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Adaptation of temperate crops to support local food production for Molokai

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By

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INTRODUCTION

Rationale

The island of Molokai is a small community in Hawaii that relies mainly on imported foods for the majority of residents' diets. This system is neither cost effective nor environmentally responsible. The direct costs associated with imported foods are passed on to the consumer, making the state of Hawaii's, and thus Molokai's food prices much higher than the national average. The carbon footprint associated with transporting food over thousands of miles of ocean is substantial. Some foodstuffs are perishable and require the added environmental burden of refrigeration, which utilizes harmful chemicals to maintain adequate temperatures. Others are quite heavy, making them both expensive and inefficient to ship as they require more fuel.

Food can have a negative impact on the environment even after purchasing. Spoiled food is a significant contributor to landfill waste (Buzby 2014), which is a major concern on islands like Molokai where space is a valuable resource. Many tropical fruits have a short shelf life that is further reduced due to the time required for shipping. In addition to the environmental reasons for producing more food locally, local food production has become desirable as our culture goes through a transition from wanting the cheapest products to being aware of what we consume. This transition has seen the rise of many food trends, including the organic, heirloom, gluten free, specialty, and food sovereignty movements. For rural communities, locally grown foods can help assuage concerns about the freshness of food, the chemicals used in preservation, and the fossil fuels associated with transport.

Another issue with Molokai's heavy reliance on imported foods is that the entire island could be rendered helpless in the wake of a natural disaster. The island of Molokai is physically somewhat more protected than other islands of Hawaii, but still very vulnerable to hurricanes, tsunamis, earthquakes, and wildfires. The population is small, and the local stores cannot stock excess for emergencies. Due to the difficult terrain, Molokai only has one wharf and one airstrip, and emergency supplies and rations easily could be blocked by damage to the infrastructure. Even during normal, non-emergency times, the barge bringing grains, dairy, produce, and animal feeds to the island arrives once every 3–4 days. Indeed, interruption of regular barge service results in low supplies and empty grocery store shelves.

A large portion of the island's reliance on imported foods is due to the western acculturation of resident's diets. The population of Molokai no longer eats the same tropical foods that they did 100 years ago. This dietary shift has led to many issues, one of which is the mismanagement and underutilization of Molokai's natural resources. Molokai has land suitable for food production and good water resources, but much of it has become weedy with invasive species due to lack of active management. Animal protein sources are no longer managed in a way that provides for the local production and distribution of pork, chicken, fish, and venison, thus the portion of the Molokai population that does not hunt or fish relies heavily on imported meats.

Another issue stemming from this dietary shift is the fact that many Molokai residents now face serious health concerns, such as heart disease and diabetes. The high cost of imported fresh produce, dairy, and meat contributes to this issue, causing people to choose cheaper and less healthy processed foods.

By producing more nutritious, shelf stable foods locally, the shipping costs would be eliminated, which would result in lower prices, thus making locally sourced foods more competitive with their processed counterparts. Due to the health concerns prevalent in many indigenous populations, there is a substantial effort to move people towards a healthier, and in some cases more plant-based, diet. One option to solve many health concerns and utilize available resources would be to return to an indigenous diet. An issue with this option is that many tropical foods don't store well and can't be preserved, contributing to landfill waste. A possible solution to this issue is the adaptation of temperate fruits and vegetables with longer shelf lives to the Molokai climate.

Objectives

The purpose of this paper is to identify target crops and breeding methods which would enable the local production of staple foods for Molokai, focusing on adaptation of food crops for backyard gardening or small-scale farm production that would stay within the island chain. Large-scale production for export markets will not be addressed. The focus of this paper is on sustainable food sovereignty for the island of Molokai in a way that requires minimal-to-low investment for small farmers with a marginal-to-high return, with the main goal being to provide low cost local nutritious food for the entire island.

Secondary consideration will be given to how this information could be utilized to improve health by altering diet, or by altering the nutritional profile of foods that represent a large portion of current diets. This paper will introduce some possibilities to address health issues, but the primary goal remains to outline a plan for the adaptation of crops so that Molokai might supply food that is currently available in grocery stores through local production instead of through imports.

Thirdly, this work will be analyzed to identify its usefulness in other regions as they change to gradually warmer or unstable temperatures due to climate change. As the temperature of our planet is currently rising, adapting crops for tropical regions will result in pre-adapted varieties for the future when harsh growth conditions due to climate change are a reality.

BACKGROUND

At 261 square miles (676 km^2), Molokai is the 5^{th} largest island in the Hawaiian island chain. Since Hawaii assumed statehood in 1959, the two neighbor islands of Lanai and Molokai have been grouped together with the island of Maui to form Maui county. Thus, the majority of the island is subject to the same politics (taxes, fees, etc.) as two other islands with completely different economies. A small portion of Molokai also belongs to an isolated peninsula that is the home of the Kalaupapa settlement, which due to its incredibly unique circumstances will not be addressed in this paper.

The island itself was formed by volcanic activity followed by cycles of erosion and sediment disposition. This has left Molokai's north shore rugged and inaccessible; it is home to the highest sea cliffs in the world. The earliest human inhabitants of Molokai (circa 1200 AD) lived mainly on the coastal plains, which had rich soils and access to fresh water. These areas were farmed for many centuries. Polynesian colonists managed natural resources through a system based on those found in other Polynesian islands, known locally as the feudal Ahupua'a system. This set the boundaries of each watershed from mountain to reef, ensuring that each community had access to all the resources it needed to survive and thrive through their own local production of food and goods. Sometime later, there was a period of more intense development and more than 50 shoreline freshwater/brackish fishponds were built to ensure a stable source of animal protein for the entire island (Roberts 2000).

Before western colonization, Molokai's economy was based on agriculture and aquaculture. Farmers cultivated sweet potato, taro, and fish. They hunted and gathered to supplement the rest of their diet. Molokai's people always had plenty and thus the island gained the reputation of the land of the "fat fish and kukui nut relish" a term representing its abundance of both land and sea. The island was often referred to as

"'Āina Momona," or "Land of Plenty" (Members of the Molokai Community 2008). Because of Molokai's very strong agricultural history, the high school sports teams have even taken the mascot of the Molokai Farmers.

With the arrival of more western influence, land usage began to change very rapidly, as did culture and diet. In the late 1700's, grazing animals were introduced, but were all property of the king. These were used to supply the royal court, and as goods to trade with passing ships. The herds of sheep, goats, cattle, and later deer increased rapidly on the abundant land, and began to overpopulate. This overpopulation decimated entire native plant ecosystems. Native trees such as sandalwood began to be over-harvested for trade as well (Roberts 2000). Thus began the decline of the native plant population, which reduced the capacity for a traditional diet and way of life.

One of the largest cultural shifts was the move to private land ownership. In the great Mahele of 1848–1854, land was divided by the king and private ownership became possible. This was a time when many wealthy foreigners were granted or purchased large tracts of land which altered the way the natural resources of Molokai were managed. These large landowners brought large scale cattle ranching and plantation style cultivation of sugarcane and pineapple, which continued into the 1900s and destroyed much of the native landscape by continuing to over-graze native plants, introducing invasive species as forages, and disregarding the natural contours of the landscape in terms of storm water diversion and erosion. In 1912, the Molokai Forest

Reserve was established in an attempt to reverse some of the damage done by poor resource management, but by then much of the damage had already been done. In 1921 the Hawaiian Homestead Program was developed to grant land back to people of Native Hawaiian ancestry for 99 years at the terms of $1.00 so that they might become economically self-sufficient (Hawaiian Homes Commission Act 1921). The Hawaiian Homestead Program has been instrumental in keeping much of the island in an agricultural designation.

Table 1. Department of Hawaiian Homelands land use acreage summary for the island of Molokai *(Department of Hawaiian Home Lands 2005)*

Land Use Designation	ʻUALAPUʻE (Acres)	KAPAʻAKEA, MAKAKUPAIʻA, KAMILOLOA (Acres)	KALAMAʻULA, PALĀʻAU (Acres)	KALAUPAPA, PALĀʻAU (Acres)	HOʻOLEHUA (Acres)	TOTAL (Acres)
Residential	25	264	398	0	55	742
Subsistence Agriculture	0	0	213	0	2,138	2,350
Supplemental Agriculture	0	0	0	0	5,862	5,862
Pastoral	0	465	539	0	923	1,927
General Agriculture	299	2,165	2,353	0	3,681	8,498
Special District	85	2,247	1,719	847	660	5,558
Community Use	3	61	83	14	73	234
Conservation	0	0	0	609	46	655
Commercial	0	0	13	4	40	58
Industrial	0	16	0	0	0	16
TOTALS	**412**	**5,218**	**5,318**	**1,474**	**13,478**	**25,899**

Over the last 100 years, the sugar and pineapple industries left Molokai. The fishponds and taro lo'i have fallen into disrepair, and despite the efforts of many non-profit agencies, many areas are overrun by invasive plant species that were once introduced as forage crops and feral ungulates which do not eat them. Cattle ranching still exists on a small scale, and various economic and political factors have left much of the island's farmable acres vacant. The small farms that do exist do not produce a sufficient amount to provide the island with a steady supply of food.

Much of the population of Molokai lives in the small, somewhat concentrated urban areas of the island. Other than the land dedicated to Hawaiian homesteads, the rest of the island is currently owned by less than a dozen large landowners or held in parks and conservation programs. Thanks to the construction of the Molokai Irrigation System (MIS) in the 1960s, the infrastructure exists to deliver rainfall catchment irrigation water to much of the lower elevation farmable acreage (including Department of Hawaiian Homelands) of the island which would not receive enough rainfall for crop production on their own. Water rates through the MIS are currently much lower than potable water, and thus generally not an obstacle for most farmers. The land and water resources exist for Molokai residents to produce their own, locally grown, healthy, and vitamin and nutrient rich foods in order to achieve food sovereignty. Given the strong agricultural history of the community, consideration for utilizing and managing these resources in a culturally appropriate way.

Local Food Customs

The population of Molokai varies but has held steady around 7000 people for the last decade. The primary ethnic groups on Molokai are Full/Partial Native Hawaiian/ Pacific Islander, Full or Partial Asian, and Full or Partial Caucasian. A majority of the Asian population is ethnic Filipino, followed by Japanese. A small subset of the population also identifies as Native American/Native Alaskan, and African American. The last two decades have not seen much change in the population dynamics. The last major census took place in 2010, with another scheduled for 2020. Data for the years in between is mainly displayed by county, and thus hard to separate out Molokai, which as previously discussed is combined with the island of Maui and Lanai to form Maui County. The demographics from the 2010 census show many races, primarily Hawaiian (4642 people), Asian (3535 people), Caucasian (2924 people), American Indian/ Native Alaskan (186 people) and African American (120 people) with an overall population of 7345. The numbers totaling more than that as some residents identify with more than one race (Cluett 2012). A chart representing the primary ethnic groups is shown below. Data from (Cluett 2012).

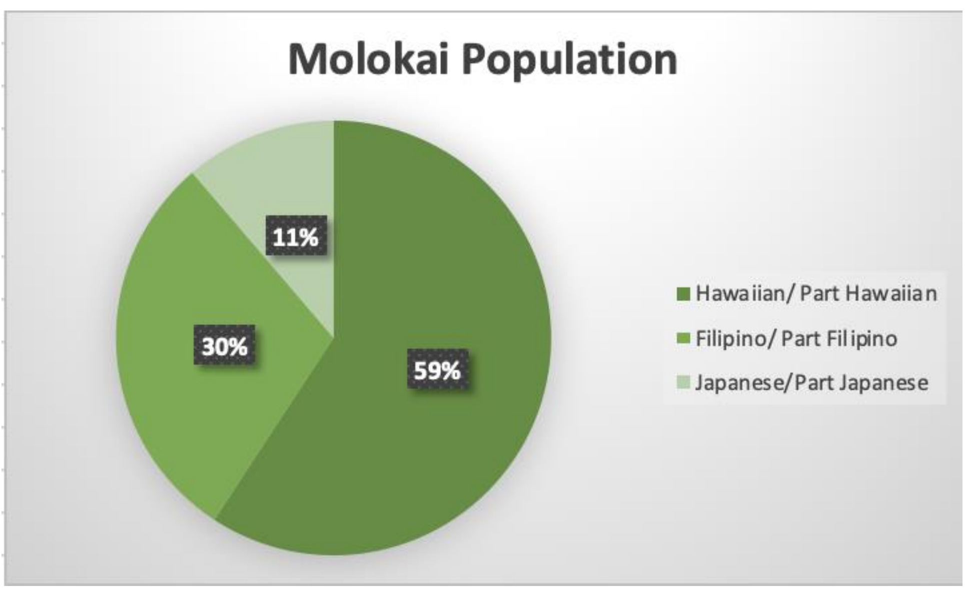

Figure 1. Demographics of Molokai Population

Although Hawaii has become much more westernized over the last 200 years, the state as a whole has a very different demographic than that of the mainland United States. This leads to different food customs and preferences which are more pronounced on Molokai. Local favorites in the 21st century include rice, spam and other processed meats, fish, venison, mayonnaise-based side dishes, eggs, saimin, fatty cuts of beef, chicken, and pork which are offset with some fruits and vegetables. Much of the population enjoys a mix of modern western foods, traditional Filipino foods, traditional Hawaiian foods, and Asian cuisine including some Japanese, Korean, and Chinese influences. These preferences toward “comfort food” lead to an average diet that is too high in salt and fat, and/or lack essential vitamins and fiber for a modern lifestyle. In a modern society with less daily activity than our ancestors, an unhealthy diet can lead to diabetes, obesity, heart disease, and other unhealthy conditions (Gellert 2006, Anderson 2006).

Many residents of Molokai suffer from health concerns including baby bottle tooth decay, childhood obesity, diabetes, asthma, heart disease, high blood pressure, and substance abuse. Out of 27 communities throughout the state, Molokai ranks fourth worst for combined socio-economic and maternal and child health risk (Molokai Community Health Center 2019). None of these concerns can be completely alleviated by the availability of locally grown food, nor can any of them be solved by diet alone, but proper nutrition is a cornerstone of good health, and providing fresh affordable healthy food provides the essential foundation. The Bill and Melinda Gates Foundation is working to address nutritional challenges by changing the way food is produced, marketed and consumed around the world, especially in rural communities. They believe that by growing more affordable and nutritious foods they can help solve dietary deficiencies (Gates Foundation 2019).

Many healthy dietary staples are only available seasonally, and at a fairly high cost from local merchants. Many of these foods are imported from other areas via the mainland. This creates an issue for the general public due to the high costs associated with importation, especially of perishable products. This high cost can also be detrimental to local merchants who are unwilling or unable to provide sufficient financial investments for the expenses associated with these products. This leads to lack of availability in the stores, and lack of variety in people's diets.

Many of these health concerns have been shown to arise from the dietary acculturation from a traditional islander diet to a westernized diet. Studies show that Asian and Pacific Islanders are the fastest growing minorities in the United States, but amongst the least studied regarding obesity and related diseases. There is much evidence supporting the hypothesis that transitioning from their traditional to a westernized culture is increasing the rates of cardiovascular disease, diabetes and insulin resistance. This would support data higher risk factors for these health concerns in Native Hawaiians (Grandinetti 2005).

A westernized diet also has been shown to account for a host of health concerns in native Filipinos. A recent study on dietary acculturation among Filipino Americans showed that having a western diet significantly increased caloric, fat, and carbohydrate intake. It also is associated with a higher Body Mass Index and waist circumference (Vargas 2015).

There is evidence that these health concerns could be addressed through a fully traditional diet. A study called the Waianae Diet was done in 1991 where 20 Native Hawaiians went on a traditional (pre-western contact) diet for 21 days. The traditional diet included low fats (12%), high carbohydrates (77%) and medium protein (11%). There were no caloric restrictions, and the people participating the study were encouraged to keep eating until they were full at every meal. Despite this the participants consumed less calories, lost weight, and gained healthier cholesterol and blood pressure levels (Shintani 2001). This demonstrated that when some Hawaiians eat a traditional diet consisting of tropical foods, they can gain many health benefits. A traditional diet, while quite healthy and containing fish, kalo, uala, and local fruits and vegetables should not be confused with a local modern diet. The local modern diet includes these traditional foods as well as imported fruits and vegetables, high fat, high salt, and altered and processed additions.

Re-acculturation back to a fully traditional Hawaiian diet would require a whole host of medical and social research to be implemented successfully over a long-term study. In 2004 a literature review was published which studied the traditional Hawaiian diet programs implemented over the last 20 years and showed that while most participants lost weight, few were able to sustain it. The difficulties in keeping the weight off were attributed to lack of fresh affordable produce and lack of support systems. The literature review also recommended greater access to land and ocean, land for home and community gardens, local food production, removal of processed food vending machines, healthier foods to be served in schools, and physical education programs and sports (Fujita 2004).

These are very interesting ideas but would require further research that is out of the scope of this paper. The fact remains that obesity is an increasing concern for all Americans, not just these ethnic groups or the people of Hawaii, so breeding temperate plants for cultivation in a tropical climate could help provide greater access to less expensive fruits, vegetables and grains, which may make them more appealing than high calorie processed foods.

Environmental Concerns

As it is so geographically isolated, and such a small-scale consumer, the amount of fuel used to transport food to the island of Molokai is quite substantial. There is not enough economy of scale to ship food in bulk, so the small, frequent shipments of are very inefficient. Another issue with such a heavy reliance on imported perishable foods is the carbon footprint due to shipping refrigerated containers, and both the extra weight and the cooling mechanisms warrant concern. Because of the small population of Molokai, the total effect may seem small, but the environmental cost per capita of each imported food is quite high.

While there is hope that local food sovereignty would provide a huge benefit to the environment by lowering the carbon footprint of a small island like Molokai, the amount by which greenhouse gas emissions may actually be reduced by local food production is a multi-faceted question that has been addressed by many people over the last several years. Currently, no studies specifically pertaining to Hawaii, let alone Molokai, have been conducted. The imports with the highest environmental impacts seem to be meat and dairy (Heller 2013, Avetisyan 2014). Molokai does import these items, but this paper will only address grain production for feed and legumes as a protein substitute; it will not cover the feasibility of ranching or game management.

Demand for Local Production

There was a document created in 2008 by several members of the Molokai Community themselves, which states that one of their future goals is productivity. The Molokai Community plan calls for a strong diversified production economy built on small local businesses with thriving local agriculture and aquaculture. They state that they want the farmlands and fishponds to be revitalized and productive. They want an abundance of jobs and food with Molokai returning to its reputation of “'Āina Momona” (Members of the Molokai Community 2008). This is just one illustration of how strongly residents of Molokai believe in being able to produce all of their food locally.

Another of the community goals is to cultivate a healthy community. The community plan calls for physically, mentally, and spiritually healthy families (Members of the Molokai Community 2008). This can also be accomplished at least in part through increased access to a variety of locally produced fresh fruits and vegetables. These opinions of the community are recognized for their complexity and relevance but there is also a need for more systematic research and review of if/ how these opinions may be accomplished (Gupta 2014).

There is already one existing entity set up to sell and distribute locally grown food and produce: Sust ‘aina ble Molokai. Sust ‘aina ble Molokai seeks to promote a new green economy, with the goals of keeping Molokai’s money local to support the on-island economy. They want to build a strong community of producers and consumers, so everyone knows where their food comes from. They also want fresher and more nutritious produce that hasn’t travelled 2500+ miles. They want to help decrease the carbon footprint through less transportation of imported food which they believe will lower the amounts of fossil fuels burned and greenhouse gasses released. They want small local producers to be the norm because they believe supporting community relationships strengthens the traditional Hawaiian way of life (Sust 'aina ble Molokai 2009). The success of Sust ‘aina ble Molokai speaks to the island’s willingness to embrace local production. However, the availability and variety of food and plants for sale is dependent on local producers and their supply, which leaves large gaps for consumers wanting to buy solely local.

APPROACH

The first step in developing a plant breeding program is to determine what, if any, crops could and should be adapted to Molokai. This study begins by assessing the market and determining which foods are imported and which already have varieties that could be produced locally. Next, the crops that would benefit from adaptation to a tropical growing environment are determined: what barriers are there to their success, and how those may be overcome. Third, from among the many opportunities to adapt crops to Molokai's future environments, crops are prioritized based on their nutritional impact to local residents' diets, physiological constraints to adaptation, economic viability, and impact to the local ecosystem. Last, breeding methodologies which would allow for the target crops to be adapted are proposed.

Market Assessment

The potential crops for adaptation are identified through purchasing trends at local stores. On Molokai, the local grocers always carry a variety of canned and processed frozen foods. While these are all imported, as a general rule the processed/value-added market may be less well suited for local production on Molokai. It would be advisable to do an economic study in order to see if the small local economy could support the volume that is necessary for the capital investment of processing equipment to manufacture these items to the proper legal standards.

Local observations show that the two small grocery stores on Molokai regularly have fresh cuts of beef, pork, and fish available. Imported frozen chicken and processed meats are likewise available, as well as dairy and eggs imported from the mainland and other Hawaiian Islands. There are imported apples and grapes available and very popular. Imported berries, pears, and stone fruits are usually available, at variable costs that are commonly 2–3x higher than mainland prices and generally of lower quality. The local grocery stores also carry oranges, limes, lemons, sweet potatoes, onions, green peppers, and some other tropical fruits that can be (and sometimes are) grown locally. In addition to the high price, it is not uncommon for packaged baking supplies and starches to become expired or fall prey to weevils in the time from production to sale.

The first option for improving local food production is to choose crops that are adapted to the area or are closely related as a suitable tropical substitute. Molokai is home to many tropical species of fruits and vegetables, as well as fish. Axis deer are plentiful. Pigs, goats, and fowl may be hunted, and there is still a small ranching economy. Also, many people raise a few chickens or 1–2 pigs each year in their backyards.

There are two issues associated with fruits and vegetables currently grown on Molokai. Most tropical fruits are not well suited for transport or storage, although they are nutritious and grown by home gardeners. Also, tropical fruits are seasonal, whereas the growing climate is suitable for year-round production. If another crop could fill gaps between harvests with crops adapted to tropical conditions, they would contribute toward the goal of food self-reliance.

Taro

One of the most common starches in Hawaii is taro (*Colocasia esculenta*), also known as kalo. Taro is very popular in many other tropical areas as well. There are many Hawaiian varieties of both dryland and wetland taro, which have all been successfully cultivated on Molokai for hundreds of years. The corms of the taro plant are low in fat (0.3-0.6% by dry weight) protein (11% protein by dry weight) but high in starch content. It is also high in many vitamins and minerals such as thiamin, Vitamin C, iron, folic acid, calcium, copper, potassium, Vitamin B, and other nutrients. Taro contains both soluble and insoluble fiber (Temesgen 2015). Taro has many uses, but due to its high concentration of calcium oxalate crystals, it causes significant irritation when eaten raw (Allen 1933). Future taro breeding projects could focus on reducing the calcium oxalate content so the plant can be better utilized.

One of the most common and most healthful ways to prepare taro is by steaming the corms (destroying the calcium oxalate crystals) and mashing them, then leaving them to ferment into a substance known as poi. A truly traditional Hawaiian diet hinges on poi, although, it is an acquired taste. Poi is known for the small size of its starch molecules and thus its exceptional digestibility (Allen 1933). This is one of the reasons that poi is often the first food given to babies; it's easy to digest. Fresh poi has a mild flavor, is high in B vitamins, and has not been associated with allergic reactions.

Poi can be an adequate food when eaten as the majority of a person's diet. It is estimated that early Polynesians consumed as much as 10–20 pounds of poi each day (Allen 1933). Up until the mid-1900s residents of Hawaii were still consuming quite a bit of poi, and it was still the primary component of many people's diets. In the 1930s the Hawaii Agricultural Experiment Station analyzed the amount of poi being sold and consumed and concluded that an adult who ate nothing but poi, would consume about 5 pounds of poi per day (Allen 1933). Taro is already a fairly productive plant, and in the 1800's when it was still a primary part of everyone's diet in Hawaii, it had been estimated that 640 acres would provide all the necessary calories for about 12,000 people for a full year (Allen 1933). This means that a little over 364 acres of taro would provide adequate nutrition for every resident of Molokai for a full year. So, if just 10 Hawaiian homestead farmers successfully grew taro on 40-acre plots, the island could become self-sufficient producers of caloric needs, and with subsidies, it may be economically feasible. The nutritional profile of taro (Huang 2000) would suggest that these numbers may still hold true. However, these data are quite old and would require further study to determine if this amount would be sufficient for a modern lifestyle, not to mention the fact that current residents enjoy a western diet, filled with variation.

Returning to a historic diet with a sole source of calories would be an extreme measure that would need to be studied for other impacts before recommendation.

Due to influences of immigration after the Polynesians, current residents of Hawaii enjoy a varied diet with many different fruits, vegetables, meats, and processed grains. People still consume poi, especially at celebratory occasions, but the population as a whole no longer consumes it as a major staple of their diet. The primary source of starch in current Hawaiian diets is from imported rice.

Rice

In the 19th century, as more and more immigrants came to Hawaii, they brought their favorite foods with them. The large influx of people from Asian countries in the 1800s brought a demand for rice. As the population dynamics changed, many wetland taro patches (locally known as lo'i) were converted to long grain rice paddies. As the population dynamics continued to evolve, the preference went from long grain rice, which was being produced in Hawaii at that time, to short grain rice, which was imported from California. Hawaii's method of rice cultivation was based on hand labor, so economically local production could not compete with California's mechanization. In spite of efforts to revive the rice industry in the early 20th century, there is no longer any rice production in the state (Hawaii Rice Fest n.d.).

Rice remains a staple of the modern local diet, and short grain rice remains the preferred type. The prices of rice are reasonable, so this makes it one food that may actually not be economically viable to produce locally, especially with no existing paddy infrastructure. However, in the pursuit of food sovereignty, rice could be considered for cultivation. There are rice varieties that are already adapted to the Molokai climate, and the possibility of breeding short grain rice for a greater nutritive value could provide a local niche market.

Is it worth breeding rice with specific nutrient profiles when most commercially available rice is enriched? A study in 2005 determined that most long grain rice sold in Hawaii was labeled as enriched, while most medium-grain rice was not. Even amongst those labeled as enriched, samples pulled from Hawaii and Guam seldom met the minimum enrichment requirements for the United States" (Guerrero 2009). With non-enriched short and medium-grain rice being the local preference and the lack of adequate enrichment even in non-preferential long-grain rice, there is potential for a breeding program to develop short grain rice with greater nutritive qualities for small-scale production on Molokai. Pricing strategy and possibilities for ensuring adequate compensation for growers would need to be further investigated. There are several economically important crops that already are grown or have a history of being grown on Molokai, but not for direct consumption by local residents. These crops have the potential for new variety development that would make them more suitable for production for local use.

Soybeans

There are soybean (*Glycine max*) varieties that are well suited to grow in a tropical area with poor soil, such as FT-Cristalina, BR-9, etc. (Wysmierski 2013). However, Molokai does not possess the land mass that other countries such as Brazil or Bolivia do, making the island less well suited for large-scale crop production. Without the infrastructure for processing and shipping, it is hard to justify the production of oil or mainstream commodity crops for export, particularly on a large scale that could compete with Latin American countries, however, it could be feasible to grow soybean as supplemental feed for local livestock production

All grain-finished meats sold on Molokai are currently imported. The ranching industry on the island produces grass fed cattle or sends its cows off-island for grain finishing, which would imply that it's not currently economically feasible to run a finish feed lot on Molokai. This may not be the case if feed could be produced locally at a lower price point than imported feed, but that subject requires further economic study.

In regard to small batch production of essential fats and oils, avocados and coconuts grow well in many areas of the island. Their oils also currently fetch a higher market value than soybeans, so they could result in a higher profit margin for those willing to grow and process them.

Soybeans could be a profitable crop if grown for more niche markets such as edamame, natto, or shoyu varieties. Edamame is essentially the same as commercial soybeans. Both are the species *Glycine Max*; however, edamame is bred to have large seeds with a “sweet, nutty flavor, and better digestibility” (Kaiser 2016). Edamame is a very popular snack in Hawaii, often marinated in shoyu, garlic, and various other spices. Cartons of marinated ready-to-eat beans can always be found on grocery store shelves, but virtually all of the beans themselves are imported. The University of Kentucky published an economic viability report for edamame beans. It showed that most frozen edamame is imported from Asia, Arkansas, and a few other states (Kaiser 2016). Growing soybeans in Hawaii has been a fairly underutilized idea thus far. As of yet, only one variety of edamame soybean seems to be on the market for Hawaii, and that is the University of Hawaii developed variety ‘Kahala’ (University of Hawaii n.d.).

Edamame could represent a value-added local crop if bred to grow in a more tropical environment. There are also many health benefits of edamame. They are very high in protein and contain highly beneficial phytochemicals (Kaiser 2016). A tropical breeding program could combine environmental adaptations, flavor, and protein phytochemicals beneficial to health to create a crop for local Hawaiian diets.

Shoyu is a favorite local condiment. It is a type of soy sauce produced by a Japanese fermentation method. Although the most popular brand sold in Hawaii is already produced on Oahu, growing the beans for it could be a good way to cut down the environmental impact from importation. Shoyu is an unlikely contender for a “health food” yet its properties have been studied and found to have many benefits. Soy sauce enhances gastric juices, thus promoting digestion (Kataoka 2005). It has antimicrobial activity which can fight against infective bacteria. It contains an I-converting enzyme inhibitor which gives it antihypertensive properties. When fed to mice, soy sauce has anti-carcinogenic effects (Kataoka 2005). The flavor components of shoyu specifically have been shown to exhibit antioxidant and anticarcinogenic effects in mice. Two of the flavor compounds also inhibit cataracts in mice. Shoyu contains three isoflavone derivatives called shoyuflavones which inhibit some histamine production. And relatedly, although two of the key ingredients in shoyu are wheat and soy which many people are allergic to, there is an absence of these allergens after the fermenting process turns the ingredients into shoyu (Kataoka 2005). A recent review of soy-based ferment foods reinforces many of these claims (Cao 2019).

While there are already many low sodium shoyu varieties on the market, there has been little work done to capitalize on the other health benefits of the soybeans used in production, such as developing a breeding program for high nicotianamine soybeans. The flavor components in shoyu would have to be studied further to determine what type of biochemical profile the soybeans used in shoyu production would need to produce a higher antioxidant concentration after fermentation.

Maize

Maize (*Zea mays*) has been grown on Molokai since the early 1960s and does quite well in most regions of the island. It is very possible to grow maize as well as small grains to be used for both direct human consumption and animal feed on Molokai.

There is an economic issue with the growing of maize for feed or finishing of cattle or other meat animals, simply because as discussed above with soy, Molokai does not possess the landmass needed to support a grain feed production facility. The seed industry has existed on Molokai for several decades, but all of the grain is shipped off island as part of global production or research trials. Sweet corn is occasionally grown in backyard gardens and small local farms. There are already many varieties developed for their suitability to the Hawaiian environment.

One crop observed to grow well, but not grown for local use, is silage maize. There are already many existing varieties that are adapted to tropical regions, and those could easily be grown on Molokai to help facilitate the cattle and dairy industries.

Potential Crops for Adaptation

In addition to the foods identified above, there are some others which would have merit for adaptation to the Molokai climate. Based solely on popularity, apples, grapes, and berries may be good choices. Peaches have already been studied for production value on Molokai because they would fill a seasonality gap (Arakaki 2014, Teves 2014). There are several legumes that would be good choices for protein substitutes, and several small grains which could replace imported feeds for the backyard animal husbandry market and enable more fully integrated local production of eggs and possibly meats and dairy.

Apples

Hawaii already has a type of fruit that is referred to as mountain apple (*Syzgium mlaccense*). In Hawaiian, the name is ohi'a 'ai. These trees are not related to Malus species. The issue with these fruits is that they bruise easily and do not store well, so they are not a good option for market/resale in Hawaii. The trees also tend to become weedy and invasive. They are what is called a 'canoe plant'; they are not native to Hawaii but are thought to have been brought to the islands by early Polynesian settlers.

Apples (*Malus domestica*) are a popular seller in our grocery stores but are all imported due to the fact that they require a chilling period to produce fruit. Some studies have been done specifically looking at the energy use and environmental impact of locally grown apples versus imported apples. None of these were done for Hawaii specifically, but several studies focused on the UK had interesting results and showed that there are many factors other than distance travelled which influence the carbon footprint of imported apples. When considering the highest rates of energy used in apple production transportation was found to be responsible for more energy consumption than the actual production of the apple crop (Jones 2002). A newer life cycle assessment of Apples in the Mediterranean also supports this data by showing that the agricultural stage of the apple life cycle only accounts for 36% of the carbon footprint, and the greater amount is from the rest of the lifecycle which includes cleaning, processing, transport, market and disposal (Vinyes 2017).

Storage loss was a huge contributor overall and varied greatly from 5–40% total loss of product due to environmental pressures and spoilage (Canals 2007). If apples were adapted to grow on Molokai, would the losses due to insect and disease pressure prohibit the crop from becoming economically viable, or would a comprehensive breeding program impart resistance, which may not be prevalent in a more temperate growing environment?

Apple trees need a certain number of chill hours to develop successfully. Without sufficient chilling, many buds won't form into flowers and yield will be reduced. In addition, lack of chill can be very stressful to temperate fruit trees (Kamas 2015, Ratna 2015).

There are already some existing varieties of apple with a low number of chill hours. Two long-standing low-chill varieties of apples currently on the market are "Anna" and "Dorsett Golden". These both require 350–400 chill hours (Kamas 2015, Kataoka 2005). There are several other varieties that require 250–400 chill hours which make them able to grow in southern regions of mainland United States.

There has been some Molokai specific work done by University of Hawaii Extension agents which states that "Varieties requiring 100 to 200 chill hours are the best bet in Ho'olehua, while others up to 300 chill hours may fruit in Kalae and Maunaloa" (Teves 2014). Despite these promising data, there have not been any recorded apple trees grown on the island of Molokai. A few home gardeners have been known to start some trees from seeds of the grocery store apple variety "Fuji". It remains to be seen if any of these will ever set fruit. “Fuji” is noted to need about 600 chill hours to set fruit, but higher elevation regions of Molokai, such as Kalae, have been known to produce peaches and cherries, so these regions may be able to produce a suitable enough climate. The chances of success are low but could be surprising.

Grapes

Grape (*Vitis vinifera*) is a crop that has the potential to have a great impact on Hawaii’s economy. One of Hawaii’s largest sources of income is tourism. Many tourists visit the few wineries in the islands already, including prominent wineries on Maui. Molokai currently does not have any wineries or vineyards, but the soil and climate are similar to Maui. Grape cultivation is possible and, with better adapted cultivars, could be a means to provide economic and food independence. In addition to Maui, Brazil provides an example of the potential for successful viticulture in tropical areas.

Tropical grape production still has many hurdles to overcome, including bud dormancy, low fertility, disease susceptibility and overall lack of vigor. The Brazilian Agricultural Research Agency is working to develop new cultivars which combine solutions to the previously mentioned issues with grape quality (Camargo 2000). Their breeding program consists of a cross between *V. vinifera* and *V. labrusca* cultivars, and their hybrids with wild tropical species of *Vitis*, with many populations potentially suitable for tropical production in Brazil. Wine cultivars seem sufficient at F1, but juice and table grapes need to be advanced to at least the F2 generation to capture all of the positive palatability characteristics of *V. vinifera* and the disease resistance and adaptation characteristics of *V. labrusca* (Camargo 2000, Faust 1995). With the conditions of grape growing regions in Brazil being generally similar to Hawaii, these newly developed varieties should be able to grow well on the island of Molokai as well or could provide a base for a Hawaiian breeding program.

Wine is not a dietary staple, especially in this day and age when tap water is quite safe to drink. However, wine is widely distributed on the island and it is expensive to import, resulting in economic losses and a large carbon footprint. Producing wine locally may not completely compensate for these negative aspects, as people tend to prefer characteristics assumed by wines of different areas, but wineries could provide opportunities for ecotourism and may be able to help Molokai's economy.

Berries

Strawberries (*Fragaria ananassa*), raspberries (*Rubus* species), blackberries (*Rubus* species) and blueberries (*Vaccinium* species) are generally available in Molokai grocery stores, but quality, quantity, and price vary greatly by season. The high relative cost of berries is often prohibitive for local consumers. Frozen berries are available year-round but also are relatively pricey and use excess energy to keep frozen in transport and after purchase until consumption.

Berry cultivation in Hawaii varies from region to region. University of Hawaii Extension agents are currently undertaking cultivar trials for low-chill blueberries that may be suitable for production on Molokai. Both raspberries and blackberries have proven to do well in in the higher elevation areas of Molokai. Patches spread through natural means can often be seen in areas of Kalae and Lua Na Moku Iliahi (the Sandalwood Pit) area. Some home gardeners have been successful in the cultivation of berries in several areas of Molokai.

The University of Florida is currently working to develop low-chill highbush blueberry cultivars through recurrent selection, since many different attributes must be changed to develop a plant that will withstand a sub-tropical or tropical environment. Several issues have arisen in the low-chill blueberry breeding program, including leaf and flowering time reversal, where flowers set fruit before a leaf canopy is formed, resulting in abortion of most fertilized flowers (Lyrene 2005). In Hawaii, the limited blueberry trials show that the bushes may remain evergreen all year round, so this problem could possibly be avoided. However, other issues could develop due to the leaves remaining on the bush for more than one season. Blueberries are very susceptible to many plant diseases prevalent on Molokai, including rust, leaf spot and powdery mildew. These diseases are even more prevalent in the higher elevation regions, where blueberries are likely to grow best because these areas receive more rainfall and more cloud cover.

Since the temperatures on Molokai do not drop below 0 C, even at the highest elevations, it is unlikely that fruits will be destroyed by freezing weather. It is assumed that blueberries would function like raspberries and blackberries and set fruit several times each year. This makes Molokai a desirable location for a specific blueberry breeding program, because more generations could be observed in a shorter amount of time, thus lowering the length of time needed to develop new cultivars.

Peaches

Peaches (*Prunus persica*) present an opportunity for a fruit crop that would fill the gap left by other tropical fruits. Peaches, having a fleshy fruit similar in some respects to mango, but with a different flowering time than mango, could be a good substitute to extend the fresh fruit season. Peach cultivation on a commercial scale in Hawaii may be possible, especially in some of the cooler high elevation regions of Molokai.

There have been ongoing peach trials at the University of Hawaii–College of Tropical Agriculture and Human Resources on the Applied Research and Demonstration farm on Molokai. Dr. Alton Arakaki recently retired but spent the last 30 years evaluating peach varieties that would provide a tasty, marketable, and reliable peach crops. Four of the varieties are commercially available (Tropic Snow, Tropic Beauty, Tropic Prince, and Tropic Sweet), one variety developed in California, but named 'Hawaiian', and a few others which were gifted for the study from unknown origin, but which had been growing in various gardens mainly in Maui county (University of Hawaii Office of Communication Services 2015, Arakaki 2014). Dr. Arakaki has successfully produced peaches with zero chill hours in the Ho'olehua region of Molokai and perhaps these varieties will be successful at higher altitudes, where they may not be exposed to "chill hours" in the traditional sense but might gain from exposure to lower winter temperatures. One of the main traits that tropical peaches should be bred for, besides low chilling requirements, is skin that is thicker or less susceptible to fruit flies. This issue remains to be addressed through future breeding programs.

Legumes as a Protein Source

In addition to the soybeans, there are many other legumes that could be grown on Molokai. Legumes are typically very healthy, as they contain very little fat and cholesterol and generally high concentrations of vitamins, fiber, and healthy fats. One healthy legume which is very popular, but exclusively imported to Hawaii, is adzuki beans (*Phaseolus angularis*). There is no literature indicating that adzuki bean varieties can be grown in Hawaii. However, they have been produced as far south as Florida, so some tropical varieties may grow on Molokai, or new, adapted varieties might be bred (T. Nelson 1987).

Some other legumes that could be grown commercially on Molokai include cowpeas (*Vigna catjang*), jack bean (*Canavalia ensiformis*), pigeon pea (*Cajanus indicus*), velvet bean (*Stizolobium* spp.), mung bean (*Vigna radiata*) and alfalfa (*Medicago sativa*). There was some research done in the early 1900s which suggested these leguminous crops could be cultivated in Hawaii (Krauss 1911). Despite this work which showcased available varieties that could be grown successfully in Hawaii, the legume industry never developed. That being said, the production of any of these legumes as a food, or a feed/forage source for the ranching industries, contribute to Molokai's food sovereignty plan. Varietal trials would be required first, with the possibility of enhancing existing varieties for optimized production in Hawaii.

Grains to Be Used as Feedstocks

It was previously mentioned that maize is already grown on Molokai, and that other grains could be adapted as well in order to supply the feed industry. Many people raise pigs or cattle on grass and leftover food waste from their own meals or collected from local schools, etc. Goats, deer, boar, and fish are harvested by hunters and many people raise backyard chickens. Chickens and many of the other animals raised for consumption are fed a diet that includes imported grain-based feeds or are sent off-island for grain finishing. The primary components of many grain feeds are soy, sorghum (*Sorghum* spp.), barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), and canola (*Brassica* spp.). Soy and sorghum are already grown on Molokai. As was previously discussed, large-scale soybean production is probably not economically feasible. However, due to the ability to produce higher yielding varieties on Molokai, profitable sorghum production may be possible. The most recent published work on the possibilities of growing several of these grains in Hawaii was done over 30 years ago. Sorghum experienced several issues in its early field trials, including bird, insect, and disease pressure. Bird pressure is not as much of an issue on Molokai where there is no wild parrot population, but insect and disease resistance would need to be addressed via breeding. Grain shatter is also an issue that could be addressed by breeding (Brewbaker 1982).

Barley, rye, wheat, and oats (*Avena sativa*) have been grown in Hawaii in the past, but never on a large scale. Most of the species do better at higher elevations (Brewbaker 1982), so some areas of Molokai may be suitable for producing these small grains. However, specific varieties may still need to be optimized for production in Hawaii.

Wheat was first introduced to Hawaii in the early 1800s. Winter wheat could not be grown in Hawaii at all because it needs vernalization. Spring wheat could be grown without artificial vernalization, but at the time yields could not compete with mainland USA wheat production, and thus it was not economically feasible to grow wheat in Hawaii (Brewbaker 1982). There are some rumors of wheat being grown on Molokai by the Molokai Ranch in the 1900s (Advertiser Staff 2008), but no published record of wheat varieties or how successful they were exists. Wheat has not been grown on Molokai since then, but that doesn't mean it isn't possible if the right varieties are developed. It could be economically feasible to export wheat, but there would need to be a study to determine if this is possible, or if there could be enough produced to help support a local feed and flour market.

There is no record of canola ever being produced in Hawaii. There was some work done to determine the feasibility of growing canola in Brazil, which would be very applicable to the Hawaiian climate. These experiments followed two varieties of canola, which showed some promising results but would need to be better adapted to a tropical environment for actual production (Tomm 2011).

Prioritization of Potential Crops

There are several crops mentioned above, and all of them have their own contribution to local food production on Molokai. However, cultivar development requires investments of time and resources. Thus, a set of criteria needs to be established in order to be able to prioritize these crops for adaptation. Purchasing trends were briefly discussed above, which is what led to the list of potential crops. The first aspect to consider is, whether there are existing varieties of any of these crops. Some may be available after varietal trials, rather than an actual breeding program for new cultivar development. After that, the main categories to consider for prioritization of these potential crops would be nutritional contribution to a healthy diet, potential for adaptation to the local environment, economic viability and environmental impact to the local ecosystem, with specific criteria defined for each.

The first crops to exclude from the priority list would be those currently being produced on Molokai: Taro, Maize, Blackberries, Raspberries, Strawberries, Alfalfa and Sorghum. While these may still have room for improvement through breeding, the fact that they are currently in production shows that the existing varieties are sufficient.

The chart below outlines the history of varietal trials for each of the crops mentioned above. The term "unknown" was used to describe crops where no record could be found for that species to being grown on Molokai. The Hawaii State Census of Agriculture does point out the production of all of these crops, but only breaks down by county, not by island, and many of the crops of interest are only shown to be grown in Hawaii County (Hawaii island) (USDA, Hawaii census of agriculture 2017), which has different conditions than Molokai, or even Maui county, due to its geography.

Table 2. Varietal trial history and food use of potential crops for adaptation

Potential Crop	Suitable for trials of existing varieties?	Consumed as a primary or secondary source of food or used for feed?
Taro	yes- currently produced	primary food
Soy-edamame	unknown	primary food
Soy-shoyu	unknown	secondary food
Soy-feed	yes- previous trials	feed
Maize	yes- currently produced	primary food
Apples	unknown	primary food
Grapes	unknown	primary food
Blueberries	maybe-trials underway	primary food
Blackberries	yes- currently produced	primary food
Raspberries	yes- currently produced	primary food
Strawberries	yes- currently produced	primary food
Peach	maybe-trials underway	primary food
Adzuki Bean	unknown	secondary food
Cowpea	yes- previous trials	feed
Jack Bean	yes- previous trials	feed
Pigeon Pea	yes- previous trials	feed
Velvet Bean	yes- previous trials	feed
Mung Bean	yes- previous trials	primary food
Alfalfa	yes- currently produced	feed
Sorghum	yes- currently produced	feed

Barley	yes- previous trials	secondary food
Wheat	yes- previous trials	secondary food
Canola	unknown	secondary food
Rye	yes- previous trials	secondary food
Oats	yes- previous trials	secondary food

The next lowest on the priority list would be the crops which have already had varietal trials. Although none of these went on to be successfully cultivated for profit on Molokai, this would show that some varieties exist that would be satisfactory, especially since most of those trials were conducted several decades ago, and new varieties have most likely come to market since. This would lead us to exclude soy for feed, cowpeas, jack beans, pigeon peas, velvet beans, mung beans, barley, wheat, rye, and oats.

Of the remaining crops, the priority would lie with those that could be consumed as a primary source of food. Thus, soybean for making shoyu, adzuki beans, and canola would also be excluded. Finally, for the remaining crops, we would need to look deeper into the specific objective criteria of our four main categories.

Nutritional Contribution

Concerning nutritional contribution to a healthy diet, specific criteria to be considered would be protein content per serving, fat content per serving, fiber content per serving, and specialty properties (antihistamine, antioxidant, vitamin content, etc.) It should also be taken into consideration, if the crop is consumed directly or used as an input into a secondary product that would be consumed by people (i.e., feed, oil, condiments, etc.).

One serving of apples has been shown to provide around 1 gram of protein, 3 grams of fiber, no fat, no cholesterol, 25 grams of carbohydrates, and 19 grams of sugar. Apples also contain flavonoids which function as anti-inflammatory agents and antioxidants, as well as many vitamins, which may help protect pancreas cells from damage, thus helping patients control Type 2 diabetes. The soluble fiber in apples has been shown to help lower LDL and may help prevent certain chronic disease. It may also possibly slow digestion, making patients feel full longer, thus aiding in weight loss (Harvard 2019, USDA, SNAP-Ed Connection n.d.).

One serving of shelled edamame provides approximately 11 grams of protein, 9 grams of fiber, 2.5 grams of fat, 13 grams of carbohydrates, and no sugar, but does provide many vitamins and minerals. On the negative side, 1 serving of edamame contains around 15 milligrams of sodium (Garden-Robinson 2017, USDA, SNAP-Ed Connection n.d.).

One serving of grapes contains 1 gram of protein, 1 gram of dietary fiber, no fat or cholesterol, 16 grams of carbohydrates, and 15 grams of sugar. Grapes also provide some calcium, iron, and potassium (USDA, SNAP-Ed Connection 2019).

Blueberries contain 1 gram of protein, 4 grams of fiber, 1 gram of fat, no cholesterol, 22 grams of carbohydrates and 15 grams of sugar per serving (USDA, SNAP-Ed Connection 2019).

One serving of peaches contains 1 gram of protein, 2 grams of fiber, no fat, no cholesterol, 14 grams of carbohydrates, and 13 grams of sugar. One serving of peaches also provides some calcium, iron and potassium (USDA, SNAP-Ed Connection 2019).

Looking at the nutritional profiles overall, Edamame may be a good candidate for a tropical breeding program as it is high in protein, and fiber, but does not contain any sugar. Considering the health concerns outlines in the beginning of the paper, increasing consumption of some of the higher sugar fruits could possibly contribute to health issues, if they became the primary component of people's diets.

Table 3. Nutrition content of select crops

Nutritional Content in grams/ per serving					
Crop	Protein	Fiber	Fat	Carbohydrates	Sugar
Apples	1	3	0	25	19
Edamame	11	9	2.5	13	0
Grapes	1	1	0	16	15
Blueberries	1	4	1	14	13
Peaches	1	2	0	14	13

Concerns for Adaptation

Potential for adaptation to the local environment could specifically be quantified for insect resistance, disease resistance, photoperiod, salt tolerance, drought tolerance, and chill requirements.

Insect Resistance

Planting temperate crops in a tropical environment will expose them to a whole new realm of insect pressure. This should be considered for both plant health and fruit quality. Because of the constant warm temperatures, insect pressure is generally no small task to manage on a tropical farm. There is no forced fallow period (i.e., no winter) on a tropical farm, so growers must learn new ways to manage pests. One of the most useful things that can happen is growing crops with native resistance in the germplasm. There are already several well-known genes that infer fairly broad-spectrum Lepidoptera resistance, but not much has been studied in the way of resistance to scale, thrips, fruit flies, or any of the borers.

Many compounds exist in plants already that confer some resistance to herbivorous insects. Some research has been done to determine the compounds behind some natural sources of resistance to these pests. One study showed that chlorogenic and feruloyl quinic acid, which are naturally occurring in chrysanthemums, improve a plant’s resistance to thrips (Leiss 2009). The genes that control the production of these acids have not yet been mapped but could be mapped and used to find paralogs in the germplasm of edamame, apples, grapes, blueberries, or peaches.

There is a large amount of variation in the level of resistance that host plants exhibit in field trials, but the phenotypes are not fully heritable. Many insect resistance genes have been identified, but very few have been cloned or inserted into target crops (Broekgaarden 2011). Genotyping by sequencing allows for the possibility of a wider scope for genetic analysis of reference populations. This could also have potential to examine the entirety of all of the world's gene banks, thus allowing for easier identification of paralogs for beneficial genes in our crops of interest (Yu 2016, Nelson 2017).

Another consideration when breeding is that Hawaii as a whole has very strict pesticide regulations. When breeding new varieties specifically for the Hawaiian Islands, care should be taken to incorporate as much disease and pest resistance as possible since chemical means of prevention may not be available due to lack of registration of products.

Disease Resistance

Much like insect pressure, temperate crops grown in a tropical environment may be exposed to new diseases or new conditions more favorable to disease than their home environment. There will likely also be exposure to the same disease pressures as a temperate environment, but through different vectors, rendering current pest management practices ineffective. Since seasons are different in Hawaii than for mainland USA, there must be adaptations either by plant or by grower to manage the crop in rainy season, extreme heat, drought, and humidity and the respective diseases that come along with each season. There have already been many genes identified that confer resistance to diseases, but that will require a thorough review of existing literature. One of the main disease concerns for breeding for Molokai would be the presence of various rusts. There have been several LLr genes identified that could help manage leaf rust (Feuillet 2003).

Photoperiod

In order to allow plants to grow year-round and/or possibly flower and set fruit more than once per year, it is important that photoperiod be considered when breeding for new varieties. There has been some work done on genes controlling flowering time for the major row crops that should be able to provide a basis for the development of a breeding strategy for crops of interest. Photoperiod sensitivity of the potential crops does not appear to have been studied.

Salt Tolerance

Molokai is fortunate to have a rainfall catchment irrigation system, but at low elevations and close to shore plants are still exposed to salt in the air and brackish water in low lying areas. In addition to that, many small farms or residential areas on Molokai with private wells are somewhat brackish. Genes that enhance salinity tolerance have been identified (Deinlein 2014) including sodium transporters and reactive oxygen species scavengers. These can be capitalized on to breed more salt tolerant varieties (Deinlein 2014). Apples, soybeans, grapes, peaches, and blueberries all have some possibility for salt tolerance, and some potential genes have already been identified in each crop (Yonghong 2010, Dubrivina 2016, Ramirez 2016, Bernal-Vicente 2018, Chen 2017).

Drought Tolerance

Another consideration of climate change would be drought tolerance. Many temperate varieties are already subject to long hot, dry spells that are similar to tropical summers, but yield and productivity still suffer under these conditions. Drought tolerance is also something that should be addressed in order to ensure the cultivation of tropical crops continues as the temperature of the earth warms and rainfall patterns become less stable. Fresh water is a valuable commodity, and drought resistant plants can help conserve water. Drought response is a very complex mechanism, and it is very important to crop production, so much work has already been done on this topic. There are many studies that show the possibility of overexpressing or regulating stress related transcription factors resulting in increased drought tolerance (Xiong 2006, Messina 2015). A homolog of the Arabidopsis thaliana gene ATG18a has been found in apples (MdATG18a) and its heterologous expression has shown enhanced drought tolerance (Sun 2017). Overexpression of the soybean gene GmFDL19 has also been shown to enhance drought and salt tolerance (Li 2017). Grapes also possess genes, for examples VlbZIP36, and VvbHLH1, which have been shown to enhance drought tolerance in transgenic Arabidopsis thaliana (Tu 2016, Wang 2016). Blueberries and peaches seem to have variang natural degrees of drought tolerance, but no specific genes appear to be indetified at this time.

Suitable Chill Period

Edamame does not have a chill requirement. Apples, grapes, blueberries and peaches are generally produced in environments where they undergo chilling. The plants are in a state of dormancy during this chill period, it remains to be seen if they were grown in a tropical environment, would they never go dormant, or would they need a mechanism to break out of dormancy. There is also the question of whether lack of a dormant period would affect growth or fruiting.

There has been some research done on genes that control dormancy, but overall the mechanisms are still not very well understood and there are not a lot of conclusive research. For example, (Lyrene 2005) demonstrated that chilling is not translated throughout the plant, so simply exposing part of the plant to artificially cold temperatures would not be enough to trick the entire plant into breaking dormancy. The one thing that we do know is that chill period is heritable, and when a high-chill x low-chill cultivar cross is made, the progeny segregate in a manner that would make it seem as though multiple genes were involved (Lyrene 2005).

There are three types of dormancy: paradormanacy, endodormancy, and eco-dormancy. A plant is in endodormancy when it will not grow even when the temperature, lighting, etc. is optimal. This is believed to be a mechanism to keep plants from budding or leafing out during a winter warm spell, or too soon in the spring when a hard freeze could occur. A plant is said to be in a state of eco-dormancy when chill requirements have been met and it is ready to grow, but temperature, lighting, etc., are not yet optimal (Longstroth 2013).

Paradormancy is regulated by factors outside of the bud, but inside of the plant. It is also been known to be called summer dormancy. An example would be shoots not growing out in the summer, but rather having to undergo a winter defoliation before they will grow. This type of dormancy can be overcome through chemical or physical treatments, and normally does not require chilling (Faust 1995).

Two genes, ppDAM5 and ppDAM6, are proposed to control internal growth inhibitors that are responsible for preventing buds from resuming growth after winter dormancy requirements are met. (Yamane 2011) has shown that during cold months, Pp-γTIP1 *and* Pp-PIP1 are more highly expressed in high-chill cultivars of peaches than they are in low-chill cultivars. This work has not been inversely explored, but it is within the realm of possibility that silencing Pp-γTIP1 *and* Pp-PIP1 could lead to a no-chill variety or make low-chill varieties more vigorous or better yielding.

Endodormancy is known as winter dormancy, and basically means that the plant will not grow during winter to protect its cells from damage by the cold conditions. There has been some work showing that expression of δTIP1 *and* PIP2 in peach buds and bud cushions increased while the chilling requirement was being completed to break endodormancy. Water content in the cushions recovered to about 100% after the end of endodormancy. This means that δTIP1 *and* PIP2 are most likely involved in water transport from the stem to the bud after the plant has met the conditions for endodormancy. From (Gemma 2009) we could infer that overexpressing *δTIP1* and *PIP2* could possibly keep water moving to the buds and inhibit dormancy.

This theory is supported by research which shows that aquaporin genes are downregulated during the transition between dormancy phases in raspberry buds; overexpressing *PgTIP1* exhibits reduced cold acclimation ability (Peng 2007). Aquaporin regulation is thought to have some effect on dormancy, and many examples were given, though no conclusions have been drawn about their physiological role in low-temperature acclimation during winter dormancy (Gemma 2009).

A study of 73 apple accessions grown and characterized in Israel (which is by no means a direct climate model for Molokai) measured the time of bud break as an indicator of chill requirement. They then genotyped all the accessions against markers that they had developed by sequencing the genome of the popular low-chill cultivar "Anna". Their results showed that most of the plants with early bud break were not close genetic relatives, but they all shared "a unique haplotype in a region of ~190 kb, within a previously identified QTL for bud-break time, on chromosome 9" (Trainin 2016). This haplotype was not found in any of the plants with late bud break. One can thus infer that this region can be used to develop markers to help assist in breeding new apple cultivars that are better adapted to tropical climates (Trainin 2016).

Breaking dormancy (or avoiding dormancy all together) is just one of the many issues we need to face in order to adapt temperate foods to a tropical habitat. The research mentioned above is promising, but much more work is needed to specifically breed varieties acclimated to the Molokai environment.

Economic Viability

Economic viability would consider the cost of importing the crop and the cost of producing the crop locally. When considering the cost to produce the crop locally, the land and water requirements of each crop should be considered as well as the infrastructure required for scale production and processing. If crops require fertilizer or specialty inputs, this should be considered in the production strategy. Apples, grapes, blueberries, and peaches have been observed to have higher prices than they would on the mainland. Local prices seem to show edamame to be about equal. The cost of producing these crops on Molokai is unknown, but Apples, grapes, blueberries, and peaches may have an advantage as orchard crops, they continue to bear fruit for several years after establishment, whereas edamame must be replanted each season.

Impact to local Ecosystem

Impact to the local environment should of course be considered. There are many examples on Molokai of plants brought in without an environmental impact study which have wreaked havoc on native ecosystems. Thus, by looking at these criteria as a precursor to any breeding activities, the negative impacts may be able to be avoided. The specific criteria for environmental impact would be weediness potential, potential to interbreed with wild species, and pest impact on already established crops. The impact to the local ecosystem is unknown for the potential crops, but none of them are listed on the Hawaii Noxious weeds list or invasive species profile (HISC 2019). There do not appear to be any native homologs, but this should be further investigated before committing any new crop to a breeding program. Pest impact could be quite significant and should also be investigated.

Summary of Prioritization

The chart below summarizes the specific criteria which were evaluated to see which crops would be the best fit for adaptation to a tropical environment. The more boxes each crop is able to check equates to a higher potential for adapting to tropical production. Based only on known characteristics, Apples and Edamame have the highest potential for a breeding program, but when we consider the potential of the unknown criteria, blueberries, grapes and peaches could also be very feasible, but would need further study.

Table 4. Summary of Prioritization Criteria

		POTENTIAL CROP				
		Edamame	Apples	Grapes	Blueberries	Peaches
Nutritional	High Protein	x				
	Low Fat		x	x	x	x
	High Fiber	x	x		x	x
	Specialty Compounds	x	x	x	x	x
Adaptability	Exisiting Resistance to Tropical Insects		unknown	unknown	unknown	
	Exisiting Resistance to Tropical Disease		unknown	unknown	unknown	
	Photoperiod	unknown	unknown	unknown	unknown	unknown
	Salt Tolerance	x	x	x	x	x
	Drought Tolerance	x	x	x	unknown	unknown
	Suitable Chill Period	x		unknown	unknown	unknown
Economic Viability	High Cost to Import		x	x	x	x
	Low cost to Produce		unknown	unknown	unknown	unknown
Environmental Impact	No known wediness potential	x	x	x	x	x
	No known interbreeding potential	x	x	x	x	x
	No known impact to existing pest populations					

Possible Breeding Methodologies

We can divide breeding methodologies into two main categories: introgression of a few genetic alleles from donors to recipients and recurrent selection applied to polygenic traits. Within the introgression category are transgenic and non-transgenic approaches.

There are many benefits to both strategies. We can also categorize breeding strategies by the issues that need to be addressed. The main issue with many temperate crops is dormancy. There needs to be an adequate mechanism or growth modification that ensures that crop plants will not require a chill period to grow, fruit, or flower. Beyond that, there are many other aspects to consider when breeding food crops for a tropical environment. These include yield, drought and salt tolerance, insect resistance, and virus and disease resistance. Lastly, there is a group of traits which must be considered regardless of the intended climate. These traits include color, scent, flavor, shelf-life, and anything that would make a consumer more or less likely to purchase one variety above another. The last thing to consider would be ability of the community to accept the new varieties and ecological impact of bringing a new variety into a closed ecosystem.

Trait Introgression

Trait introgression is the process by which individual genes are moved into a new genetic background. This process can be quite efficient considering the traits which would be necessary to adapt temperate crops to a more tropical environment. Many of these traits have known genes, either in other species, or within their own species that could be integrated into the genome of the new variety. All of the crops identified through the criteria above have existing cultivars that create value for them as a crop. Different varieties are known for their excellent flavor, high yields, or other characteristics that make them economically viable. However, these varieties are all lacking something that would make them better adapted to a tropical environment. For example, stone fruits all lack a mechanism to break dormancy without an adequate chill period. In theory, if the necessary traits for adaptation could be identified as solely controlled by one gene, then introgression may be a viable breeding method for adaptation. Trait introgression is generally achieved through backcross breeding, where a parent containing a specific gene or set of genes is crossed to another parent lacking those genes but containing some other characteristics of interest. The resulting progeny are then crossed back to the parent without the gene, with some mechanism to ensure the presence of the gene of interest at each round of crossing. This process is repeated until a desirable percentage of the recurrent parent genetics is recovered, while ensuring that the gene of interest is present and expressing.

Transgenic Introgression

Transgenic breeding is a very useful tool in the breeder's toolbox. It involves changing a specific targeted portion of the plant's DNA. This method is very convenient when genes and pathways are known, and it is used extensively in row crops and other high-dollar mass-produced species. One benefit is that foreign genes can be inserted into existing plant genomes. If a beneficial gene is found elsewhere, such as in an unrelated species, it can sometimes be inserted into the genome of a valued crop, allowing the beneficial trait to be present in the target species. There are only three transgenic fruit crops so far: papaya, plum, and apple (Tanuja 2017).

Non-Transgenic Introgression

Native traits can also be introgressed into the genome of a different cultivar of the same genus and species. This can be especially useful if a specific gene can be mapped in an existing cultivar and then introgressed into a variety that is already more tolerant to tropical cultivation.

Recurrent Selection

Recurrent selection is a method of breeding in which a population of plants with superior traits is selected. These traits can be phenotypically selected, or genetic markers for known genes can be utilized in a process deemed marker assisted selection. These plants are then self-pollinated. The self-pollinated seeds are harvested and replanted via single seed descent. Those plants are intercrossed, and seeds are harvested. On the third generation, plants are self-pollinated again, and so on and so forth with selection taking place at every selfing cycle.

There are two general ways to go about recurrent selection for tropical adaptation (Lyrene 2005). The first is beginning with wildtypes that grow well in hotter regions, then breeding them for beneficial agronomic traits. This is not quite the case for the above-mentioned fruits and the island of Molokai, as no endemic species of these plants exist. However, there could be wildtypes of any of the previously mentioned plants found in other parts of the Southern United States, Mexico, or Puerto Rico, all of which may be a suitable starting point for a breeding program.

The other breeding scheme would be to start with the productive commercial varieties and breed them to be adapted to grow in warmer climates.

The disadvantage of recurrent phenotypic selection is that it is time consuming, especially for species that take years before they flower and produce seed. Genomic recurrent selection offers the potential to replace pedigree breeding for genetic improvement (Gaynor 2017), especially in long-life crops.

To date, much of the work that has been done to develop low-chill cultivars has been through traditional crossing of native low-/no-chill varieties with high-chill varieties that possess desirable characteristics for the production market. The University of Florida has developed many low-chill fruits using this traditional method, including blueberry, peach, apple, pear, and plum. Subtropical apricot and sweet cherries are currently in development.

Recurrent selection has great advantages for adapting temperate foodstuff to a tropical environment. This is because the mechanisms known to induce, and break dormancy are not well understood. Even in the unlikely event that these obstacles could be overcome with a simple gene edit, there are several other issues that come with growing unadapted species in a tropical climate, that are undoubtedly controlled by independently segregating genes. These phenotypic traits can all be selected for together using recurrent selection.

Summary and Discussion

Several food plants already exist that are adequate for a complete healthy, nutritious diet that could provide for the entire island of Molokai. However, due to western dietary acculturation, almost no one currently eats a wholly traditional Hawaiian diet. In order to keep imported produce from our grocery store shelves, some plants will need to be adapted to a more tropical environment.

Molokai has a strong preference towards locally grown foods for many reasons, including price, freshness, and supply. People of the island want to be able to provide enough food for themselves on a regular basis, but also the residents of Molokai know that they are not immune to natural disasters. A tsunami or hurricane could cut off all outside contact for as long as 14 days (State of Hawaii 2019) and after the event, repair to shipping/import infrastructure would take even longer. Being able to grow all the foods available in our stores would be a step in the right direction to ending our dependency on imports.

There are several likely candidate foods that have been identified via purchasing trends. These include many different temperate crops, some of which are known to have issues that must be overcome through breeding before they can be grown on Molokai, but others have existing varieties that may be successful but have yet to be tested.

Transgenic crops may be possible but may not be economical for the island of Molokai. It is also safe to assume that transgenic crops would not currently be met with a high degree of enthusiasm and may be the target of outright protest. In 2014, there was an attempt to ban the cultivation of any GMO crop in Maui County. This initiative passed but was unable to be enacted since the courts ruled that a county regulation could not supersede a state or federal regulation (Imada 2016). Although the initiative did not receive enough votes to pass on Molokai, there was still much concern and many broken relationships across the island (Leong 2015).

In addition to breeding for low-chill cultivars, insect and disease resistance must be considered. In a tropical environment, there is no winter chill to break the insect cycle. Likewise, in a year-round cropping environment, there is almost always an available host for insects and favorable conditions for viruses, fungi, and pathogens. This is where transgenes providing resistance to these pressures could be a very viable solution and be incorporated to varieties that would be suitable for many locations.

Recurrent selection can also be used to breed new cultivars, but it is time consuming. The primary benefit to recurrent selection is that you can incorporate many unlinked beneficial traits all at once, rather than individually integrating genes of interest into the target genome. It can also be cost effective since many of the traits required to adapt plants to a tropical environment, such as drought tolerance or chill requirements, can be phenotypically selected and would not require any genetic selection.

When developing new varieties for a specific region, especially an island community, one aspect that must be taken into consideration is the variability of base genetics. An adequate amount of genetic variability should be preserved to ensure the ability to withstand disease and pest pressures. An excellent example of this can be found in the native Wiliwili tree (*Erythrina sandwicensis*), which was on the verge of extinction after a gall wasp epidemic in the early 2000s. The genetic base was so narrow, that one wasp infestation was able to wipe out nearly the entire population. A wider genetic base gives the opportunity for plants to have varying degrees of resistance to pests.

Another concern when breeding for an island environment would be the weediness potential. An environmental impact study should be conducted to ensure that releasing new cultivars or new species would not create an invasive weed problem. It should also be ensured that these new species would not easily spread, push out native species of plants, or wreak havoc on existing species of animals, insects, or on entire ecosystems. There is also the possibility of intentional deforestation and destruction of cultural areas in order to add crop land. This should not prove an issue for the island of Molokai since much of the area is protected through parks and state managed lands, but there still exist some large, privately owned areas that could be exploited if the proper regulations were not put in place before large-scale cultivation of an adapted crop began.

Conclusion and Recommendations

The people of Molokai want food sovereignty, and this report provides a foundation for identifying crops and breeding strategies that will enable local food production.

Producing more foods locally could lower the price and increase the availability of fresh produce, thus encouraging people to choose healthier options at the grocery store. Making healthier food choices would alleviate many of the health concerns plaguing pacific islanders, or anyone with cardiovascular disease, diabetes, or obesity. As mentioned in the background, there is a strong desire for local production amongst many Molokai residents, however, further social and economic analyses would need to be conducted in order to determine if Molokai residents would be willing and able to adequately compensate growers for their investments.

The adaptation of temperate foodstuffs to a tropical environment would not only benefit the island of Molokai, but this work could be translated into other island regions that want to lower the carbon footprint of their imported goods. It could also provide a basis for other communities facing overall temperature increase due to climate change. It is hard to quantify just how much of our global emissions is coming from the transportation of foodstuffs from South America to the mainland US and then to Hawaii, or the transportation of food anywhere around the globe, but the fact remains that atmospheric carbon is around 30% higher now than it was in pre-industrial times, and continues to increase (Vijay 2011).

Increased atmospheric carbon correlates with increased surface temperatures, changes in precipitation patterns, shifts in climatic mean and shifts in climatic variability. These changes could be devastating to all types of ecosystems. It is estimated that the Earth's mean surface temperature will probably rise by 1.8 to 4 degrees Celsius by the end of this century. Since the 1980's changes in temperature have correlated to an absolute response to plant phenology (Vijay 2011). Thus, all temperate food crops will likely eventually be threatened by climate change. Due to the time it takes to breed new varieties, this work should begin now. In the event that climate change is slowed or reversed, this work would still be valuable to the Hawaiian Islands and other tropical regions.

Bibliography

Advertiser Staff. 2008. "Molokai ranch timeline." *Honolulu Star Advertiser*, March 26: online archive.

Allen, O., and E.K. Allen. 1933. *The manufacture of poi from taro in Hawaii: with special emphasis on its fermentation.* Honolulu: Hawaii Agricultural Experiment Station, 1-30.

Anderson, I., S. Crengle, M.L. Kamakana, T. Chen, N. Palafox, and L. Jackson-Pulver. 2006. "Indigenous health in Australia, New Zealand, and the Pacific." *The Lancet* 367: 1775-1785.

Arakaki, A. 2014. "Peaches on Molokai." *Molokai Dispatch*, August 4.

Avetisyan, M., T. Hertel and G. Sampson. 2014. "Is local food more environmentally friendly? the GHG emissions impacts of consuming imported versus domestically produced food." *Environmental and Resource Economics* 58 (3): 415–462.

Bernal-Vicente, A., D. Cantabella, J.A. Hernandez, and P. Diaz-Vivancos. 2018. "The effect of mandelonitrile, a recently described salicylic acid precurser, on peach plant response against abiotic and biotic stress." *Plant Biology* (https://doi.org/10.1111/plb.12894) 20 (6).

Brewbaker, J.L., J.R. Thompson, P.P. Rotar, D.J. Heinz, U. Urata, H. Kamemoto, H.Y. Nakasone, R.A. Hamilton, P.J. Ito, J.C. Gilbert, J.S. Tanaka, and R. Terry. 1982. "Crop improvement in hawaii: past, present, and future." Compendium based on Proceedings of a Conference Sponsored by the College of Tropical Agriculture and Human Resources, University of Hawaii and the Hawaii Crop Improvement Association, Hawaii Agricultural Experiment Station College of Tropical Agriculture and Human Resources University of Hawaii, Honolulu.

Broekgaarden, C., T. Snoeren, M. Dicke, and B. Vosman. 2011. "Exploiting natural variation to identify insect-resistance genes." *Plant Biotechnology Journal* 9 (8): 819-825.

Buzby, J., H. Wells, and J. Hyman. 2014. *The estimated amount, value, and calories of postharvest food losses at the retail and consumer levels in the United States.* Economic Information Bulletin 121, USDA.

Camargo, U.A. 2000. "Grape breeding for the subtropical and tropical regions of Brazil." *Acta Hortic* (International Society for Horticultural Science) 528: 479-480.

Canals, L.M.I., S.J. Cowell, S. Sim, and L. Basson. 2007. "Comparing domestic versus imported apples: A focus on energy use." *Environmental Science and Pollution Research Institute* 14 (5): 338-344.

Cao, Z., J.M. Green-Johnson, N.D. Buckley, and Q. Lin. 2019. "Bioactivity of soy-based fermented foods: A review." *Biotechnology Advances* 37 (1): 223-238.

Chen, W., J.Shao, M. Ye, K. Yu, S.Y. Bednarek, X. Duan, and W. Guo. 2017. "Blueberry VcLON2, a peroxisomal LON protease, is involved in abiotic stress tolerance." *Environmental and Experimental Botany* 134: 1-11.

Cluett, Catherine. 2012. "Tracking molokai's population: the latest stats." *The Molokai Dispatch.* https://themolokaidispatch.com/tracking-molokais-population-the-latest-stats/, March 7.

Deinlein, U., A.B. Stephan, T. Horie, W. Luo, G. Xu, and J.I. Schroeder. 2014. "Plant salt-tolerance mechanisms." *Trends in Plant Science* 19 (6): 371-379.

Department of Hawaiian Home Lands. 2005. "Molokai island plan." https://dhhl.hawaii.gov/wp-content/uploads/2012/05/Island_Plan_Molokai_2005.pdf, June.

Dubrivina, A., K.V. Kiselev, V.S. Khristenko, and O.A. Aleynova. 2016. "VACPK21, a calcium-dependent protein kinase gene of wild grapevine Vitis amurensis Rupr., is involved in grape response to salt stress." *PCTOC* 124 (1): 137-150.

Faust, M., D.Liu, S.Y. Wang, and G.W. Stutte. 1995. "Involvement of apical dominance in winter dormancy of apple buds." *International Society for Horticultural Science* 47-55.

Feuillet, C., S. Travella, N.Stein, L. Albar, A. Nublat, and B. Keller. 2003. "Map-based isolation of the leaf rust disease resistance gene Lr10 from a hexaploid wheat (Triticum aestivum L.) genome." *PNAS* (https://doi.org/10.1073/pnas.2435133100) 15253-15258.

Fujita, R., K. Braun, and C.K. Hughes. 2004. "The traditional Hawaiian diet: A review of the literature." *Pacific Health Dialogue* 11 (2).

Garden-Robinson, J. and P. Halsted. 2017. *North Dakota State University Field to Fork Edamame!* February. Accessed November 2019. https://www.ag.ndsu.edu/publications/food-nutrition/field-to-fork-edamame#section-4.

Gates Foundation. 2019. *Nutrition strategy overview.* Accessed November 2019. https://www.gatesfoundation.org/what-we-do/global-development/nutrition#OurStrategy.

Gaynor, C., G. Gorjanc, A.R. Bentley, E.S. Ober, P. Howell, R. Jackson, I.J. Mackay, and J.M. Hickey. 2017. "A two-part strategy for using genomic selection to develop inbred lines." *Crop Science* (http://dx.doi.org/10.2135/cropsci2016.09.0742) 57 (5): 2372-2386.

Gellert, K., K. Braun, R. Morris, V. Starkey. 2006. "The ohana day project: A community approach to increasing cancer screening." *Preventing Chronic Disease* 3: A99.

Gemma, S., Y. Sumiko, S. Yoshihiko, and S. Hiroshi. 2009. "Differential adaptation of high- and low-chill dormant peaches in winter through aquaporin gene expression and soluble sugar content." *Plant Cell Reports* 29 (1709).

Grandinetti, A., H.K. Chang, A. Theriault, and J. Mor. 2005. "Metabolic syndrome in a multiethnic population in rural Hawaii." *Ethnicity & Disease* 15.

Guerrero, L.R.T., S.E. Gebhardt, J. Holden, M.J. Kretsch, K. Todd, R. Novotny, and S.P.Murphy. 2009. "White rice sold in Hawaii, Guam, and Spain often lacks nutrient enrichment." *Journal of the American Dietetic Association* 109 (10): 1738-1743.

Gupta, C. 2014. "Sustainability, self-reliance and aloha aina: the case of Molokai, Hawaii." *Internal Journal of Sustainable Development and World Ecology* 389-397.

Harvard. 2019. *T.H. Chan School of Public Health.* Accessed November 2019. https://www.hsph.harvard.edu/nutritionsource/food-features/apples/.

Hawaii Rice Fest. n.d. *History of rice in Hawaii.* Accessed September 2019. http://ricefest.com/all-about-rice/.

Hawaiian Homes Commission Act. 1921. Stat 108 (Hawaii State Constitution, July 9).

Heller, M.C., G.A. Keoleian, and W.C. Willett. 2013. "Toward a life cycle-based, diet-level framework for food environmental impact and nutritional quality assessment: a critical review." *Americal Chemical Society* (Environmental Science and Technology) 12632-12646.

HISC. 2019. *Hawaii Invasive Species Council.* Accessed November 2019. https://dlnr.hawaii.gov/hisc/info/invasive-species-profiles/.

Huang, A.S., C.A. Titchenal, and B.A. Meilleur. 2000. "Nutrient Composition of Tasro Corms and Breatfruit." *Journal of Food Composition and Analysis* 13: 859-864.

Imada, L. 2016. "Anti-GMO law is effictively dead." *The Maui News*, November 19.

Jones, A. 2002. "An environmental assessment of food supply chains: a case study on dessert apples." *Environmental Management* 30 (4): 560-575.

Kaiser, C. and M. Ernst. 2016. *Edamame.* College of Agriculture Food and Environment Cooperative Extension Service, College of Agriculture Food and Environment Cooperative Extension Service, University of Kentucky, Lexington: Center for Crop Diversification Crop Profile.

Kamas, J., M. Nesbitt, and L. Stein. 2015. *Apples: Texas fruit and nut production.* Extension Fruit Specialists, The Texas A&M University System, College Station: Texas A&M Agrilife Extension.

Kataoka, S. 2005. "Functional effects of Japanese style fermented soy sauce (shoyu) and its components." *Journal of Bioscience and Bioengineering* 100 (3): 227-234.

Krauss, F.G. 1911. *Leguminous crops for Hawaii.* Bulletin No. 23 of the Hawaii Agricultural Experiment Station, Honolulu: Hawaii Agricultural Experiment Station.

Leiss, K.A., F. Maltese, Y.H. Choi, R. Verpoorte, and P.G.L. Klinkhamer. 2009. "Identification of chlorogenic acid as a resistance factor for thrips in chrysanthemum." *Plant Physiology* 1567-1575.

Leong, L. 2015. "Facing future." *Hawaii Business Magazine*, March 17.

Li, Y. , Q. Chen, H. Nan, X. Li, S. Lu, X. Zhao, B. Liu, C. Guo, F. Kong, and D. Cao. 2017. "Overexpression of GmFDL19 enhances tolerance to drought and salt stresses in soybean." *PLOS One* (doi.org/10.1371/journal.pone.0179554).

Longstroth, M. 2013. "Winter dormancy and chilling in woody plants." *Michigan State University Extension*, January 16: 1.

Lyrene, P.M. 2005. "Breeding low-chill blueberries and peaches for subtropical areas." *Horticultural Science* 40 (7): 1947–1949.

Members of the Molokai Community. 2008. *Molokai Future of a Hawaiian Island.* Community Planning, Kaunakakai: https://www.molokai.org/files/Molokai.Future.of.a.Hawaiian.Island.pdf.

Messina, C.D., T.R. Sinclair, G.L. Hammer, D. Curan, J. Thompson, Z. Oler, C. Gho, and M. Cooper. 2015. "Limited-transcription trait may increase maize drought tolerance in the US corn belt." *Agronomy Journal* 107 (6): 1978-1986.

Molokai Community Health Center. 2019. *overview of organization.* Accessed September 2019. http://molokaichc.org/overview-of-organization/.

Nelson, R. , T. Wiesner-Hanks, R. Wisser, and P. Balint-Kurti. 2017. "Navigating complexity to breed disease resistant crops." *Nature Reviews Genetics* 19: 21-33.

Nelson, T. 1987. *Adzuki Bean.* Extensiion Service Publication, Grain legumes as alternative crops,: University of Hawaii, 67-76.

Peng, Y., W. Lin, W. Cai, and R. Arora. 2007. "Overexpression of a panax ginseng tonoplast aquaporin alters salt tolerance, drought tolerance and cold acclimation ability in transgenic Arabidopsis plants." *Planta* (226): 729-740.

Ramirez, L. , and C. Massiel. 2016. *Quantative trait loci (QTL) for salt tolerance in soybean and physiological response to salt stress during early growth stage.* Thesis Dissertation, University of Arkansas.

Ratna, R., S. Joshi, S. Roy, O. Singh, M. Samir, and A. Chandra. 2015. "Implications of changing climate on productivity of temperate fruit crops with special reference to apple." *Journal of Horticulture* (DOI: 10.4172/2376-0354.1000135) 2 (2).

Roberts, L.M. 2000. *Historical changes in land use in relation to land erosion and sedimentation on the reefs of South Molokai.* 9th Pacific Congress on Marine Science and Technology: PACON, Honolulu: Hawaii Institute of Marine Biology, University of Hawaii at Manoa.

Shintani, T.T., S. Beckham, A.C. Brown, and H.K. O'Connor. 2001. "The Hawaii diet: ad libitum high carbohydrate, low fat multi-cultural diet for the reduction of chronic disease risk factors: obesity, hypertension, hypercholesterolemia, and hyperglycemia." *Hawaii Medical journal* 60: 69-73.

State of Hawaii. 2019. *Hawaii Emergency Management Agency.* Accessed November 2019. https://dod.hawaii.gov/hiema/get-ready/prepare-your-family/.

Sun, X., P. Wang, X. Jin, L. Huo, R. Che, and F. Ma. 2017. "Improvement of drought tolerance by overexpressing MdATG18a is mediated by modified antioxidant system and activated autophagy in transgenic apple." *Plant Biotechnology Journal* (https://doi.org/10.1111/pbi.12794) 16 (2).

Sust 'aina ble Molokai. 2009. "Resource Guide 2009." *Sustainable Molokai.* Accessed September 2019. http://www.sustainablemolokai.org/wp-content/uploads/2012/04/SM-Resource-Guide-2009.pdf.

Tanuja, P., and Kumar, A.L. 2017. "Transgenic fruits crops- a review." *International Journal of Current Microbiology and Applied Sciences* (doi.org/10.20546/ijcmas.2017.608.241) 2030-2037.

Temesgen, M., and N. Retta. 2015. "Nutritional potential health and food security benefits of taro colocasia esculenta (L.): a review." *Food Science and Quality Management* 36: 23-30.

Teves, G.L. 2014. "Low chill temperate fruits." *Molokai Dispatch*, March 27: Community Contributed.

Tomm, G., O. Smiderle, R. Raposo, G.A. Dalmago, A.Soares, E. Figer, A. Luft, E. Batistella, V. Scarantti, and F. Benin. 2011. "Can canola be produced in tropical areas?" *13th Annual International Rapeseed Conference Proceedings.* Prague. 2-5.

Trainin, T., M. Zohar, E. Shimoni-Shor, A. Doron-Faigenboim, I. Bar-Ya'akov, K. Hatib, N. Sela, D. Holland, and T. Isaacson. 2016. "A unique haplotype found in apple accessions exhibiting early bud-break could serve as a marker for breeding apples with low chilling requirements." *Molecular Breeding* (https://doi.org/10.1007/s11032-016-0575-7) 36 (158): 1-13.

Tu, M., X. Wang, T. Feng, X. Sun, Y. Wang, L. Huang, M. Gao, Y. Wang, and X. Wang. 2016. "Expression of a grape (Vitis vinifera) bZIP transcription factor, VlbZIP36, in Arabidopsis thaliana confers tolerance of drought stress during seed germination and seedling establishment." *Plant Science* 252: 311-323.

University of Hawaii Office of Communication Services. 2015. "Pretty Peachy." *Impact Stories*, November 23: 1.

University of Hawaii. n.d. "Soybean." University of Hawaii, College of Tropical Agriculture and Human Resources Home and Garden Vegetable Series No. 14.

USDA. 2017. "Hawaii census of agriculture." https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_County_Level/Hawaii/.

—. 2019. *SNAP-Ed Connection.* Accessed November 2019. https://snaped.fns.usda.gov/seasonal-produce-guide.

Vargas, P., and L.F. Jurado. 2015. "Dietary acculturation among Filipino Americans." *International Journal of Environmental Research and Public Health* (doi: 10.3390/ijerph13010016.) 13: 16.

Vijay, P., A. Singh, and R. Pandey. 2011. *Vulnerability of trees and fruit crops to climate change.* Vol. and Tomorrow's Printer and Publishers, in *Climate Change: Impacts and Adaptations in Crop Plants*. New Delhi.

Vinyes, E., L. Asin, S. Alegre, P. Munoz, J. Boschmonart, and C.M. Gasol. 2017. "Life cycle assessment of apple and peach production, distribution and consumption in mediterranean fruit sector." *Journal of Cleaner Production* 149: 313-320.

Wang, F., H. Zhu, D. Chen, Z. Li, R. Peng, and Q. Yao. 2016. "A grape bHLH transcription factor gene, VvbHLH1, increases the accumulation of flavonoids and enhances salt and drought tolerance in transgenic Arabidopsis thaliana." *PCTOC* 125 (2): 387-398.

Wilson, Juan. 2019. "Island Breath." *Hawaiian land divisions: a new way to access the Moku and Ahupuaa divisions of the islands of Hawaii.* http://www.islandbreath.org/mokupuni/M3Molokai/M3MolokaiPlotFile.pdf, April 26.

Wysmierski, P.T. and N.A. Vello. 2013. "The genetic base of Brazilian soybean cultivars: evolution over time and breeding implications." *Genetics and Molecular Biology* 36 (4): 547-555.

Xiong, Li., R.G. Wang, G. Mao, and J. Koczan. 2006. "Identification of drought tolerance determinants genetic analysis of root response to drought stress and abscisic acid." *Plant Physiology* 142: 1065-1074.

Yamane, H., R. Tao, T. Ooka, H. Jotatsu, R. Sasaki, and K. Yonemori. 2011. "Comparative analyses of dormancy-associated MADS-box genes, PpDAM5 and PpDAM6, in low-and high-chill peaches (Prunus persica L.)." *Journal of the Japanese Society for Horticultural Science* 80 (3): 276-283.

Yonghong, L. , Y. Zhang, F. Feng, D. Liang, L. Cheng, F. Ma, and S. Shi. 2010. "Overexpression of a Malus vacuolar Na+/H+ antiporter gene (MdNHX1) in apple rootstock M.26 and its influence on salt tolerance." *PCTOC* 102 (3): 337-345.

Yu, X., X. Li, T. Guo, C.Zhu, Y,Wu, S.E. Mitchell, K.L. Roozeboom, D. Wang, M.L. Wang, G.A. Pederson, T.T. Tesso, P.S. Schnable, R.Bernardo, and J. Yu. 2016. "Genomic prediction contributing to a promising global strategy to turbocharge gene banks." *Nature Plants* 16150.