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Hawaiian Kalo, Past and Future

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Taro, *Colocasia esculenta* (L.) Schott, called *kalo* in Hawaiian, is one of the oldest cultivated crops.(8, 41) A member of the plant family Araceae, which comprises at least 100 genera and more than 1500 species, taro is a major staple in the diets of people around the Pacific and is the world's fourteenth most-consumed vegetable.(34)

Movement of taro into Polynesia

Cytological and archaeological studies indicate that taro probably originated in the Indo-Malaysian Peninsula over 50,000 years ago.(53) Taro may have been grown for thousands of years in Southeast Asia and the western Pacific islands, including New Guinea, as archaeological evidence indicates human use of the plants 28,000 years ago in the Solomon Islands.(35) Evidence from the fields of biogeography and plant genetics indicates that taro domestication may have occurred independently in different areas long before people first moved into Polynesia. This movement likely began in about 1600 to 1200 BC, when long-distance voyaging canoes were developed and taro was taken further east into Fiji and western Polynesia (Samoa and Tonga), then into eastern Polynesia with the movement of migrating voyagers to the Cook, Society, and Marquesas Islands around 800 to 900 AD.(8, 17, 18, 29, 31, 56, 57)

Taro arrives in Hawai‘i

Around 900 to 1000 AD, a rapid colonization of all of Polynesia occurred that included the discovery and

Photo: Hanalei Valley, Kaua‘i, a major center of flooded kalo production.

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settlement of Hawai‘i.[2, 3, 4, 5, 29, 54, 56, 57] Archaeological evidence suggests that kalo, banana, breadfruit, coconut, mountain apple, sugarcane, and yam were among the foods introduced to the islands by Polynesians, most likely in multiple arrivals.

The Hawaiian staff of life

The early Hawaiians planted kalo in marshes near the mouths of rivers. Over years of progressive expansion of kalo lo‘i (flooded taro patches) up slopes and along rivers, kalo cultivation in Hawai‘i reached a unique level of engineering sophistication.[30, 31] As a food crop, kalo played an important role in the diet of the Hawaiian people.[32] In places like Kona, where conditions for its cultivation were not optimal, other crops, including breadfruit in the moist uplands and sweetpotato in the drier lowlands, were significant, but taro remained the favored food.[39, 44]

To Hawaiians, growing kalo was not merely an activity of food production but was strongly bound to their culture and beliefs about creation. According to one legend about creation, sexual union between the god-beings Wākea (male) and Papa (female) first formed the islands. Their union produced a child named Hāloa-naka, who did not survive and was buried. From the child's body grew the first kalo plant. The next child, named Hāloa, became the first human to live in the islands, and from him the Hawaiian people descended. Thus, some believe that the kalo plant, arising from the prior-born child, is superior to and more sacred than man. The younger Hāloa would respect and care for the elder brother and in return would receive sustenance and nourishment.[21, 26, 38]

Because kalo was a principal food source for most early Hawaiians, it had great social importance. Certain kalo cultivars had ceremonial significance and were used as offerings to the gods; others, such as the red cultivars Lehua and Pi‘i ali‘i, were reserved to be eaten only by the chiefs (ali‘i); and some, including those with low acridity such as Lauloa and Haokea, were used for medicinal purposes in healing.[20, 21] The Hawaiian concept of family, ‘ohana, is derived from the word ‘ohā, the axillary shoots of kalo that sprout from the main corm, the makua. Huli, cut from the tops of mākua and ‘ohā, are then used for replanting to regenerate the cycle of kalo production.[20, 21]

The Hawaiian kalo cultivar ‘Ula‘ula Poni was also the source of a red dye for kapa (tapa) cloth.

Nutritional value

Kalo starch is one of the most nutritious, easily digested foods.[33] Kalo corms are high in carbohydrate in the form of starch and low in fat and protein, similar to many other root crops. The starch is 98.8 percent digestible, a quality attributed to its granule size, which is a tenth that of potato, making it ideal for people with digestive difficulties. The corm is an excellent source of potassium (higher than banana), carbohydrate for energy, and fiber. When eaten regularly, kalo corm provides a good source of calcium and iron. Kalo leaves eaten as a vegetable (called lū‘au in Hawaiian) are excellent sources of provitamin A carotenoids, calcium, fiber, and vitamins C and B_2 (riboflavin), and they also contain vitamin B_1 (thiamin).[40, 42, 50]

Kalo, like other plants in its family, is considered poisonous because its tissues contain an acrid component; thorough steaming or boiling eliminates this and allows it to be eaten.

Nutritional value of cooked taro

	Unit	Leaf	Shoot	Corm
		(amounts per 100 g)		
Water	g	92.15	95.3	63.8
Energy	kcal	24	14	142
Protein	g	2.72	0.73	0.52
Total lipids	g	0.41	0.08	0.11
Carbohydrate	g	4.02	3.2	34.6
Fiber	g	2.0	no data	5.1
Minerals				
Calcium	mg	86	14	18
Iron	mg	1.18	0.41	0.72
Magnesium	mg	20	8	30
Phosphorus	mg	27	26	76
Potassium	mg	460	344	484
Sodium	mg	2	2	15
Zinc	mg	0.21	0.54	0.27
Copper	mg	0.140	0.094	0.201
Manganese	mg	0.371	0.130	0.449
Selenium	mg	0.9	1.0	0.9
Vitamins				
Vitamin C	mg	35.5	18.9	5.0
Thiamin	mg	0.139	0.038	0.107
Riboflavin	mg	0.38	0.053	0.028
Niacin	mg	1.267	0.81	0.51
Pantothenic acid	mg	0.044	0.076	0.336
Vitamin B_6	mg	0.072	0.122	0.331
Folate, total	mg	48	3	19
Vitamin B_{12}	mg	0	0	0
Vitamin A	IU	4338	51	84

Source: USDA National Nutrient Database for Standard Reference, Release 17 (2004)

Expansion of kalo production in Hawai‘i

Early settlers probably brought only a few varieties (cultivars) of kalo. During the early years of colonization, production was mainly confined to the wet, windward sides of the islands. As the population increased, people spread throughout the island chain, again mainly on wet windward sides, and kalo still was mostly grown under flooded conditions. From 1100 to 1650 AD, the Hawaiian population expanded to over 400,000 people,[30, 49, 56] and settlements were dispersed throughout windward zones of all islands and extended into dry leeward valleys and coasts.[30, 31] It is estimated that at the peak of kalo production, areas under its cultivation covered more than 20,000 acres (about 31 square miles) over six islands.[30]

Decline of kalo production

Since the early to mid-1800s, following the arrival of Captain Cook and the subsequent immigration of non-Polynesians, kalo cultivation and the demand for kalo has markedly declined, and many of the ceremonial, medicinal, and upland kalo cultivars became neglected and were lost. The reduction in kalo cultivation can be attributed to a variety of causes, including the following:

- Diseases introduced with the arrival of foreigners dramatically reduced the Hawaiian population, which affected both the supply of and demand for kalo.[10, 49]
- Much agricultural knowledge was lost with the passing of Hawaiian elders as a result of natural causes or the new diseases.[10, 44]
- Alternative foods arrived, and starches such as rice, grown in flooded areas formerly used for kalo, and imported wheat supplanted kalo, sweetpotato, and breadfruit as dietary carbohydrate sources.
- Beginning around 1819, many Hawaiians were directed to the harvest of sandalwood, which left kalo crops poorly attended.[1]
- The breaking of the kapu system after 1820 allowed Hawaiians more individual freedoms, including being allowed to eat the kalo previously reserved for ali‘i and to undertake other means of obtaining sustenance than working in the lo‘i.[14]
- After the Great Mahele of 1848, some Hawaiians walked away from traditional lands to pursue other opportunities, some rented out their lands, and some were forced off the land by those who had been granted it or who used the court system to acquire it.[12, 14]
- Extensive subsistence kalo production by Hawaiians in small lo‘i was replaced by intensive commercial production in larger, rice-paddy–shaped kalo patches patterned on the agricultural styles of immigrant farmers from Asia, who began farming the available agricultural land.[11, 12]
- Many kalo lands were converted to produce other crops (mostly sugarcane grown by plantation companies, but also rice grown by immigrant farmers), or in some cases to housing.[11, 12, 19]
- Plantations used the courts to acquire rights to the water that had fed lo‘i.[60]

In 1900, it was estimated that about 1280 acres were being used for kalo production.[45] By 1907, rice had become a major crop, occupying about 10,000 acres.[13] At that time, farmers of Chinese ethnicity were growing about half the kalo crop and milling 80 percent of the poi. By 1937, the major kalo growers were Japanese.[13] With the outbreak of World War II in 1941, demand for kalo declined and production dropped to 920 acres.[23]

Today, less than 400 acres of kalo are planted. The crop is dominated by just a few of the most productive cultivars: Maui Lehua (the major one) and Moi for poi, and the Chinese cultivar Bun Long for lūʻau and chips. Maui Lehua, a high-yielding cultivar, was selected in the 1960s and has largely replaced the once-dominant commercial cultivar, Lehua Maoli (also called Kauai Lehua).

Today's kalo production under flooded conditions occurs in four major river valleys. Hanalei on Kauaʻi accounts for approximately two-thirds of the kalo produced in Hawaiʻi annually, while the remaining third is grown in Waipio, on the Hāmākua coast of Hawaiʻi, and in Keanae and Wailua on Maui. Flooded kalo can also be found in several smaller areas on Kauaʻi and Maui (Waiheʻe Valley). About three-fourths of the flooded kalo grown is made into poi.

As early as 1900, agricultural researchers noted that pests and diseases were adversely affecting kalo production in Hawaiʻi. The second bulletin of the federally funded Hawaii Agricultural Experiment Station, titled "The Root Rot of Taro," was published in 1902,[47] with a condensed version translated into Hawaiian published the following year.[48] The appearance of additional new pests in recent decades has further reduced kalo productivity and made it more difficult for growers to make a profit. The new problems include taro leaf blight (caused by *Phytophthora colocasiae*), pocket rot of kalo corms, apple snail, taro root aphid, and root-knot nematode. Very little resistance to these pest problems is found in Hawaiian kalo cultivars.

Hawaiʻi taro statistics (2005)

Number of farms	110
Acres	360
Annual production	4.3 million pounds
Average price per pound	$0.54
Annual sales	$2.32 million

Source: Hawaiʻi Agricultural Statistics Service

Recent concerns for taro producers

1953–1982:	Production declines as urbanization and other opportunities lure farmers from the land. Acreage declines on Oʻahu and Hawaiʻi but increases on Kauaʻi.
1982, 1992:	Hurricanes Iwa, Iniki curtail production.
1990–1996:	Upland production increases, at one point accounting for 45% of production.
1996–now:	Pests including apple snail, pocket rot, leaf blight, and root aphid become significant problems.

Preservation of Hawaiian kalo cultivars

During a period of intense agricultural activity lasting several hundred years, necessitated by the expanding population, Hawaiians may have accumulated over 300 kalo cultivars[22] from selected natural mutations,[22] additional importations from other islands, and, possibly, deliberate breeding.[21, 25] In the early 1900s, in perhaps the first systematic study of Hawaiian kalo cultivars, MacCaughey and Emerson[36, 37] suggested that about half of the named cultivars were duplicates. They concluded that there may have been only 150 to 175 unique cultivars, many of which either were not widely grown or had been selected for their adaptation to the upland conditions of leeward growing areas.

A major effort was made between 1928 and 1935 by agricultural scientists at the University of Hawaiʻi's College of Tropical Agriculture and Human Resources (UH-CTAHR) to collect, characterize, and preserve kalo cultivars grown in Hawaiʻi before they were lost. They collected 200 named cultivars, many of which were duplicates; only 84 distinct types could be identified. These included 69 derived from native Hawaiian plants, 10 from the South Pacific, 3 from Japan, and 1 from China.

The cultivars could be separated into eight morphological groups based upon distinct features.[54] These groups represented a significant reduction from the 27 groups previously recognized in the 1880 Hawaiian Almanac and Annual, which included ʻApuwai, Haokea, Kai, Mana, Hāpuʻupuʻu, Ipulono, Lauloa, Mahaha, Lehua, Pualu, Poni, Kūmū, Nohu, Uahiapele, Mamauea, Lola, Naua, ʻApowale, ʻElepaio, Mākohi, Mākoko, Piko, Nāwao, Kūʻoho, Ualehu or Heʻualehu, Kāniʻo, and Manini. Important groups lost included ʻĀhē, Ēulu, and Lau. Further, cultivars within each group have also been lost. For example, older Hawaiians recognized at least five cultivars in the groups Piʻi aliʻi and ʻApuwai, but the UH effort collected only one in each group.[36, 37, 54]

Some cultivars that were collected were the major ones grown for food, but many, such as Lauloa Keokeo, which was used to treat pulmonary aliments, had medicinal, cultural, and ceremonial significance to Hawaiians.[54] Haokea was used as an offering to the gods, and its lūʻau was highly prized by the kāhuna. Piʻi aliʻi, meaning ascending from the aliʻi, is one of the oldest cultivars and was held in high esteem by the chiefs. Uahiapele, meaning smoke of Pele due to the smoky appearance of its leaves, was prized for medicinal purposes and as an offering to the gods.

For over 70 years, UH-CTAHR has been preserving these valuable cultivars in a living collection at the Kauaʻi Agricultural Research Center; the collection has served as a source for many plantings around the state. However, the security of the collection has often been compromised. In 1992, only 70 of the original 84 remained in the center's nursery. After Hurricane Iniki in 1993, feral pigs consumed and eliminated an additional 10 cultivars, and they caused further damage to the collection in 2005. A decline in UH-CTAHR's budget during the past couple of decades poses a more serious threat to the collection. Appropriate maintenance of this important collection will require an infusion of funding and a long-term strategy for preservation of these heirloom materials for future generations.

Kalo breeding for the future

Since at least 1936, UH-CTAHR scientists have used classical plant breeding techniques, such as may have been practiced by ancient Hawaiians, to try to improve commercial kalo cultivars, stem the decline in production, and stabilize the kalo industry.[22, 27] In 1988, Dr. Ramon de la Peña[15, 16] made further attempts to breed cultivars with higher yields and pest resistance. Several hybrids were generated in this program, and one hybrid, called 50 Baby, is grown today in small amounts, primarily for home use. Most of the other hybrids from that program are only recently being evaluated for yield and taste, and thus far nothing looks outstanding.[58]

In 1995, Dr. Eduardo Trujillo and his colleagues[51, 52] made crosses between a Hawaiian commercial cultivar, Maui Lehua (the standard poi kalo grown in Hawaiʻi), and a Palauan cultivar, Ngeruuch, resistant to taro leaf blight (TLB). Two hundred hybrids were generated from this cross, and three TLB-resistant hybrids were selected. One of these (cultivar Paʻlehua) matured earlier and had twice the yield potential of Maui Lehua, suggesting it as a possible replacement for Maui Lehua. Unfortunately, subsequent field trials, particularly in Hanalei under wetland conditions, found Paʻlehua to be susceptible to corm rots, probably caused by a *Pythium* pathogen. Currently, only a few Hanalei growers produce small amounts of Paʻlehua, and it is cultivated by a few growers on Oʻahu,[59] but the commercial potential of this hybrid is uncertain.

In 1998, another cultivar improvement program[6, 7] was initiated by one of the authors (Cho) to improve commercial kalo cultivars through traditional breeding; the goals are to increase resistance to pests such as TLB and aphids, increase plant vigor and yield, and develop new cultivars that will be attractive for the restaurant and landscaping trades. In this program, Hawaiian kalo cultivars are being used to provide desirable corm color, low acridity, soft-rot tolerance, early maturation, and attractive leaf color. Although there are many Hawaiian kalo cultivars, their genetic background is similar, which makes them susceptible to the same pests and diseases. This limits their usefulness in contributing genetic variation for resistance in a breeding program.[6, 7, 25] Therefore, cultivars from India and Southeast Asia, the genetic home and area of greatest genetic diversity for kalo, are being used to broaden the genetic base and contribute increased pest resistance and yield.

Introduced cultivars from Micronesia, Palau, Indonesia, Papua New Guinea, Thailand, and Nepal are being used to increase resistance to TLB. Cultivars from Micronesia and Indonesia are being used to increase aphid tolerance.[9] The breeding strategy seeks to combine different sources of pest resistance to increase durability of the resistance. This requires at least two breeding cycles that together involve about 6 to 8 years of crossing, evaluation, and selection. The technique uses traditional cross-pollination between a Hawaiian cultivar and introduced cultivars.

Harvest from a single mature plant (ʻohana) of UH–CTAHR hybrid BC99-6 grown for 12 months in Hanalei on a commercial wetland kalo farm. Average yield per ʻohana of BC99-6 was 13 lb on one farm and 12.7 lb on a second farm, compared to 5.8 lb and 9 lb at the two farms, respectively, for the industry standard, Maui Lehua. Huli for replanting are at right.

Kalo grower Clarence Kanoa stands in a planting of a new hybrid kalo (BC99-7) from the CTAHR breeding program; the shorter plants in the background are Maui Lehua, planted at the same time.

Kūpuna on Oʻahu taste-testing poi from new kalo hybrids.

In the first breeding cycle, crosses are made between commercial cultivars and introduced ones. The resulting hybrids are evaluated for desirable horticultural traits, and the best (elite) hybrids are selected for the next cycle. Two crossbreeding approaches are employed. One is to cross commercial kalo with TLB-resistant wild types from Thailand and Papua New Guinea. In this effort, additional breeding (modified backcrossing) is needed to produce elite hybrids. This requires at least four years. The second is to cross commercial kalo with TLB-resistant kalo from Palau[51, 52] and Micronesia. In this effort, elite types can be selected in the first year.

Many of the elite hybrids selected in the first cycle are more pest resistant and productive than the industry standard cultivars, and commercial growers could grow some of these hybrids profitably. The CTAHR program has been successful in selecting elite hybrids with commercial potential through a close working relationship between CTAHR's research and extension personnel and kalo farmers and processors. Accordingly, after four years of on-farm evaluations, Hanalei wetland kalo grower-cooperators have selected three elite hybrids (BC99-6, BC99-7, and BC99-9) for commercial production. The three hybrids have greater tolerance to taro leaf blight and pocket rot and yield about 30 percent more than the industry standards, to which they are comparable in taste and color. Two commercial poi millers have used the new kalo hybrids for commercial production of poi. Currently, there are ongoing grower distributions of the three hybrids to growers interested in evaluating them for suitability at different farm locations on Kauaʻi, Maui, Hawaiʻi, and Molokaʻi. Further adoption of these hybrids by more growers will result in a substantial increase in kalo production.

The proof is in the poi

In the second breeding cycle, two to three sources of TLB resistance are combined by making crosses between elite hybrids. As in the first breeding cycle, the resulting hybrids are evaluated for desirable horticultural traits, and the best of them are selected for the final cycle, where crosses are made with elite aphid-tolerant hybrids. Final-cycle crosses from this program continue to generate possible additional hybrids for the kalo industry.

Several promising elite candidates from the latest final-cycle crosses have already been identified, and their potential role in commercial kalo cultivation is being evaluated. The true measure of success for the CTAHR kalo breeding program is the acceptability and adoption of these new hybrids by the industry (kalo growers and poi millers) and, ultimately, Hawai‘i's kalo corm, lū‘au, and poi consumers.

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