, also known as reservations, and the selling of land to non-natives (Maillacheruvu, 2022). The limitation of lands initiated a pattern where Native communities began losing their connection to tribal foodways. They became increasingly dependent on commodity foods and had to adapt to unfamiliar farming and grazing practices in these constraining environments (Maillacheruvu, 2022). The widespread industrial agriculture added pressure on living ecosystems and the natural world, often referencing the earth's gift as merely "natural resources" to be extracted. Industrialization limited vital sources of sustenance, such as water, and reduced agrobiodiversity (Gonzalez, 2012). In recent times, climate change has become the driving force for communities to acknowledge the issue and take responsibility to participate in restoration and make positive changes in their food system environmentally, socially, and politically (Gregory et al., 2005).

Tribes, such as the Blackfeet reservation in Montana, created programs to restore the Bison into their rangelands, food systems, and cultural practices (Shamon et al., 2022). The program provides bison conservation and cultural efforts for the tribe to maintain herds in a social, ecological, and environmental way. They all work together, where the social includes youth learning to harvest the meat in its natural environment (Shamon et al., 2022). In these sessions, community members eat together; it is also a learning opportunity of how the grasslands and Bison work together, and lastly, how the Bison meat or herd brings revenue to the tribe with local sales. The Blackfeet program is an example of regaining food sovereignty by culturally connecting land (Bison) and people through revitalizing cultural teachings and maintaining the food system for their local tribal members (Shamon et al., 2022; Mihesuah & Hoover, 2019).

Another critical point is that many different food systems struggle with different inputs of Food, Energy, and Water. In communities that struggle with health, their system can be adapted to their expected diets on seasonal availability by cultivating or harvesting wild food (Loring, 2022). Examples of mitigating this issue are networking with local businesses, responding to feedback, implementing policies, and diversifying the food systems (Sundkvist et al., 2005). Heirloom seeds are essential for tribal nations and for consumers in general. Besides growing heirloom for flavor and taste, we must see heirloom seeds as a time capsule of historical lineage ready to be restored for knowledge or agrobiodiversity (Lauterbach & Bantle, 2022). When we share knowledge from what we grow, we pass down lifetime teachings to sustain ourselves in the environment. Seed bank organizations or seed sanctuaries are outlets for distributing seeds or labeling seed packages with information (Lauterbach & Bantle, 2022). These outlets help distribute heirlooms and contribute to genetic research on drought adapted varieties.

Seed Saver Exchange is an organization that keeps heirlooms growing by collecting seeds, connecting people to seeds, education, and building a network around saving heirlooms (*About Seed Saver Exchange*, 2023). They have worked with many seed collectors, such as an heirloom bean collector John Withee, who transferred his extensive collection to Seed Saver Exchange in trust to conserve and diversify crops (Curry, 2019). The trust continued over the years and upgraded to properly storing a larger seed collective network (Curry, 2019). Other seed organizations include the Indigenous SeedKeepers Network, which is dedicated to restoring the food system and aims to build relationships with each other and the land (Mihesuah & Hoover, 2019). Through grants, they acquire agriculture skills, peer mentoring for youth, build platforms for policy and advocacy around food systems and reestablish Indigenous Trade Routes ("Indigenous SeedKeepers Network | NAFSA," 2014). They socially approach seed collecting by building workshops, respectively storing and sharing seeds among tribes. These organizations are essential to saving heirloom varieties for teaching, cultural purposes, or other views for genetic purposes when environments decline.

An example of implementing a food systems policy to help with food insecurities on tribal land is discussed in Chapter 3**, '**Challenges in the Navajo Nation. In contrast, ways to sustain food sovereignty include expanding your garden or field to noncommercial polyculture to improve one's diet, reduce health risks, and conserve soil quality (Holt-Giménez et al., 2012). It takes motivation and determination to continue helping your community; from these examples, some have built social networks to continue their goals of food system sustainability. These social network gatherings have helped by providing feedback loops for growers to make sustainable changes to food systems and, most importantly by having the community participate (Sundkvist et al., 2005). Gathering and expressing concerns builds relationships, which can help negotiate policy changes for the food system (Rebecka, 2020). Lauterbach & Bantle, (2022) conducted research based on social surveys of heirloom varieties. From this study, they offered gathered marketable suggestions such as willingness to pay for heirloom varieties because of flavor preferences and the authentic knowledge that heirlooms hold.

In summary, food security and sovereignty can be complex to define because many communities face food insecurities on different levels. I gave examples to show the people's efforts to access food and to know about nutritional food so they can also make changes within their households. It begins with building relationships and expanding those to other networks to set goals politically, socially, environmentally, and culturally, and place those goals into positive changes to share with others in your community.

Chapter 3 - Challenges in the Navajo Nation

It started in 1864 when Kit Carson and his troops forced Navajos off their homelands to walk to Fort Sumner, a four-year incarceration (Evans, 2005). This catastrophic event forced Navajos to leave their livelihood of livestock, ceremonies, and natural resources. By 1868, survivors from the long walk were released to return to part of their homelands when, eventually, by 1870, a reservation was set aside for them (Hoover, 1937). Like many other tribes, the forced relocation to reservations resulted in the loss of cultural foods and wild game. It resulted in tribes to adapt to their new environments and to rely on government food distribution. Unhealthy commodities of flour, lard, cheese, and sugar were given to tribes to adapt to their new environments (Mihesuah, 2005).

Introducing commercially processed foods and distributing government food commodities has changed indigenous diets and cooking practices throughout indigenous communities (Mihesuah, 2005). The rise of heart disease, diabetes, and cancer has taken a death toll on elders holding onto cultural knowledge. The Navajo Nation is one of many tribes that face these health concerns today. The Nations landscape is high-desert plains with mesas, deep canyons, mountain ranges with lakes and natural resources (Hoover, 1937; Lombard et al., 2020). Its abundant of coal, oil, and historic uranium mines have been stripped away from the land for economic development for the United States. The continuation of mining and abandoning them also caused economic infrastructures and health issues for residents (Begay, 2018; Curley, 2021; McGuire et al., 2019).

It is the largest reservation in the United States, with more than 16 million acres, and many residents live in a food desert community today, depending on their Chapter region (Lombard et al., 2020). The USDA used the term “low-income and low-access” to describe food desert communities with inadequate transportation access, low numbers of food stores, and low income (Dutko et al., n.d.). The Nation faces "low-income and low access" to food because residents live 30 miles from the nearest supermarket, rely on the nearest convenience stores with minimum options, and experience high unemployment (Lombard et al., 2014; Pardilla et al., 2014). Other food source alternatives include trading posts and flea markets where you can find traditional food (blue corn, squash, mutton) and medicinal herbs (tobacco, tea, and mixed herb remedies (George et al., 2021). Type 2 diabetes and obesity are still the leading illnesses the Navajo Nation faces regarding maintaining good health. However, dietary programs are willing to help residents make healthier food choices and make political changes within the food system (Eddie et al., 2022). Improving a diet may require preparing unfamiliar food a certain way; therefore, knowing how to incorporate more vegetables is essential.

In 2014, the Navajo Nation became the first tribe to implement the first tax policy by introducing a 2% tax on unhealthy foods and waiving a 6% sales tax on fruit, vegetables, and water (Eddie et al., 2022). The policy was used to promote healthy eating at affordable prices. The policy directly changed gas stations, grocery stores, convenience stores, and trading posts as they are the primary resource for selling unhealthy snacks like prepackaged chips and sugary beverages such as soda (Eddie et al., 2022). Recent research observations in 2019 from George et al. (2021) show that local grocery stores and convenience stores made price improvements, increased the availability of traditional foods, and increased promoting positive health through signage. Policies like the Healthy Dine Nation Act and the partnering programs from the tribe's public health department, Navajo Nation Health Survey, and Navajo Epidemiology Center use data to set goals and policies to ensure the tribe's access to healthy foods (Pardilla et al., 2014).

Tribes that face similar concerns can use the Navajo policy as an outline to better their community and adjust it to their situation.

Looking into the future, electricity and running water are some economic efforts the Navajo Nation is trying to improve. The Navajo Tribal Utility Authority (NTUA) is the largest multi-utility enterprise owned by a tribal nation, providing running water, electricity, and communication services (Begay, 2018). As stated above, residents living 30 miles from the nearest grocery store may need access to running water or electricity. Implications from this do not allow residents to have refrigeration to store food safely for an extended period or have running water to supply drinking and household needs (Bain et al., 2004). Residents living off-grid, meaning they lack grid-tied power or distribution, are slowly accessing electricity (Begay, 2018).

The Navajo Nation has taken steps to develop solar energy through NTUA, which currently serves 102 residents with photovoltaic energy (Begay, 2018; Bain et al., 2004). The estimated cost to get electricity for off-grid residents will exceed $350 million, and a 40-year project to get every home with electricity (Louie et al., 2023). It is a big project that will bring economic opportunities such as increasing employment rates and receiving clean energy. The "Navajo Nation Council Committees" annual report for the year 2022 showed positive changes in how NTUA and its partner Salt River Project (SRP) constructed solar panels to provide over 55 megawatts of solar energy to 28,000 homes on the Navajo Nation ("Navajo Nation Council Committees," 2023). Providing electricity to those in need is an example of the Navajo Nation gaining resiliency to the challenges they face. No matter the circumstances and the amount of time, they will do it for their people.

Agriculture methods include dry farming, home gardening, and hoop house greenhouse operations. During drought seasons, dry farming is the common practice used; at this time, seeds are planted deep into the soil, and having to tend to them properly physically and spiritually in every growing season (Wall & Masayesva, 2004). Water supply includes relying on monsoon runoff from the mountain into the canyons and the valley. Other sources include hauling water from wells or waiting on the local chapter to release water into irrigation systems for farming practices such as flood irrigation and dry farming. There are 110 chapters in the Navajo Nation; within those chapters, a farm board committee is established to supply accessible resources for community members who are grazing and farming. According to the Navajo Legislation Code, the purpose of the farm boards is to ensure proper operation, maintenance, and improvement of local irrigation systems (Navajo Nation Legislative Code, 2010). The farm board must update the Navajo Department of Agriculture about investments, grant approvals, community concerns, and plans regarding land, farming, and grazing. (Navajo Nation Legislative Code, 2010). More specifically, updates include community engagement, program networking to supply training, and agricultural product investing. Farm board committees, profit/non-profit organizations, and the public health departments are the driving forces to ensure people regain access to our own food, electricity, and water needs.

The Navajo Nation is a tribal nation that faces specific economic, social, and environmental concerns. Here, I discussed a few situations the tribes continue to face. From it, you can see a similar pattern between each issue: lack of funding in a household or a community, living in a rural environment with little access to natural resources. However, this does not stop the tribe from applying for grants or receiving funding to bring community events and supply resources like water, food, and electricity. We live in a new era where extreme weather conditions are becoming the norm, and it is up to the household, farmers, and graziers to adapt to the change while supporting each other. The positive change is implementing policies, supporting local growers to receive accessible local goods, and hosting training/classes regarding healthy diet, workforce, and farming techniques to reduce environmental impact.

Chapter 4 - Methods and Materials

Research location

This research was located on the Willow Lake Student Farm, just north of Manhattan, Kansas. The student farm is part of the 40-acre Geyer Forestry Research Center. The student farm covers over 7 acres of land and is used as a horticultural classroom setting for gaining experience, earning certificates, and providing research plots for students and faculty. The farm created a space for my research to partake in a two-year research study of tomatoes, Anaheim peppers, and winter squash. Using Google Earth Pro, Figure 4 shows a satellite view of the Willow Lake Student Farm and a visual aid of my research plot size for 2021 and 2022. More specifically, for the years 2021 and 2022, I used a 90x90ft. garden plot, heirloom and hybrid tomatoes (*Solanum lycopersicum)* 'Cherokee Purple' vs. 'Medusa', Anaheim- chili peppers (*Capsicum annuum)* 'Anaheim 118' vs. 'Charger' and Butternut squash (*Cucurbita moschata*). 'Neck Pumpkin' vs. 'Waltham' vs. 'Avalon' vs. 'Paula'. The vegetables were grown in the Kansas soil: fine silty loam. Although water management is related to Chinle Arizona rainfall, despite soil texture, it is a loamy wash with saline-sodic soil.

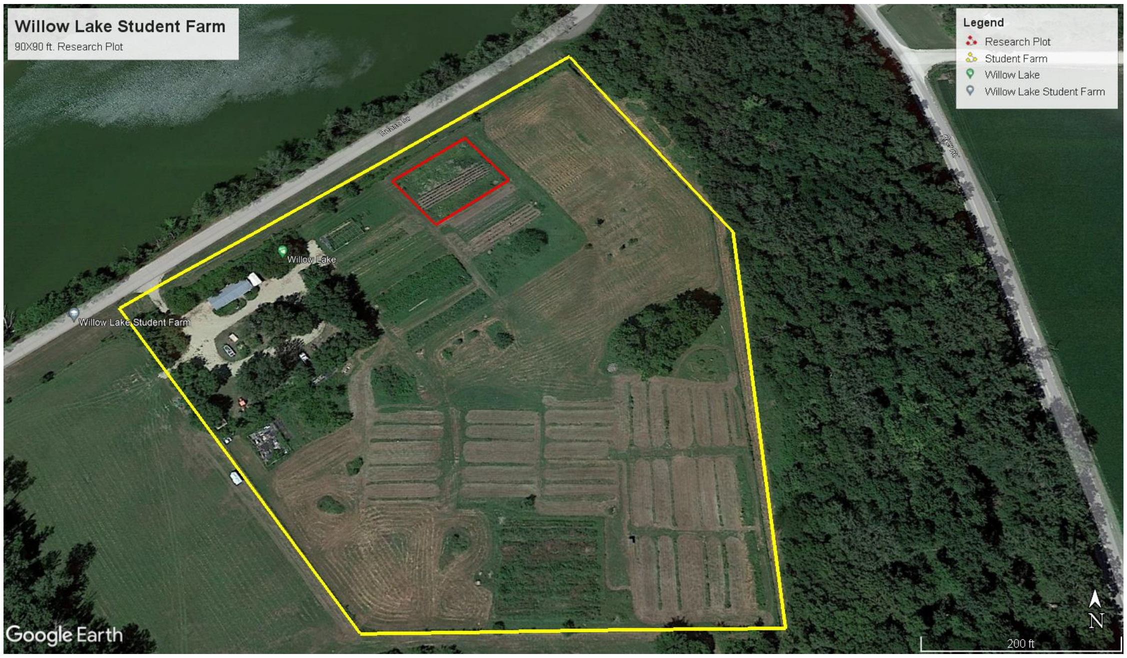

Figure 4.1. Yellow line shows border of Willow Lake State Farm and red line is 2021-2022 research plot.

Weather

Although Arizona and Kansas have a yearly climatic difference, the research watering method mimicked the drier Arizona climate by waterings a maximum of once per week, depending on weekly rainfall. The average rainfall of Chinle Arizona is 9 inches compared to the average of 35 inches per year in Manhattan, Kansas. Figure 4.2 and Figure 4.3 are time series plots for 2021 and 2022 weather data from the nearby Rocky Ford Turf Center via Mesonet system (Kansas Mesonet, 2023) for total weekly rainfall during the summer of 2021 and 2022. The line graphs start from the beginning of May to the end of September, four months because we want to understand the rainfall effect on vegetable yields. The total rainfall for summer 2021 is 21.95 inches, and 24.37 inches for summer 2022. However, precipitation was much less variable in 2021, ranging from 3.01 to 7.45 inches per month, compared to a range of 1.08 to

9.57 inches in 2022. The highest rainfall for summer 2021 was in July, with 6.89 inches, whereas in 2022, rainfall peaked in June at 3.7 inches.

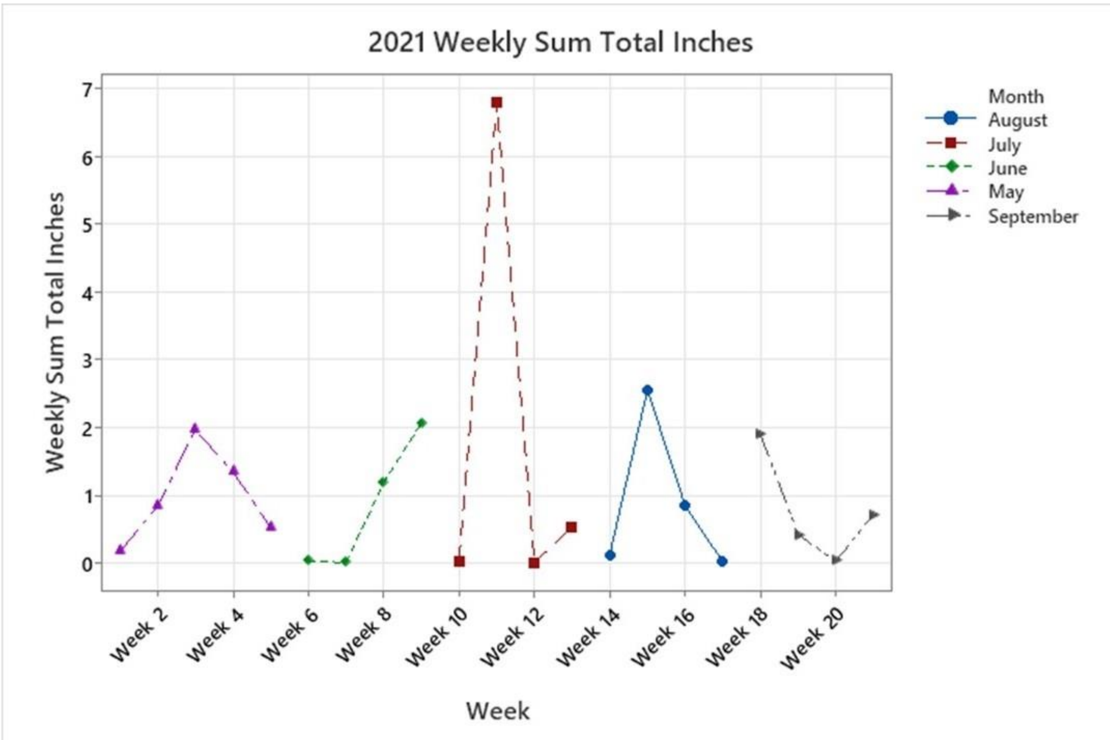

Figure 4.2. 2021 summer precipitation.

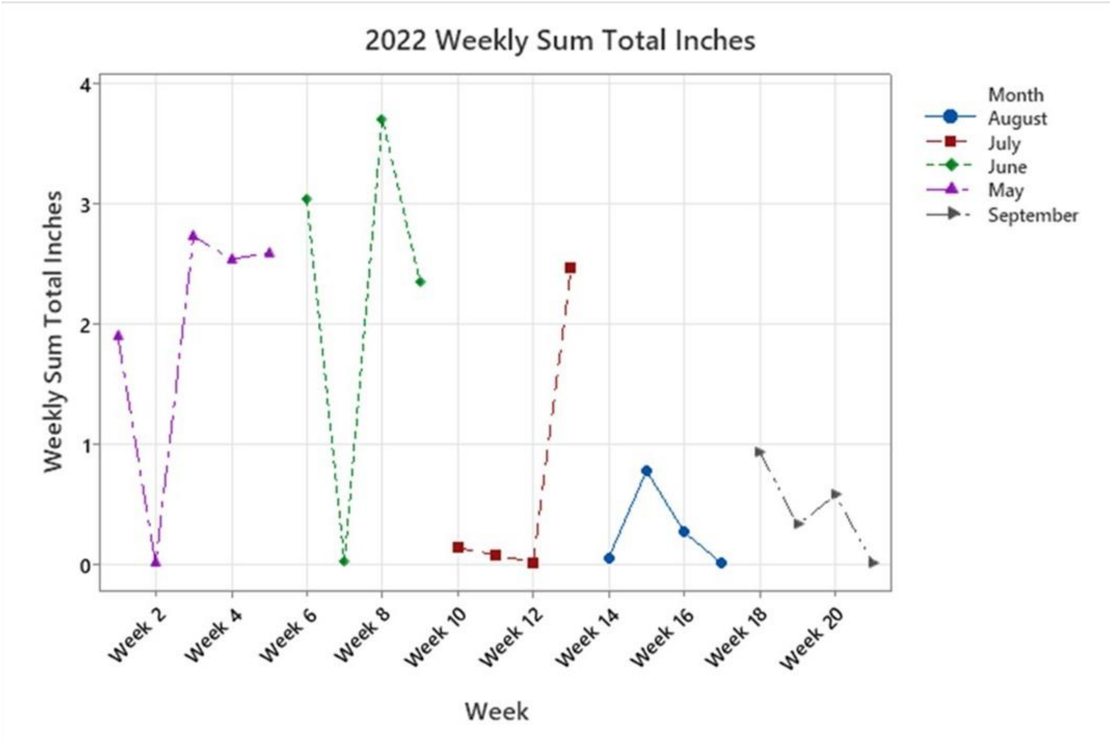

Figure 4.3. 2022 summer precipitation.

Cultivars

Seeds for the tomatoes, Anaheim chili peppers, and butternut squash were bought from Harris Seeds. In the second year, the ‘Neck Pumpkin’ seed was purchased from the Thresh Seed Company due to crop failure in the Harris Seeds supplier with growing fields in India. The Chinle Public Health Department donated the Three Sisters Garden seeds. Specifically, only two true heirloom varieties used in this research were 'Cherokee Purple’ tomato and ‘Neck Pumpkin’ winter squash. ‘Anaheim 118’ and ‘Waltham’ butternut are older, open-pollinated cultivars. They are not hybrids, so they come true from seed. The hybrid varieties are the tomato ‘Medusa’, hybrid Anaheim peppers ‘Charger’, and two hybrid winter squash ‘Avalon’ and ‘Paula’. All tomatoes and peppers were started in the greenhouse mid-March and transplanted to the field to the beginning of May. Tomatoes and peppers were transplanted when the risk of frost was past. The squash seeds were directly seeded in the second week of May, but the zucchini trap crop and marigolds were started a few weeks earlier in the greenhouse. T-posts and twine were used to keep rows lined up correctly, and trellising the tomatoes and peppers using the Florida weave method (Kelbert et al., 1966).

Figure 4.4. (Left) Tomatoes transplant stage. (Middle) Direct seeding of butternut squash next to a transplanted zucchini trap crop. (Right) Florida weave method on tomatoes

Experimental Design 2021-2022

The research plot was 90x90ft. with seven rows, including four rows of tomatoes, one row of peppers, and two rows of squash. Tomato and pepper rows were 5 feet apart. The plot layout included four rows of heirloom and hybrid tomatoes (*Solanum lycopersicum)* 'Cherokee Purple' vs. 'Medusa'. The tomato rows have four replications of two types of mulch treatment: plastic, straw, and control. One row of Anaheim- chili peppers (*Capsicum annuum)* 'Anaheim 118' vs. 'Charger'. We did apply straw mulch to the peppers in 2021 and not 2022; however, for this research, we only compare yield differences by cultivar. Two rows of butternut squash

(*Cucurbita moschata*) ‘Neck Pumpkin’ vs. ‘Waltham’ vs ‘Avalon’ resulted in 8 replicated hills per cultivar. Wooden stakes were placed at the hill to label the specific variety. Twenty-four tomatoes were planted in each row with 5 feet spacing in each treatment and 6 feet spacing to differentiate treatments. In total, 96 tomatoes were transplanted. 32 pepper plants in total were transplanted with 2 feet spacing and 3 feet spacing to differentiate cultivars. Two rows of squash were 10 feet apart from each other and the peppers. Squash replication was decreased to 4 in 2022, due to adding the cultivar ‘Paula’.

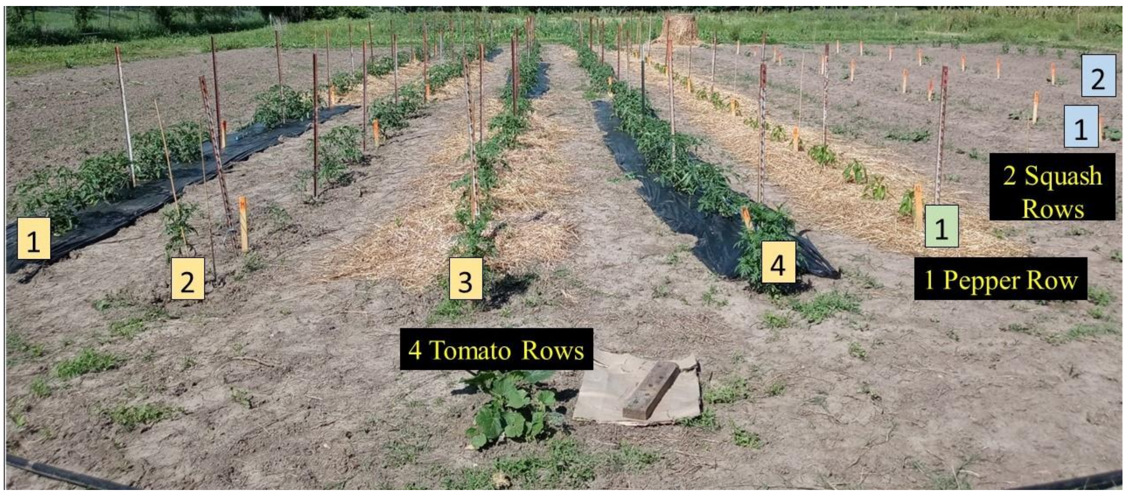

Figure 4.5. Summer 2021 research plot tomato rows (yellow box) include plastic and straw mulch. Pepper row (green box) and two squash rows (blue box).

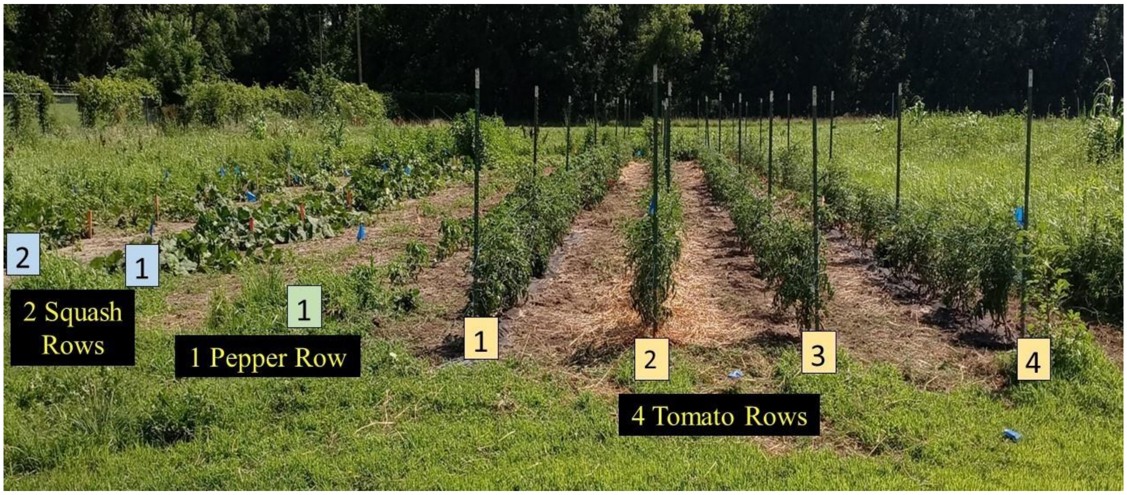

Figure 4.6. Summer 2022 research plot, tomato rows (yellow box) include plastic and straw mulch. Pepper row (green box) and two squash rows (blue box).

Mulch Type

Figure 4.4. shows a visual example of the mulch treatment layout for the tomato rows using all three mulch applications. The thickness for 2022 straw mulch was less than that of 2021 and may have played a role in yield data. Notice in Figure 4.4 that straw was applied to the chili peppers and not for the year 2022, as shown in Figure 4.5 One unique observation from the squash rows for both years was that the extended vines and the broad leaves provided enough shade to reduce moisture loss and required no watering efforts until leaves showed signs of drought stress by curling up. Figure 4.7 (Left) and (Middle) show both years of the leaves providing shade and the vines growing into the peppers and outside the plot boundaries, requiring us to till weeds to make room. Lastly, 'Neck Pumpkin' should be used for future research because recently, in the fall of 2022, it sprouted in my family's front yard as shown in Figure 4.7 (Right).

Mulch application is a practice where a grower can manage weeds, increase yield, and retain soil moisture. Thermoplastic mulch, such as polyethylene plastic materials that are either black or clear, is used as a topsoil cover to maintain soil moisture (Bhardwaj, 2013). For this research, we used black plastic mulch. Maintaining soil temperature and moisture can boost water movement from capillary and steam activity to increase carbon sources for photosynthesis (Farah et al., 2021). When weed are well managed, there are no photosynthesis competitors around vegetable production; as a result, larger fruits and higher yields are produced (Mahadeen, 2014). *Organic mulch* is a plant-based material that includes wheat straw, hay, compost, cover crops, and woodchips. For this research, we used straw mulch. Organic mulch aims to improve soil quality over time, prevent erosion, increase soil bioactivity, and limit the contribution of plastic waste (Bhardwaj, 2013). Like plastic, the shade cover from organic mulches suppress temperatures to minimize competitive weeds and increase growth (Bucki & Siwek, 2019). It is essential to consider the thickness of the mulch to keep weeds from germinating and maintain soil moisture under certain environmental conditions. For example, Barley straw mulch in a windy environment can blow mulch away, therefore increasing soil temperature and weeds (Anzalone et al., 2010).

Figure 4.7. (Left) 2021 squash leaf area intertwining. (Middle) 2022 squash leaf area intertwining and extending vines. (Right) ‘Neck Pumpkin’ cultivar growing well in the Chinle soil.

Weed control

Crop rotation was applied for both seasons for squash bug management. Since weed species were consistent for both growing seasons, weed control was applied. For summer 2021, labor help was at a maximum of four people to help eliminate weeds. Mechanical and hand hoe were used for all seven rows. Plastic and straw mulch helped a lot in managing weeds, preventing them from growing abundant and competing with the tomatoes and peppers. Weeding was applied in each row every two to three days every week until the tomato and pepper harvest increased. Bermuda grass (*Cynodon dactylon*) and crabgrass (*Digitaria sanguinalis*) are two of the main weed species that needed weekly pulling due to the rooting of rhizomes and frequent expansion. Ragweed (*Ambrosia artemisiifolia*) is another weed that grows frequently and requires chopping as the stem grows thick when ignored. Yellow nutsedge (*Cyperus esculentus*) is an easy weed to pull and manage when growing under the base of the tomatoes and peppers.

Bindweed (*Convolvulus arvensis L.*) is a weed that grows at the base of all plants and is difficult to control when climbing up tomatoes and peppers. In the summer of 2022, a roto-tiller was used more than the hand hoe and rake. Labor help increased to six people and was beneficial for splitting labor in managing weeds and pests. The roto-tiller was used between rows, and a hand hoe was used for the weeds at the base of the tomatoes, peppers, and squash. Hand-pulling the weeds was used during germination to avoid damaging emerging squash cotyledons.

Figure 4.8. Shows the roto-tiller, hoe, and hand weeding in action.

Disease Management

Plant diseases for all cultivars were not managed nor identified in 2021 but were later identified and slightly managed in 2022. The most common diseases for the tomatoes were early blight and an unidentified plant disease as shown in Figure 4.9 (Middle). To control the spread of the disease, we trimmed off the dead leaves. The peppers also experienced early blight and were slightly trimmed. Since Kansas weather is humid, powdery mildew was common for both years but not managed, nor did it seem to affect yield. When we encountered leaves that exhibited a disease, we trimmed them off as much as possible.

Figure 4.9. (Left) Early blight. (Middle) Unidentified disease. (Right) 2022 tomato trimming of dead leaves.

Pest management

The tomato horn worn (*Manduca quinquemaculata*) and Ash gray blister beetle (*Epicauta fabricii*) were difficult to manage and required frequent and precise pest scouting. The tomato horn worn can be difficult to spot due to its bright green color resembling leaves. The gray blister beetle can quickly hide under leaves and appear with a swarm overnight. Ultimately, both pests can cause damage to the leaf and stem, shown in Figure 4.10 (Left). The third pest included corn earworm (*Helicoverpa zea*), but was less of a concern. Lastly, the most difficult pest to manage was the raccoon (*Procyon lotor*), as they ate a row of tomatoes once during harvest time. The tomatoes were taken throughout the growing seasons, but it was not common with peppers and squash.

Figure 4.10. (Left) Tomato Horned worm damage. (Right) Racoon bite on tomato results in no harvest.

Pest management for the peppers was limited to two types of stink bugs: the squash bugs (*Anasa tristis*) andgreen stink bug (*Pentatomidae*). The squash bugs damaged peppers when juvenile squash bugs increased to a high population. Squash bug eggs were laid on the underside of the pepper leaves, making it difficult to find and remove them. Because the peppers were planted next to the squash, the vines could expand to the peppers. The squash bugs did damage a few pepper skins by piercing and sucking from their mouths. Managing the squash bugs numbers will be discussed in the next section.

Figure 4.11. (Left) High populations of juvenile and adult squash bugs. (Right) Cluster of fresh hatched squash bugs managed with duct tape

Pest management for butternuts includes planting trap crops of Zucchini (*Cucurbita pepo*) and yellow squash (*Cucurbita pepo* var. *recticollis*) between plants for both rows. The trap crops were beneficial to control squash bug numbers as adults started laying eggs. Cardboard traps were placed in between squash plants as a source to capture squash bugs. The cardboard worked by mimicking the large leaves of squash and making it easy to capture squash bugs. Another beneficial practice included using duct tape to remove egg clusters for peppers and squash, as shown in Figure 4.11 (Right). At the same time, the squash bugs managing numbers were placed in water to avoid odor when being crushed, as shown in Figure 4.12 (Right).

The last resort to manage the squash bugs included spraying insecticide Spinosad (an approved organic chemical) and finally Sevin (carbaryl) only on the squash. Spinosad was sprayed once a week to manage nymphs and juvenile squash bugs. The adult squash bug was controlled by spraying Sevin once a week for several weeks later in the season. We stopped spraying when population numbers increased, and the squash skin colors changed from yellow to light brown, indicating maturity. However, one pest that was difficult to control was the Squash Vine Borer (*Melittia cucurbitae*). From observations, a squash plant will perform well for a couple of days and suddenly die the next day. Squash disease was observed but did not affect the squash plant growth, as the main objective was to manage squash bug numbers.

Figure 4.12. (Left) Zucchini Trap crop luring squash bugs away from butternut squash. (Middle) Card board trap luring in squash bugs. (Right) Squash bugs place in water to avoid odor.

Figure 4.13. (Left) Squash vine bore damage. (Right) Sevin insecticide

Watering and harvest

Tomatoes and peppers are watered either once or twice a week depending if the leaves were wilting. Drought stressed plants display curling of the leaves, wilting, and sunscald on the fruit. For the year 2021 a hose spray was used for watering and took roughly three minutes for each row to be complete. For the year 2022, a bucket and a cup were used for watering and the complete time for each row was 4 minutes each due to the help in labor. One key factor facilitating the harvest was trellising the tomatoes using the Florida stake weave in order to keep the tomatoes off the ground.

Tomatoes for 2021 had a total of eight harvests and 2022 had a total ten harvests and could potentially show year difference but not cultivar. Peppers had a total of 4 harvests for 2021 and seven harvests for 2022. The squash had a total of three harvest for 2021 and two harvest for 2022. Tomatoes were harvested at ‘Breaker’ stage when they were slightly pink or red at the blossom end or when they were 90% red (U.S. Department of Agriculture, 2023). Peppers were harvested when they turned completely red or large in size. In addition, there were tomatoes and peppers that needed to be harvested due to skin damage or diseases. Harvest techniques include using hand baskets with cardboard dividers for separating each plot’s harvest. Another alternative for the basket were brown paper bags to harvest the peppers and tomatoes. The squash however was harvested by numbering each squash numerically and measuring vine length from the fruit to its planting origination. When all vegetables were harvested, supplies such as wooden stakes and t-posts were stored away. Plastic mulch was recycled and straw mulch along with plant residue was placed in the compost pile.

Figure 4.14. (Left) Tomatoes display leaf curling due to moisture stress through the leaves. (Middle) Basket harvest. (Right) Brown paper bag harvest.

Tomato Grading

After each harvest, the tomatoes are weighed using the lab scale and then graded using the "USDA Tomato Grades and Standards" to determine what could be sold to consumers (U.S.

Department of Agriculture, 2023). My target customers were local business owners and the Haskell Library staff willing to take tomatoes home for family use. Business owners include Fridas Food Truck, Little Grill, Ana's Burger Shack, and Blue Rivers Traders. All tomatoes were sold at 1 dollar per pound, totaling 311 dollars for both years combined. Color and defect classification was used to grade marketable tomatoes (U.S. Department of Agriculture, 2023). The size and tolerance, such as handling/shipping of the tomato, were not considered in the grading process as customers did not mind the size and how the tomato was delivered. It is important to note that the marketable tomatoes were not rated as No.1, No. 2, and No. 3 but with their overall appearance. The Figure 4.15 (Left) below show the unmarketable tomatoes and Figure 4.15 (Right) show marketable tomatoes.

Regarding the unmarketable tomatoes, the color and defect grading scale, most damaged tomatoes ranged from Serious Damage to Very Serious Damage (U.S. Department of Agriculture, 2023). U.S. grading of tomatoes, the left figure is coded in abbreviations to fit the picture size. (IB) stands for insect bite that looks like holes, and (GC) stands for growth cracks where the skin is stretched out. (CF) stands for 'Catfaces,' when the blossom ends enlarged. (Z) stands for 'Zipper' because the skin has a line scar resembling a zipper, and grading varies in line size (U.S. Department of Agriculture, 2023). Although, customers did not mind a little catface and zipper, as shown in the right figure.

Marketable tomatoes had a 90% red color with similar varietal characteristics like fairly smooth (FS), well developed (WD) to clean (C) (U.S. Department of Agriculture, 2023). When all harvest and sales were complete, the total marketable tomatoes were summed into a bar graph using Minitab software. The graphs show the hybrid ‘Medusa’ consistently in having the most marketable tomatoes for both years. However, there was no significant difference in which was more marketable, but if a grower needs a marketable variety, the hybrid ‘Medusa’ could be a good choice.

Figure 4.15. (Left) Shows unmarketable tomatoes. (Right) Shows marketable tomatoes.

Squash Shelf-life Grading

After weighing all squash harvests for 2021, a shelf-life storage trial started on October 27, 2021, and ended on March 3, 2022, a 19-week observation. Research for the 2022 storage trial was attempted but not completed due to needing more butternut squash, and by the second week of the trial, some squash was taken by an unknown individual. The results and discussion section shows a time series graph for 2021. The shelf-life trial process were three treatments with three replications for each cultivar, 'Neck Pumpkin', 'Avalon', and 'Waltham'. Weekly observations were noted for each squash's physical appearance and condition to designate a proper grading.

The USDA grades and standards were used to determine the physical condition of the squash but were not rated as No.1 and No. 2. This is because the standard grading was strict for markable squash, and we did not intend to sell the squash. In this case, I developed a rating scale from 1 to 5, one being the most damaged rating and five being in good condition, as shown in the figures below. If the squash were marketable, the Number 5 rating would be rated No.1. USDA standard (Figure. 4.16). It is rated a No.1 because they are free from decay, cuts, and defects, and their size is healthy and uniform (U.S. Department of Agriculture, 2005). The number 4 rating would be a No.2 (Figure. 4.17) because it is free from decay, cuts, and defects and should not interrupt the appearance of grading (U.S. Department of Agriculture, 2005). Any number after four is not considered marketable because it shows signs of decaying, the squash's size shrinks, and skin damage begins to break down (Figures 4.18 and 4.19). Fusarium Rot, Rhizopus Rot, and Black Rot were common molds seen on the squash, which correlates with the USDA grading standards (U.S. Department of Agriculture, 2005).

Figure 4.16. 5 Rating: Smooth skin, Hard flesh, Heavy in weight, Perfect color, Uniformity

Figure 4.17. 4 Rating: Signs of shrivels, Getting Lighter in weight, small scabs

Figure 4.18. 3-2 Rating: Light in weight, signs of soft skin wrinkles, Flesh is slowly degrading, Mold Spotting.

Figure 4.19. 1 Rating: Leaking from the skin, loss of weight, mold spotting is soft, skin is soft, Squash is thrown away.

Squash Sugar content

As the shelf-life grading continued, the sugar content was also measured randomly from the lab room or the treatment, depending on the squash condition or the amount left. The final weight is recorded, even if the cultivar came from the treatment. Lastly, the squash is sliced and placed in the freezer overnight. The cut pieces are taken out the following day to thaw, and the sugar content is ready to be taken at noon. Sugar content is gathered using a white cloth, and the squash juices are squeezed out onto an analytical Brix refractometer and an analog Brix refractometer to record sugar content.

Figure 4.20. Thawed sliced squash ready for analysis.

Figure 4.21. (Left) Digital Brix Refractometer. (Right) Analog Brix Refractometer.

Three Sisters Demonstration

We planted a Three-Sisters demonstration around the research plot, but we did not analyze it for research. The Chinle Public Health Services donated the ‘Navajo’ and ‘Pima’ Blue corn seeds. The gourd seeds were donated from a local grower in Wamego, KS, and the ‘Kentucky Blue’ pole bean came from the Harris Seeds company. My Navajo (Diné) teachings come from my grandparents and parents, and we continue these teachings to this day. Before every planting, a prayer is said with a corn pollen offering to our deities, and we ask for plentiful rain, a good growing season, and a good harvest to feed our family. To achieve these prayers, we must do our part and respect our crops every time we step in our garden because I was taught our crops can listen, smell, and talk through physical appearance. That is why we must dress appropriately for the garden, disregard any negative thoughts, and always be mindful that we must continue this teaching because it is a place of healing and learning.

At the end of the demonstration, we had plentiful gourds that were later used in student workshops on building birdhouses or a painting décor. A moderate amount of corn was harvested and taken home for consumption after sharing with the raccoons! The corn tassels were very useful for me as I could gather corn pollen to continue my offerings in the future. The demonstration and the research plot healed me by creating my own space to teach and showed me why tribal teachings should continue even if you’re far from your homelands.

Figure 4.22. (Left) Corn-pollen Harvest. (Right) Student farm garden tour.

Figure 4.23. (Left) Garden workshop discussing squash bug management. (Right) Pitcher gourd workshop to build bird houses.

Chapter 5 - Results

Tomatoes

Every tomato harvested from one plant is weighed in pounds using a lab scale and then imported categorically into an Excel spreadsheet to make bar graphs. Data from Excel was imported to Minitab software for statistical data analysis by comparing *p-values* for yield differences about mulch application by summing the total harvest weight of each plant. Figure 5.1 and Figure 5.2 are bar graphs expressing both cultivars' total weight yield and how it performed under a control, plastic, and straw mulch. Next, it shows the yield count for both cultivars to show accuracy with the total weight per plant. There was no significant difference in yield by cultivar or mulch treatment. The graph shows both 'Cherokee Purple' and 'Medusa' performed fairly well under plastic and straw mulch for both years.

Plastic mulch for 'Medusa' was consistent with a total yield of 12.6 lbs. for 2021 and 14.8 lbs. for 2022 per plant. Plastic mulch for 'Cherokee Purple' was almost as consistent, with a total yield of 12.0 lbs. for 2021 and 13.4 lbs. for 2022. Straw mulch for 'Medusa' was virtually compatible with 12.6 lbs. for 2021 and 13.0 lbs. for 2022. Straw mulch for 'Cherokee Purple' has slightly different yields of 13.4 lbs. for 2021 and 9.8 lbs. for 2022. Mulch differences could be due to the amount of mulch applied to the treatment or the plants dying. When viewing data just between cultivars, then there were no differences. The control data consistently showed no significant differences for both years, with 9.6 lbs. for 'Medusa' and 10.6 lbs. for 'Cherokee Purple' in 2021. In 2022, control data was 11.6 lbs. for 'Medusa' and 13.4 lbs. for 'Cherokee Purple'.

The yield count data for 2021 is shown in Figure 5.3 and shows the consistency of yield count of both cultivars in the plastic and straw staying in the 60 range and the control staying in the 50 range. Yield count data for 2022 is shown in 5.4 and shows higher yield compared to 2021 due to more harvest dates. Yield count for both cultivars in plastic stay in the range from 90 to100, however the straw count ranged from 78 to 87. The control for both cultivars was slightly higher but showed no real differences as the yield count was 80 to 99.

The data is not statistically significant if the *p-value* is greater than 0.05. Table 5.1 shows the lack of statistically significant differences between Cultivar and Mulch for 2021, with *the p-value* being 0.700, and in Table 5.2 *p-value* of Cultivar versus Mulch for 2022 being 0.216. Based on the determined p-value for both years, there was no significant difference between the cultivar and its performance with mulch. If looking specifically at cultivar performance, there was a borderline *p-value* difference for 2021 being 0.070, and no significant difference for 2022 *p-value* being 0.389. Table 5.2 and Table 5.4 is a Tukey table that shows the mean difference in both cultivars with mulch and just cultivars. According to the Tukey definition, “Means that do not share a letter are significantly different.” In both tables, ‘Cherokee Purple’ and ‘Medusa’ share the same letters, indicating no significant difference.

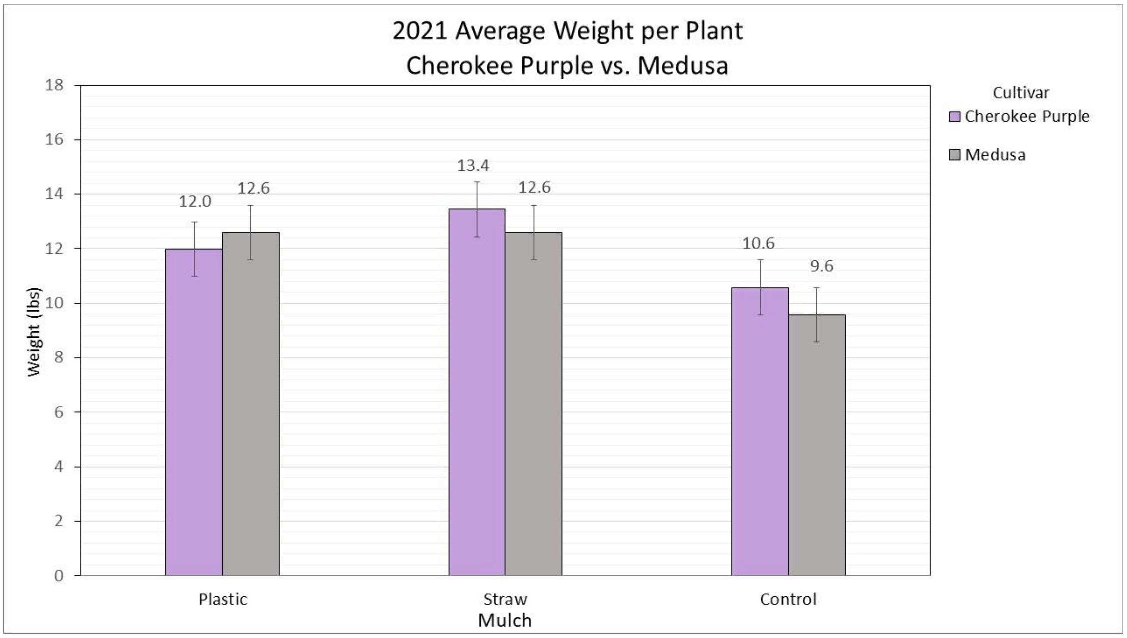

Figure 5.1. 2021 Average Weight per Plant

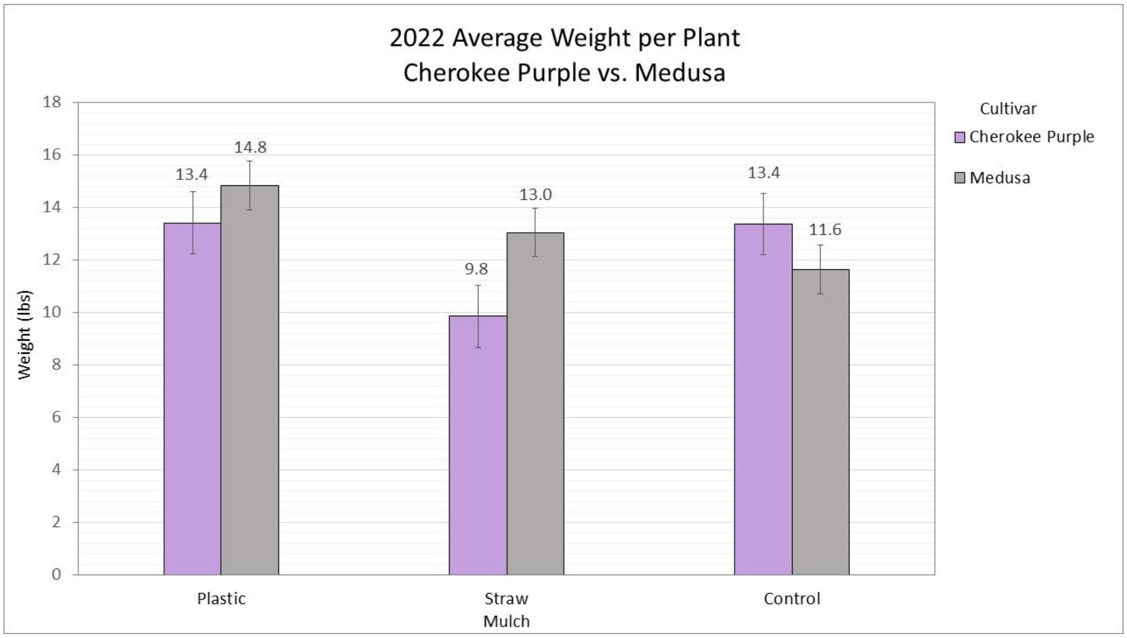

Figure 5.2. 2022 Average Weight per Plant

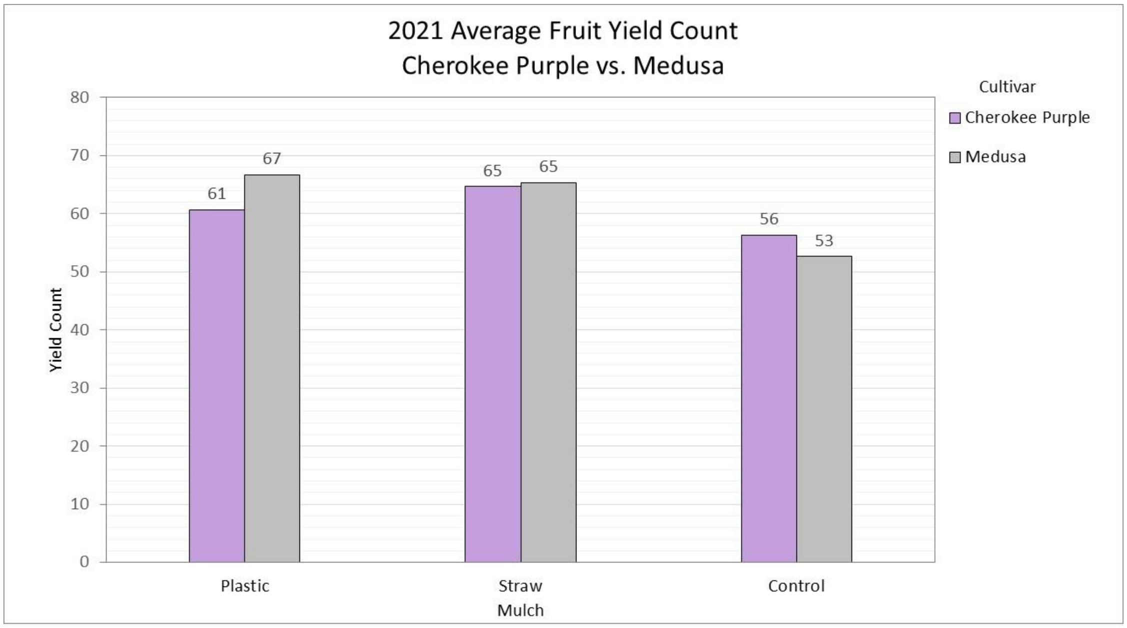

Figure 5.3. 2021 Average fruit yield count

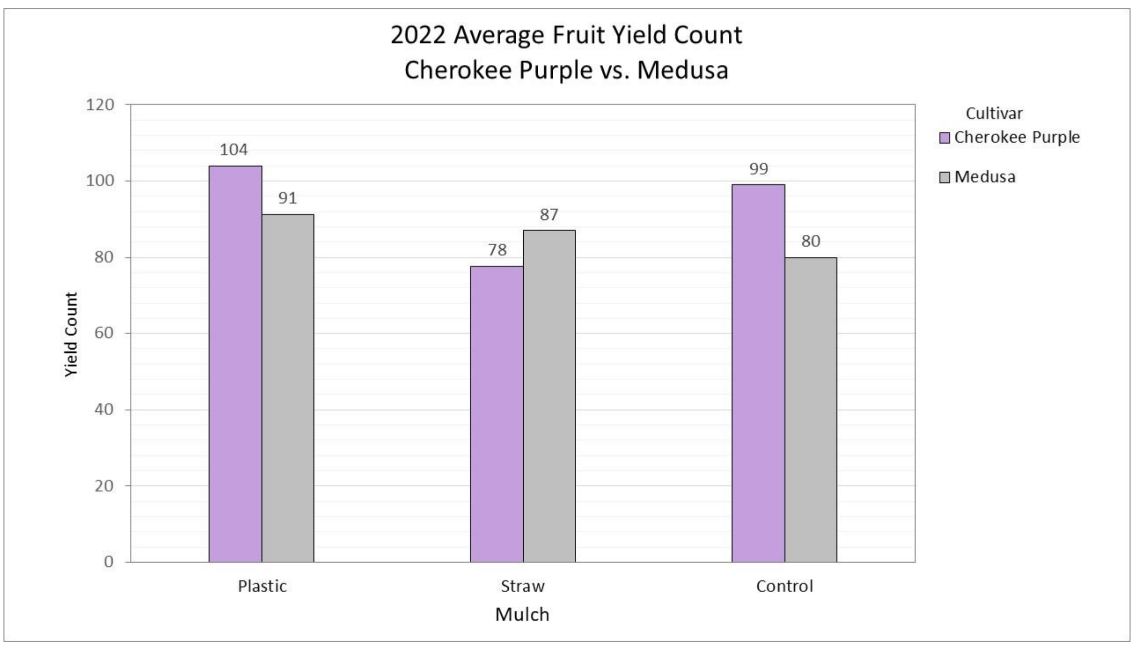

Figure 5.4. 2022 Average fruit yield count

Table 5.1. 2021 Statistical Analysis

2021 Statistical Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Cultivar	1	0.297	0.2966	0.21	0.649
Mulch	2	7.652	3.8261	2.67	0.070
Cultivar vs. Mulch	2	1.020	0.5099	0.36	0.700
Error	570	815.599	1.4309		
Total	575	824.568			
2021 Coefficients					
Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	1.1039	0.0498	22.15	0.000	
Cultivar					
CP	0.0227	0.0498	0.46	0.649	1.00
Mulch					
Control	-0.157	0.0705	-2.23	0.026	1.33
Plastic	0.0406	0.0705	0.58	0.564	1.33
Cultivar*Mulch					
CP Control	0.0406	0.0705	0.58	0.564	1.33
CP Plastic	-0.058	0.0705	-0.82	0.411	1.33

Table 5.2. 2021 Tukey table

2021 Grouping Information Using the Tukey Method and 95% Confidence			
Cultivar*Mulch	**N**	**Mean**	**Grouping**
CP Straw	96	1.26026	A
MU Straw	96	1.18023	A
MU Plastic	96	1.17977	A
CP Plastic	96	1.10923	A
CP Control	96	1.01017	A
MU Control	96	0.8835	A
2021 Cultivar Grouping Information Using the Tukey Method and 95% Confidence			
Cultivar	**N**	**Mean**	**Grouping**
Cherokee Purple	288	1.12656	A
Medusa	288	1.08117	A

Table 5.3. 2022 Statistical analysis followed by Tukey Method

2022 Statistical Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Cultivar	1	0.28	0.2821	0.19	0.664
Mulch	2	2.83	1.4126	0.95	0.389
Cultivar vs. Mulch	2	4.59	2.296	1.54	0.216
Error	714	1066.40	1.4936		
Total	719	1074.10			
2022 Coefficients					
Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	0.9313	0.0455	20.45	0.000	
Cultivar					
CP	-0.0198	0.0455	-0.43	0.664	1.00
Mulch					
Control	0.0066	0.0644	0.10	0.918	1.33
Plastic	0.0732	0.0644	1.14	0.256	1.33
Cultivar*Mulch					
CP Control	0.0862	0.0644	1.34	0.181	1.33
CP Plastic	0.0202	0.0644	0.31	0.754	1.33

Table 5.4. 2022 Tukey Method

2022 Grouping Information Using the Tukey Method and 95% Confidence			
Cultivar*Mulch	**N**	**Mean**	**Grouping**
CP Plastic	120	1.00486	A
CP Control	120	1.00431	A
MU Plastic	120	1.00415	A
MU Straw	120	0.97761	A
MU Control	120	0.87157	A
CP Straw	120	0.72539	A
2022 Cultivar Grouping Information Using the Tukey Method and 95% Confidence			
Cultivar	**N**	**Mean**	**Grouping**
Medusa	360	0.951108	A
Cherokee Purple	360	0.911521	A

Marketable Yield

Figure 5.5 shows a bar graph of the Total grading sum for 2021 and 2022, with the hybrid ‘Medusa’ consistently having the most marketable tomatoes for both years. For 2021 ‘Cherokee Purple’ had a marketable yield count of 283 counts, and 310 counts for ‘Medusa’. For 2022, ‘Cherokee Purple’ had a grading count of 175, and 199 counts for ‘Medusa’. When observing the graph, a grower can decide with the hybrid ‘Medusa’ if it would be the choice for market sales.

Figure 5.5. 2021 and 2022 total marketable sum.

Peppers

Every pepper harvested from one plant was weighed in pounds using a lab scale and then imported categorically into an Excel spreadsheet. Data from Excel was imported to Minitab software for data analysis to compare yield differences by getting the mean of the total weight of each plant. Figure 5.6 shows a bar chart of the summer 2021 and 2022 total weight per plant. In 2021, the average weight per plant for both cultivars was 5 lbs. with 'Anaheim-118' being 5.2 lbs. and 'Charger' being 5.3 lbs. For 2022, both cultivars' average weight per plant was in the 4 lb. range with 'Anaheim-118' being 4.3 lbs. and 'Charger' 4.8 lbs. The yield count graph determines which cultivar performed better; with the results presented, there was no significant yield count difference between each cultivar. 'Anaheim-118' average yield per plant is 36, and 'Charger' has 32 for 2021, and for 2022, 'Anaheim-118' has 44, and 'Charger' yielded 42.

We observe the yield performance between each cultivar for the pepper results and not yearly differences. The table below is a Statistical General Linear Model of the "Average Weight per Yield" that expresses the relationship between the two cultivars; more specifically, the *p-value* is determined. The *p-value* for 2021 is 0.903, showing no significant difference between each cultivar. The same goes for 2022, with the *p-value* being 0.195. Table 5.6 and Table 5.8 is a Tukey table that shows the mean difference between the cultivars. According to the Tukey definition, "Means that do not share a letter are significantly different." 'Anaheim-118 and 'Charger' both share letters, indicating they are not significantly different.

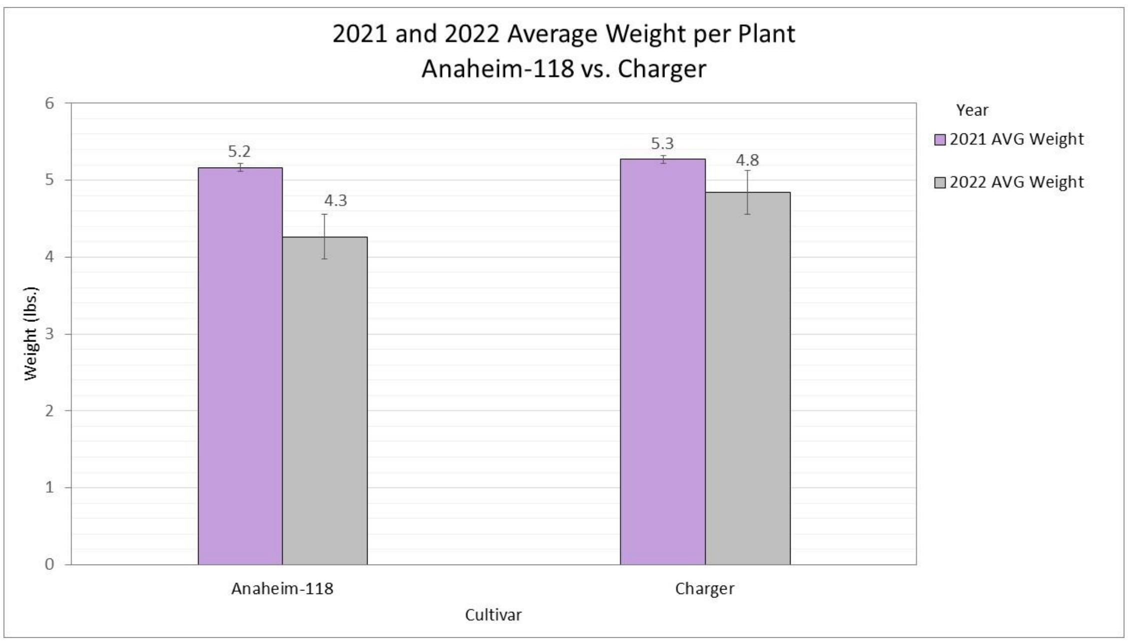

Figure 5.6. 2021 and 2022 Average weight per plant

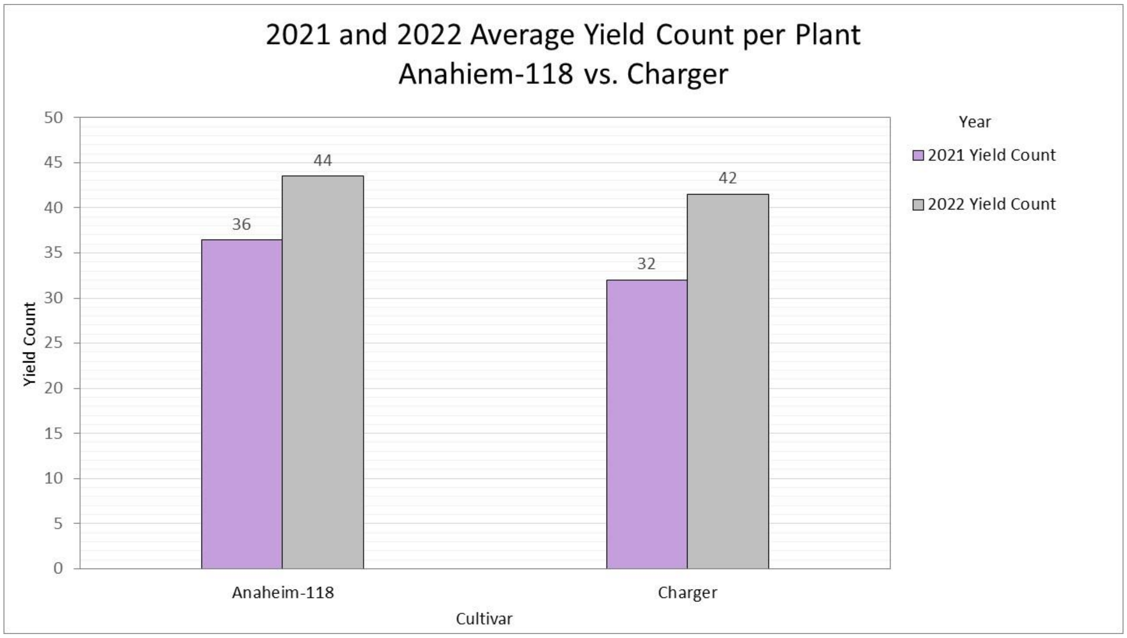

Figure 5.7. 2021 and 2022 average yield count.

Table 5.5. 2021 Statistical analysis.

2021 Statistical Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Cultivar	1	0.017	0.01715	0.01	0.903
Error	94	107.805	1.14686		
Total	95	107.822			
2021 Coefficients					
Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	1.304	0.109	11.93	0.000	
Cultivar					
Anaheim-118	-0.013	0.109	-0.12	0.903	1.00

Table 5.6 2021 Tukey table

2021 Grouping Information Using the Tukey Method and 95% Confidence			
Cultivar	**N**	**Mean**	**Grouping**
Charger	48	1.31745	A
Anaheim-118	48	1.29071	A

Table 5.7. 2022 Statistical analysis.

2022 Statistical Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Cultivar	1	0.8714	0.8714	1.69	0.195
Error	166	85.5309	0.5152		
Total	167	86.4022			
2022 Coefficients					
Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	0.6300	0.0554	11.38	0.000	
Cultivar					
Anaheim-118	-0.0720	0.0554	-1.30	0.195	1.00

Table 5.8. 2022 Tukey table

2022 Grouping Information Using the Tukey Method and 95% Confidence			
Cultivar	**N**	**Mean**	**Grouping**
Charger	84	0.701978	A
Anaheim-118	84	0.557939	A

Squash Yield Data

Every squash harvested was weighed in pounds using a lab scale and imported categorically into an Excel spreadsheet. Data from Excel was imported to Minitab software for data analysis to compare yield differences between each cultivar. The sum of the eight replications of all harvests included was used to determine the total yield for 2021, and the four replications yield for 2022. The number of replications for both years is different, and this is shown when comparing yield data for the bar graph below. When comparing cultivar performance to minimal watering, the heirloom' Neck Pumpkin' showed highly statistically significant better yields than the 'Avalon' hybrid and 'Waltham' open-pollinated cultivar.

Figure 5.8 the heirloom' Neck Pumpkin' showed yield differences by yielding 375.9 lbs. for 2021's eight replications average combined and 169.2 lbs. for 2022's four replications. ‘Avalon’ showed yield differences by weighing 171.9 lbs. in 2021 and 61.3 lbs. in 2022. 'Waltham' was consistent in yield for both years. 'Waltham' showed no significant difference for both years, having been 70.1 lbs. in 2021 and 84.0 lbs. in 2022. Since the replications were split in half by the second year, the yield data replicates less yield for all cultivars in 2022, except for ‘Waltham’. Regarding the consistency of yield for both open-pollinated varieties, if the grower is looking for the maximum yield of product, then the 'Neck Pumpkin' would be beneficial, but if they want good yields of a more familiar vegetable, then 'Waltham' is suitable.

Table 5.9 and 5.11 shows the General Linear Model expressing statistical differences between each cultivar's weight. The Cultivar *p-value* for 2021 is less than 0.01, making a significant difference between yields. *P-values* for 2022 were also less than 0.01, indicating a significant difference in yield. When observing 2021's count and weight graphs, the heirloom 'Neck Pumpkin' produced 136 squashes, weighing close to 400 lbs., twice as much as 'Avalon' and 'Waltham'. However, for 2022, 'Waltham' produced more yield count, but the 'Neck Pumpkin' still has twice as much weight as 'Waltham' and 'Avalon'. From observations, 'Neck Pumpkin' was large, and 'Waltham' was small, indicating that more edible flesh will come from 'Neck Pumpkin'. Table 5.10 and 5.12 showed Tukey tables showing the mean difference the cultivars share, and according to the Tukey definition, "Means that do not share a letter are significantly different." For 2021 and 2022, 'Waltham' and 'Avalon' share the same letter and leaving 'Neck Pumpkin' without therefore indicating a significant difference.

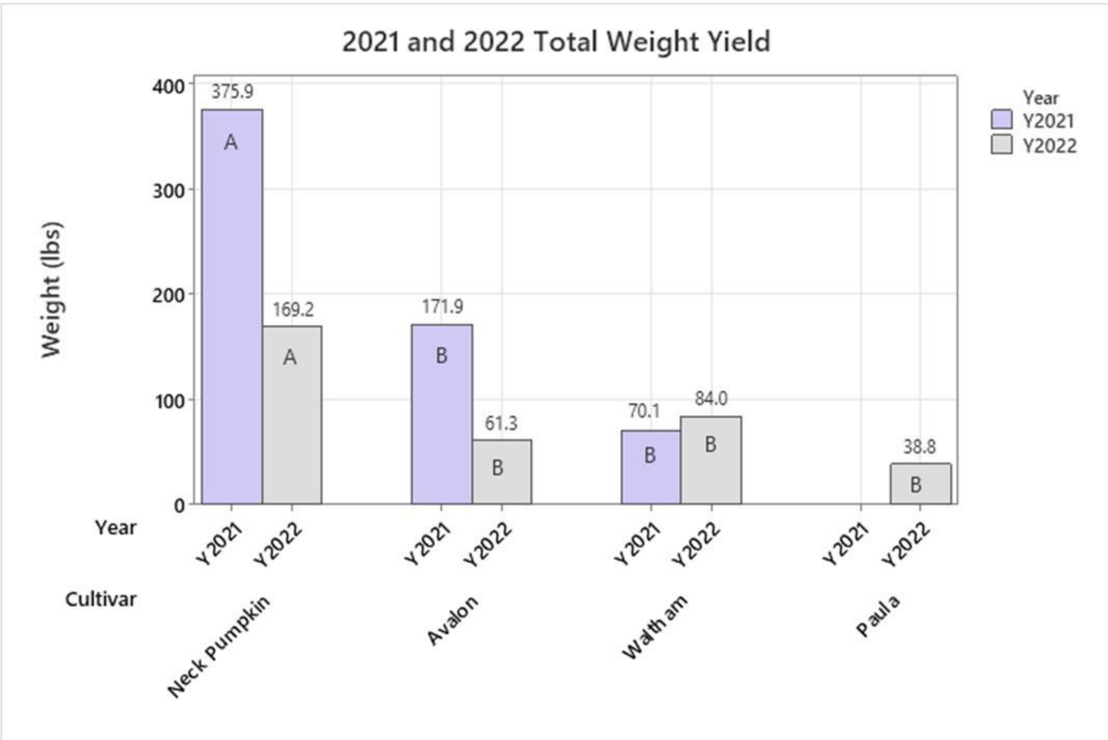

Figure 5.8. 2021 and 2022 bar graph total yield per year

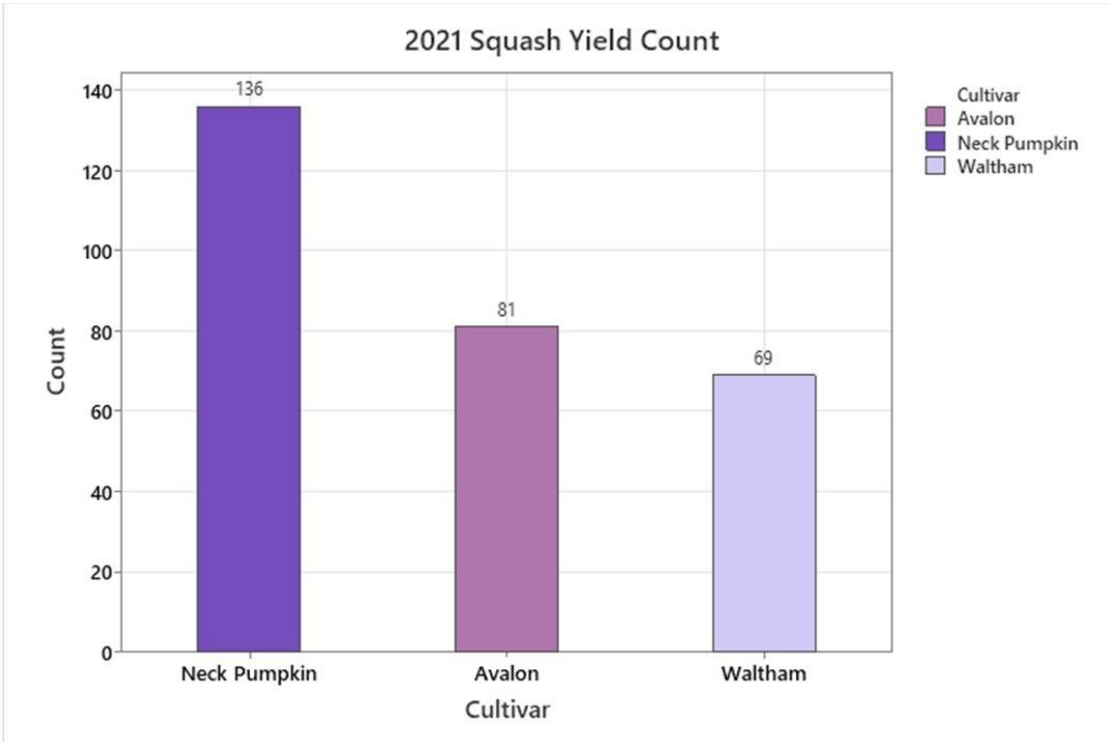

Figure 5.9. 2021 bar chart of yield count bar graph

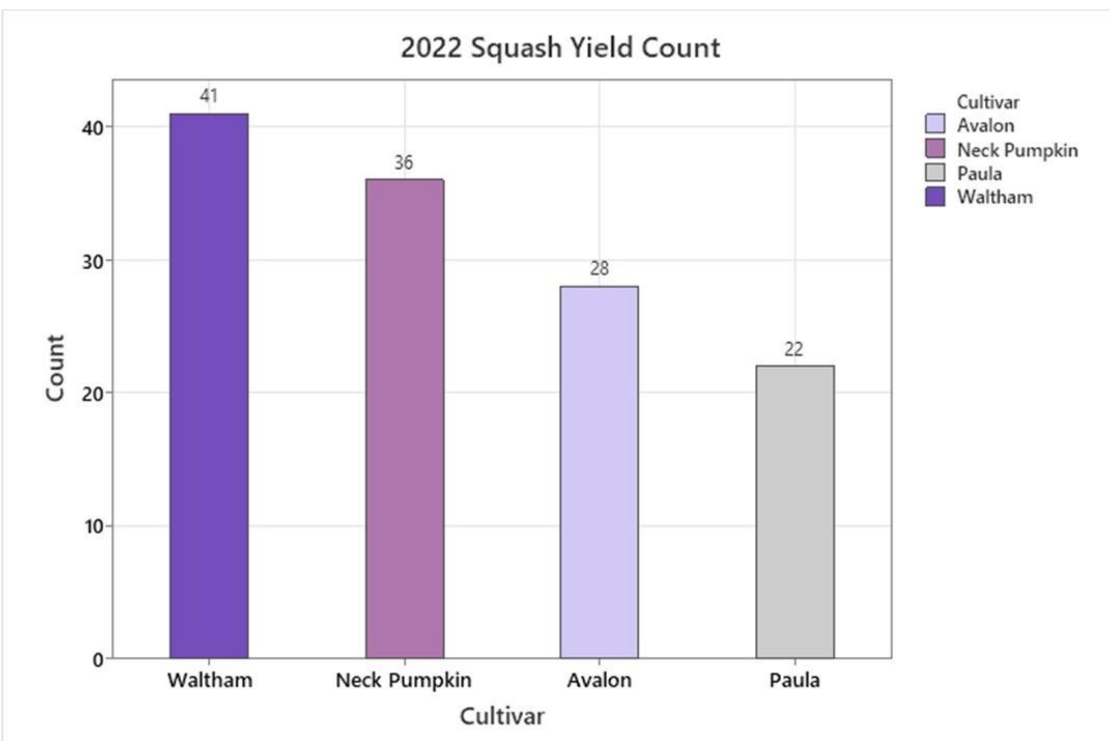

Figure 5.10. 2022 bar chart of yield count bar graph

Table 5.9. 2021 Statistical analysis.

2021 Squash Statistical Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Cultivar	2	633.5	316.753	69.62	0.000
Error	135	614.2	4.549		
Total	137	1247.7			
2021 Coefficients					
Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	4.246	0.192	22.07	0.000	
Cultivar					
Avalon	-1.333	0.250	-5.32	0.000	1.08
Neck Pumpkin	2.983	0.257	11.59	0.000	1.08

Table 5.10. 2021 Tukey table.

2021 Grouping Information Using the Tukey Method and 95% Confidence				
Cultivar	**N**	**Mean**	**Grouping**	
Neck Pumpkin	52	7.22849	A	
Avalon	59	2.9132		B
Waltham	27	2.59582		B

Table 5.11 2022 Statistical analysis.

2022 Squash Statistical Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Cultivar	3	214.3	71.435	49.16	0.000
Error	120	174.4	1.453		
Total	123	388.7			
2022 Coefficients					
Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	2.756	0.111	24.84	0.000	
Cultivar					
Avalon	-0.569	0.196	-2.91	0.004	1.76
Neck Pumpkin	2.219	0.184	12.09	0.000	1.71
Paula	-0.994	0.213	-4.67	0.000	1.85

Table 5.12. 2022 Tukey table.

2022 Grouping Information Using the Tukey Method and 95% Confidence				
Cultivar	**N**	**Mean**	**Grouping**	
Neck Pumpkin	34	4.975	A	
Avalon	28	2.1875		B
Waltham	40	2.10081		B
Paula	22	1.76222		B

Squash Vine Length

The vine length was recorded as the distance from the harvested squash to its hill of origin, and analyzed following each squash harvest using the Minitab software. The calculated medians created an interval plot to understand vine length and which row produced the most fruit yield. ‘Neck Pumpkin’ had the highest median vine length for 2021 and 2022, ranging from 6ft to 8ft. ‘Neck Pumpkin’ also produced the highest weight yield, with eight replications in 2021 and four replications in 2022.

However, when looking at which cultivar grew the longest vine, you will see a slightly substantial difference in 2021 Cultivars' *p-value* being 0.043. More specifically, the difference with the 'Neck Pumpkin' *p-value* being 0.013, indicating it had the longest vine between the two cultivars. For 2022 data, 'Neck Pumpkin' significantly differed in vine length than cultivars 'Paula' and 'Avalon'. The p-*value* for 'Neck Pumpkin' was 0.002, 'Avalon' *p-value* was 0.033, and 'Paula's *p-value* was 0.070. In 2022, both rows were planted in a linear, no circular configuration. Table 5.14 and Table 5.16 are Tukey table that shows the mean length difference the cultivars share. According to the Tukey definition, "Means that do not share a letter are significantly different." For 2021, all cultivars share the same letter, indicating no significant difference in length. For 2022, 'Neck Pumpkin' and 'Waltham' share the same letter, while 'Waltham', 'Avalon', and 'Paula' with the same letter. This shows 'Neck Pumpkin' being significantly different in vine length and 'Waltham' intermediate and not significantly different than either group.

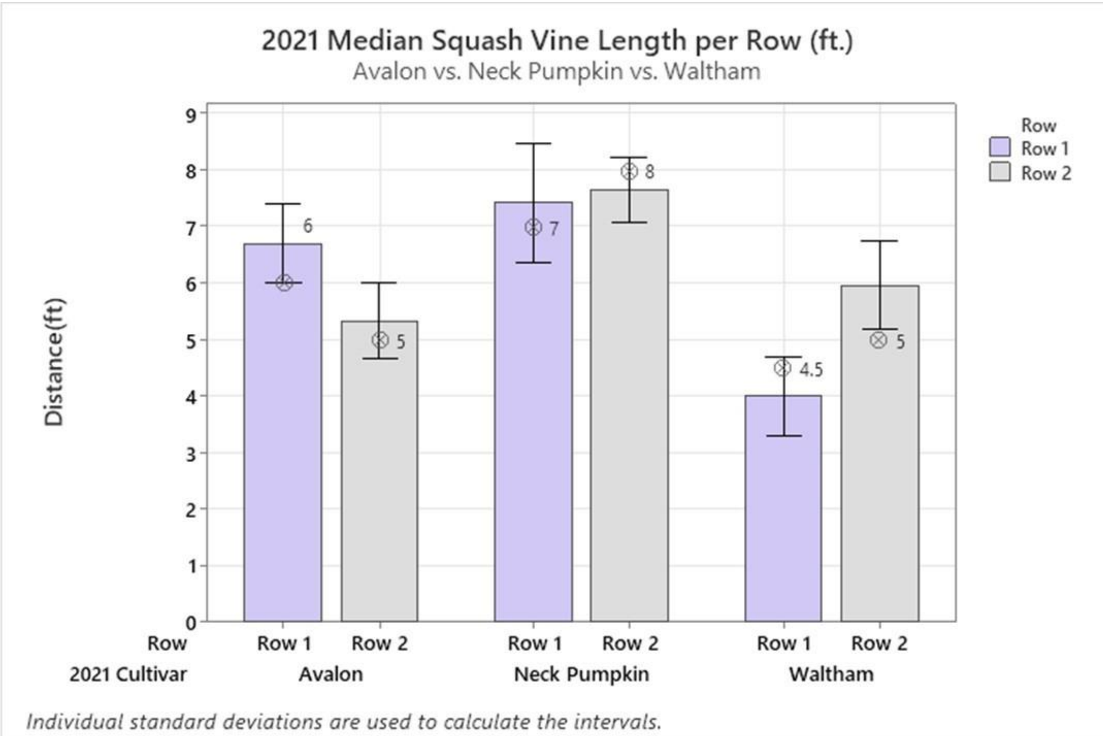

Figure 5.11. 2021 average squash vine length.

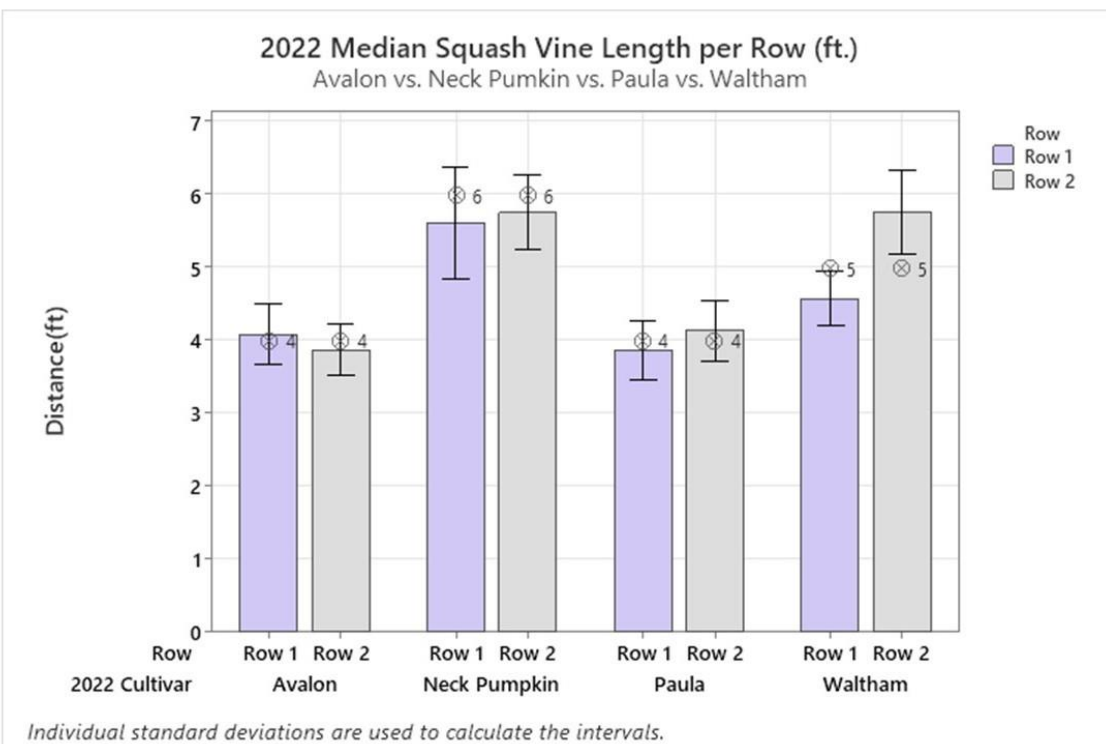

Figure 5.12. 2022 Squash average vine length.

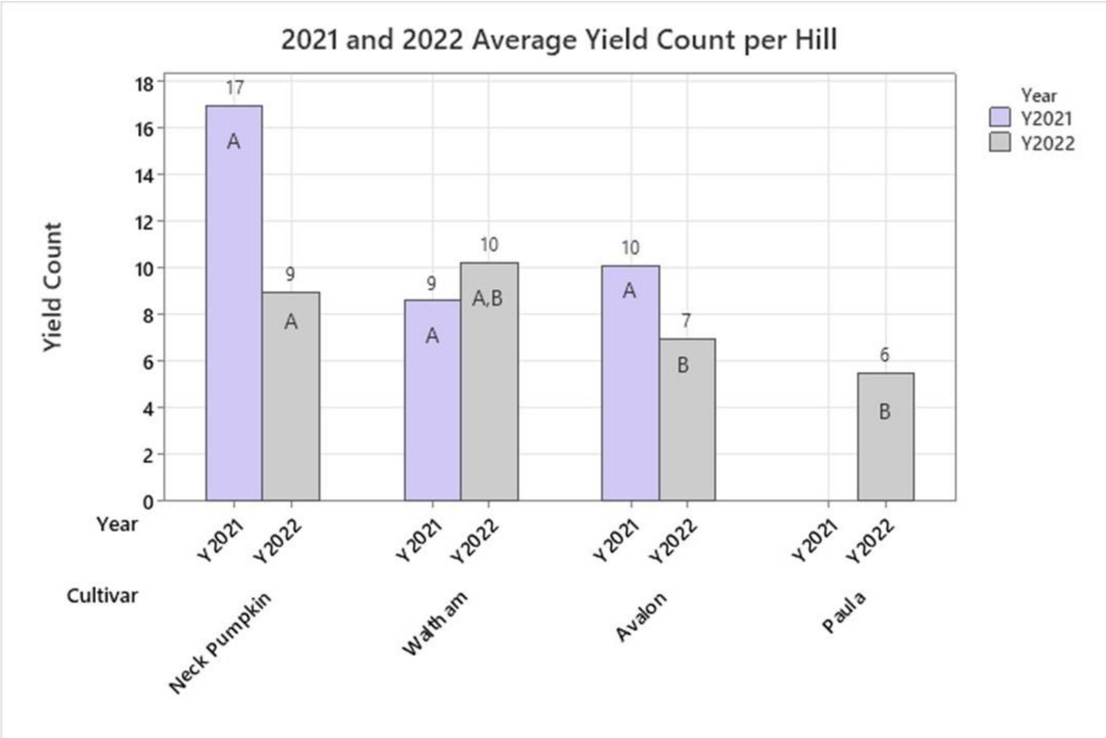

Figure 5.13. 2021 and 2022 average yield count per hill.

Table 5.13. 2021 Squash length statistical analysis.

2021 Length Statistical Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
2021 Cultivar	2	88.01	44.007	3.25	0.043
Row	1	1.24	1.236	0.09	0.763
2021 Cultivar*Row	2	26.31	13.153	0.97	0.382
Error	109	1476.83	13.549		
Total	114	1574.17			
2021 Coefficients					
Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	6.178	0.443	13.94	0.000	
2021 Cultivar					
Avalon	-0.159	0.603	-0.26	0.792	1.67
Neck Pumpkin	1.359	0.535	2.54	0.013	1.56
Row					
Row 1	-0.134	0.443	-0.30	0.763	1.65
2021 Cultivar*Row					
Avalon Row 1	0.819	0.603	1.36	0.177	1.37
Neck Pumpkin Row 1	0.025	0.535	0.05	0.962	1.66

Table 5.14. 2021 Squash Vine length Tukey table.

2021 Cultivar Length Grouping Information Using the Tukey Method and 95% Confidence			
2021 Cultivar	**N**	**Mean**	**Grouping**
Neck Pumpkin	52	7.53687	A
Avalon	36	6.01852	A
Waltham	27	4.97826	A

Table 5.15 2022 Squash length statistical analysis.

2022 Length Statistical Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
2022 Cultivar	3	62.724	20.908	4.94	0.003
Row	1	3.427	3.427	0.81	0.370
2022 Cultivar*Row	3	9.380	3.127	0.74	0.531
Error	118	499.490	4.233		
Total	125	578.825			
2022 Coefficients					
Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	4.701	0.194	24.27	0.000	
2022 Cultivar					
Avalon	-0.729	0.337	-2.16	0.033	1.81
Neck Pumpkin	0.974	0.315	3.09	0.002	1.78
Paula	-0.705	0.385	-1.83	0.070	2.11
Row					
Row 1	-0.174	0.194	-0.90	0.370	1.10
2022 Cultivar*Row					
Avalon Row 1	0.279	0.337	0.83	0.409	1.85
Neck Pumpkin Row 1	0.099	0.315	0.32	0.753	1.78
Paula Row 1	0.036	0.385	0.09	0.925	2.19

Table 5.16. 2022 Squash Vine length Tukey table.

2022 Cultivar Length Grouping Information Using the Tukey Method and 95% Confidence				
2022 Cultivar	**N**	**Mean**	**Grouping**	
Neck Pumpkin	35	5.675	A	
Waltham	41	5.16071	A	B
Paula	22	3.99524		B
Avalon	28	3.97179		B

Squash Shelf-life Data

The 5-month storage trial was categorized using Excel and analyzed using Minitab software—Figure 5.14 shows the 19-week grading period for the three cultivars' condition and appearance. Figure 5.15 shows the time series plot where you start seeing a steep decline in quality. It is important to note that all three storage treatments were graded together and averaged the rating of each cultivar. Julian dates were used because 'Minitab assigns the column a text or numeric data type', and with my data, I wanted my columns to be numeric (Date/Time Formats That Minitab Recognizes, 2021) to show the exact observation date. Focusing on Figure 5.14, the heirloom cultivar Neck Pumpkin and hybrid Avalon had consistent grades of 5 and 4 until week 11. From Week 2 to Week 11, the average squash grading for both cultivars included having a hard flesh, uniform shape, and heavyweight. Focusing into Figure 5.15 by week 13, 'Neck Pumpkin' and 'Avalon' showed a decline in appearance and condition by rating roughly a four. The 4 rating is spotting shrivels, losing weight, and spotting scabs, but still considered edible. By week 11 the cultivar 'Waltham' drastically declined from a four at week 7 to a 1 rating by week 14, meaning most Waltham's did not make the 19-week shelf-life period.

To summarize the time series plot, the hybrid 'Avalon' and heirloom 'Neck Pumpkin' had a good shelf-life. A critical observation from 'Neck Pumpkin' when rated as a 3 is that some parts of the neck still had edible flesh to consumed before discarding them altogether.

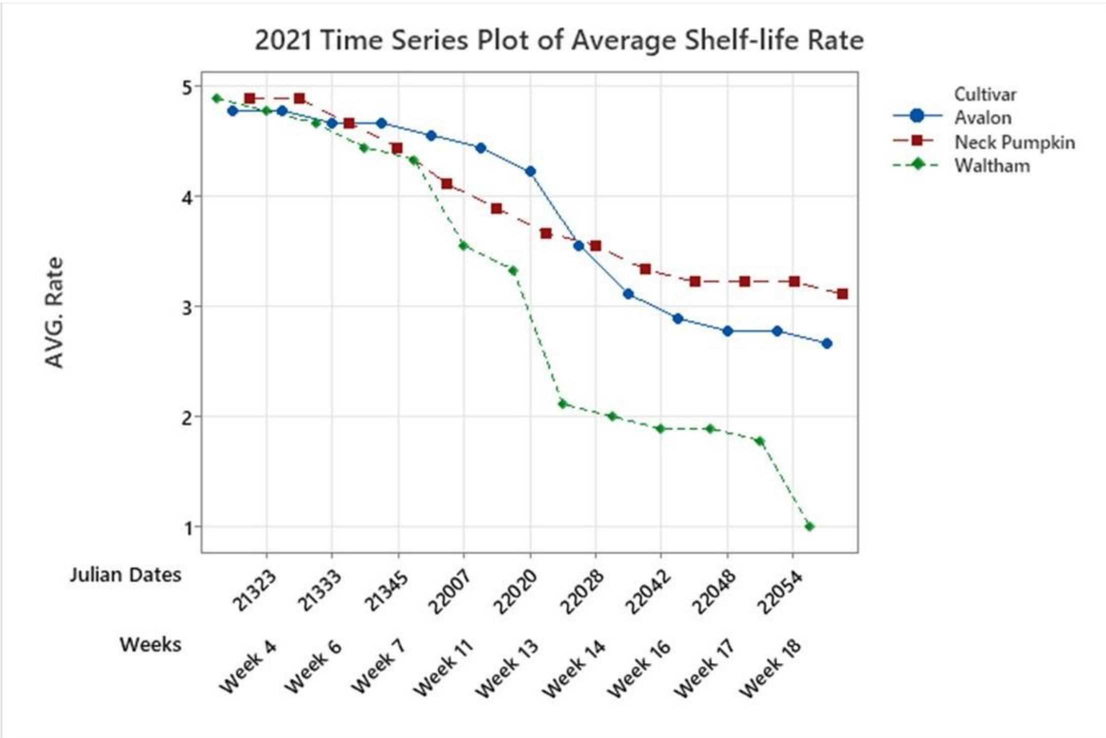

Figure 5.14. 19-week observation.

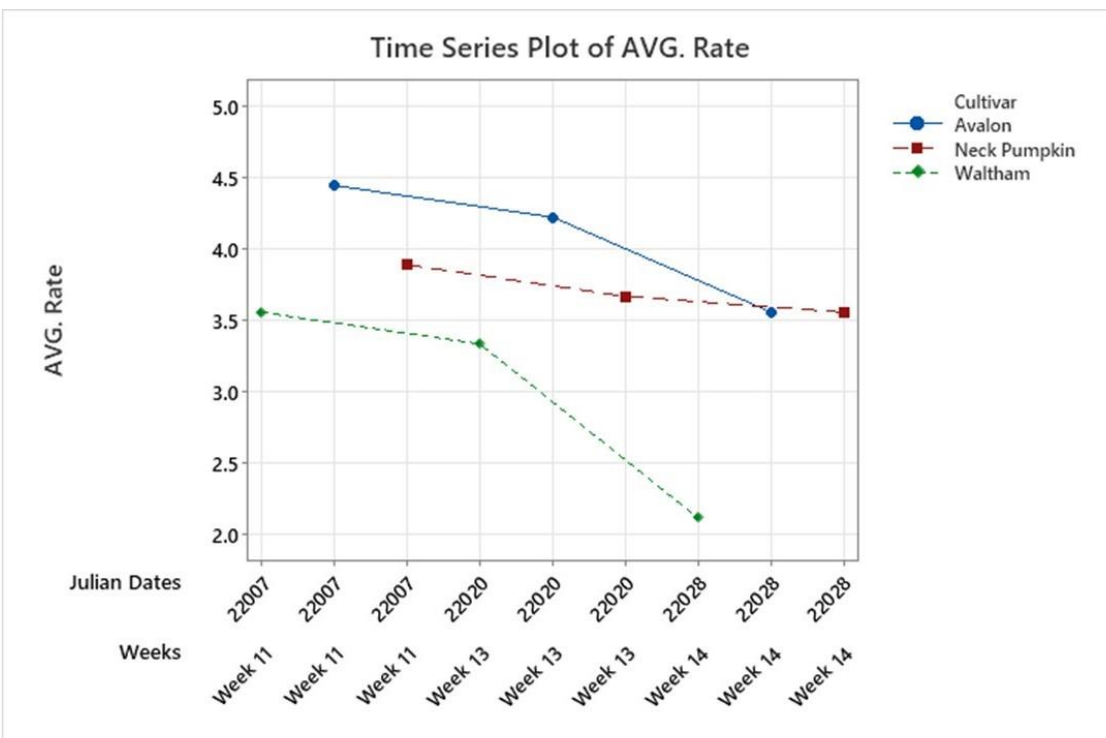

Figure 5.15. A three-week observation.

Brix Data Results

Four brix readings were recorded starting in October, December, January, and March. Months were not used as a time series graph. The total sum brix reading determined which cultivar had the most sugar content and nutritional flesh. Figure 5.16 shows the OP ‘Waltham’ having the highest sugar content and the hybrid ‘Avalon’ and OP ‘Neck Pumpkin’ following after Table 5.17 show the Statistical Analysis below shows a *p-value* of 0.072, suggesting no significant difference. Table 5.18 is a Tukey Table showing the mean difference the cultivars share, and according to the Tukey definition, “Means that do not share a letter are significantly different.” All cultivars share the same letter, indicating no significant difference in sugar content. The table and graph show that ‘Waltham’ vs. ‘Neck Pumpkin’ vs. ‘Avalon’ are not significantly different.

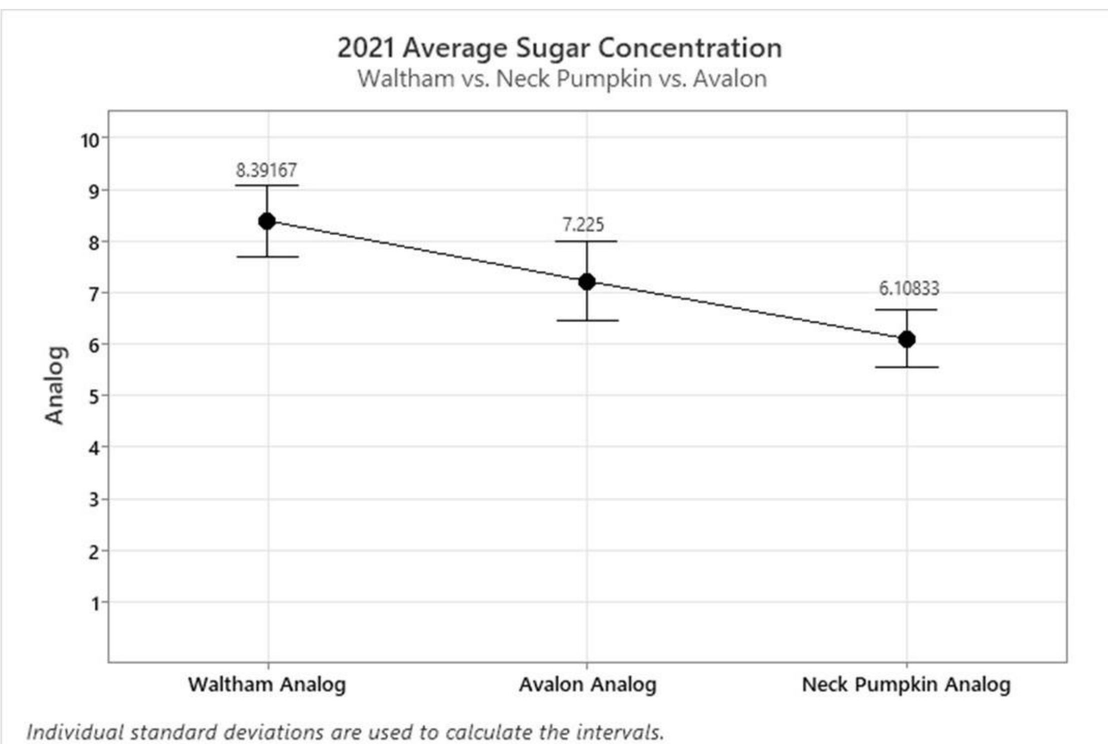

Figure 5.16. 2021 Average brix reading.

Table 5.17. 2021 Brix statistical analysis.

2021 Brix Statistical Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Factor	2	31.29	15.643	2.86	0.072
Error	33	180.70	5.476		
Total	35	211.99			

Table 5.18. 2021 Brix Tukey table.

Grouping Information Using the Tukey Method and 95% Confidence			
Factor	**N**	**Mean**	**Grouping**
Waltham Analog	12	8.392	A
Avalon Analog	12	7.225	A
Neck Pumpkin Analog	12	6.108	A

Chapter 6 - Discussion

Tomatoes

Because there were no yield significant differences due to mulch, it may not matter if the grower uses plastic or straw. The use of any mulch will reduce labor costs for weed control, although this was not documented in this project. If the grower wants to avoid using plastic, the straw would benefit both naturally and for compost to improve soil quality. After using the straw mulch, we placed it in the compost area to break down over time, and from this, we contributed to feeding microorganisms living in the compost pile. Feeding the organisms within the soil helps aerate the soil, provide uniform moisture, and increase the breakdown of mulch materials (Bhardwaj, 2013). The year plays a role in differences due to yearly rainfall, but so does the thickness of mulch application, as discussed in other research and literature (O'Connell et al., 2012; Anzalone et al., 2010). Both mulch applications helped manage weed competition; however, the thickness of the mulch for 2022 was less than in 2021, which may have influenced the yield reduction, along with the reduction in summer rain fall.

'Cherokee Purple' and 'Medusa' had similar yields when grown under black plastic mulch. Integrated irrigation methods such as drip irrigation help minimize water runoff and captures as water vapor as condensed water droplets under mulch cover (Bhardwaj, 2013). Water droplets within the plastic create efficient water access for roots to absorb. The positive outcome of plastic mulch is that it is a marketable material and a source to meet worldwide food demands (Bandopadhyay et al., 2020). Since both cultivars performed relatively equally, the straw and black plastic mulch helped secure water to the tomato roots as we watered at the base, or for the 2021 water method, the hose water directed to the roots.

Research from Galgamuwe, (2013) had similar results when they compared cultivar differences of 3 heirlooms ‘Cherokee Purple,’ ‘Abraham Lincoln,’ ‘German Giant’, and one F1hybrid ‘Jet Star.’ The hybrid had the highest yield for two years but yield was not significantly different from the ‘Cherokee Purple’ and ‘Abraham Lincoln.’ ‘Jet Star’ and ‘Cherokee Purple’ also had good marketable yields. These results are similar to this research when we look at cultivar yield without mulch and marketable yield shown in Figure 5.5. The graphs show that the hybrid ‘Medusa’ consistently had high yields of marketable tomatoes for both years. However, there was no significant difference in which was more marketable, but if a grower needs a marketable variety, the hybrid Medusa would be the choice. As stated above, despite ‘Medusa’ being marketable, the customers had no issues buying both, as ‘Medusa’ had the appearance of an heirloom. Other research concurs that ‘Cherokee Purple’ performs well in yield and marketable aspects (O’Connell et al., 2012; Francis & Stark, 2012).

Pepper

Regarding weather conditions such as drought, the hybrid variety Charger, and OP Anaheim-118 have high yields that showed no significant difference, indicating secure food access. Research in 2013 from (Galgamuwa, 2013; Galgamuwa et al., 2015) indicate Anaheim-118 yielded higher than Charger, but for my 2021 and 2022 yield data, Charger had a slightly higher yield count. Arthur et al., (2023) provided research from 2020 to 2021 on eight heirloom chili peppers evaluating plant growth, fruit yield, and fruit quality grown in containers. ‘Anaheim’ along with two heirlooms ‘Ancho or Poblano’ and ‘Big Jim’ all produced high yield weights, but when comparing quality ‘Anaheim’ with the two other cultivars, had the highest marketable yield (Arthur et al., 2023). Despite the cultivars grown in containers, the Anaheim heirloom produced a good yield. The good yield performance shows other growing techniques for peppers if seasons change or climates decline. When a grower decides what cultivar to grow, research suggests either ‘Anaheim-118’ or ‘Charger’ because both did well for both years, even with minimal watering. It also indicated adapting to their environments as 2021 mulch was applied, and 2022 had no mulch. Indeed, other cultivars are suggested for future research to observe and compare yield differences. From observations and results, ‘Anaheim-118’ and ‘Charger’ would be good candidates for marketable yields on my reservation, as hot peppers are popular. We attempted to sell the peppers, but customers from Kansas had no interest in buying hot peppers; they suggested growing bell peppers. Therefore, bell peppers are another suggestion if your customer base does not prefer to eat spicy vegetables. The peppers and tomatoes that were not marketable were given away to students and staff at the K-State Horticulture Department as well as the Manhattan Emergency Shelter, Inc.

Squash

The surprisingly heavy yield results from the heirloom ‘Neck Pumpkin’ show an avenue for food security because minimal watering and the large leaves in the ‘Neck Pumpkin’ helped shade the soil and conserved soil moisture and allow the vines to flourish. Research on winter squash yield and eating quality says, ‘once fruit begin to proliferate, vegetative growth and leaf area peaks and begins to decline with leaf senescence’ (Loy, 2014). The leaves from NP and its neighboring leaf cultivars ‘Avalon’, ‘Waltham’, and ‘Paula’ must have helped with yield because vine lengths crossed each other and helped with ground cover even when the seeds were planted at their recommended ‘Between Row’ distance of 8ft (Bachmann, 2010; Oregon State University, 2010). Other research suggests that high-density spacing of squash crops can increase leaf area, resulting in high yield, fruit quality, and weed suppression for summer and winter squash (Loy, 2004; Brown, 2016). Other research on ‘Waltham’ and ‘Avalon’ showed results of

‘Avalon’ having longer vines than ‘Waltham’; however, based on our results, it was the opposite but was not significantly different from one another (Brown, 2016). If we had changed to 8 replications for 2022, the 90x90ft plot would have high-density spacing for all four cultivars with zucchini trap crops. From my family observations in Chinle Arizona, a seedling volunteer of 'Neck Pumpkin' grew out in our front yard, and this can be a cultivar for companions because of leaf size, ground cover, and yield. The plot allowed me to provide garden tours to community members, journal writers, and growing companies.

Spoilage and shrinking are common when butternut squash is stored longer than three months (Oregon State University, 2010). Since this was common in the 2021 storage trial, cultivars like ‘Waltham’ and ‘Avalon’ had no significant difference in sugar content than 'NP.' High sugar content results when the starch within the squash is secured from breaking down (Loy, 2014). ‘Waltham’ showed signs of depleting, but the sugar contents were still high, and this can be due to the development of starch not breaking down and then generating a high sugar content. Those experiencing mold are the breakdown of starch within the squash, making it watery and less pasty (Loy, 2004). The unique observation from ‘NP’ was that it remained heavy after the storage trial ended and an especially large specimen was later used in other workshops. The workshop included me sharing pest management methods on squash bugs and discussing growing and storage observations of ‘NP’. Additional research must be done on the hybrid ‘Paula’ in terms of storage shelf-life and fruit yield.

In summary, there was no significant difference in tomato yield between types of mulch, we suggest applying it to crops to conserve soil moisture and build up soil organic matter as the mulch decomposes. A soil moisture probe is another tool suggested for future research because it can provide readings to show the relationship the mulch has when the plant is under heat stress.

It will also provide readings to identify mulch performance differences under water stress. Growing an heirloom or hybrid will depend on the grower's decision, as they may grow for yield, profit, or accessible needs. The 'Cherokee Purple' tomato and 'Neck Pumpkin' squash are better candidates for all three choices, especially if the grower aims to grow only heirlooms. Peppers were not graded enough to give marketable suggestions, but both 'Anaheim-118' and 'Charger' are good candidates for consistent yields and could be marketable in other growing systems.

Chapter 7 - Conclusion

In conclusion, food security must be adequate to achieve food sovereignty in a system. The findings from this research do not achieve food sovereignty but provide a framework for food security by using companion planting through trap crops, thus creating food diversity, and growing to educate or bring people together through research, workshops, and garden tours. The benefits include implementing cultural knowledge throughout the growing season and providing a social income opportunity by engaging with the community members. When engaging with community members, I can share background on how the cultivars are grown and why they should consider growing or buying them.

The leaf area in the squash cultivars could be helpful for ground cover in Arizona and potentially increase yield if growing techniques such as “High-density planting” are included. Squash is a popular vegetable grown back home, and using the pest management practices from this research can help reduce hatching numbers with duct tape or include trap crops for adult squash bugs. Lastly, the heirloom ‘Neck Pumpkin’ cultivar can be grown in Arizona. It is an example of food security because it provides enough yield and edible flesh. As stated above, a volunteer happily sprouted in my family’s front yard. The plastic and straw mulch on tomatoes show positive outcomes from the increase in yields compared to bare soil. We recommend those experiencing heat stress use appropriate plastic and straw mulch suitable for their cultivars. More research on the effectiveness of mulch vs. cultivars is needed by adding moisture probes to understand the physical differences between soil and cultivars. Since tomatoes and peppers experienced low watering effort and had no differences in yield, I would encourage growers in Arizona to plant the cultivars and, if not, consider using an appropriate mulch type to improve food production and soil.

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