

# CTAHR and Taro

Taro Research by the  
College of Tropical Agriculture  
and Human Resources



**College of Tropical Agriculture  
and Human Resources**  
University of Hawai'i at Mānoa

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## Overview

Over the past century, personnel associated with the UH College of Tropical Agriculture and Human Resources (CTAHR) and its predecessor institutions have done many types of research with taro (*Colocasia esculenta*). Efforts have included work on

- disease avoidance through good agricultural practices
- yield improvement through better soil and plant nutrient management
- control of pests including weeds, insects, nematodes, and plant disease pathogens
- mechanization of planting, harvesting, and processing
- postharvest handling practices
- food product processing methods
- genetic studies and breeding to develop new varieties.

Publications resulting from these many and diverse efforts are listed in a bibliography at the end of this report.

Most of this work has been welcomed and accepted by those engaged in taro growing, processing, and marketing in Hawai'i. In recent years, however, there has been discomfit in some sectors of the populace about some aspects of the last research area listed, genetic studies and breeding.

Work on the taro genome in Hawai'i has not always been a target of criticism. The collection, characterization, and preservation of the taros introduced by early colonizers, over the centuries when humans first populated the Hawaiian archipelago, before the arrival of Europeans, has been a goal of the college's agricultural scientists for the past century. A concerted program on this in the 1930s by L.D. Whitney and colleagues became a foundation for subsequent efforts. Since the early 1970s, college scientists including Jill Wilson, Ramon de la Peña, Vincent Lebot, Eduardo Trujillo, John Cho, Susan Miyasaka, and Xiaoling He have studied taro genetics and the taro breeding system.

Three general areas of concern for recent critics of CTAHR taro work are (1) the introductions of *Colocasia* genetic materials from elsewhere, and their use in breeding, (2) patenting of plants developed through breeding, and (3) genetic engineering.

Considerations about introductions of new genetic taro materials should begin with what is known, or, more relevantly, is *not* known, about the taros called Hawaiian varieties. These are preferred by many people who grow, process, and consume taro, and by some people they are venerated and even considered to be ancestors. Taros introduced by ancient voyagers very likely consisted of the varieties favored by various groups of Polynesians that migrated to the islands, at various times. No one knows how many of these introductions there were, but eventually the separate importations blended into the large group of cultivated varieties, with their many different qualities and purposes, that we know as the traditional Hawaiian taros. We can only wonder if any of these importations crossbred, by chance or grower design, to result in any new types of taro that are



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truly endemic to Hawai'i. Even the currently popular Maui Lehua taro, despite its Hawaiian name, may be a mixture that includes taros other than the original "canoe plants" that constitute the Hawaiian cultural heritage.

By introducing new taros from elsewhere in the world, agricultural scientists have continued an ancient tradition of seeking the best, most useful, most resilient forms of taro. When breeding can combine new traits with the favored qualities of the traditional Hawaiian types to produce plants that grow better and resist diseases, the new plants ensure a continued supply of a cherished traditional food source. The current set of taro pests and pathogens, including some known problems that may yet arrive here from afar, is a formidable challenge to the relatively narrow genome of the traditional Hawaiian taro varieties, compared to the resources available within the full *Colocasia* genome, and the broadening of the taro genetic resource obtained by sharing taros with other regions could be seen as an advantage, not a threat. Sharing of the improved plant materials developed from breeding efforts in Hawai'i with researchers in other countries could be considered a reciprocal, collaborative advantage that may yield unanticipated future benefits.

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The second concern, patenting, is covered in detail in this report. The bottom line on this issue is that taro patents obtained in the 1990s were later renounced by the university, ornamental colocasias patented recently do not contain any traditional Hawaiian taro genetic material, and any further seeking of patents on food taros derived from Hawaiian taros will be done in consultation with appropriate Hawaiian cultural groups.

The third concern, genetic engineering, is considered by most scientists to be a potentially promising technology for taro improvement, offering perhaps quicker results than traditional breeding methods and opening the possibility of incorporating favorable traits from beyond the set available in the *Colocasia* genome. The opposition to this avenue of taro development is complex and not solely derived from Hawaiian cultural sources. However, because of the expressed concerns of some Hawaiian cultural constituencies about this issue, the college administration has declared a moratorium on further genetic engineering research on Hawaiian taro. Because of the cultural sensitivity surrounding this heritage crop, any future application of genetic engineering biotechnology to taro will be done only after appropriate consultation with the community.

In the meantime, as of the date of this report, the status of the transgenic Chinese taro materials developed in the genetic engineering research program described in this report is uncertain. "Ownership" of the genetically transformed materials is shared with a private organization, and the student who did the transformations has intellectual property rights relating to the materials. CTAHR faculty involved in the research have no plans for further work with the materials produced under the program, and CTAHR's administration is working to resolve issues standing in the way of destruction of the experimental plants.

## Introduction

*CTAHR has devoted countless years of faculty time to taro and produced hundreds of journal articles, theses and dissertations, and research and extension publications on the crop.*

This report describes the work of the University of Hawai‘i’s College of Tropical Agriculture and Human Resources (CTAHR) on taro, *Colocasia esculenta*, an important crop in Hawai‘i, the Pacific, and worldwide. Following an overview of a century’s history of serving the taro industry, it provides a description and explanation of taro cultivar (or variety) development work conducted, during the past two decades, primarily by three members of the CTAHR faculty, Dr. Eduardo Trujillo, Dr. John Cho, and Dr. Susan Miyasaka. In the past several years, a public controversy has arisen over the research done by these faculty members. This paper will present the facts regarding these research programs and consider their relation to the current controversy.

CTAHR is the descendent of the founding college of the University of Hawai‘i. It is part of the federal system of land grant institutions, and its mission comprises *instruction* (formal education on the UH Mānoa campus), *research* (through a statewide network of research stations and research faculty assignments, formerly known as the Hawaii Agricultural Experiment Station), and *outreach* (nonformal education, through faculty assignments to offices of the Cooperative Extension Service on Kaua‘i, O‘ahu, Moloka‘i, Maui, and Hawai‘i). The land grant system was established to assist U.S. states and territories with scientific research in support of developing successful communities by creating, improving, and maintaining agricultural production systems. Thus charged with assisting (among other agricultural industries) the taro industry, over the past century CTAHR has devoted countless years of faculty time to taro and produced hundreds of journal articles, theses and dissertations, and research and extension publications on the crop.

The recent opposition to, or dissatisfaction with, CTAHR work on taro cultivar development arises from several sources. One source of opposition, and perhaps the most locally relevant, is members of a segment of the Hawaiian community that regard taro as a revered ancestor. They perceive manipulations of the taro genome as a desecration of their legendary heritage.\* This objection may, with some justification, be related to a broader resentment about usurpation of Hawaiian hegemony over the islands by Euro-American foreigners, and it also may be related to the current, diverse movement toward Native Hawaiian sovereignty. CTAHR, as a state and federal institution, may in some sense be a proxy for entities responsible for the historical intervention that ended the Hawaiian monarchy, resulted in the annexation of Hawai‘i by the United States, and led to Hawai‘i becoming a state.

Another source of opposition is those who consider the Hawaiian taro varieties to be superior to any others. They believe that the problems affecting taro production in Hawai‘i today are due not to introduced pests but to restrictions imposed by government on access to land and, particularly, water resources.

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\*Strong cultural traditions tied to taro are not unique to Hawai‘i. For a comprehensive review of taro lore (and current taro growing conditions) in the Solomon Islands, see [http://www.terracercircle.org.au/pmn/report/hidden\\_taro.html](http://www.terracercircle.org.au/pmn/report/hidden_taro.html).

*As this paper will try to show, CTAHR faculty working with taro have pursued their professional objectives in line with their ethics, the principles of academic freedom, and their obligations as scientists and members of a land grant university faculty.*

A third source of opposition is a movement that opposes globalization and the use of biotechnology in agriculture and other areas. In particular, some adherents of this movement are suspicious of genetic engineering biotechnology and fearful of its possible negative consequences for the “natural order” of life on Earth. This anti-GMO (genetically modified organism) activist segment is a subset of a broader group which believes that “organic agriculture” produces foods more conducive to human health than do other forms of production, and that the methods it involves are more favorable to sustaining a “healthy” environment.

As this paper will try to show, CTAHR faculty working with taro have pursued their professional objectives in line with their ethics, the principles of academic freedom, and their obligations as scientists and members of a land grant university faculty. At their best, these efforts have combined innovation with practical application, attracting grant funding for discovery and demonstration, while minimizing the timeframe for developing solutions to real-farm problems. Unfortunately, certain of these research efforts have resulted in the college becoming an object of criticism by some individuals and groups who desire that their beliefs and agendas gain broader attention. This situation is not unusual in context of the many seemingly intractable controversies that plague the U.S. body politic and strain national unity. Assertions of values or cultural values, which may have religious connotations, do not readily find common cause with the principles that motivate the professional activities of CTAHR faculty, activities that are (and, constitutionally, must be) secular.

It is hoped that a candid description of CTAHR’s recent taro variety development projects will dispel rumors and allow citizens and their elected decision-makers to assess the controversy over this work and come to informed conclusions about CTAHR’s efforts to support Hawai‘i’s agriculture and economy.

## CTAHR's History of Care for Taro

The predecessor of today's College of Tropical Agriculture and Human Resources (CTAHR) was founded in 1907, but the college's roots extend back to 1901, when the federal Hawaii Agricultural Experiment Station was established. Since that time, many scientists and extension agents have devoted their efforts to taro and its farmers, in recognition of its status as a unique, treasured heritage plant and an important crop for Hawai'i's culture and agricultural economy. One of the station's first projects was to investigate the root rot disease that was plaguing taro. The station's workers sought to understand the optimum production environment for taro, to identify the causes of diseases affecting the crop, and to find the best ways to provide supplemental plant nutrients so that taro would be produced at optimal levels.

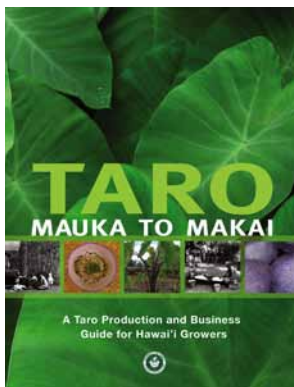
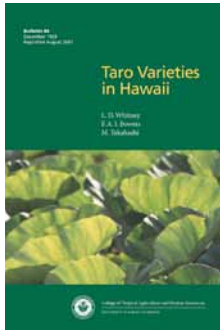


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After some work at the new research station on the east side of Punchbowl Crater, agriculturalist Thomas Sedgwick published *The Root Rot of Taro*. This bulletin addressed a problem affecting many taro patches, especially ones that were not cared for in the traditional way. It suggested that taro growers simply were not taking the best possible care of their crop, and that lack of proper care was leading to the root rots, and it gave recommendations on practices that could reduce disease incidence. (The factors contributing to the lack of proper care of taro at the time were outlined in the 2007 CTAHR publication by Cho et al., *Hawaiian Kalo, Past and Future*.) Sedgwick's bulletin was later translated (*Na Hoao No Ke Pale Ana I Ka Pala O Ke Kalo*) for Hawaiian readers. In 1911, E.V. Wilcox, special agent in charge of the Hawaii Agricultural Experiment Station, and Frederick Clowes, superintendent of its substations on Hawai'i, wrote another bulletin titled *No Ka Hooulu Ala I Ke Kalo* (*The Cultivation of Taro*), which was published only in Hawaiian.

The improvement of varieties for productivity and taste was also of great interest to early researchers and extension agents. Frederick G. Krauss, considered the father of agricultural extension in Hawai'i, grew varieties of taro on his New Era Homestead farm in Ha'ikū, Maui, after moving there in 1915. In 1918, taro was a big hit at the First Territorial Fair held where the Ala Wai golf course now stands. Many people wanted to take planting materials back to their home gardens as a result of displays they viewed at the Fair. In 1919, applied research on taro root rot was undertaken on Moloka'i in cooperation with the Bernice P. Bishop estate. The diseases were still taking a big toll on production, however, and wheat flour often substituted for poi in times of shortage, unless there was a war on, and then even wheat was restricted.

There was a push to resuscitate taro production in the 1930s, with work on cataloging and preserving varieties, improving plant nutrition to reduce plant disease, and processing. A large project was funded by the federal Sugar Act, known as the Jones-Costigan Act, in 1935, when \$50,000 was invested in "taro rehabilitation and study," funding innovative taro processing work developed by college researchers in partnership with the Kalihi Poi Company. At the Pensacola Street Station, a garden of 140 taro accessions was planted and maintained, and the



Two popular taro publications are CTAHR's *Taro: Mauka to Makai* and *Taro Varieties in Hawaii*.

collection ultimately led to the 1939 classic bulletin, *Taro Varieties in Hawaii*, by Whitney, Bowers, and Takahashi. This collection has been maintained by the college (despite some losses) and is one reason that many Hawaiian taro varieties still exist in Hawai'i today. Hawaiians, once the predominant taro producers, had been gradually replaced in that role by immigrants, at first Chinese and then Japanese, for whom taro was not as important a heritage plant, and who may have lacked the Hawaiians' appreciation for the taste and ceremonial uses of their heirloom cultivars.

Although the scientists had noticed that seed production in taro was rare, they attempted some breeding work when flowers occurred in the collection. They reported that despite the rarity of flowering in taro, they successfully self-pollinated or crossed some plants.

Disease work by G.K. Parris, funded by the Sugar Act, helped farmers get a better understanding of the problems they faced and possible solutions. As it turned out, most of the problems, even back to the early 1900s, were related to lack of fallow periods, poor nutrition management, and difficulties with pest control.

WWII and a decline of sugar money interrupted the work on taro, except for the college's introduction of the plastic bag as a way for taro millers to distribute their product to a larger market. *The Manufacture of Poi from Taro in Hawaii: With Special Emphasis upon its Fermentation* was published in 1933 by A.N. Allen and E.K. Allen; it remains the key reference in understanding poi from the micro-biological standpoint.

In the 1970s CTAHR scientists Donald Plucknet, Ramon de la Peña, and H.C. Ezumah, working on Kaua'i, again took up research on taro nutrition, pest management, cultivar collection, and breeding. Working with the Kaua'i Agricultural Research Station's collection of taro varieties, de la Peña developed a promising new variety, but the processors did not find it acceptable. M. Ray Smith developed a harvester for flooded taro, but it never really took off with growers.

Starting in the late 1980s, as a result of the college's Industry Analysis process, another attempt was made to bolster the declining market for taro-based products and strengthen the taro production system. A marketing newsletter, *The Taro Tattler*, was produced from 1989 to 1994. This newsletter was one inspiration for various taro festivals that were started then, the first being at Windward Community College in Kane'ohe in 1989.

A Japanese firm was interested in having taros with white corm flesh grown in Hawai'i to make hypoallergenic foods, and a conference on white taro in 1990 generated a lot of interest. A large-scale upland taro harvester was developed, and a processing plant to produce the flour product was designed. Alvin Huang and James Hollyer received a patent for their work on taro flour processing. Huang continued to work with taro product manufacturers on value-added products. Interest in the project ran out when the Japanese economic "bubble" collapsed during the 1990s.



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Led by Hollyer, a group of taro experts from the college and the community developed a production guide, *Taro, Mauka to Makai*, in 1997. A second edition, extensively revised, was published in 2008. The revision included much new work on problems such as pocket rot, apple snail, and nutrient deficiencies that had been done by CTAHR faculty and others since the first edition was published.

Building on and extending this century-long history of concern for taro, CTAHR continues to maintain its collection of taro varieties at several of its research stations and to make propagation materials available to the public at little or no cost. The variety improvement work described below has been done to ensure that taro continues to be a successful crop and a thriving agricultural industry. Some of the breeding work was done in response to requests from growers in Hanalei, Ke'anae, and other taro production areas. The emergence of the idea that the improvement work is detrimental to taro as a Hawaiian heritage plant has been distressing to those in CTAHR who carry on its tradition of applying science for the benefit of Hawai'i's crops and farmers.

## Breeding for Resistance to Taro Leaf Blight

Taro farmers in Hawai'i, the Pacific, and other parts of the world face many problems that reduce taro yields, and one of the worst is taro leaf blight disease. Most taro cultivars are susceptible to attacks by the blight pathogen *Phytophthora colocasiae*, a fungus-like organism that infects the leaves, destroying tissues and thereby reducing plant growth and corm size and quality. It is believed that this pathogen was introduced into Hawai'i in about 1920. It is suspected to have caused a lot of damage thereafter, including loss of dozens of the more susceptible Hawaiian heirloom varieties, but when it became recognized as a unique, new pathogen here is uncertain.

When the disease reached the islands of Samoa in the early 1990s, it reduced taro production by 97 percent and contributed to a steep decline in agriculture's value to those countries' economies. Within two years of the disease's introduction to the Caribbean in 2004, taro yields in the Dominican Republic were reduced by 80 percent, and in Puerto Rico the taro crop loss was total.

During the early stages of the disease outbreak and epidemic in the Samoas, CTAHR plant pathologist Eduardo Trujillo responded to requests for assistance received through CTAHR's Pacific-focused Agricultural Development in the American Pacific project. He embarked on an effort to produce taro cultivars that would resist (or tolerate) leaf blight (the phytopathological distinction between resistance and tolerance is obscure; in the following, "resistance" generally means "tolerance"). Trujillo screened taros from Guam, Rota, and Palau for blight disease resistance at Hakalau, on Hawai'i, in 1995–96. Among the blight-resistant materials he found, he selected a Palauan cultivar, Ngeruuch, that was resistant to most yield-limiting effects of the disease. The pathogen is capable of invading Ngeruuch leaf tissues, but only nonsystemically, producing "shot-hole" lesions—



Taro leaves infected with taro leaf blight. Taros brought by Polynesian voyagers to the Hawaiian archipelago lack resistance to the leaf blight pathogen, *Phytophthora colocaseae*. The infection is systemic in these taro varieties: the lesions will spread over the leaf, and it will die.

Photo: Janice Uchida

holes surrounded by dead tissue. Unfortunately, the Palau taros have an undesirable spreading characteristic of developing suckers on rhizomes produced by long runners, whereas taros preferred in Hawai'i have suckers ('ohā) attached closely to the makua (mother plant); also, the eating qualities of the Palau taros differ from those accepted in Hawai'i.

The leaf blight disease is also present in Hawai'i and causes major production losses during periods of rainy or overcast weather. The cultivar Maui Lehua, the most extensively grown poi taro, is susceptible to blight. This presumed Hawaiian/Polynesian taro, selected in the 1960s by a farmer on Maui, has the "red" (i.e., purple-gray) corm color of other cultivars in the "royal" Lehua family of Hawaiian taros, which were once reserved for consumption only by ali'i (Hawaiian nobility). A desirable agronomic feature of Maui Lehua is that it produces only a few suckers. Because of its outstanding qualities as a poi taro and its importance to the Hawai'i taro industry, Trujillo chose it as the female parent to be crossed with the blight-resistant Ngeruuch. In making these crosses, Trujillo used conventional plant-breeding techniques (for an overview, see Manshardt, 2004; for information on conventional techniques for breeding taro, see Wilson, 1989, Ivancic and Lebot, 2000, and Tyagi et al., 2004.)

Taro in nature is an outcrossing species, requiring insect pollinators for its perpetuation. Man has selected from among the natural hybrids resulting from outcrossing, given the selections names, and maintained the cultivars (cultivated varieties) by asexual propagation (that is, by planting huli). Crosses between hybrids result in a lot of variation in the progeny populations. In contrast to outcrossing species, crosses between self-pollinating species result in progeny in the next generation that are identical to each other in physical characteristics.



In this taro hybrid created by CTAHR's Eduardo Trujillo, a Hawaiian taro was crossed with another taro having tolerance to the leaf blight pathogen. Infection is limited to a "shot-hole" effect: the pathogen infects the leaf, but the infection is not systemic. The pathogen's spread is stopped by the genetic tolerance of the new taro variety and does not spread far from the site of infection. An area of dead tissue surrounding the point of infection falls from the leaf lamina, creating a hole. The rest of the leaf continues its role of photosynthesizing and contributing to the plant's growth and corm development.

Photo: E. Trujillo

Because multiplicities of genes usually control desirable traits in plants, and because the sexual process of cross-pollination causes many of these genes to recombine, great variation occurred in the initial generation of seedlings (the "F<sub>1</sub> progeny") from Trujillo's crosses. For example, only seven percent of the 200 F<sub>1</sub> progeny field-tested at Hakalau inherited the purple corm of Maui Lehua. In screening these progeny, the most careful attention was paid to leaf blight resistance. Other characters considered were few (less than six) suckers, and closeness of attachment of suckers to the mother plant. Five candidates were selected that had both taro leaf blight resistance and desirable suckering characteristics. Each of them was cloned by apical meristem tissue culture to increase plants for testing. Further disease assessment occurred in plantings at two locations at Hakalau, in April 1998 using tissue-cultured plants, and in January 1999 using huli produced from the April planting. Based on these and other field plantings, three improved taros were selected and named (see Trujillo et al., 2002), and huli numbers were increased so that farmers could obtain plants.

There were some problems with introducing the Palau taros. Many of them, and two of Trujillo's resulting hybrids, send out propagative runners (stolons) from the base of the mother plant. This caused some in the Hawaiian taro community to object to CTAHR introducing varieties that would "strangle" heirloom Hawaiian taros, which generally do not display this growth characteristic. There seemed to be a fear that taros that spread in this manner were capable of acting as invasive species, "escaping" into our environment and threatening our lo'i. No evidence has yet shown that this is a valid concern. In some cases, growers have accepted the long-stolon characteristic of Palau cultivars as a trade-off for their tolerance of taro leaf blight.



Corms of CTAHR's Pa'akala taro, resistant to taro leaf blight, each weighing about 20 pounds, grown on Moloka'i

Photo: Glenn Teves

Having developed new taro cultivars, Trujillo filed invention disclosures with the UH Office of Technology Transfer and Economic Development (OTTED), authorized to handle the university's intellectual property rights matters. This action was based on a contractual agreement between the University of Hawai'i Professional Assembly (the faculty union) and the UH Board of Regents (faculty contract Section 20-3-2(a) states, "All persons employed by the University shall submit their ideas for patentable inventions through their immediate supervisor to a University President."). OTTED determined that the new taro cultivars had royalty-generating potential and filed applications with the U.S. Patent and Trademark Office for three plant patents, which were obtained in 2002.

Subsequently, resentment developed in segments of the Hawaiian community about this patenting. The restriction of access to the plants, the conditions of the licensing agreement farmers obtaining them were required to sign, and the imposition of royalty fees on growers caused concern, along with the larger issue of ownership of the materials. At an emotional rally on the UH Mānoa campus in 2006, attended by 600 people, Hawaiian activist Walter Ritte proclaimed, in reference to beliefs about Hawaiian taros deriving from Hāloa, the ancestor of Hawaiians, "We are Hāloa, and Hāloa is us. No one can own us" (see Ing, 2006). This sentiment echoes a worldwide movement wherein indigenous people and developing countries try to preserve rights over their natural and cultural resources. At the Mānoa protest rally, CTAHR Dean Andrew Hashimoto explained that patenting of innovations is part of our national regulatory structure, and if UH did not patent the new cultivars, someone else could claim to have invented them.

(An overview of the patenting issue and its context was published at the time in *Honolulu Weekly*; see Lo, 2006. Articles by Groves and Wong elaborated on Hawaiian perspectives on the issue as it relates to taro. A follow-up Web posting on [islandbreath.org](http://islandbreath.org) included a memo from UH administrator Gary Ostrander, as well as various anti-GMO related sentiments; see Di Pietro, 2006.)

This contentious situation was resolved when UH relinquished its patent rights to the new taros and released them into the public domain. No royalties on production of the cultivars were ever collected.

Recently, the Palauan government requested that planting materials of the improved cultivars be sent to it. As Palau lacks the facilities to screen the materials for various viruses, the Regional Germplasm Centre of the Secretariat of the Pacific Community, in Fiji, offered to help, and CTAHR plant propagators are working with CTAHR's Agricultural Development in the American Pacific project to disinfest infected materials. Once virus-free materials are available, the Regional Germplasm Centre will be free to distribute them, without any restriction by UH. This will be helpful to many of our Pacific neighbors, as one of the new cultivars (Palehua) has twice the yield potential of Maui Lehua.

## Breeding for More Stable Disease Resistance and Improved Corm Quality

**A**t about the same time that Eduardo Trujillo was working to produce taro hybrids resistant to the *Phytophthora* leaf blight pathogen, another CTAHR plant pathologist, John Cho, stationed on Maui, initiated a related breeding program. The goals of his program were to collect, preserve, and characterize traditional Hawaiian taros and to improve commercial cultivars through conventional breeding between Hawaiian and introduced taros to develop new high-yielding hybrids with increased genetic diversity, multiple resistances, and corm characteristics suited to the requirements of Hawai'i poi millers and the preferences of Hawai'i's taro consumers. In addition to leaf blight resistance, Cho sought to incorporate tolerance of aphids using cultivars from Micronesia that had been observed either to reduce the longevity of aphids feeding on them or reduce the number or longevity of their offspring.

The new program collected almost 300 taro genotypes, including the 69 Hawaiian varieties collected by CTAHR researchers in the 1930s and preserved in a collection on Kaua'i (Whitney et al. 1939), and taros brought in for study by CTAHR researchers in the late 1980s (Lebot and Aradhya, 1991). In addition, the program assembled plant materials from throughout taro's natural center of genetic diversity, which extends from India through Southeast Asia. Taros were obtained from countries including Nepal, Thailand, Vietnam, Indonesia, Myanmar, China, Japan, and the Philippines, and from seven locations in Micronesia, four in Melanesia, and four in Polynesia.

Ancient (“canoe plant”) taro introductions to Hawai‘i were further developed by the Hawaiians into over 100 named cultivars, but this group has been shown by various analytical techniques to have only a little genetic variation (Lebot and Aradhya, 1991). Studies of the Southeast Asian taros show that they have two to three times as much genetic variation as the Hawaiian family of taros. This more diverse variation allows these taros to adapt to a broader range of environmental conditions, including pest pressures. Crossing them with Hawai‘i’s taros could introduce greater resilience. It was clear that many taros had no resistance to evolutionary pressures such as *Phytophthora colocasiae*, but that others did. Trujillo had combined a single source of leaf blight resistance with Hawaiian taro. But as a pathogen in other crops, *Phytophthora* is notorious for being able to overcome single-gene resistance. Cho, therefore, hoped to introduce multiple-gene resistance from genotypes derived from the taro populations of different countries.



Field trials of organically grown taro at CTAHR's Waimānalo Research Station.

Somewhat analogous to the way the microscope allowed scientists to see the contents of cells, modern developments in biotechnology have provided various techniques that allow breeders to “see” into DNA and make out some details of the relationships among its components (Irwin et al., 1998). Cho’s strategy involved this sort of sophisticated scientific “background” work with the taro materials, the results of which informed his selection of the most promising parental lines to cross to create hybrids. These crosses were only a first step. As the resulting crosses produced results in progeny characteristics that were similar to or distant from the parents, observations of their genetic composition could reveal, for example, locations of disease resistance genes in their DNA. This information allowed further selection among the hybrid progeny to narrow the focus of crosses and increase the likelihood of a cross producing a taro with a desirable trait. These “maps” of variation produced in the taro genome are of basic use to scientists around the world who are working to improve taro varieties for their particular environments and end-uses.

Two successful breeding strategies were used in developing hybrids suitable for commercial food production (Cho, 2003, 2007). The first strategy employed genetic crosses between a Polynesian commercial taro cultivar from Niue and blight-resistant, “wild type” taros (Bangkok, from Thailand, and PH15, from Papua New Guinea), which had long stolons, many side shoots, and small, white-fleshed corms. Initial crosses resulted in  $F_1$  hybrids that were not suitable for commercial production because of their small corm size and white corm color (purple or gray being desirable). A subsequent stage of breeding called modified backcrossing reestablished in the progeny the desirable qualities of Maui Lehua and resulted in hybrids that were more suitable for commercial production.

The second strategy employed genetic crosses between a Hawaiian commercial cultivar and blight-resistant cultivars introduced from Palau and Micronesia that had large corms, few suckers, and no (or short) stolons.  $F_1$  hybrids possibly suitable for commercial use were identified in the resulting progeny.

On the basis of cooperator field trials, three backcrossed hybrids suitable for commercial flooded production (BC99-6, BC99-7, and BC99-9) were selected. These three cultivars were generated by crossing Niue Waula and Bangkok, followed by a modified backcross between selected progeny from that cross and Maui Lehua. All three are highly blight tolerant, out-yielded Maui Lehua by at least 30 percent under flooded conditions on Kaua'i, and are comparable to Maui Lehua in color and taste when made into poi. They have been incorporated into several taro farms as a partial replacement for Maui Lehua.

Working with Hawai'i's taro farmers has been an essential element of Cho's program. Taro hybrids developed in 1999 with one source of taro leaf blight resistance from the Thailand variety Bangkok were distributed to interested taro



CTAHR extension agent Alton Arakaki (center) has hosted an Annual Taro Field Day on Moloka'i for more than two decades. Thousands of huli of rare taro cultivars have been distributed over the years.

growers on Kaua'i, Maui, Moloka'i, Hawai'i, and O'ahu. Taro hybrids developed in 2002 and 2004 were evaluated in Hanalei, and five were selected as having leaf blight resistance and better yield than Maui Lehua. A 2002 hybrid taro combined two sources of taro leaf blight resistance, from a Micronesian taro and a Thailand taro, with a commercial Hawaiian taro variety. Four 2004 selected hybrid taros included one that combined the blight resistances from a Micronesian and Palauan taro, a Thai and a Micronesian taro, a Palauan and a Thai taro, and a Thai and a Micronesian taro. With the combining of two sources of TLB resistance in each of these hybrids, it is hoped that their resistance will be more durable.

Possible commercial hybrids were also selected for non-flooded taro production. Fourteen hybrids with two sources of resistance were selected from crossbreeding, and 14 hybrids with four sources of resistance were selected after modified backcrossing.

The goal of introducing genetic diversity was pursued by creating populations for further study. Aphid tolerance was sought by crossing the Indonesia cultivar Ketan with the Guam cultivar Gilin, while the blight-resistant P20 from Palau was crossed with the Hawaiian commercial variety Moi. Selected progeny from these crosses were then self-pollinated to create populations to observe whether the tolerances segregated among them, which could allow development of maps to identify genetic markers linked to the tolerance traits. Lack of funding kept this work from proceeding beyond its initial phase, and the materials could not be maintained.

Because of the limited extent to which the diverse array of taros found in Hawai'i long ago is grown today, caused in part by the change from extensive subsistence taro production to intensive commercial production and processing, preserving Hawai'i's genetic taro resources is of great importance. Thus as Cho's project

evolved, it included not only having variety accessions growing in nurseries and field plots and but also preserving the plants in tissue culture, maintained on nutrient media in flasks. Tissue cultured plants of several of Cho's hybrids are being maintained by the Secretariat of the Pacific Community and are currently available to scientists and future Hawai'i breeders.

## Germplasm Exchange: Helping Others to Protect and Improve their Taro Production

Cho's efforts have also benefited people in places beyond Hawai'i. *Phytophthora colocasiae* was found in Puerto Rico in 2004 and resulted in widespread taro yield losses. In the Dominican Republic, 80 percent of their Bun Long (Chinese) taro crop was lost to the disease. U.S. mainland taro chip producers took their business to Costa Rica and Mexico. Exports of taro to Caribbean expatriates in the United States dried up. Local consumption of taro by the Dominican Republic's 10 million people was curtailed.

Resistant cultivars from Cho's breeding program were introduced to Puerto Rico and the Dominican Republic for field evaluation and are currently being assessed. The crosses provided were derived from the Hawaiian cultivar Moi, which is more similar to the types favored in the Caribbean than are the Maui Lehua-based crosses from Cho's program being evaluated by Hawai'i's growers. These gifts from Hawai'i are providing a foundation for further development of taros suitable to the markets these two Caribbean countries serve.

In seeking sources of taro to use to strengthen Hawai'i's taro industry, Cho established relationships with government scientific organizations in other countries, many of which approached UH for assistance and collaboration. We have gained genetic materials directly from Palau, Thailand, Papua New Guinea, Vietnam, the Cook Islands, Tonga, Samoa, and Burma, and indirectly from Malaysia, Vietnam, Thailand, and the Philippines through the Regional Germplasm Centre of the Secretariat of the Pacific Community in Fiji. Japan has given taro materials but has not received any, as their major interest is in the araimo (or sato-imo) type of taro. We have given to Puerto Rico and the Dominican Republic but did not get anything back, and there is no reason to expect any exchange, because taro is not native there, being introduced in the 1500s with the African slave trade. However, through these transfers of technology and germplasm to other scientists' breeding programs, Hawai'i may someday benefit from genetic improvements that they make.

Taro germplasm exchange relations with China have so far been limited to one introduction of their materials, but further relations would be desirable. Although China is not considered part of the genetic home of *Colocasia esculenta* and its relatives, genetic materials probably moved between Southeast Asia (the genetic



home) and China very early in the movement of plant products during the hunter-gatherer period, prior to the beginnings of agriculture about 10,000 years ago. This movement was a good thing for the genus, because many of the different *Colocasia* species and *C. esculenta* landraces in Southeast Asia, particularly in Malaysia, have been lost due to destruction of native habitat for agriculture, and more recently due to construction of houses and buildings. Fortunately for the genus, many different species survived in China and have in recent years been identified by Chinese scientists. Exchange with China would be a good thing for breeding diversity into *Colocasia*. In all these collaborations and exchanges, Cho has conveyed his belief that disease-free food-taro materials should be available to everyone and should be freely shared.

## New Ornamental Taros

*All of the ornamental taros produced in Cho's program resulted not from genetic engineering but from conventional crossbreeding.*

A corollary to Cho's effort to improve taro for food production has been the development of taros attractive as ornamental plants. Ornamental taros are sold in the nursery trade and are especially prized in temperate regions, where they are often grown as summer container plants and brought inside during cold months. Two ornamental hybrids were named Pearl Harbor and Hawaiian Beauty and licensed to a Florida company for commercialization in 2005. Over 400 hybrids from Cho's program, none of them derived from Hawaiian taros, were evaluated for ornamental use by a commercial nursery in North Carolina. Seven of them were named, and their marketing is being managed by a California company, PlantHaven, which represents plant breeders (see [www.royalhawaiiancolocasias.com](http://www.royalhawaiiancolocasias.com)); this group of cultivars was awarded the 2008 Editor's Choice Medal of Excellence by Greenhouse Grower magazine. The names given to these new hybrids, such as Hilo Bay, Diamond Head, and Hawaiian Eye, are designed to appeal to people who are aware of Hawai'i's charms as a vacation destination. Diamond Head received a 2008 Classic City Garden Award from The Gardens at UGA (University of Georgia).

All of the ornamental taros produced in Cho's program resulted not from genetic engineering but from conventional crossbreeding. Due to concerns expressed by UH administrators about patenting materials bred from Hawaiian taros, Cho agreed that no traditional Hawaiian taro cultivars would be involved in his effort to breed new ornamental taros.

The trademark "Royal Hawaiian®" was registered by PlantHaven in support of its agreement with Cho and the university to market the ornamental *Colocasia* hybrids. The application for registration was made with the intention of protecting the company's investment in the marketing and also preventing others from passing off inferior varieties by calling them "Royal Hawaiian" cultivars. Registration of the trademark was intended to be an asset of the agreement with UH; it is not now "owned" by PlantHaven but rather is owned by the University of Hawai'i. The trademark is registered for use in connection with "Live plants, namely, Colocasias" and the registration was granted subject to the disclaimer, "No claim

is made to the exclusive right to use HAWAIIAN apart from the mark as shown.” Trademarks cannot function as the descriptive name of the goods: “Royal Hawaiian” is not descriptive of the Colocasias—it is a “brand” to lead people to a source of quality Colocasias.

It is common practice in the ornamental plant industries, even “best practice” these days, for promoted collections of plants to carry a trademark and for the hybrids themselves to be protected by patent. Having the cultivars named and described in a patent will allow the marketplace to differentiate them from other hybrids, or from plants harvested from the wild. Molecular “fingerprinting” markers will identify the cultivars to discourage piracy. Income from the patented plants will be used in research to help Hawai‘i stay ahead of the competition and to protect both the Hawai‘i name and the product.

## Plant Patenting Issues

**R**egarding patenting of plants, the university’s current policies are derived from lessons of the past. Our scientists developed 10 outstanding macadamia cultivars and made growing and processing of macadamia nuts a thriving agricultural industry in Hawai‘i between 1960 and 1990. Unfortunately, none of those cultivars were patented. They were “borrowed” from Hawai‘i by many outside competitors, and now foreign macadamia nuts compete strongly for a market that was once primarily Hawai‘i’s.

Plant patents have a life of 20 years, and the plants then become available to the public. Patents made before 1988 would have reverted back to the public domain by now; those made in 1990 would now have a life of only two more years. Plant patents were instituted in part to protect efforts devoted to development of new products by allowing a period of competitive advantage to recoup investment made and allow continued research and development for introducing new materials into the marketplace, eliminating the need to protect prior patented materials in perpetuity.

The impetus to pursue patents on plants developed by UH faculty has come about in recognition of the value of patents as a tool to secure Hawai‘i’s accomplishments and protect them, for a time, from piracy. Income from licensing Cho’s ornamental taro cultivars helps ensure self-sufficiency—funds generated will help further UH taro research and development. Markets for the ornamental potted-plant taros will be in Hawai‘i, the U.S. mainland, and worldwide, spreading their evocative names and reminding people of Hawai‘i as a desirable place to visit.

Of course, in the case of macadamia, CTAHR horticulturists used macadamia plants obtained from outside Hawai‘i in their breeding and selection programs. Most of our commercial crops and the varieties of them that have been developed for local conditions have benefited from collaborations with custodians of genetic resources from other countries. If use of introduced plant genetic resources

*Ornamental taros developed and patented by Cho do not have any Hawaiian traditional taros in their genetic makeup.*

were not the norm, Hawai'i's agricultural economy would simply not exist. Taro itself was introduced to the Pacific from the Indo-Malayan peninsula long before CTAHR breeders sought to broaden the genetic base of the Polynesian cultivars by crossing them with taros from other regions.

In exception to the general UH approach of pursuing plant patents to preserve faculty effort, the approach regarding taro has been modified in respect of the wishes of Hawaiian cultural practitioners. Patents obtained on Trujillo's cultivars have been released into the public domain by the university. Ornamental taros developed and patented by Cho do not have any Hawaiian traditional taros in their genetic makeup. Cho has stated that he will not seek patents on food taros he developed for Hawai'i's taro industry, regardless of their genetic origin.

The university has benefited from patents on techniques for producing flour from taro; it will benefit from proceeds related to patents on Cho's ornamental taros; it may in the future benefit from patents on next-generation food taros, or taros for markets that are not in competition with Hawai'i's taro industry.

## Exploring Genetic Engineering of Taro

Ramon de la Peña's program in the 1980s had done conventional breeding of taro varieties, using the plant hormone gibberellic acid to induce flowering. Later, Eduardo Trujillo's program had found a source of resistance to taro leaf blight in certain Pacific island taro varieties, and conventional breeding of one of these with Maui Lehua had transferred the resistance, although some of the desirable characteristics of Maui Lehua for the Hawai'i market were lost. John Cho's program had used a different selection of parental taro varieties in a conventional breeding effort to broaden blight resistance by including resistance sources from more than one taro variety. He developed taro hybrids with better quality characteristics but lower leaf blight resistance compared to hybrids developed by Trujillo's program.

Conventional breeding of taro over the past 20 years in Hawai'i has achieved some positive results, but it remains to be seen if the promising hybrids developed will receive widespread commercial acceptance. Conventional breeding takes time and is subject to chance. Sexual reproduction always results in a complex shuffling of the two parents' genes, with only vaguely predictable consequences. Genetic engineering, in contrast, permits the insertion of a single gene into one parent's DNA. The key is to isolate the gene carrying the desired trait, and then to integrate it into the commercial variety's genome, thus preserving all the desirable characteristics of the commercial variety while improving one trait, such as disease resistance.

CTAHR scientists, working with faculty at Cornell University, had a pioneering success in this sort of crop improvement when they genetically engineered papaya

to resist infection by the papaya ringspot virus (PRV). The disease caused by this virus had all but removed papaya from the list of crops that Hawai'i farmers could grow commercially. The resistance resulted from transferring a gene for the coat protein of the virus into the papaya DNA, making it heritable in the new variety from one generation to the next, without otherwise altering the other qualities of the original papaya variety. The government agencies that carefully oversee the development of genetically engineered organisms concluded that no harm could come from consuming a tiny fragment of PRV in the new fruit.

The desire to have the capacity to perform this type of crop-saving intervention with taro, should the need arise, motivated Dr. Susan Miyasaka, a CTAHR agronomist, to team with members of the Hawaii Agricultural Research Center in a research program to do some preliminary work exploring the possibilities. These scientists believed that without the capabilities obtainable through genetic engineering technology, we would lack the potential to preserve taro as a crop beset by new invasive pests and diseases. Taro is grown typically in Hawai'i from vegetative propagules, not from seed. As a result, it lacks the recombination of genes that occurs through sexual reproduction. In addition, the taro varieties brought as canoe plants by the native Hawaiians have a very narrow genetic diversity, making them more vulnerable to new pests and diseases. In the South Pacific, a deadly viral complex called alomae-bobone kills susceptible taro varieties (FAO, 1999). Hawaiian taro varieties have been tested in the South Pacific, and all were found to be susceptible to this viral complex. Insects capable of spreading this viral complex are found already in Hawai'i and could quickly spread this disease when and if it reaches Hawai'i.

Miyasaka's initial project sought to develop a "transformation system" with taro to learn if and how it could be genetically modified within the confines of the laboratory. The transformation attempt with Maui Lehua was abandoned, because it was not successful. Work with the commercial taro cultivar Bun Long (or Bin Liang), from China, was successful, and it prompted a second project. None of the plants developed by genetic engineering techniques were grown outside of strictly controlled laboratory environments.

At the project's outset in 2001, there had been no reports of genetic transformation of taro (since that time, a group of scientists in Japan successfully inserted a marker gene into a Japanese taro variety). The first step in the project was to regenerate taro in the laboratory using meristem (shoot tip) tissue, so that the nearly ubiquitous dasheen mosaic virus could be eliminated, and then grow the tissue in artificial media culture from which new plantlets could be generated. The second step was to determine which of two methods for introducing new genes into the cultured tissue was more effective. The third step used the more effective method to introduce a gene construct including a disease resistance gene and additional genes that allow selection and screening of transformed tissue. Because no TLB-resistance gene had been isolated from taro, the project used genes from rice, wheat, and grape that had been shown earlier to confer disease resistance.

The final step, at the project's conclusion in 2006, was to challenge the transformed taro with the disease in the laboratory. In Chinese taro transformed with a disease-resistance gene from wheat, the spread of TLB was completely arrested. In comparison, untransformed Chinese taro was almost dead 12 days after inoculation with the pathogen. These preliminary results with transgenic Chinese taro in the laboratory are very promising; however, field-testing would be needed to verify the TLB resistance of these taro lines.

As mentioned in the introduction to this report, some groups in Hawai'i have objected to any genetic modification of indigenous Hawaiian taro varieties, while other more broadly focused groups protest any form of genetic engineering. These groups had become more vocal during the time of Miyasaka's research project. In response to the objections of the Hawaiian cultural practitioners, CTAHR's dean signed an indefinite moratorium on genetic engineering research with Hawaiian taro cultivars. As for the Chinese taro that was transformed in the laboratory, there are no plans for field tests in Hawai'i, due to the natural ending of project funding, as well as the current controversy.

On Makira in the Solomon Islands, it only took 15 years from the accidental introduction of the alomae-bobone viral complex for the disease to wipe out taro production. Of course, our first line of defense should be to keep out taro pests and diseases, but our record of keeping out invasive pests is not encouraging, given the recent accidental introductions, to name a few examples, of the apple snail, the coqui frog, the little fire ant, the erythrina gall wasp, and the varroa mite pest of honeybees. Second lines of defense are not always timely, or successful. In the effort to overcome the papaya ringspot virus threat to Hawai'i's papaya industry, it took 14 years to develop an approved virus-resistant papaya variety through genetic engineering. As this paper has described, conventional breeding for tolerance of taro leaf blight is possible, because resistance is found naturally within the taro gene pool. Natural resistance to the alomae-bobone viral complex within the taro gene pool has been reported, but the germplasm apparently was lost, and the hunt for it would have to begin again. The ability to genetically engineer viral disease resistance may turn out to be critically important as a timely intervention to save Hawai'i's taro production and preserve heirloom Hawaiian taros in the event that the alomae-bobone viral complex reaches these islands.

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Most CTAHR publications issued after 1995 are available in pdf format at [www.ctahr.hawaii.edu/freepubs](http://www.ctahr.hawaii.edu/freepubs), and direct links to them appear when they are searched for in the CTAHR Publications database. Some pre-digital publications have been scanned and are available at <http://scholarspace.manoa.hawaii.edu/handle/10125/1877>; more of these out-of-print publications will be added as resources permit. All CTAHR publications, theses, and dissertations are held in UH Manoa's Hamilton Library. Many CTAHR publications are also available from the Hawai'i State Library System. Hamilton Library contains most of the journal series items, either in the books or journals in which they were originally published, or in offprints of the articles stored in the library's Hawaiian and Pacific Collection.

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