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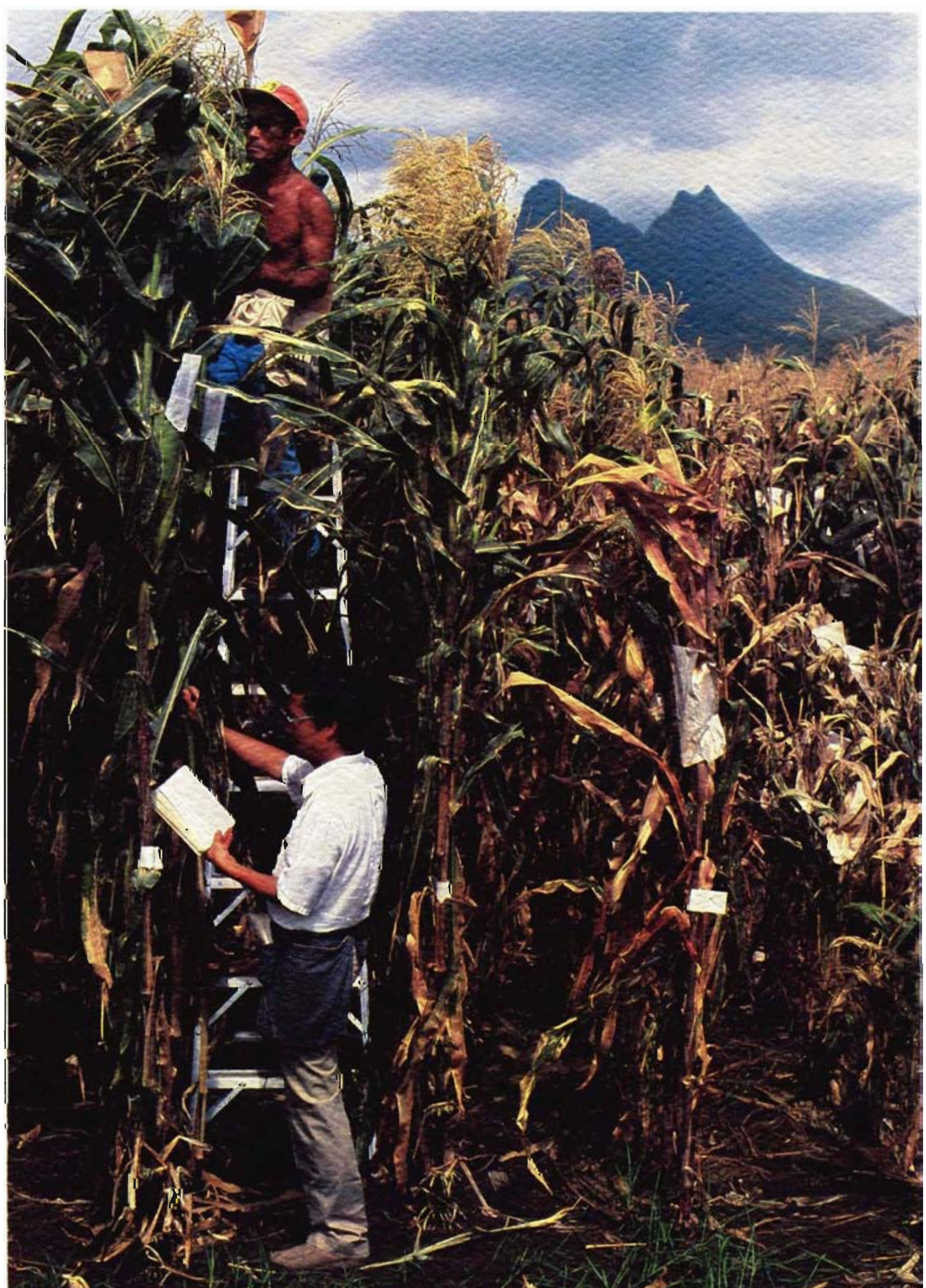
CROP IMPROVEMENT IN HAWAII: Past, Present, and Future

Edited by James L. Brewbaker



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Careful hand pollinations of corn by Jack Kanazawa at the Waimanalo Research Station have resulted in more than 400,000 pedigreed progenies to improve tropical production; Rye Huang helps keep the pedigree records on this tall Guatemalan variety.

CROP IMPROVEMENT IN HAWAII:
PAST, PRESENT, AND FUTURE

Edited by James L. Brewbaker

Compendium based on
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CROP IMPROVEMENT IN HAWAII: PAST, PRESENT, AND FUTURE

Edited by
James L. Brewbaker

INTRODUCTION

James L. Brewbaker
Professor, Department of Horticulture
and
Executive Secretary, Hawaii Crop Improvement Association

The fourth annual conference of the Hawaii Crop Improvement Association, founded in 1968, was held at the Manoa campus of the University of Hawaii on January 21 and 22, 1972. The theme was "Crop Improvement in Hawaii: Past, Present, and Future." Speakers reviewed both the progress and the challenges faced in the improvement of Hawaii's basic crops. The major papers from this conference, together with selected invited contributions, have been updated and compiled for this compendium.

The agriculture of Hawaii is based almost entirely on crops introduced to the State in the past two centuries. Only a few crops accompanied the earliest settlers into Hawaii in the first millenium A.D.; these crops included taro, sweet potato, and the banana. Hawaii's crop production relies increasingly on varieties bred in the State from progenies of introduced lines, selected for local adaptation and pest resistance. From the time of its organization by Jared G. Smith in 1901, the Hawaii Agricultural Experiment Station focused much of its effort on the introduction and improvement of crop plants.

The plant collector for Hawaii has few limitations ecologically, as the State provides environments suitable for virtually every major crop of the world. Many crops have thus appeared at one time or other in Hawaii, often gaining momentary popularity, and then fading away—notable among these have been sisal, rice, pigeon pea, wheat, cotton, and edible canna. Brutal economics often dictated their demise, but so have the pests and diseases introduced to the Islands. Most of the world's agriculture has the unheralded annual advantage of a cold winter or a dry season that interrupts crop production and also interrupts the growth of diseases, insects, and other crop pests. Hawaii's crops are not so fortunate, growing in an environment equally congenial to pests and crops; therefore, crop improvement for pest resistance assumes a role of special significance in Hawaii.

With few exceptions, the major crops of Hawaii rely exclusively on Hawaii-bred varieties. Notable among these is Hawaii's sugarcane crop, a complex of varieties with outstanding yield performance that represents a triumph of plant breeding. Sugarcane is the only Hawaiian crop, however, for which improvement has relied solely on private funds. Public support has made possible virtually all other improvement research reported in this compendium. Increasing private and public commitment to the introduction, evaluation, and breeding must be encouraged for crops that are to remain economically viable for the Islands in the future. This is underscored by extremely high production costs, land values, and labor costs, and a fragile and often fickle market. Varieties with exceptional quality and yield have resulted from Hawaii's breeding programs, and the authors of this compendium have been generally much too modest in assessing the contributions that Hawaiian varieties have made throughout the world, often notably in developing countries, as well as in the State of Hawaii.

CORN

James L. Brewbaker and John R. Thompson
Professor, Department of Horticulture, and
Professor, Department of Agronomy and Soil Science, respectively

Corn (*Zea mays* L.) was introduced to the Hawaiian Islands soon after the arrival of the first explorers. Known as "Indian corn", it was being included by the 1850s in crop contests sponsored by the Royal Hawaiian Agricultural Society. A $500 prize was offered to anyone who could control corn's lowland insect pests (Emerson, 1855)—a feat not achieved for 100 years. At higher elevations, however, corn thrived. Production had increased to almost 10,000 acres by 1900 on the Islands of Hawaii and Maui. Very good yields of 60 bushels per acre were recorded from the 'Leaming' and 'Boone County White' dent cultivars growing at 3000 feet near Kula, Island of Maui, at the turn of the century (Smith, 1903). An early review of methods of corn culture was made by McClelland (1913).

Corn did not thrive at lower elevations in Hawaii, a fact first attributed to the leafhoppers and other insects abounding there. The true cause was later discovered to be a dwarfing disease now known as Maize Mosaic Virus I, or MMV. This disease was recognized to be distinct from sugarcane mosaic virus by Kunkel (1917), who later showed that it was transmitted solely by the leafhopper *Peregrinus maidis.* The leafhopper thrived only at low elevations. It could transmit the virus for periods up to 4 weeks and was blown widely around the Islands (Carter, 1941). Brewbaker and Aquilizan (1965) later showed that MMV resistance was simply inherited, and the gene was found only in corn races that had evolved in the Caribbean Islands.

Two early Hawaii Agricultural Experiment Station (HAES) introductions of corn showed high MMV resistance—a large-seeded white corn from Guam, and 'Cuban Red', a hard, reddish flint (Sahr, 1919: pp. 46–47). Neither variety was accepted immediately for local use, but both slowly gained respect since they were the only varieties surviving at low elevations in Hawaii. Yellow strains of the Guam corn were developed at HAES by agronomists J. M. Westgate and H. L. Chung.

SWEET AND SUPERSWEET CORNS

Sweet corns introduced to Hawaii also fell prey to the mosaic. Several hybrids were produced at HAES prior to 1935 in an attempt to breed in resistance. In 1935, the Puerto Rican variety 'USDA34', a close relative of 'Cuban Red', carrying the sweet corn gene *sugary,* was found to be resistant and soon gained wide acceptance. By this time an exceptional sweet hybrid, 'Golden Cross Bantam', had been released at Purdue University. Although highly susceptible to MMV and almost completely unadapted to Hawaii's short winter days, 'Golden Cross Bantam' remains in gardens in Hawaii 40 years after its release, reflecting its unusual quality and appeal.

'Hawaiian Sugar'

During World War II, interest in agricultural self-sufficiency in Hawaii encouraged a brief broadening of the crop research interests at the Hawaiian Sugar Planters' Association (HSPA). 'USDA34' had shown itself to be a good parent for MMV resistance in HAES crosses (Takahashi et al., 1938: pp. 14–16). The director of HSPA's Genetics Department, A. J. Mangelsdorf, hybridized 'USDA34' and 'Golden Cross Bantam', developing from this cross a variety greatly improved over 'USDA34' in tenderness and taste but resistant to MMV and earworms. It was named 'Hawaiian Sugar' and remains an important open-pollinated sweet corn variety throughout the tropics today. It is widely adapted to poor light conditions and is resistant to MMV, *Fusarium*, earworms, and other maize pests. A primary current version of it is 'Hawaiian Sugar (c)' of HAES, which has added rust and blight resistance, and lower ear position with better brace-rooting. 'Hawaiian Sugar' enters the pedigree of nearly all significant HAES sweet corns (Brewbaker, 1965).

'Hawaii H68'

Released in 1968 (Brewbaker, 1968), 'Hawaii H68' has become the major sweet corn hybrid marketed in Hawaii (Fig.1). It is also sold widely throughout the world by the Northrup-King seed company under the name 'Trop III'. 'Hawaii H68' is the cross of AA8, an inbred derived directly from 'Hawaiian Sugar', with a line bred from Illinois, inbred 442. Some sweet corn hybrids had been developed at HAES many years before by M. Takahashi and D. L. Van Horn (1948, p. 29). Relying heavily on 'USDA 34', these hybrids suffered from tough pericarp and did not gain acceptance. 'Hawaii H68' was chosen from over 600 hybrids and was produced and evaluated in the 1960s for its unusual tenderness and sweetness, yield, reliability, and pest tolerance. It has outyielded all competitive hybrids at Hawaii's low elevations (Brewbaker et al., 1966). Several improved versions of the 'Hawaii H68' hybrid have appeared, enhancing its resistance to mosaic, rust, and blight.

'Hawaiian Supersweet'

Supersweet corns carry genes that lead to very high sugar levels in the kernel and high keeping quality after harvest (Fig. 2). Nine open-pollinated varieties bred in Hawaii

Figure 1. Hybrid 'Hawaii H68', the first HAES hybrid sweet corn, has high tolerance to ear and plant pests and diseases.

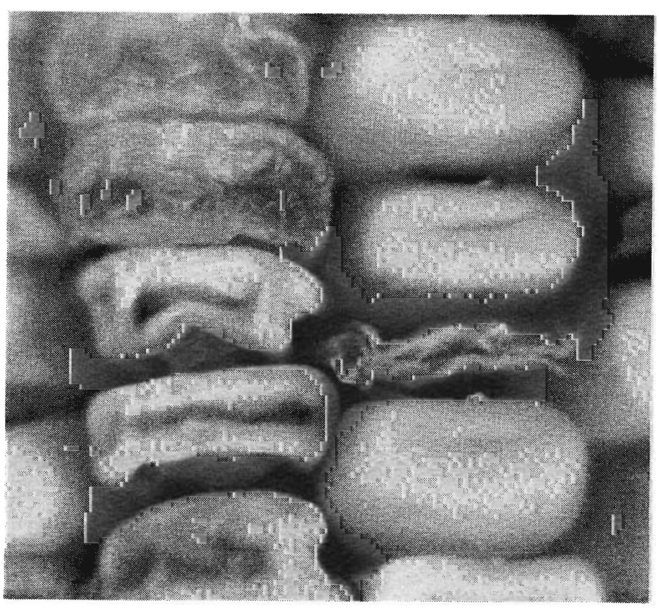

Figure 2. Supersweet, sweet, and field corn seeds segregating on a single ear. Supersweet seeds (*bt* gene) are collapsed and deeply dented, while sweet seeds (*su* gene) are wrinkled and glassy. One kernel can be seen with both genes, and is completely collapsed, having little or no starch.

Figure 3. Seed production field of hybrid 'Hawaii H68' towers over Lilia Brewbaker. Four rows of AA8, detasseled to serve as female, alternate with two rows of 442a serving as male. (Courtesy: Northrup-King Seed Co.)

have been released to farmers (Brewbaker, 1971), the latest in 1977. 'Hawaiian Supersweet No. 9' (based on the gene *brittle*-1) is now the most widely grown of these, and is widely dispersed in the tropics (Brewbaker, 1977). Variations No. 7 and No. 8 contain the high-lysine gene *opaque*-2, noted for improving protein quality of corn. Several of the Hawaiian supersweets have been adopted for market production elsewhere in the tropics and are noted for high retention of quality following harvest. 'Hawaiian Supersweet No. 6' (Brewbaker, 1975*b*) was the first supersweet corn based on the gene *brittle*-2, and earlier releases were based on the gene *shrunken*-2. Hybrid supersweets have been produced and tested in Hawaii since 1975, and were released in 1981.

FIELD CORN

Field corn production in Hawaii generally decreased after 1920, as livestock production became more firmly based on grass-fattening at higher elevations and as corn yields continued to be decimated by MMV in the lowlands and by blight in the highlands. Strains selected by HAES at

Haiku, Island of Maui, were dubbed the 'New Era' varieties (Chung, 1921: p. 56), but evidently failed to usher in a new era. Several varieties of field corn became well-entrenched local favorites, as illustrated by their names. 'Waimea Dent' evolved in the mid-20s from open-pollinated corn growing on the Parker Ranch in the Kamuela area on the Island of Hawaii that was extremely blight tolerant with high ears. 'Kohala Yellow' evolved similarly on the north shore of the Island of Hawaii, and 'Haiku Yellow' on the Island of Maui, each having intermediate resistance to blight and mosaic. 'Mayorbello', introduced from Cuba, brought superior MMV resistance and high yield capacity, and 'Tuxpan' (or 'Tuxpeno'), a noted favorite in Mexico and a possible parent of the Guam corns, became established at high elevations.

'Hawaiian Yellow'

Many of the varieties described above were put into a melting-pot or polycross by Dr. Mangelsdorf at HSPA during World War II, and the resultant variety was dubbed 'Hawaiian Yellow'. A hard, yellow flint, it was selected rigidly for MMV and earworm resistance and showed fair hybrid vigor due to its broad ancestry. It remains in limited production today and has been widely used in varietal and hybrid development in Hawaii and abroad, especially in the Philippines (as 'Philippine Yellow Flint').

Field corn improvement was reinstituted briefly at HAES by Takumi Izuno in the early 1960s. He developed a series of tropical varietal hybrids, including dwarf (*brachytic*-2) counterparts. These have been maintained and expanded by Thompson, with emphasis on blight-resistant and short-stature types for Hawaii's mid-elevations.

'H610' and other hybrids

A quartet of hybrids—'H610', 'H652', 'H763', and 'H668'—includes present favorites of those developed by the senior author since 1970. The first three are single crosses and the last a double cross. All involve tropical parents crossed with Corn Belt lines of noted combining ability (Brewbaker, 1974). All are adapted primarily to lowland production, with high mosaic, earworm, and rust resistance. The latter disease (*Puccinia sorghi*) has become an increasing problem in Hawaii as irrigation has increased year-round corn production and thus year-round sporulation for the disease (Kim and Brewbaker, 1976, 1977). Many additional HAES hybrids are undergoing evaluation, and their parentage now encompasses nearly all of the significant types of corn. Some are selected for high grain production, others as silage hybrids, some for lowlands, and some for highlands. Together with superior commercial corn hybrids, notably 'X304C' of Pioneer Hi-Bred International, the Hawaiian hybrids currently support grain and silage production on 3500 acres annually in Hawaii.

Ongoing improvement programs for field and sweet corns in Hawaii involve the participation of the authors and of Jeri J. Ooka, pathologist, and Ramon de la Peña, agronomist, on the Island of Kauai; Yoshio Seigaku, research associate, on the Island of Hawaii; and Jay H. Chung and Rye Huang, agronomists, on the Island of Oahu. Primary research associates on Oahu are Jack Kanazawa, breeder, and Mardonio Orsino and Choki Higa, seedsmen. Research on corn diseases and insect resistance has been reviewed (Brewbaker, 1975*a*), and major improvements have been made in earworm tolerance (Brewbaker and Kim, 1979). Almost a dozen publications based on related research at HAES describe biochemical studies of genes and enzymes in Hawaii's corn (reviewed by Peirce and Brewbaker, 1973). Horticultural releases also include a colored "Indian corn" bred for the tropics, with the Hawaiian name for calico, 'Kalakoa' (Brewbaker, 1972).

SEED PRODUCTION

Winter corn seed production was introduced to Hawaii following the description by Brewbaker and Hamill (1967) of the superior winter yields possible in leeward areas such as those near Kaunakakai, on the Island of Molokai. Corn seed production grew from the time of its introduction to a $3 million industry in 1981. Over 50 of the 200 companies that market hybrid corn in the United States were represented in Hawaii for winter or year-round nurseries in 1981. Major seed research has been concentrated on corn, but also includes sorghum, soybeans, rice, and other crops. In 1969, the seed growers and breeders established the Hawaii Crop Improvement Association, which has sponsored symposia such as that of Brewbaker (1975*a*) and the conference serving as the basis for this present publication on crop improvement in Hawaii. As this seed industry turns its attention increasingly to demands of the tropics, Hawaii will be the beneficiary (Fig. 3).

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SORGHUM

Peter P. Rotar
Professor, Department of Agronomy and Soil Science

With recent changes in the agricultural industry of Hawaii, serious efforts have been made to produce feed grains locally. It has been recognized that sorghum could be a replacement crop for agricultural lands released from sugarcane production. A feasibility study by Drew (1972) indicated that sorghum could be a profitable enterprise if annual yields of 200 to 300 bushels per acre could be realized (Figure 1). These figures are realistic under ratoon culture in Hawaii, with projections of 120 days for a plant crop and 105 days for each of two ratoon crops (Plucknett et al., 1971).

Two large-scale farm operations, one at the former Kilauea Plantation on the Island of Kauai and the other at the Kohala Sugar Plantation on the Island of Hawaii, went into grain sorghum production in the 1970s. Both operations quickly ran into difficulties and predicted grain yields, based on small trial plantings, were never realized. Several problems developed, including a lack of adapted hybrids and the fact that birds, insect pests, and diseases caused greater difficulties than anticipated (Rotar, 1978).

From the beginning, it was realized that birds would be a problem, but not to the extent that they would wipe out large acreages. Hawaii's landscape is well dissected by ravines and provides excellent nesting sites for birds adjacent to production fields. Bird damage is severe. At the Waimanalo Research Station, ricebirds, sparrows, doves, Brazilian cardinals, and pigeons feed on unprotected plots. Ricebirds are the worst offenders, eating the developing grain during the milk and soft-dough stages and causing serious loss due to shattering of ripe grain. Experimental plots cannot be left unprotected at any experimental farm in the Islands, as birds quickly learn how to tear open the kraft paper bags used to protect the developing grain. The first planting in any area may escape serious depredation, but the birds quickly discover the new source of feed and succeeding crops are severely damaged. Effective bird-control measures are lacking: chemicals are expensive and may be hazardous to other birds; noise devices work for small plots but are annoying to the human population. At this time, there are no suitable bird-resistant sorghum

Figure 1. Outstanding cultivars of grain sorghum, introduced from Thailand, can produce up to 300 bushels per year in Hawaii when ratooned.

varieties available; so-called bird-resistant varieties contain tannins that discourage birds but also reduce quality of grain.

Insects may be just as serious as birds. The sorghum midge (*Contarinia sorghicola*) can completely wipe out any grain. The midge, less than one-eighth inch in length, oviposits in the exposed flowers, and the developing larvae destroy the ripening grain. The life cycle of the midge is about 17 days. Control is difficult and timing of control measures is critical. The commercial operations on the Islands of Kauai and Hawaii lost large acreages to the midge during the 1973–74 winter season, as inclement weather prevented sustained control measures. Where sorghum is flowering over long periods of time, early varieties escape with little midge damage but late-maturing varieties are badly damaged.

Other insect pests include aphids, webworms, pineapple souring beetles, corn earworms, grasshoppers, and green stinkbugs. The exposed grain is quite vulnerable, and closed or semiclosed head types provide ideal hiding places for insect pests. As much as 25 percent loss has been estimated due to insect-damaged grain. Aphids are usually kept in check by natural predators; however, aphid populations can build up and destroy experimental plots even though natural predators are abundant. In stored grain the seed weevil can be a very serious pest.

Major sorghum disease problems in Hawaii include leaf rust and leaf blight. Most Mainland varieties are susceptible to these diseases. In wet locations, yields may be seriously reduced by the destruction of leaf tissue during grain filling. Lodging is a problem in one of the best-adapted Mainland varieties BR 79 (de Kalb). Other diseases that may cause trouble are stalk rots, sugarcane mosaic virus, head blights, and root rots. Downy mildew, a serious disease in the southern half of the continental United States, is not present in Hawaii. Experimental lines that are resistant to these diseases are available, but need further development and evaluation before they can be released as varieties. Yield trials of commercial U.S. hybrids are summarized by Rotar et al. (1975).

A much better use for sorghum and sorghum-sudangrass hybrids may be that of a cut forage. The forage types grow rapidly and are not troubled to the same extent as grain types by birds and insect pests.

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CEREAL, FIBER, AND DIVERSIFIED AGRONOMIC CROPS

James L. Brewbaker and John R. Thompson
Professor, Department of Horticulture, and
Professor, Department of Agronomy and Soil Science, respectively

Hawaii's climate endows its agriculture with almost unlimited versatility. Sugarcane is often believed automatically to be Hawaii's major crop; however, experiments have made it clear that sugarbeets could be equally productive in Hawaii, despite much more intensive research on cane improvement for the State (Younge and Butchart, 1963). Cereal, fiber, leguminous, and other crops from both mid-tropics and cool temperate regions often yield well in Hawaii. Many of these agronomic crops have been grown successfully, but few remain today as economic crops. This report deals with agronomic crops not fully explored elsewhere in this compendium. Any serious student of the subject is referred to David L. Crawford's impressive early treatise, *Hawaii's Crop Parade* (1937), and Marie C. Neal's classic book, *In Gardens of Hawaii* (1965).

An amazing variety of crops has been commercially significant in Hawaii at one time or other. The major cereal crop has been variously rice, wheat, sorghum, or corn. The latter two crops are discussed elsewhere in this volume.

WHEAT

Wheat (*Triticum aestivum*) was one of the first cereal grains to be introduced to Hawaii, brought by Spanish botanist Don Marin in 1815. The early American immigrants did not readily adjust to the starch sources of the Hawaiians (poi from taro, and cooking bananas), and urged the early planting of wheat. Emerson and Green (1852) wrote about the early imported wheat flour, noting that "what reached us . . . was barely tolerable . . . a chisel and mallet were needed to prepare the way for sifting . . . oftentimes a pickax and crowbar seemed necessary. Usually it was musty and sometimes sour and often riddled with bugs and worms. I have little doubt that the ill health of many of the early residents had its origin in imported flour."

Wheat production developed in such areas as Kula on the Island of Maui, and by 1853 over 5000 barrels of flour were milled annually in Honolulu. During the California gold rush, wheat was exported to the West Coast. (If previous experience is any indication, the California gold miners may have had additional use for their pickaxes.) Wheat production was based on the spring wheats, which did not require vernalization (cold treatment). Yields and production costs could not compete with those of the high-yielding winter wheats of the Mainland, and the industry soon died. Little has been written of wheat in the Hawaii Agricultural Experiment Station (HAES) record, and no serious varietal introduction or breeding has been done. In recent years, however, the seed industry has expanded its interest in obtaining additional generations of wheat and barley in Hawaii. Artificial vernalization has been used to bring many varieties to flower, and growth and seed yields have been quite satisfactory (Thompson, unpublished).

RICE

Crawford (1937) wrote that in 1853 about $12,000 was being spent annually to import Chinese rice for ". . . a crop which might as well be grown here." The arrival of Oriental immigrants increased the need for rice, and production increased rapidly. Over 13 million pounds were exported from Hawaii to the Mainland in 1887. Competition from the Orient became very great after 1900, however, and production soon dwindled.

In 1906, F. G. Krauss was hired by HAES to improve crop production methods. Experimental rice plots, using 130 varieties and a range of cultural practices, were somewhat successful. By 1910 production had increased to more than 10,000 acres, much of it on the Island of Kauai, and it was then Hawaii's second most important crop ($2.5 million vs. $30 million for sugar). Increased competition from California then drove down prices for rice, and the death knell for rice in Hawaii was sounded in 1928 with the introduction of the rice stem borer.

OTHER SMALL GRAINS

Small acreages of oats, barley, and rye have been grown commercially in Hawaii. Triticale, a cross of wheat with rye, has shown some promise at high elevations and is in limited use in local breads. For forage purposes, triticale would probably exceed yields of other small grains, as it also may for dry grain. Oat varieties from the Mainland's upper Midwest have produced the highest yields in studies near Waimea, on the Island of Hawaii.

COTTON

Cotton (*Gossypium* spp.) was introduced widely to the Islands in the early 1900s, particularly the Sea-Island cotton, *G. barbadense* (Krauss, 1909). Production did not prove economic due to the severity of the cotton bollworm (also known as corn earworm and tomato bud-worm). An indigenous species of cotton, *G. tomentosum*, is native to the coastline of the Islands, but has never been produced commercially.

SISAL

Sisal (*Agave sisalava*) was imported to Hawaii in 1893, and 3000 acres were under cultivation by 1918. Several companies processed the fiber into binder-twine, marine ropes, and even hula skirts on the Islands of Kauai, Maui, and Molokai before the industry slowly died. Varietal variation and the agronomy of this plant were discussed by Wilcox and McGeorge (1912).

PYRETHRUM

Pyrethrum (*Chrysanthemum cinerariaefolium*) has been grown successfully in Hawaii, with efforts to establish a small industry in 1909 (Crawford, 1937). Trial plantings were made by HAES in the ensuing years, in the 1930s using seeds from Colorado. A recent report on the feasibility of pyrethrum as a crop for Hawaii was prepared by Brewbaker (1974) that encouraged a limited but long-range research program on varietal selection and mechanization of this crop.

SUGARBEET

Sugarbeet (*Beta vulgaris*) is not grown in Hawaii, but might assume a healthy competitive position with sugarcane. Highly respectable yields of beets have been obtained in Hawaii, both in public (Younge and Butchart, 1963) and in private (unpublished) efforts. This is also true in other subtropical countries, and the effectiveness of either crop hinges more on local culture and traditions than on adaptability. A serious appraisal of modern varieties of sugarbeets, and introduction of contemporary equipment, might make sugarbeet hybrids a serious competitor with sugarcane in Hawaii.

EDIBLE CANNA

Canna edulis was the subject of serious appraisal by HAES scientists as a source of starch from its roots. J. C.

Ripperton spearheaded the canna root research, which included extensive varietal introductions and some hybridization (Ripperton, 1927*a*, 1927*b*, 1931; Ripperton et al., 1928, 1929). However, this crop never became a serious challenger to cereal crops, despite research enthusiasm.

SOYBEANS

The soybean (*Glycine max*) has been evaluated and grown widely as a vegetable crop in Hawaii (see companion report by J. C. Gilbert). No serious production has been made of the beans as a grain legume, however, despite evidence as early as 1932 (Wilsie and Takahashi, 1933) of the successful production of several imported varieties. Daylength-insensitive and disease-tolerant varieties now available in the world collection of the International Soybean Institute, University of Illinois, are currently being evaluated in Hawaii.

PEANUTS

Peanuts (*Arachis hypogea*) can be grown with ease in the more sandy soils of Hawaii, making an excellent product. Yields exceeding 1 ton/acre (cured weight of seeds) in 160 days were reported in the early varietal trials of F. G. Krauss (1910). However, no significant production has developed in the Islands.

RUBBER

The rubber tree (*Hevea brasiliensis*) was the subject of major early research bulletins of HAES (Smith, 1905; Smith and Bradford, 1908). The productivity and quality of Hawaiian rubber of the Ceara, Para, and Panama lines were competitive with those of major producing nations, but labor and land costs precluded successful plantation development, and no selection work continued.

TOBACCO

Tobacco (*Nicotiana tabacum*) grows well in Hawaii, and the poisonous tobacco species *N. glauca* also appears as a common escaped weed in the Islands. Production was encouraged and methods were discussed by Smith and Blacow (1905), and the methods of cultivation were more fully explored in a later bulletin (Smith and Blacow, 1907). An industry developed on the Kona coast, Island of Hawaii, but was severely set back by leaf diseases. In 1912, a fire destroyed buildings and stored tobacco in Kona, from which the industry never recovered.

COFFEE

The coffee industry of Hawaii is entirely based on one variety of *Coffea arabica*. There have been no major varietal evaluations published on coffees in Hawaii, and no breeding work with them. The industry has slowly dwindled in importance in the past decade.

OTHER AGRONOMIC CROPS

Many other agronomic crops have been grown in Hawaii, occasionally attracting research and agribusiness interests. Forest crops have perhaps been the most neglected by HAES in its plant introduction and breeding efforts. This is due in part to the extensive introduction programs of the USDA Forest Service, through its Honolulu-based Institute of Pacific Islands Forestry.

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SUGARCANE

Don J Heinz
Vice President-Director of Experiment Station, Hawaiian Sugar Planters' Association

Through the late 1800s and early 1900s, the only sugarcane clones available in Hawaii for commercial use were those belonging to the species *Saccharum officinarum*. They were indigenous to New Guinea and surrounding islands and were distributed as cuttings throughout the Pacific Islands by Polynesians, and later around the world by Caucasian explorers in the 18th and 19th centuries.

Attempts to improve sugarcane through breeding in Hawaii began in 1851 under the direction of the Royal Hawaiian Agricultural Society. The first successful germination of sexual seed was done in Java in 1885; another success occurred in 1887 in Barbados. Modern cultivars are entirely derived from seed selection programs. Crossing programs were soon underway in Java, Barbados, India, Demerara, and Martinique. In Hawaii the first successful crosses were made in 1904. It was from these that the first outstanding clone 'H109' was developed from *Saccharum officinarum* parents.

An embargo was imposed on further importation of sugarcane into Hawaii in the early 20th century, since insects and diseases had been introduced with asexual sugarcane cuttings. It was not until 1923 that importation was again permitted, using a disease-free facility on the Island of Molokai. These introductions included many species of the genus *Saccharum* and related genera. Interspecific hybrids of *S. officinarum* and *S. spontaneum* from Java became early parents of our present commercial cultivars.

An intensive breeding program was started by the privately supported Hawaiian Sugar Planters' Association (HSPA) in 1926 under the direction of A. J. Mangelsdorf and is still continuing (Mangelsdorf, 1946, 1950, 1953). As a result of this effort and the further development of adapted agronomic practices, Hawaii has the highest yield of sugar per acre of any sugar-producing area in the world.

Many innovations were developed to exploit the basic *Saccharum* germplasm (Heinz, 1967; Warner, 1953). These include the use of melting pots (polycrosses); the development of sulfur-dioxide solutions to preserve cut stalks; the raising of large numbers of seedlings (2.5 million each year); the use of bunch plantings; the development of a large group of regional variety stations for selection and evaluation; the development of cell and tissue culture techniques as a useful tool for the breeder of asexual crops (Heinz and Mee, 1969, 1970); and the intensive use of computers for data storage, retrieval, and analysis.

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PASTURE GRASSES

Ukio Urata
Assistant Professor, Department of Agronomy and Soil Science

Pasture grass improvement in Hawaii has occurred largely by introductions in the 20th century, although some breeding work with napiergrass, pangolagrass, and kikuyugrass has been done. At the beginning of this century, the dominant grasses of Hawaii were bermudagrass (*Cynodon dactylon*) at lower elevations and Hilograss (*Paspalum conjugatum*) at higher elevations (Smith, 1903). Under very wet conditions, Hilograss could be found down almost to sea level. The dominant grass in very dry areas was piligrass (*Heteropogon contortus*), but it was suffering from overgrazing and had almost disappeared by 1900 (Smith, 1903). Hilograss is undesirable in pastures, being relatively unpalatable (Whitney et al., 1939). Bermudagrass is highly palatable and of good nutritional quality, but is relatively unproductive in Hawaii.

Little plant breeding had been conducted on grasses at Hawaii Agricultural Experiment Station (HAES) prior to 1970, most of this on napiergrass (*Pennisetum purpureum*) in the 1930s (Takahashi et al., 1943). This work was unfortunately cut short, and the napiergrass clone still widely grown in Hawaii is an early importation, the variety 'Merker', that is resistant to the eyespot disease. A number of promising recent introductions of pasture grasses are being tested widely in Hawaii (Whitney, 1975). These include species and varieties that have performed well elsewhere in the tropics. Limpograss (*Hemarthria altissima*), 'Molopo' buffelgrass, and *Brachiaria decumbens* all appear very promising from initial trials (Whitney, 1975).

The five major pasture grasses in Hawaii are all introduced–kikuyugrass, pangolagrass, guineagrass, paragrass, and buffelgrass. A short description of the adaptation, usefulness, and improvement of these species follows.

KIKUYUGRASS

Kikuyugrass (*Pennisetum clandestinum*) was first introduced from highland Africa to Hawaii in 1924 (Hosaka, 1958). It now covers much of the wet, subtropical high-elevation rangelands of Hawaii from 1500 to 5000 feet, although it occurs both above and below these elevations in some areas. It requires fertile soils, and is found preferentially on volcanic soils throughout the world. Kikuyugrass produces both rhizomes and stolons, and persists quite well under grazing. In many areas it will withstand conditions of seasonal drought. It produces about 40 percent of the pasture forage in Hawaii, and has no serious diseases, although *Helminthosporium* leaf spot and *Piricularia* leaf spot occur at times.

Kikuyugrass is highly nutritious under good management. It occurs mixed with pangolagrass in many areas, and it will encroach on pangolagrass when fertilized and will retreat when unfertilized. Kikuyugrass combines well with temperate legumes like white clover and big trefoil.

Kikuyugrass flowers only when cut or cropped short, with a single major flowering period from November to January. It is normally propagated from cuttings, although seeds are now available in the world market. Kikuyugrass breeding at HAES presently involves plants derived from seeds. An original planting of 3500 plants was reduced in several stages to 9 selections, and these are under intensive evaluation in the State.

PANGOLAGRASS

Pangolagrass (*Digitaria decumbens*) was first introduced to Hawaii in 1950 by HAES (Hosaka and Goodell, 1954). It filled a real need at the time, replacing nonproductive grasses in warm, moist areas of relatively poor fertility. Pangolagrass replaces kikuyugrass in areas in which their ranges overlap if soil fertility is low. Pangolagrass has a number of weaknesses: its annual period of maximum growth is relatively short, and it becomes unpalatable after flowering, although cattle graze it if given no alternatives. Its relative unpalatability at maturity results in management problems in mixtures with legumes, although it combines fairly well with white clover, big trefoil, and 'Greenleaf' desmodium. Pangolagrass is generally susceptible to rust caused by *Puccinia oahuensis*, but the variety 'Dwarf Pangola' is resistant.

Pangolagrass is a sterile triploid that is propagated by stolon cuttings. By doubling its chromosome number with colchicine, making it a hexaploid, it was rendered partially fertile (Rotar and Urata, 1966). It was then hybridized to a diploid *Digitaria pentzii*. A selection of this cross was released in 1975 after 8 years of testing and was given the designation 'Mealani' (Urata, 1975).

'Mealani' is a tetraploid clone and is apparently completely sterile. It is superior to common pangolagrass in yield and palatability, and has a longer season of good growth. It also carries resistance to *Puccinia oahuensis* rust. Its range of adaptation is similar to that of pangolagrass with a possible extension into somewhat cooler areas. It is more of a bunch-type grass, producing a smaller number of stolons than pangolagrass. This is a negative factor because only the stolons root easily to permit vegetative propagation.

GUINEAGRASS

Guineagrass (*Panicum maximum*) is best adapted to the lower elevations and to well-drained areas with seasonal rainfall. It was introduced about 1870 (Hosaka and Carlson, 1952), and was in extensive HAES trials by 1912 (McClelland, 1915). It is a bunchgrass that grows to 8 feet in height. A much smaller variety, 'Green Panic' (*P. maximum* var. *trichoglume*), is adapted to conditions drier than those suitable for ordinary guineagrass and also occurs as a weed pest in Hawaii. Guineagrass grows best in areas adapted to sugarcane, and it is thus often reserved for slopes too steep for sugarcane cultivation.

Guineagrass does not grow well above 2000 feet. It is apomictic, producing seedlings that develop into plants identical to the parent. Guineagrass combines well with the legume, koa haole (*Leucaena leucocephala*).

PARAGRASS

Paragrass (*Brachiaria mutica*) has often been called "California grass" in Hawaii. It was introduced in 1902 (McClelland, 1915), and grows best in low-lying areas that are swampy or have a high water table. In well-drained soils it has a reputation of disappearing under heavy grazing. Paragrass is often used for green chop. It remains green throughout the dry season in poorly drained areas, enabling it to obtain much nutrient material from runoff. It does not set seed in Hawaii although it flowers periodically, and is propagated from cuttings.

BUFFELGRASS

Buffelgrass (*Cenchrus ciliaris*) was first introduced to Hawaii in 1935 (Hosaka and Carlson, 1957), and took over large areas of dry lowlands that were formerly devoid of a perennial range grass. Buffelgrass is a grass of the lowlands, except for a variety called 'Molopo' buffelgrass that is adapted to the middle-elevation, alternating wet-and-dry, leeward areas up to about 3500 ft. In the lowlands it grows under kiawe, which is a leguminous tree that produces edible beans for cattle, and the dropped leaves and flowers provide nutrition for the grass undergrowth.

OTHER PASTURE GRASSES

Other grasses of Hawaii's ranges have included many genera, of which few have proved to be of satisfactory quality and yield for wide-scale production. Reviews of Hawaii's native and introduced grasses have been made by McClelland (1915), Whitney et al. (1939), and Rotar (1968).

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FORAGE AND FOREST LEGUMES

James L. Brewbaker and Peter P. Rotar
Professor, Department of Horticulture, and
Professor, Department of Agronomy and Soil Science, respectively

All of Hawaii's pasture legumes have been introduced since the time of Captain Cook, in 1778. In an early review of Hawaii's leguminous crops, Krauss (1911) reported alfalfa and pigeon pea to be the major pasture and forage species in Hawaii. The State has a very small assortment of native legumes, including the koa (*Acacia koa*) and mamani (*Sophora chrysophylla*) trees that provide some animal browse and wood for craft use. These were the only two indigenous species, however, cited by Hosaka and Ripperton (1944) in their definitive report on 49 legumes found in Hawaiian pastures. Herbaceous genera cited by the authors as of major importance included *Cajanus*, *Crotolaria*, *Desmanthus*, *Lespedeza*, *Lotus*, *Medicago*, *Stylosanthes*, *Trifolium*, and *Vicia*. Important arboreal genera cited were *Leucaena* and *Prosopis*. Since the time of their report, crop introductions have included relatively few additional species, notably the *Desmodium* and *Glycine*. Breeding work in Hawaii has been very limited on the legumes, concentrating on the genera *Desmodium* and *Leucaena*, although continuing introductions and evaluations have been made in several species.

FOREST LEGUMES

Koa haole (*Leucaena leucocephala*) has been the principal arboreal, or forest, legume in Hawaii Agricultural Experiment Station crop improvement research (Fig. 1). Koa haole is expanding in world importance as a source of fuelwood and forage, and in a variety of lesser roles (Anon., 1977). Koa haole was introduced to Hawaii, probably from the Philippines, in the early part of the 19th century, and has become widespread and often dominant in dry low-

Figure 1. Rapid growth of koa haole is illustrated by cultivar 'K8' at Waimanalo Research Station, Oahu, only 3 months after transplanting of 10-week-old seedlings.

lands. Its value as a browse and forage legume was recognized in the management studies of Takahashi and Ripperton (1949) and Kinch and Ripperton (1962), who showed it to be one of the most hardy, productive, pest-free legumes for Hawaii. The Islands' leucaenas showed little genetic variability, and a world collection of 700 leucaenas, largely from Central America, has been assembled since 1962 at HAES (Brewbaker and Hutton, 1979). Forage yield trials identified superior cultivars among these lines (Brewbaker et al., 1972), of which cultivar 'K8' was released to growers in 1974 (Brewbaker, 1975). 'K8' and related varieties of the Salvador type can grow to be very large trees, and it is in this role—as source of wood for fuel, paper, and wood products—that they have become best known in the tropics. New varieties are being developed to reduce the content of mimosine, an alkaloid toxic to nonruminant animals, and to provide better forest trees for wood-fuel production (Gonzalez et al., 1967).

Kiawe, or algaroba (*Prosopis pallida*), was introduced to Hawaii in 1828, and seeds from a single tree account for most of the populations now widespread in dry regions of the Islands (Hosaka and Ripperton, 1944). Kiawe provides valuable additional feed and shade for animals in lowland areas, and the wood makes a respected charcoal. It is perhaps more important simply as forest cover in these otherwise denuded, dry areas of the State. Although most kiawe trees are thorny, variations occur in size of spine, and are assumed to be simply inherited.

One of Hawaii's few native legumes is the important craftwood, koa (*Acacia koa*), a dominant tree in wet midlands of the Islands. A related small tree, *A. koia*, has been distributed by ranchers into drier areas of the State. Despite heavy forest removal in the 1800s, the koas abound on most islands, and show extensive genetic variation. Identification of superior trees and collections of seeds throughout the State have been made as a basis for future tree improvement studies (Brewbaker, unpublished). Hawaii's second major forest legume is mamani (*Sophora chrysophylla*), a dominant tree of cold highlands. It is ravaged by goats and makes excellent hardwood posts, but has not been entered into tree evaluation or improvement studies.

Several objectionable forest legumes have become widespread in sections of Hawaii. These include opiuma (*Pithecellobium dulce*), a thorny tree that becomes a pest in pastures; *Cassia* spp., common weeds of poor pastures and waste places; klu (*Acacia farnesiana*), a thorny shrub that is a serious pest in pastures; black wattle (*Acacia decurrens*), a rapidly spreading tree on Maui; and gorse (*Ulex europaeus*), a very spiny European shrub made notable by Winnie-the-Pooh. Although not a tree, the sensitive plant, or hilahila (*Mimosa pudica*), could be added here as a spiny leguminous pest in pastures, browsed by animals when feed is limiting.

ALFALFA

Alfalfa (*Medicago sativa*) was introduced in 1895 to Hawaii and has been produced on small acreages throughout the State ever since. Limited varietal introductions were made, but management and fertilizer tests were expanded on alfalfa in the 1940s. Varietal evaluations were then expanded in the 1970s by J. R. Thompson (unpublished). Commercially available, nondormant cultivars were shown by Thompson to yield very well under continued monthly clipping, averaging over 10 tons dry matter annually under intense management near sea level.

TREFOILS

Several trefoil species (*Lotus* spp.) are adapted to the mid- or high elevations in Hawaii (Hosaka and Ripperton, 1944). Big trefoil (*L. pedunculatus = uliginosis*) has proved to be well suited to wetter highland areas, where phosphorus is limiting to white clover, and superior varieties have been identified by Whitney (1975). Several outstanding varieties of birdsfoot trefoil (*L. corniculatus*) from South America also have been identified and observed to compete well with kikuyugrass, while Mainland varieties perform less well in Hawaii (Whitney, 1975).

WHITE CLOVER

Several species of the clover genus, *Trifolium*, have been introduced to Hawaii, of which white clover (*T. repens*) is the most studied and the most widely dispersed. It is an important leguminous feed in highland pastures, growing well in combination with aggressive grasses when soils are fertile and overgrazing is curtailed. Extensive varietal variation has been identified among local clovers, but introduced lines of the large-leaved ladino clovers appear superior in yield. Alsike clover (*T. hybridum*), red clover (*T. pratense*), hop clover (*T. procumbens*), subterrannean clover (*T. subterranneum*), and the species *T. ambiguum* have been introduced but less widely evaluated or adapted in the State.

DESMODIUM

Among the most important forage legumes of Hawaii are species of the tropical herbaceous legume, *Desmodium*. The most widely dispersed and attractive of these have been 'Greenleaf' desmodium (*D. aparines = intortum*) and kaimi clover (*D. canum*). Introductions of Spanish clover (*D. sandwicense*) and 'Silverleaf' desmodium (*D. uncinatum*) have been important in improvement programs. The beggarweeds (*D. discolor*, *D. tortuosum*, and *D. triflorum*) are other species common in the State. The desmodiums are aggressive, rapidly growing plants that are generally relished by animals. *D. aparines* is an upright to spreading, large-leaved

Figure 2. 'Kuiaha' desmodium, an aggressive high-yielding variety of *Desmodium aparines* in kikuyugrass pasture (Rotar and Palmer, 1971).

species that competes aggressively with grasses and can yield very well (Younge et al., 1964). Kaimi and Spanish clovers also provide significant leguminous forage in mid-elevation pastures of the Islands. Genetic studies have focused on Spanish clover (Park and Rotar, 1968) and on its fertile hybrids with *D. aparines* and *D. uncinatum* (Rotar et al., 1967; Rotar and Chow, 1971). A synthetic variety of *D. aparines*, named 'Kuiaha', was bred and released to growers by Rotar and Palmer, 1971 (Fig. 2).

PIGEON PEA

The pigeon pea (*Cajanus cajan*) is a native of Asia that probably came to Hawaii soon after Captain Cook in 1778. Major introductions, however, were made from Puerto Rico around 1900 (Krauss, 1911). The pigeon pea is an important food legume (green beans) in the Caribbean. It can also be grown as a perennial and used for animal feed or green manure, although protein levels of mature foliage are relatively low. In the early part of the 20th century, pigeon pea production approached 10,000 acres annually in Hawaii, and it was distributed throughout the Islands; "pigeon pea beef" was even a hallmark of some ranches (Krauss, 1932). Production and management of this hardy crop were reviewed in detail by Krauss (1932), with extensive data on the genetics and varietal variation in the species. Pure-line selection among progenies of several hundred hybrids produced by HAES breeders resulted in strains with outstanding forage performance, known as the 'New Era' cultivars. Methods for mechanizing the forage harvest of these varieties were refined, but the crop has attracted diminishing attention in recent decades. Interest in this important species has been eroded by its low nutritional value, and by general trends toward calving in highlands (where pigeon peas do not thrive) and toward pen-feeding in lowlands with high-energy, high-protein feeds.

CREEPING INDIGO

Creeping indigo (*Indigofera endecaphylla*) was introduced to Hawaii in 1941 from Sri Lanka, and was extensively evaluated. An aggressive, drought-tolerant, relatively palatable legume, it has many characters of an excellent pasture legume and is well adapted in Hawaii. However, it carries a high level of the toxic alkaloid, indospicine, that can cause severe abortion in pregnant cattle, among other effects (Norfeldt et al., 1952). Little improvement work occurred on the plant after this discovery, since there was no indication of varieties lacking the toxin. An erect, woody indigo (*I. suffruticosa*) is more of a pest than an important forage and has been little studied.

MISCELLANEOUS LEGUMES

Many other leguminous species have been introduced and evaluated in Hawaii, although limited crop improvement studies have been conduced on them. *Stylosanthes guianensis*, an increasingly significant tropical legume, was introduced to Hawaii in 1938, and improved Australian varieties have been evaluated in the 1970s (Whitney et al., unpublished). It is an excellent leguminous feed adapted to lowland pastures. *Macroptilium atropurpureum* cv. Siratro is the first major tropical legume to result from a breeding program. It was introduced in the 1960s from Australia and may have promise for lowland and midland pastures, especially if additional disease resistance can be incorporated into it. Several varieties of *Glycine wightii* were also introduced from Australia in the 1960s. The *G. wightii* varieties have turned out to be productive, palatable legumes adapted to Hawaii's lowlands (Whitney, unpublished).

Several temperate, herbaceous legumes occur in Hawaiian pastures, but have not been extensively studied by breeders; these include the lespedezas, medicagos, sweet clovers, trefoils, and vetches. The lespedezas are important pasture legumes in warm climates, and improved varieties of the common lespedeza (*L. striata*) have been tested under grazing in Hawaii. These species have not become important, however, due to virus diseases and difficulty of establishment and maintenance of stands.

Two species of *Medicago* occur widely in Hawaii; they are *M. hispida* (bur clover) and *M. lupulina* (black medic). These Eurasian species reproduce generously from seed, and are considered important leguminous components of some pastures, but are short-lived. The sweet clovers, *Melilotus alba* and *M. indica*, occur in Hawaii and thrive on more marginal, alkaline soils. They have not been widely tested due to their tendency to cause bloat in animals feeding during early growth stages. The vetches, *Vicia sativa* and *V. villosa*, are European species that also occur in cool, moist pastures of Hawaii and that reproduce annually from seeds.

Tropical lowland legumes of Hawaii also include *Crotolaria* and *Desmanthus* species. The rattle pods, *Crotolaria* spp. (including *C. incana*, *C. longirostrata*, and *C. mucronata*) are low shrubs that are widely naturalized in Hawaii and occasionally browsed by animals. They are more important as green manure plants than as forage. *Desmanthus virgatus* is a bushy, woody legume native to tropical America that is seen throughout Hawaii and is a browse plant for animals but rarely survives in pastures. No breeding work has been done on *Crotolaria* or *Desmanthus*, but Takahashi and Ripperton (1949) conducted extensive studies on *Desmanthus* management, concluding it to be inferior to *Leucaena* (koa haole) as a forage legume.

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ORNAMENTALS

Haruyuki Kamemoto
Professor, Department of Horticulture

Practically all of Hawaii's economic ornamentals—cut flower crops, potted plants, foliage crops, shade trees, turfgrasses, and others—were brought into the Islands. From the first introductions by Polynesian immigrants, there has been a steady stream of new introductions. Numerous individuals, from both private and public sectors, have contributed to the present rich assemblage of ornamental plants in Hawaii (Beaumont, 1950; Neal, 1965).

Improvements by private individuals have been noteworthy. Intensive hybridization of orchids soon after World War II resulted in Hawaii's becoming one of the important orchid-improvement centers of the world. Anthurium hybridization has given rise to outstanding cultivars, which have formed the basis of a viable cut-flower export industry. Other ornamental crops improved through breeding are the hibiscus, ti, and plumeria.

Research on ornamental crop improvement at the University of Hawaii has a relatively short history. Hibiscus breeding was initiated in 1947, anthurium and orchid breeding in 1950, and plumeria breeding in 1963. Orchids and anthuriums have received continued attention. Past and present activities in ornamental crop improvement at the University are summarized below.

ANTHURIUMS

The anthurium improvement program at the University of Hawaii early emphasized development of high-yielding, good-quality whites and pinks, since good oranges and reds were already available. Results to date include the naming and release of cultivars 'Uniwai' (white), 'Marian Seefurth' (pink), 'Anuenue' (coral obake), 'Chameleon' (white obake), 'Manoa Mist' (white), 'Calypso' (pink, cupped), 'Trinidad' (white with pink tinge, cupped), 'Red Elf' (miniature red double), and, most recently, 'Mauna Kea' (white obake) (Kamemoto et al., 1977) and 'Paradise Pink' (dark pink to light red) (Kamemoto et al., 1981).

Spadix rot, or anthracnose, caused by the fungus *Colletotrichum gloeosporioides* is a serious disease of anthuriums. Although Maneb and Benlate sprays give adequate control (Aragaki, 1964; Higaki and Aragaki, 1972), disease resistance in cultivars is highly desirable as a control measure. 'Marian Seefurth' was determined to be highly resistant (Aragaki et al., 1968). 'Manoa Mist', a hybrid of 'Marian Seefurth' and 'Uniwai', is also highly resistant. Present emphasis is on development of disease-resistant, high-yielding red and orange cultivars. The University's Department of Plant Pathology has developed an efficient and effective method of laboratory screening by inoculating flowers with spores of the fungus.

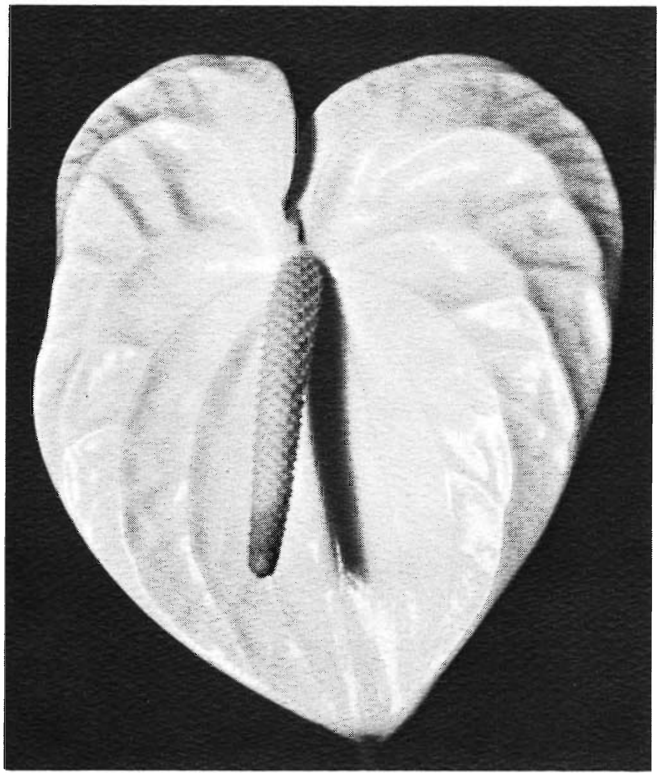

Figure 1. 'Manoa Mist', a high-yielding white anthurium hybrid.

Other desirable characteristics for anthuriums include short internodes, long and erect flower stems, and good keeping of flowers, both on the plant and after cut. Novelties such as double spathes, "tulip" types, miniatures, and new flower colors are also being pursued. Listed below are eight of the cultivars that have been released to date.

'Uniwai'

This white-flowered cultivar, the first to be released, showed an exceptionally high yield of 7.7 flowers per plant per year. The smooth, pliable white spathe is broadly heart-shaped, and often develops a pink tinge during the spring months. Sucker production is poor (Kamemoto and Nakasone, 1963).

'Marian Seefurth'

This attractive pink cultivar has erect flower stems and short internodes, and yields 6.9 flowers per plant per year. The spadix reclines when young but becomes upright with age. This cultivar has been shown to be highly resistant to anthracnose (Kamemoto and Nakasone, 1963; Aragaki et al., 1968).

'Anuenue'

'Anuenue' is a roundish coral obake, about 11 inches long and 9 inches wide. The flower stem is erect and sturdy. Its yield of six flowers per plant per year can be considered good for obake cultivars, and it is highly resistant to anthracnose. Sucker production is poor (Kamemoto et al., 1969).

'Chameleon'

The name 'Chameleon' was chosen because this cultivar changes from white to white obake during the winter and spring months. Its flower stem is long, and its yield of 7 flowers per plant per year is excellent. It is highly resistant to anthracnose. The fusion of the basal lobe is, however, an undesirable characteristic (Kamemoto et al., 1969).

'Red Elf'

'Red Elf', a novelty type with two relatively small red spathes, originated from a cross between 'Red Double' (Accession 94) and 'Nitta'. This cultivar tends to be small in both plant and flower size, and is therefore suitable for pot culture. The outer red spathe is about 5 inches long and 3 inches wide, while the inner spathe is much smaller, about 2 by 2 inches. Most flowers produced are double, although occasional singles appear (Kamemoto et al., 1969).

'Manoa Mist'

'Manoa Mist', which originated from a cross between 'Uniwai' and 'Marian Seefurth', carries the high-yielding capacity of both parents and the anthracnose resistance of 'Marian Seefurth' (Fig. 1). Its white spathe, which may develop a tinge of pink during the cooler months, is heart-shaped with overlapping basal lobes, and is carried on the stem at an angle of 45 degrees. The internodes are relatively short, and the yield is about 7.3 flowers per plant per year (Kamemoto et al., 1971).

'Calypso'

This attractive cultivar has an upright cupped spathe, 4¼ inches long and 3 inches wide, carried on a long (24 inches), straight, sturdy flower stem. The inner surface of the spathe is dark pink to light red. Its red-purple spadix is straight and upright, about 4-1/8 inches long, and susceptible to anthracnose. Average yield is 6.5 flowers per plant per year, and plant habit is sturdy and upright with relatively long internodes. It produces suckers sparingly, and foliage tends to be excessively large (Kamemoto et al., 1975).

'Trinidad'

This cultivar's general characteristics are similar to those of 'Calypso'. The spathe is white with a flush of red-purple, and tends to be smaller and less cupped than 'Calypso'. The spadix is slightly darker than the spathe. Leaf size, yield, keeping quality, and susceptibility to anthracnose are about equal to those of 'Calypso', but sucker production is better (Kamemoto et al., 1975).

ORCHIDS

Investigations on the cytogenetics of orchids revealed the significance of polyploidy in the improvement of hybrids (Kamemoto, 1950, 1958; Kamemoto et al., 1961, 1972). Triploids, tetraploids, and pentaploids were determined to be generally superior to their diploid counterparts. The general breeding behavior of these polyploids was also ascertained.

A breeding program was recently started at the University to develop improved dendrobium cultivars for commercial cut-flower production. The dendrobium is a relatively new crop, with tremendous potential for development as an export crop because of good vase life, its exotic nature, a diversity of types, and ease of packing for shipment. Major objectives of the breeding program are high yield, freedom from bud drop, improved flower quality, and long vase life. The development of the meristem culture technique provided added impetus to the program because an outstanding selection can now be increased rapidly for commercial cropping (Kim et al., 1970; Sagawa and Shoji, 1967).

Hybrids between the *Phalaenanthe* section (P genome) and the *Ceratobium* section (C genome) in the genus *Dendrobium* have provided the best types for commercial cut flowers. The intersectional hybrids, *Dendrobium* Jaquelyn Thomas (*D. phalaenopsis* × *D. gouldii*) and *D.* Neo Hawaii (*D. phalaenopsis* × *D. grantii*), are outstanding. The amphidiploid with PPCC genomes appears to be superior in overall performance to the diploid PC. Also under investigation are tri- and tetra-genome combinations (Kamemoto et al., 1974). The cultivars below have been released by the University.

Figure 2. 'Uniwai Blush', a profusely flowering white dendrobium tinged with pink.

'Uniwai Blush'

'Uniwai Blush' is the selfed progeny of a tetraploid Jaquelyn Thomas plant that arose among otherwise diploid progeny (Fig. 2). Flowers of 'Uniwai Blush' are white tinged with pink. Natural spread of the flowers is 2½ inches; the spikes are sturdy, averaging 20 inches and carrying about 19 fragrant flowers. Yield and keeping quality are good, and bud drop is low. Like other Jaquelyn Thomas plants, it tends to peak in summer, although some flowers are obtained throughout the year. This cultivar was initially released in 1972 (Kamemoto et al., 1974; Kamemoto and Kunisaki, 1980).

'Uniwai Profusion'

This high-yielding cultivar resulted from crossing a tetraploid *Dendrobium* Jaquelyn Thomas and *D. d'albertsii*. Flowers are white and rather small, 2¼ inches across. Spikes average 21 inches and carry about 18 flowers. Bud drop is about 1 percent. Important attributes are its high yields and year-round flowering; major weaknesses are relatively small flowers, sometimes drooping spikes, and bud drop tendency (Kamemoto et al., 1975*a*).

'Nat Seefurth'

A cross between two tetraploid Jaquelyn Thomas plants (white 'Y166-1' and purple 'H10-1') produced a relatively uniform progeny. Plant No. 7 appeared to be superior to its siblings, and, therefore, was mericloned and released as 'Nat Seefurth'. It is floriferous, peaking around June and November. Spikes average about 18 inches, are erect to arching, and carry about 19 flowers closely arranged to give a compact spray. Petals and sepals are curved back. Stems are sturdy, upright, and reach about 4 feet (Kamemoto et al., 1975; Kamemoto and Kunisaki, 1977).

'Uniwai Supreme'

Jaquelyn Thomas 'Uniwai Supreme' is the second seed-propagated dendrobium cultivar released by the University of Hawaii. It is a cross between tetraploid Jaquelyn Thomas 'UH44-50' and tetraploid Jaquelyn Thomas '0580', which arose from meristem culture. The former is white with a tinge of lavender, the latter two-toned purple-violet. This seed-propagated cultivar is relatively uniform. The yield is somewhat intermediate between the high yield of 'Uniwai Blush' and the poorer one of tetraploid '0580'. The sprays are erect to arching and carry about 20 two-toned, purple-violet flowers, similar in color to that of the '0580' parent (Kamemoto et al., 1976; Kamemoto and Kunisaki, 1980).

HIBISCUS

In 1947, John A. Johnson, one of Hawaii's leading hibiscus hybridizers, donated his entire collection to the University of Hawaii. Subsequent observation and evaluation of seedling selections led to the naming and release of four new cultivars (Nakasone and Hamilton, 1952). The hibiscus improvement program was discontinued soon thereafter. The four cultivars are described below.

'Ballerina'

The flower of 'Ballerina' has a deep oxblood-red throat. The petals are begonia-red with strawberry-pink edges, crinkled, and ruffled along the overlapped edges. The column is rose-red at the base and becomes white along the upper region, with light orange-yellow pollen and flame-scarlet stigma. The flower is 5 to 6 inches in diameter.

'Gaudy'

'Gaudy' has a carmine-red throat, with an eosin-pink border around it. The petals are mikado-orange, fully overlapping, with ruffled margins, crinkled surface, and good texture. The column is spectrum-red at the base to la France-pink along the upper region, with cadmium-yellow pollen and scarlet stigma. The flower is 5 to 7 inches in diameter.

'John A. Johnson'

'John A. Johnson' has a deep bordeaux-red throat and petals of pomegranate-red, with rose-red margins and occasional small white spots, mostly concealed under the overlap of the petals. The texture is extremely firm. The column is carmine at the base and tyrian-pink along the upper region, with light cadmium-yellow pollen and spectrum-red stigma. The flower is 5 to 7 inches in diameter.

'Sunset'

This flower has a carmine-red throat and spectrum-red petals with begonia-rose margins. Petals are firm, fully overlapping, with slightly ruffled edges. The column is carmine-red at the base and begonia-rose along the upper region, with apricot-yellow pollen and spectrum-red stigma. The flower is 5 to 7 inches in diameter.

PLUMERIA

The University's plumeria hybridization program was initiated by J. T. Chinn and J. L. Brewbaker in 1963, following a 3-year research grant by Donald Angus. Existing cultivars were assembled and important characteristics recorded. Pollination studies resulted in a successful technique for hybridizing plumerias (Watson et al., 1965). Seven new cultivars were named and released, the four cultivars described below, and 'Dean Conklin', 'Lurline', and 'Iolani' (Chinn and Criley, 1982).

'Donald Angus'

This cultivar produces large panicles of well-shaped flowers suitable for leis. It originated from open pollination of 'Common Yellow'. The 3-inch flower is red, with a large orange-yellow center and dark-red bands on front and back. The petals are wide, oval, and overlapping. The keeping quality is good.

'Dwarf Singapore'

This cultivar's unique feature is its compact height, with semiglossy leaves and small white flowers. 'Singapore' is the seed-bearing parent, and 'King Kalakaua' the probable pollen parent. Its lemon-scented flowers measure 1½ inches in diameter. It is recommended for use in landscaping.

'Elena'

This large flower, 3¾ inches in diameter, is white, with a large brilliant yellow center and narrow pink bands on the back. The broad petals are heavy textured. Keeping quality is good.

'Kimo'

This flower, about 3 inches in diameter, is orange-yellow, with moderate pink bands on the back. Its petals are wide, overlapping, and heavy textured. 'Kimo' originated as a seedling of 'Gold'.

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FRUIT CROPS

Henry Y. Nakasone
Professor, Department of Horticulture

Assemblage of Hawaii's crop plants began with the arrival of the Polynesians in Hawaii more than 1500 years ago. They brought with them such basic food crops as taro, banana, coconut, and breadfruit. After the discovery of the Hawaiian Islands by Captain Cook in 1778, a diverse array of crops was introduced. Many became popular items for backyard cultivation, while others developed commercial potential. During the 1800s, the sugar industry assumed its dominant role of Hawaii's agriculture, and later pineapple emerged as a second dominating industry.

Organized crop improvement began with the establishment of the Federal Hawaii Agricultural Experiment Station in 1901, and later, in 1919, the University of Hawaii assumed the responsibility for agricultural research, which broadened the foundation for crop improvement and diversification. For over three-quarters of a century many crops were tried; some were eliminated and others flourished for periods of time and then died. One of the most significant factors that stopped the commercial export production of tropical fruits was the introduction of the Mediterranean fruit fly in 1910 (Crawford, 1937).

Tree crop improvement is difficult by conventional breeding methods because of the long life cycles. In many instances only one seed is produced for each fruit, and this is further complicated in such plants as citrus and mango, which produce apomictic embryos, and in such plants as banana, which produce seedless fruits. Reviewed below are some of the fruit crops considered to have economic potential by horticulturists, and the methods used in their improvement.

BANANA

The banana is considered to be one of the first foods of man, its origin in South and Southeastern Asia (Reynolds, 1951). It was distributed very early in history through much of Asia, Africa, and the Pacific islands. The Polynesians are credited with its distribution throughout the Pacific islands, including Hawaii. Cultivars brought by them were of the plantain type (high-starch, cooking types), and many are still in demand today.

The familiar dessert types that are grown today in Hawaii were all introduced. The 'Dwarf Cavendish' (Chinese banana), 'Brazilian', 'Red Spanish', and others were introduced during the latter half of the 1800s, followed by 'Bluefields' ('Gros Michel') in 1903 (Simmonds, 1959). Crop improvement continued with the introduction of 'Golden Beauty' and 'Monte Cristo' in 1951 (Beaumont, 1955*a*). The latter cultivar has since been identified as synonymous with 'Hamakua', which was already established in Hawaii. 'Williams Hybrid' was introduced from Australia in 1954 and has become one of the major commercial cultivars in Hawaii. Its name is misleading, inasmuch as it originated as a mutant or bud sport from the 'Dwarf Cavendish' (Chinese banana) in Australia (Hamilton, 1958).

Banana improvement through breeding has been largely confined to Jamaica and Trinidad, where the Imperial College of Tropical Agriculture (now the University of the West Indies) initiated its program in 1922 (Simmonds, 1959). Primary objectives were to breed for resistance to the Panama wilt and leaf spot diseases in a cultivar retaining other characteristics of the 'Gros Michel' ('Bluefields'). Since the 'Gros Michel' has three sets of the *Musa acuminata* genome, disease-resistant strains of *malaccensis*, a subspecies of *M. acuminata*, were used to pollinate the 'Gros Michel'. Some tetraploids were produced with 'Gros Michel' contributing unreduced gametes and the *malaccensis* contributing the normally reduced gametes. The progeny resembled the 'Gros Michel' in most respects except for fruit and bunch characteristics. The 'Golden Beauty' is a product of this breeding program (Simmonds, 1959).

Using more desirable male parents has yielded nothing superior to the 'Gros Michel' in quality. In areas heavily infested with Panama wilt disease, the more tolerant cultivars of the Cavendish group are replacing 'Gros Michel'. Thus, selection of naturally occurring budsports has been the main source of cultivar improvement in bananas.

PINEAPPLE

The pineapple is similar to the banana in that seedlessness and parthenocarpic fruit prevail. Like the banana, it is easily propagated vegetatively. It differs, however, in being a fertile diploid from which seed-derived hybrids are easily obtained. The genetic control of self-incompatability and cross-fertility of pineapple was determined by Brewbaker and Gorrez (1967).

Pineapple improvement has been conducted intensively for more than 50 years in Hawaii, Australia, Taiwan, Malaysia, Brazil, and South Africa, contributing significantly to the knowledge of cytology and genetics. However, improvements in the 'Cayenne', the world's major canning cultivar, have been made through selection of mutant types. Collins (1960) provides an excellent account of pineapple breeding in Hawaii, listing many mutant types collected and progeny tested over the years. Inter-clonal and inter-specific hybrids have also been made and tested. Because the 'Cayenne' possesses many desirable characteristics, clones of this group have been used in hybridization. Collins emphasizes that 'Cayenne' is highly heterozygous, and hybrid populations are extremely variable. In the 60 years of pineapple breeding in Hawaii's Pineapple Research Institute, clones possessing many improved characteristics were selected, but because of the confidential nature of privately supported research program, little information is available on them.

GUAVA

Guava (*Psidium guajava*) has become part of Hawaii's wild flora since its introduction between 1790 and 1800 (Hamilton and Seagrave-Smith, 1954). It is also a fruit crop believed to have commercial potential. Even during the early days, it was a popular fruit processed by housewives into jelly and jam. A small processing industry was started in the early part of this century using the wild fruits. Emphasis on commercial development began in the early 1950s, largely through the processing research sponsored by the Industrial Research Advisory Council (IRAC) in cooperation with the University of Hawaii. The reliable production of orchard guavas of uniformly high quality was urged for the development of a viable processing industry.

The guava improvement program began in 1951 with the search for superior seedlings among wild populations and the introduction of established cultivars from other tropical areas (Bowers and Nakasone, 1960). Seedlings from wild selections were also established for selection purposes. The first cultivar, named 'Beaumont', was introduced in 1960 to the processing industry (Fig. 1). Subsequently, more than 2000 seedlings derived from 'Beaumont' were established for selection purposes and were tested for yield and quality. One clone, 'Ka hua kula' (Fig. 2), was finally named and released for its high performance, darker pink flesh, and better acidity (Nakasone et al., 1976).

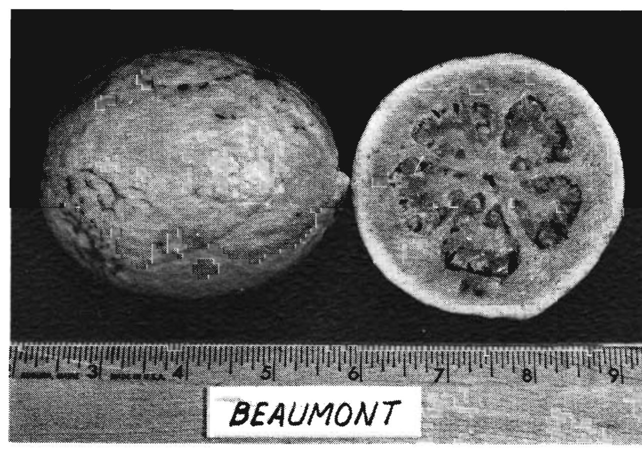


Figure 1. 'Beaumont', formerly Selection B-30, is the first commercial guava cultivar developed in Hawaii.

Figure 2. 'Ka hua kula' is the second commercial guava cultivar developed in Hawaii.

Foreign introductions have been tested for many years (Hamilton and Seagrave-Smith, 1954). Most were white-fleshed, dessert types not considered suitable for processing. The few pink-fleshed, acid clones proved inferior to 'Beaumont' in yielding ability. Currently, selections from open-pollinated seedling populations of 'Patillo' and 'Pink Acid', both from Florida, are being evaluated.

The inherent heterozygosity of the guava has provided an adequate basis for improvement until now. Guava is many-seeded and adapted to conventional breeding methods. The current emphasis on finding resistance to the red-banded thrips (*Selenothrips rubrocinctus*) may necessitate the use of more sophisticated breeding procedures. As an adjunct to breeding, studies on chromosome numbers (Hirano and Nakasone, 1969*a*), pollen germination, and compatibility of some *Psidium* species (Hirano and Nakasone, 1969*b*) have been conducted in Hawaii.

LYCHEE

The first Hawaiian introduction of lychee (*Litchi sinensis*) was in 1873 by Ching Shai; this was followed by other introductions by the U.S. Department of Agriculture and private individuals (Higgins, 1917). A significant figure in the establishment of lychee in Hawaii was Professor Groff, who resided in South China from 1917 to 1941, serving as professor and dean of the College of Agriculture of Lingnan University, Canton, China (Storey et al., 1953). Among numerous clones introduced from China, 'Kwai Mi', 'Hak Ip', and 'Brewster' (or the 'Chen Family Purple') still persist as leading cultivars in both Hawaii and other countries with established plantings. These cultivars, undoubtedly established centuries ago in China, have not been replaced by superior ones.

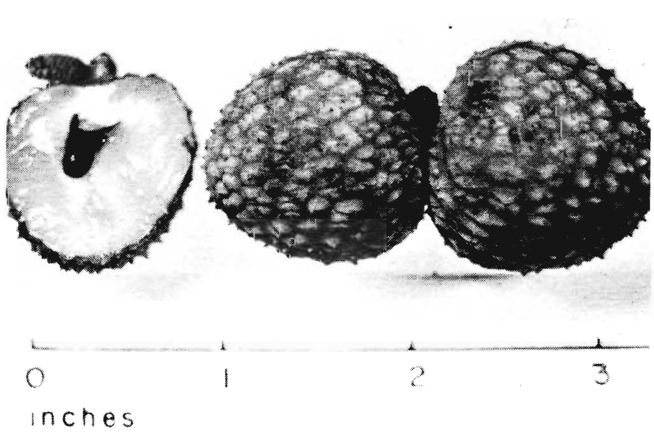


Figure 3. The 'Groff' lychee was developed in Hawaii and is known for its shrivelled seeds and later bearing, thus extending the lychee season.

Attempts to develop new cultivars have been restricted to plantings of open-pollinated seedlings of the Chinese cultivars, taking advantage of their inherent heterozygosity. According to available records, the 'Groff', which was selected and introduced to the public in Hawaii in 1953 (Fig. 3), is the only cultivar developed outside of China (Storey et al., 1953). Named in honor of Professor Groff, it is a seedling of the Chinese cultivar 'Hak Ip' and was selected for its high-quality fruits with shrivelled seeds and dependable bearing habit. Future attempts to improve the lychee through breeding are predicted to be limited by the high costs of controlled pollination and evaluation of offspring.

MANGO

Introduction of the mango (*Mangifera indica*) to Hawaii dates back to the period between 1800 and 1820 (Pope, 1929). Early introductions have become known as the 'Hawaiian', 'Manini', or simply 'Common' mango. These early mangos were of the polyembryonic type, but differ sufficiently to suggest that they were introduced from different sources. A notable introduction in 1885 is attributed to Joseph Marsden, who introduced, among others, the 'No. 9' from Jamaica that is known in Hawaii as the 'Chinese' mango. It is commonly found in older sections of Honolulu.

The introduction of Indian mango cultivars is attributed to Samuel Damon, G. P. Wilder, and others who followed (Anonymous, 1919). Cultivars introduced during this period include the 'Pirie', 'Alphonse', 'Mulgoba', 'Sandersha', 'Brindabani', 'Ameeri', and 'Bombay Yellow' (Pope, 1929). Among these the 'Pirie' has persisted because of its excellent fruit qualities, although it is highly susceptible to anthracnose blight.

'Haden' was introduced from Florida in the 1930s and has become the dominant cultivar in Hawaii because of its attractive color, large fruit, and productivity. It originated as a seedling of the 'Mulgoba' from India. Later cultivars from Florida, 'Irwin', 'Kent', 'Zill', 'Keitt', and others, were all derived from open-pollinated seedlings of earlier cultivars.

Recent cultivars originating in Hawaii are the 'Pope' (Fig. 4), 'Momi K', 'Gouveia', and 'Ah Ping' (Figs. 5, 6, 7). 'Pope' originated as a seedling of 'Irwin' (Hamilton, 1960), the others as statewide contest winners from unknown parents. Seedling populations from monoembryonic cultivars thus have provided the major basis for improvements in the mango.

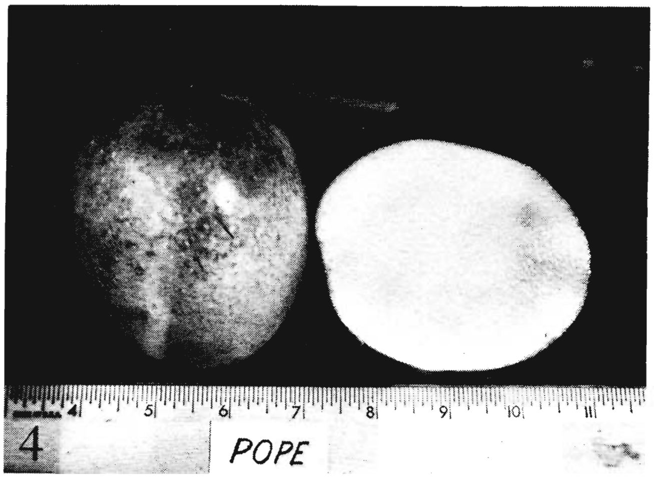
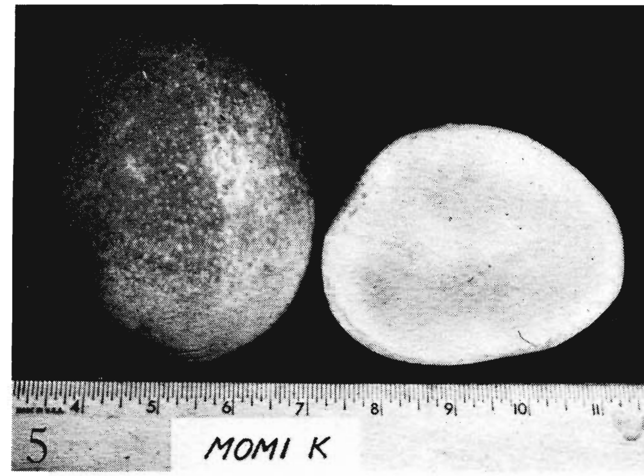
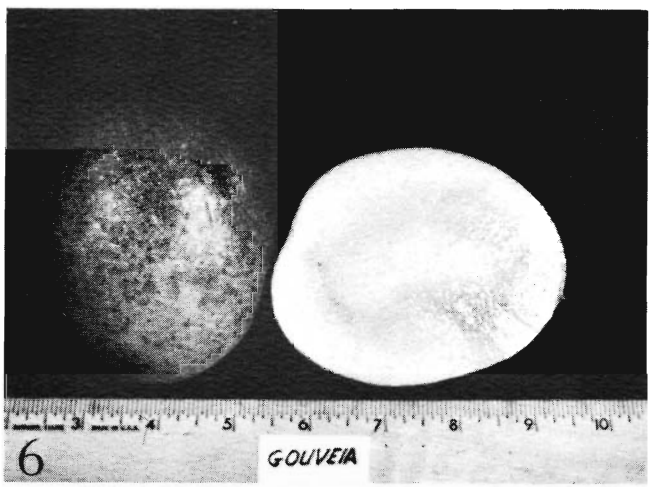
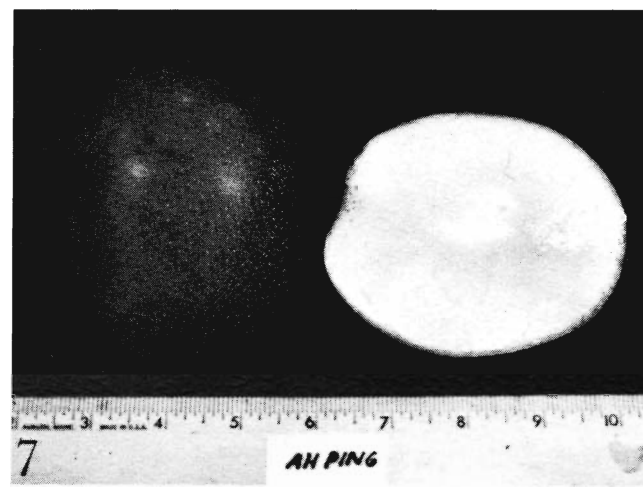


Figure 4. The 'Pope' mango was developed in Hawaii as a seedling of the 'Irwin'.







Figures 5, 6, and 7. The 'Momi K', 'Gouveia', and 'Ah Ping', respectively, are attractive, good-quality mangos derived from contests in Hawaii.

PAPAYA

The early papayas were of the large-fruited type introduced to Hawaii between 1800 and 1823 (Figs. 8, 9). By the turn of the century the papaya was widely grown as a dooryard plant. Breeding to improve the papaya was first initiated by Higgins and Holt (1914) when seeds from established and introduced cultivars were grown together for evaluation.

A significant year in the history of papaya improvement in Hawaii was 1911, when seeds of fruits described as "cucumber-shaped," "small, yellow" were introduced from the Caribbean by Gerritt P. Wilder (Higgins and Holt, 1914). Seedlings derived from this accession formed the basis for the present-day 'Solo' papaya and changed the course of papaya development in Hawaii (Fig. 10).

In 1920, W. T. Pope took over the work of J. E. Higgins and continued the papaya breeding program with emphasis on improving the 'Solo'. Pope's most significant contribution to papaya improvement was his recognition of the need to control pollination in order to maintain purity (W. B. Storey, unpublished notes). The modern era of papaya breeding began in the 1930s, when studies were initiated to resolve some of the basic problems of sex determination and the inheritance of many tree and fruit characteristics (Nakasone and Storey, 1955; Storey, 1953). By 1938, the primary flower and fruit types and sex inheritance had been determined by Storey (1938*a*, 1938*b*). These results provided methods of producing desirable seed types, eliminating unproductive males.

Sex in papaya was concluded to be determined by a single gene with three alleles, the dominant alleles being

Figures 8 and 9. Large-fruited papayas similar to the early cultivars grown in Hawaii.

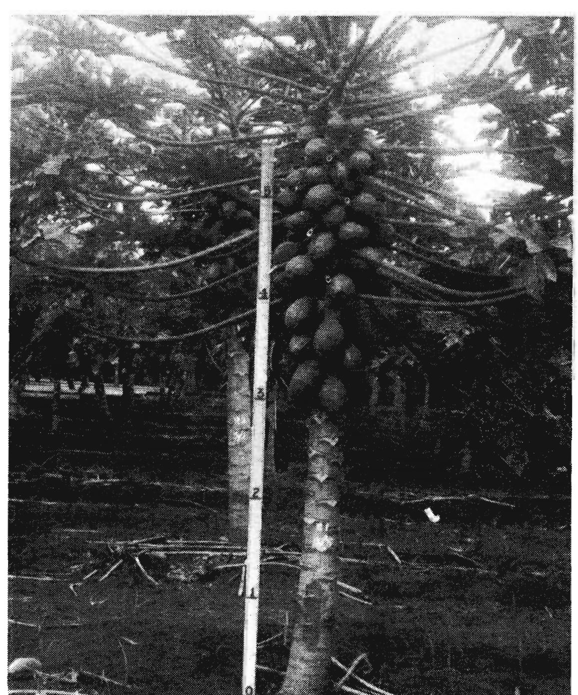


Figure 10. Low-bearing, small-fruited Solo papaya cultivar, 'Higgins'.

Figure 11. 'Line 8' Solo, commercial papaya of the 1950s; fruits soften early.

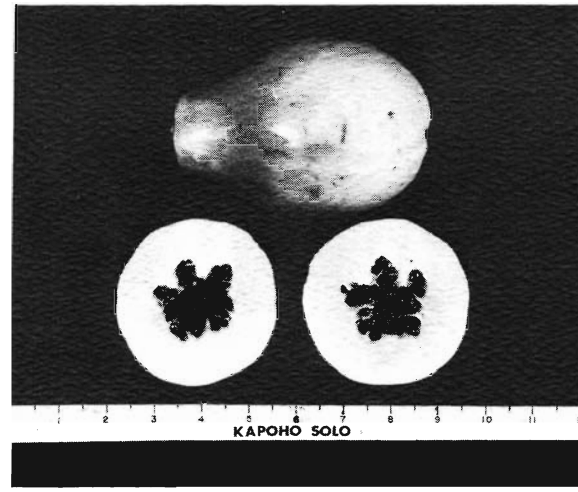


Figure 12. 'Kapoho' Solo, originally known as 'Masumoto' Solo, is now the principal export papaya cultivar in Hawaii.

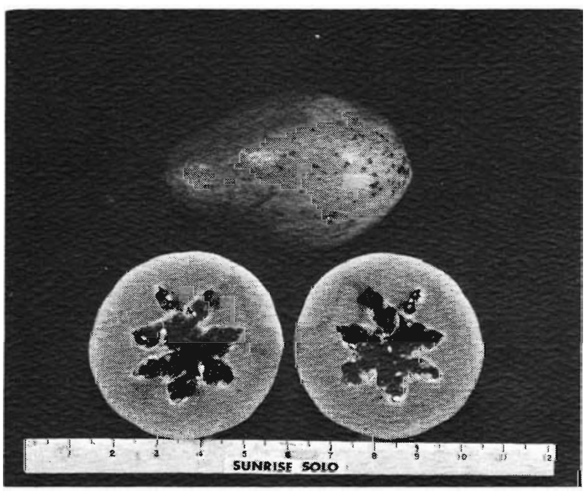


Figure 13. 'Sunrise' Solo papaya is a high-quality, red-fleshed type developed in Hawaii.

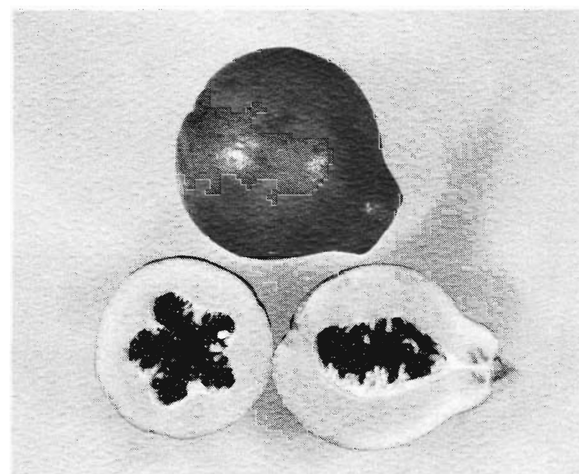
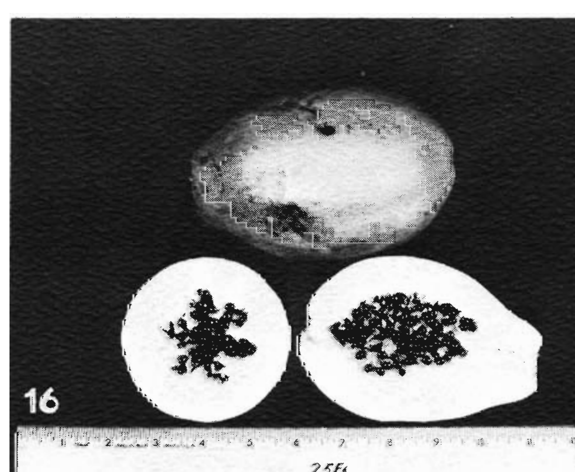


Figure 14. 'Waimanalo' Solo papaya is grown for the local market. It is low bearing with fruits too large for export.



Figures 15 and 16. 'Higgins' and 'Wilder' papayas, respectively, are small-fruited, low-bearing cultivars developed for the export trade.

assigned to male and hermaphrodite and the recessive allele to the female. All double dominants were lethal, making the males and hermaphrodites enforced heterozygotes (Storey, 1938*b*). Storey's later studies (1953) led him to propose that sex is controlled by a complex of linked genes in differential segments occupying identical regions on the sex chromosome, but behaving as unit characters. He also identified two independent sets of factors that modify sex expression in males and hermaphrodites under certain environmental conditions. One set caused stamens to become carpel-like and fuse with the pistil under cool temperatures. (Females, although carriers of these traits, are stable, exhibiting no sex changes.) The results of these studies facilitated the selection of desirable commercial cultivars from seedling populations. 'Line 5' Solo was released in 1947 (Storey et al., 1951), followed by the release of 'Line 8' Solo in 1954 (Fig. 11) (Beaumont, 1955*b*). 'Line 10', a selection from the 'Kapoho' Solo, was released in 1965. 'Kapoho' Solo is a cultivar originally selected by H. Masumoto of Hilo during the 1940s and remains the dominant export papaya in Hawaii (Fig. 12). It is especially adapted to the high-rainfall areas of East Hawaii.

All of these cultivars resulted from individual tree selections among open-pollinated Solo populations. 'Sunrise' Solo (Fig. 13), released in 1968, 'Waimanalo' Solo (Fig. 14), released in 1972, and 'Higgins' (Fig. 15), and 'Wilder' (Fig. 16), released in 1974, resulted from breeding, selection, and testing over many years (Hamilton and Ito, 1968; Nakasone et al., 1972; Nakasone et al., 1974).

A major problem facing commercial growers is the *Phytophthora* root rot, commonly referred to as the replant problem. A current breeding objective is that of developing commercially acceptable cultivars with resistance to this disease. Studies in the past decade have shown that some lines possess field tolerance to this disease (Nakasone and Aragaki, 1973). Studies are currently in progress to determine the genetic nature of this tolerance.

PASSION FRUIT

Passiflora edulis and its botanical variety, *flavicarpa*, were introduced to Hawaii in 1880 and 1923, respectively (Pope, 1935), the latter remaining commercially important today. *P. edulis*, the purple passion fruit, does best at elevations of 500–3000 ft., producing small fruits with a highly aromatic, low-acid pulp. *P. edulis* variety *flavicarpa*, the yellow passion fruit, is vigorous and productive from sea level to 1500 ft. with larger, more acid fruits. Processors have always desired a cultivar that combines the strong aroma of the purple passion fruit with the vegetative and other characteristics of the yellow. Attempts to produce such a hybrid have not been successful. Passion fruit shows strong self-incompatibility and even cross-incompatibility among certain clones (Akamine and Girolami, 1959). Hybrid seeds have been produced between the purple and yellow passion fruit only when the former was used as the female parent. The F_2 and backcross progenies have not produced a single selection that combines the desirable characteristics of both parents.

The purple passion fruit is highly susceptible to a crown rotting and wilting disease, while yellow passion fruit possesses a dominant gene for resistance (Nakasone et al., 1967). Another serious disease is brown spot, caused by *Alternaria* spp. In areas of high rainfall more than 90 percent of the harvested fruits have been rejected by processors due to infection. A search for tolerance in orchard-seedling populations has shown several lines that produce more than 75 percent marketable fruits without benefit of chemical control (Nakasone et al., 1973). Because passion fruit is seed-propagated due to poor fruit set in single-clone fields, these selections should be progeny-tested to determine the continued presence of the tolerance to brown spot.

AVOCADO

Earliest introduction of avocados to Hawaii is credited to Don Francisco de Paula Marin, a Spanish horticulturist, sometime during the early 1800s. However, a major introduction in 1853 is believed to be the first to influence distribution and cultivation of this fruit in Hawaii (Higgins et al., 1911; Pope, 1924). These early introductions and those that followed through the decades provided a wide basis for selection of desirable cultivars. The cultivar 'Macdonald' was known as early as 1900 and produced, among its open-pollinated seedling progenies, cultivars such as 'Nutmeg', 'Beardslee', 'Haley', 'Hulumanu', 'Wilder', and others. 'Wilder' gave rise to cultivars such as 'Ilialu', 'Lehua', and 'Kinau' (Pope, 1924). 'Beardslee' is still a recommended cultivar.

Among the early introductions 'Fuerte' (Guatemalan/Mexican hybrid), 'Linda', 'Itzamna', 'Hass', and 'Nabal' still persist in Hawaii today. Early cultivars provided the genetic base for recent cultivars such as 'Cho', 'Fujikawa', 'Hayes', 'Kahuluu', and 'Masami' (Yee, 1979). 'Sharwil', introduced from Australia, has shown great promise as a commercial cultivar in Hawaii.

The early prospect of the avocado becoming an export crop was killed with the discovery of the Mediterranean fruit fly in 1910. Later, shipment to the Mainland was permitted after fruit fly disinfestation, but many cultivars were found to be susceptible to injuries. Prohibition of export did not discourage the continued efforts to develop high-quality, potentially exportable cultivars. In recent years, shipment of unfumigated avocados has been permitted to Canada and Alaska. This has created renewed interest in developing an export industry. Breeding objectives include the development of exportable cultivars with small fruits, long shelf life, tolerance to disinfestation and refrigerated storage, and resistance to *Phytophthora* root rot. A large array of introduced and local germ plasm has been assembled for this purpose. During the past decade more than 2000 seedlings have been grown from which a large number of selections have been made for critical evaluation. Species and cultivars showing promise as rootstocks with resistance to *Phytophthora* root rot are continually being tested.

The improvement in Hawaii of tropical tree fruits has occurred largely by the introduction and testing of cultivars from other tropical areas, and by individual tree selection in seedling populations. The inherent heterozygosity of these crops has provided a wide basis for selection of individuals with desirable horticultural characteristics. Bud sports or mutations have also provided desirable cultivars. Inherent parthenocarpic fruit development, self-incompatibility systems, and polyembryony are factors that contribute to difficulties in employing conventional breeding methods on fruit trees. Other factors include the difficulty of controlled pollinations in single-seeded fruits, and their long life cycles.

In multiple-seeded fruits of short-cycle crops such as the papaya and guava, conventional breeding methods are feasible and much has already been accomplished with papaya. In guava improved cultivars for processing can be produced by selecting among open-pollinated seedlings, but conventional breeding methods are desirable in breeding for resistance to insects and diseases.

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MACADAMIA NUT[1]

Richard A. Hamilton and Philip J. Ito
Professor and Associate Professor, respectively,
Department of Horticulture

The macadamia nut, *Macadamia integrifolia*, a relative newcomer among crop plants of the world, is the only native food plant of Australia to achieve the status of a commercial crop. Most of its commercial development has taken place in Hawaii during the past 40 years, where more than 90 percent of the world's production of this fine dessert nut occurs. Macadamia nuts are now the most important tree crop in the State from the standpoint of acreage, production, and value.

Macadamia breeding and selection work was initiated by Hawaii Agricultural Experiment Station (HAES) horticulturists in 1934. Since then, 13 cultivars have been named among more than 100,000 seedlings examined. These are: 'Keauhou', 'Nuuanu', 'Kohala', 'Pahau', and 'Kakea' (Storey, 1948); 'Ikaika' and 'Wailua' (Hamilton et al., 1952); 'Keaau' (Hamilton and Ooka, 1966); 'Kau' (Hamilton and Nakamura, 1971); 'Mauka' and 'Makai' (Hamilton and Ito, 1977); 'Purvis' (Hamilton et al., 1981*a*); and 'Pahala' (Hamilton et al., 1981*b*). Two other cultivars, 'Chong 6' and 'Honokaa Special', although not officially named, have become known by these names and are still grown to a limited extent in the Kohala and Honokaa areas, respectively. The 13 HAES cultivars were named and introduced after extensive yield trials, quality testing, and objective evaluation of tree, nut, and kernel characteristics. Five of these cultivars presently dominate commercial orchards in Hawaii. This situation is somewhat unique among tree crop cultivars, many of which have originated by chance as superior seedlings selected by nurserymen, growers, and amateur horticulturists. Macadamia cultivars, on the other hand, have originated almost entirely as a result of breeding efforts and rigorous testing activities by HAES horticulturists and plant breeders.

TREE AND NUT CHARACTERISTICS

Vigorous trees are selected with dark green foliage, strong crotches, and ascending rather than spreading branch structure. 'Kakea' as well as 'Keaau', 'Kau', 'Mauka', and 'Pahala' have more upright growth habits than 'Keauhou', 'Ikaika', 'Makai', and 'Purvis', which have spreading growth habits. A more upright growth habit permits closer planting within the row and more trees per acre. The minimum annual production in selection programs is 100 pounds of in-shell nuts from 8-year-old trees in favorable locations, or 75 pounds from 10-year-old trees in less favorable locations.

Trees are selected that have medium-sized nuts with 10 to 20 nuts per cluster, 65 to 68 uniformly sized nuts per pound, and 38 to 48 percent kernel. Kernels are preferred if they are uniform, round, white or cream colored, without dark circles or off-color tops (Fig. 1). There should be few or no stick-tight nuts, and at least 95 percent Hawaii grade 1 kernels having a specific gravity less than 1.0 (determined by flotation testing in water).

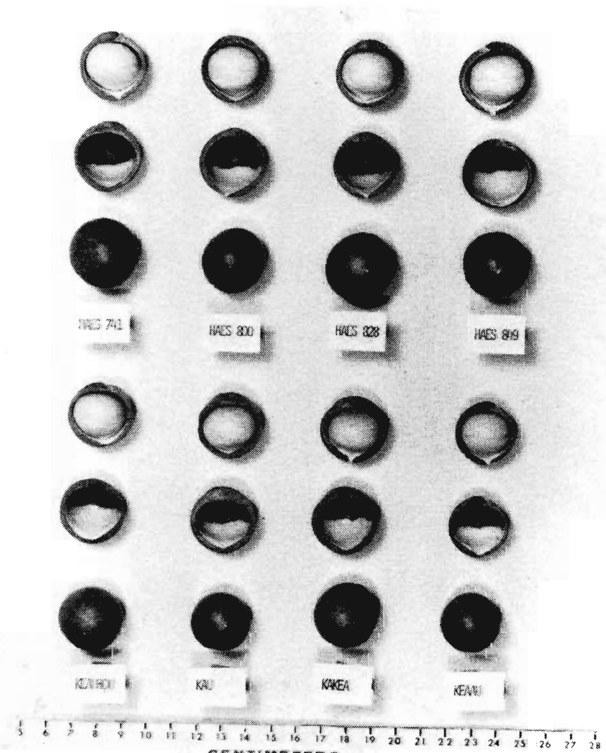

Figure 1. Kernel, shell, and nut characteristics of four standard macadamia cultivars compared with those of four more recent selections. Upper, left to right, four recent macadamia cultivars, HAES 741, HAES 800, HAES 828, and HAES 849. Lower, left to right, four standard macadamia cultivars, 'Keauhou', 'Kau', 'Kakea', and 'Keaau'.

[1] This report was published in extended form by Hamilton and Ito (1976); Hamilton and Ito (1977); Hamilton et al. (1981*a*); and Hamilton et al. (1981*b*).

Table 1. Nut and kernel characteristics of nine macadamia cultivars grown in Hawaii

Cultivar	Percent kernel	Nut weight	Kernel weight	Nuts per pound	Hawaii grade No. 1 kernels	Cooked kernel appearance
	%	g	g		%	
Keauhou*	39	7.2	2.8	63	85	good
Ikaika*	34	6.5	2.2	70	89	fair
Kakea*	36	7.0	2.5	65	90	excellent
Keaau*	44	5.7	2.5	80	97	excellent
Kau*	38	7.6	2.9	60	98	very good
Mauka	43	6.5	2.8	70	98	excellent
Makai	40	8.0	3.2	57	97	excellent
Purvis	39	7.9	3.0	58	95	very good
Pahala	43	6.5	2.8	71	96	excellent
Mean	39.5	6.77	2.73	66	94	

*Cultivars presently grown for commercial purposes.

RECOMMENDED CULTIVARS

Thirteen cultivars have been named in Hawaii and, presently, five are being grown commercially (Table 1). No one variety is outstanding enough to be recommended over all others. Choice of varieties is still made largely on the basis of adaptation to location and preference of individual growers. Detailed descriptions of tree, nut, and kernel characteristics of these cultivars have been published by the authors and others, and brief descriptions follow.

'Keauhou'

'Keauhou' is the oldest Hawaiian cultivar, selected in 1935 and named in 1948. The tree is broadly spreading, with wide crotch angles and strong branch structure. It therefore requires wider spacing in orchards than narrower, more upright cultivars. 'Keauhou' yields well and has attractive nut characteristics, but it is not as hardy or wind-resistant as 'Ikaika' or 'Kau'. 'Keauhou' is still a good clone for areas of Kona where it has performed well and produced satisfactory kernels. It is no longer recommended for planting, however, because its kernel quality has proved marginal some years in certain locations (Hamilton et al., 1975).

'Kakea'

'Kakea' is an excellent commercial cultivar, selected in 1936 and named in 1948 (Storey, 1948). It has performed exceptionally well in long-time yield trials at the Poamoho, Waiakea, and Kona experimental stations. It is reasonably hardy, producing kernels of excellent quality, and has been a consistently productive, long-lived variety in all test locations. Its growth habit is more upright than 'Keauhou' and because of this young trees need to be topped. It is also considered harder to graft than most other varieties. 'Kakea' is one of the best and most reliable varieties for commercial planting in Hawaii.

'Ikaika'

Formerly HAES 333, 'Ikaika' was selected in 1936 and named in 1953, largely because of its early bearing tendencies, dark green foliage, and vigorous tree characteristics (Hamilton et al., 1952). It has been favored in areas where wind is a limiting factor in growth and production. The nuts are relatively thick-shelled, so that recovery of grade 1 kernels is usually less than 30 percent. 'Ikaika' is hardy and precocious, but it is not presently recommended for planting because its nut and kernel characteristics are not as desirable as those of recommended cultivars.

'Keaau'

Formerly HAES 660, 'Keaau' was selected in 1948 and named in 1966 (Hamilton and Ooka, 1966). It has an upright growth habit, permitting somewhat closer planting than other cultivars without undue crowding. 'Keaau' has outstanding nut and kernel characteristics, with 42 to 46 percent kernel and more than 95 percent grade 1 kernels. The trees have performed well in most areas where this variety has been tested.

'Kau'

Formerly HAES 344, 'Kau' was first selected in 1935 but not officially named until 1971 (Hamilton and Nakamura, 1971). 'Kau' resembles 'Keauhou' in nut characteristics and productivity, but with appreciably better kernel quality in most locations. The tree form is more upright than 'Keauhou', and it is considered hardier and more wind-resistant. 'Kau' is a relatively productive variety considered suitable for commercial planting in areas where it is adapted.

'Mauka' (HAES 741)

'Mauka' is a relatively new cultivar selected in 1957 and named in 1977 (Hamilton and Ito, 1977). It has been named 'Mauka' because it has performed well in test plantings at high elevations from 1800 to 2200 feet where most other cultivars are marginal. It is a hardy tree producing nuts that are similar in size and percentage of No. 1 kernels to those of 'Kau', but they average about 43 percent kernel compared with 38 percent for 'Kau'. 'Mauka', then, has 13 percent greater recovery of No. 1 kernels from a given weight of in-shell nuts than 'Kau'.

'Makai' (HAES 800)

This promising, high-quality cultivar was first selected in 1967 and named in 1977 (Hamilton and Ito, 1977). It has been given the name 'Makai', a Hawaiian word meaning "toward the sea," and has shown better adaptation to lower elevation areas than other recent selections and older cultivars. 'Makai' is a seedling of 'Keauhou', which it most resembles in form, nut characteristics, and yield potential. The kernel quality and percent of grade 1 kernels of 'Makai', however, are significantly better than those of 'Keauhou'.

'Purvis'

'Purvis' was first selected in 1936. It was named, in 1981 (Hamilton et al., 1981*a*), after the late William Purvis, who introduced and planted the first seed nuts of *M. integrifolia* in Hawaii in 1882. It is interesting that one of the original trees from this introduction survives to date and is still producing nuts at Kukuihaele, on the Island of Hawaii. It is fitting that this cultivar, HAES 294, should be named in honor of the man who introduced macadamia to Hawaii one hundred years prior. 'Purvis' trees have consistently produced crops averaging higher in grade 1 kernels than the first cultivars named in 1948, with the exception of 'Kakea'.

'Pahala'

One of the newest varieties of macadamia, 'Pahala' was first selected in 1963. It was known previously as HAES 778 and named in 1981 (Hamilton et al., 1981*b*). Growth habit of the tree is somewhat narrow and upright. Because of this, 'Pahala' trees require less space in an orchard and can be planted closer together in a row than other varieties with larger, wider trees. Up to 120 percent more 'Pahala' trees per acre can be planted. The rate of recovery of grade 1 kernels from dry nuts of 'Pahala' was 41.2 percent, approximately 50 percent higher than that of 'Keauhou'. While overall yield capacity for 'Pahala' still must be fully tested, nut characteristics and kernel quality have been adequately tested and found to be as good as, or better than, those of the commercial varieties currently grown in Hawaii.

PRODUCTION: PRESENT AND FUTURE

Compared to original seedling orchards in Hawaii, present commercial cultivars produce approximately 4 times as many nuts per tree with 10 percent more kernel and an additional 10 percent more of grade 1 kernels. This is approximately 6 times greater yield of marketable kernels per acre.

What predictions can be made about the future and improvement of commercial macadamia cultivars in Hawaii? On the basis of new genetic material under observation, production per tree can be increased by about 25 percent. Percent kernel recovery can be improved approximately 10 percent, up to 45 percent, and percentage of grade 1 kernels from about 90 to 95 percent. This represents a potential increase of about 70 percent in grade 1 kernels per acre. An active macadamia breeding project continues in Hawaii. Selection standards will remain high because excellent commercial cultivars are available and being used as checks in selecting superior new cultivars.

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VEGETABLE CROPS

James C. Gilbert
Professor Emeritus, Department of Horticulture

Vegetable crop improvement at the Hawaii Agricultural Experiment Station (HAES) has involved many different crops. Notable breeding contributions have been made for at least a dozen of these, largely through the incorporation of disease- and pest-resistance into locally adapted varieties (Gilbert et al., 1969). Major contributions have been made with tomato, sweet corn, lettuce, green bean, and cauliflower; in each case, the local industry relies almost exclusively on HAES-bred varieties. The studies to be reviewed here will not include root crops and sweet corn, crops that are dealt with elsewhere in this compendium.

TOMATO

The tomato has long been a leading cash crop for Hawaii's growers. However, in the 1930s a spotted wilt virus, transmitted by thrips, was introduced that could destroy over half the plants. The disease had a fairly wide host range, including pineapple, ornamentals, and some common weeds. A resistant variety of tomato named 'Pearl Harbor' was introduced in 1945 (Kikuta et al., 1945). Its resistance was derived from the cherry tomato species, *Lycopersicon pimpinellifolium*, and involved work in California with small-fruited, noncommercial types (Kikuta and Frazier, 1946). Spotted wilt was no longer a problem until the 1960s when other strains of the virus appeared in Hawaii. However, the disease never again became the major threat to tomato production that it was in 1940.

Further improvements in fruit size and disease resistance in tomato were made possible by enthusiastic farmer support to HAES since the 1940s. The first commercial tomato varieties with multiple disease resistance were released by Frazier et al. (1950). These carried the genes *Sw*, *St*, and *I* for resistance to spotted wilt, gray leaf spot (*Stemphylium solani*), and *Fusarium* wilt (Frazier et al., 1947; Hendrix et al., 1946; Kikuta and Frazier, 1946). These heavy yielding, determinate, low-elevation varieties were further improved by the addition of another dominant gene, *Mi*, for resistance to common races of the southern root-knot nematode (McFarlane et al., 1946; Gilbert and McGuire, 1952, 1956). The 'Anahu' variety carried all four of these dominant genes, plus spider mite resistance and

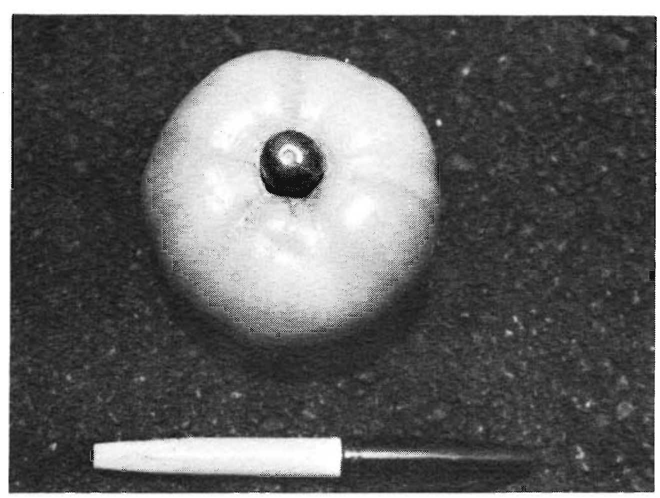

Figure 1. The cherry tomato is dwarfed by large-fruited 'Anahu', to which it contributed important disease-resistance genes through breeding at HAES.

Figure 2. Tomatoes like hybrid BWN21 have high resistance to bacterial wilt, a severe disease killing check varieties (center row) growing in the same soil.

good combining ability in commercial-type hybrids. It was the first commercial, large-fruited variety with this gene combination and was widely used for root-knot nematode resistance in other tropical and subtropical countries following its development in the 1950s. 'Anahu' also has been the source of spider mite resistance (Gilbert et al., 1966) used by U.S. Department of Agriculture (USDA) breeders for large-fruited processing-type tomatoes (Fig. 1).

Additional combinations of disease resistance with good commercial qualities met increasing problems from genetic linkage in the tomato plant. Attainment of better combinations was aided by the production of F_1 hybrids (Gilbert et al., 1961, 1969), usually with the variety 'Anahu' as one parent and an adapted, unrelated tomato as the other. When tested in competition with other tomatoes at 30 locations in the Southern United States (1957-73), 'Anahu' hybrids consistently excelled in both yield and adaptability. They have become standard types for fresh market production in Hawaii and in areas as diverse as the Pacific islands and the Arab states. The root-knot-resistant hybrids were given numbers in Hawaii preceded by the letter N (for nematode). Those that became most widely used were N 5, N 11, N 52, N 56, N 65, and N 69.

Improved resistance to tomato mosaic virus has been added in newer hybrids in N 91 and N 93. Bacterial wilt resistance (Acosta et al., 1964) was attained in the hybrid BWN 21, a large-fruited tomato hybrid. This hybrid was the first to combine root-knot and bacterial wilt resistance. Its Hawaii parent 'Kewalo' (Gilbert et al., 1974) also carried *Fusarium* and *Stemphylium solani* resistance, and represents the product of cooperative breeding programs in North Carolina and Hawaii (Fig. 2).

The root-knot-resistant variety 'Healani' has proved to be widely adapted in subtropical areas (Gilbert et al., 1969). 'Healani' represented an improvement over 'Anahu' and previous inbreds with its resistance to a physiological disorder of the fruit known as "vascular browning" associated with calm, cloudy, humid weather during cooler months in Hawaii. When the trade winds blow, this disorder disappears. In 1970, the *TM-2^a* gene for resistance to tomato mosaic virus was combined with root-knot resistance and other genes in 'Healani'. Genes for fruit quality and size were also introduced from the susceptible line STEP 559 (Vegetable Breeding Laboratory, Charleston, South Carolina). Continuing tomato breeding work at HAES is concerned with this series and other crosses in the bacterial wilt-resistance program.

LEAFY VEGETABLES

Lettuce breeding at HAES was aimed at the provision of varieties tolerating warmer climates in Hawaii (Poole, 1952). Mainland varieties could be used at high elevations but gave poor results at low elevations, especially during warmer seasons. 'Manoa' lettuce is an introduced mignonette type that does not make a heavy yield or a real head. The 'Anuenue' variety was bred from a cross of 'Manoa' and 'Great Lakes' (Poole, 1959). It resembles the former in leaf type but makes a heavier plant with a better head, yet is well adapted to warmer temperatures. A backcross to 'Great Lakes' produced a cultivar with larger heads named 'Kulanui' that was adapted to intermediate temperatures.

Cruciferous crops have received some attention in HAES breeding programs, particularly cauliflower and mustard cabbage (kai choy). An Indian-type cauliflower variety, 'Pua Kea', was released in 1953 after 4 years of selection

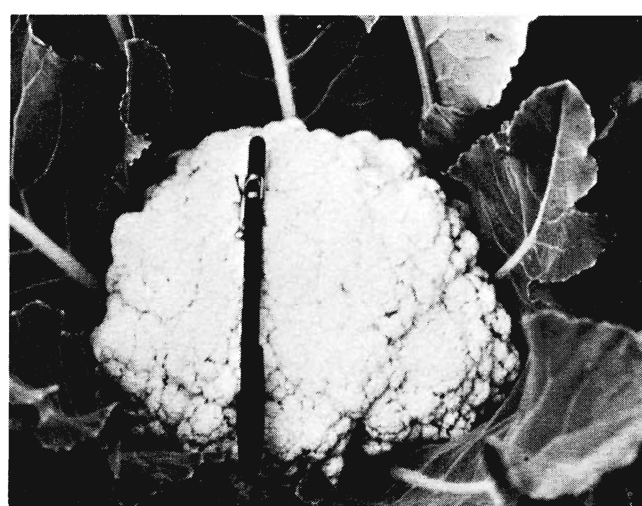

Figure 3. 'Pua Kea', an outstanding cauliflower for yield and resistance in Hawaii.

for improved quality, yield, and year-round performance in Hawaii (Gilbert, 1953, 1955). 'Pua Kea' was subsequently found adapted in South America, the Caribbean, the Philippines, and other locations where daylength and climate were similar to those of Hawaii (Fig. 3).

CUCUMBERS

The cucumber is well adapted to Hawaii's climate and soil but suffers numerous pest and disease problems. Among these are the mildew and virus diseases. Combining resistance to several diseases while maintaining good yield and fruit quality in cucumbers is complex, since each of these traits is controlled by several genes. Resistance to watermelon mosaic virus is needed in Hawaii and many other countries, but it is not found in cucumbers selected in temperate regions (Shanmugasundaram et al., 1969). Powdery mildew on cucurbits is also a problem in Hawaii. The 'Lehua' and 'Maile' cucumbers developed at HAES have resistance to both watermelon and cucumber mosaic virus, plus some field tolerance to mildew. 'Maile' was also selected for fruits having a crisp ovary wall. Both are medium length, slicing-type cucumbers. The genetics of resistance to watermelon mosaic virus was investigated with these varieties, and two recessive genes were implicated for full expression of resistance (Fig. 4).

VEGETABLE LEGUMES

In green beans, Hawaii's growers prefer pole types that yield pods over a longer period and produce the long flat type preferred locally. Bean rust became a problem during wet weather on the popular 'Lualualei' variety, introduced to Hawaii. 'Lualualei' was crossed with a rust-resistant bush type, 'Bountiful', and subsequent selections yielded a rust-resistant pole-type bean with flat pods (Frazier and Hendrix, 1949). Later work with pole green beans added root-knot nematode resistance in a cultivar named 'Manoa Wonder' (Hartmann, 1968).

Root-knot resistance was also sought in lima beans and vegetable-type soybeans (McGuire et al., 1961). Four new cultivars of soybeans were released in 1970 (Gilbert et al., 1970). They can be grown throughout the year in Hawaii, and have proved useful in rotations with root-knot-resistant tomatoes in disease-infested fields where years of frequent tomato cropping created serious replant problems. The 'Kailua' and 'Kahala' varieties of soybean have been the most popular of the new releases (Fig. 5).

The edible-podded (or "Chinese") pea is characterized by the absence of any tough epidermis in the pod and is popular for various vegetable combinations in local dishes. A serious powdery mildew disease in peas was a major obstacle to growing these peas. Vines could be completely defoliated but fungicides would contaminate the pods. This problem was solved by breeding a variety named 'Manoa Sugar' (Gilbert, 1958) with high mildew resistance, adaptability to local climate, and high yields of tender pods. No sprays for powdery mildew control are needed with this variety, which has continued to be used widely in Hawaii and in other subtropical areas.

EGGPLANT

Long, thin varieties of eggplant are preferred in the markets of the Pacific and Southeast Asia. Selections of this type were made in Hawaii, resulting in the release of

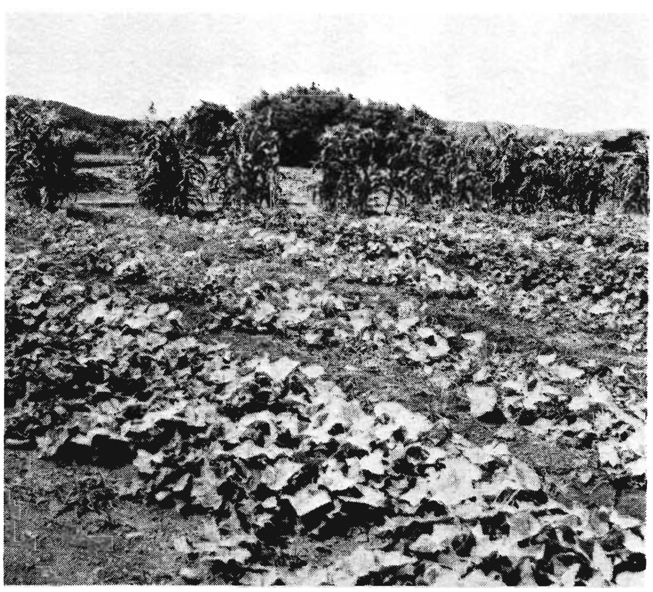

Figure 4. The 'Lehua' and 'Maile' cucumber varieties were selected in Hawaii for superior resistance to watermelon and cucumber mosaic viruses.

Figure 5. 'Kailua' is one of the best cultivars of soybeans produced in Hawaii with resistance to root-knot nematodes.

'Waimanalo Long', an improved dark-purple, cylindrical variety (Tanaka, 1972).

PEPPER

The improvement of bell pepper (*Capsicum annuum*) for adaptation in Hawaii was initiated in 1972. Major commercial cultivars and a few local lines were evaluated intensively (Tanaka et al., 1976). A selection program is continuing for improved fruit set and pest tolerance in peppers.

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ROOT CROPS

Jack S. Tanaka
Associate Professor, Department of Horticulture

The sweet potato was an important crop to the native Hawaiians. It is said to have been cultivated in Hawaii since A.D. 1000, having arrived with the taro probably from Tahiti (Neal, 1965). The improvements of root crops through selection made by the early Hawaiians are noteworthy. Many of the early cultivars still exist today in gardens in Hawaii.

Research activity on sweet potato began during the 1940s with most work directed toward producing new cultivars by crossbreeding (Poole, 1955, 1959*a*, 1959*b*). Onion breeding was initiated in 1955, followed by potato improvement in 1963. A brief summary follows of the accomplishments of root crop improvement programs.

ONION

'Awahia'

The onion breeding program was started in 1955 with emphasis on development of a pungent-flavored onion that holds its flavor when cooked in various dishes.

Strains of 'Red Creole' were crossed, resulting in the cultivar 'Awahia' (Tanaka, 1960). The onion breeding program was discontinued after the release of 'Awahia', although introduction and testing of new cultivars and production of 'Awahia' seed are continued. 'Awahia' (Hawaiian for "pungent") is a small plant 12 to 15 inches tall, with bluish-green leaves. It produces medium-size bulbs 2½ to 3 inches in diameter, averaging slightly over 5 ounces per bulb. It has an oblate (or slightly flat) shape, reddish-brown scales, purple flesh, rather strong flavor, and can be stored for months without showing signs of rot. It is adapted to the short daylength of fall-winter months.

POTATO

The potato evaluation work was started in December, 1963, when seeds of Mexican potato crosses were obtained from J. S. Niederhauser of the Rockefeller Institute. Of the hundred clones and varieties evaluated, two selections were named and released in 1970 and 1972, respectively:

'Pele' (35-S)

'Pele' is a late-blight-tolerant potato from the cross between 57-AH-9 and 'Anita'. It is late maturing and high yielding at higher elevations in the tropics, and chipping quality is relatively good. In tuber appearance, 'Pele' is similar to 'Kennebec', with medium to shallow eyes and a white skin that is slightly russetted. The flesh is white and has a good potato flavor. A major advantage of this cultivar is its high degree of resistance to late blight caused by *Phytophthora infestans* (Ito et al., 1978).

'Waimea' (25-S)

'Waimea' is a seedling from the cross of RU-74 and 'Anita'. Tubers are round to blocky, with a mean length of 75 mm, width of 65 mm, and thickness of 51 mm. Skin is white with relatively smooth texture, and eyes are pigmented and relatively deep. Flesh color is off-white. It is very late maturing, 3 to 4 weeks later than 'Kennebec' depending on the season and location. However, 'Waimea' is 7 to 10 days earlier than 'Pele'. Field tests indicate that it has a high degree of tolerance to late blight. It has also been found to be acceptable for chipping (Sekioka et al., 1974).

SWEET POTATO

Early emphasis on sweet potato breeding was directed toward producing sweet potato varieties by hand-pollination. Due to the slow progress by this method, the open polycross method was started in 1965. Leading cultivars from Asia, the United States, and Hawaii were planted and allowed to naturally cross-pollinate. This breeding method gave an abundance of open-pollinated seeds from which selection could be made. The following cultivars have been released since the program was initiated:

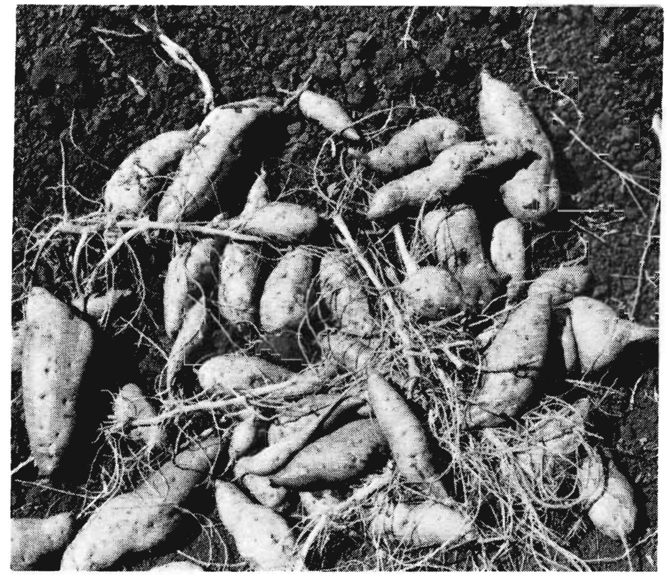

Figure 1. 'Onokeo', a dry-type sweet potato with the purple skin and white flesh colors favored in Hawaii.

'Onolena'

This cultivar was released in 1950 by C. F. Poole and has a medium brown skin and orange flesh. When properly baked, it always grades high for flavor, texture, and freedom from fibers (Poole, 1959*a*).

'Iliula'

This is an open-pollinated seedling of 'Nancy Hall', with red skin and orange flesh. It has higher yield but is not as good a baker as 'Onolena'. The chief appeal of 'Iliula' is the red skin color (Poole, 1959*b*).

'Onokeo'

A dry-type sweet potato with very good yield. 'Onokeo' has an attractive purple skin with white flesh (Fig. 1). The roots are well shaped, fusiform to oblong. A disadvantage is the prolific vine growth (Tanaka, 1972).

TARO AND CASSAVA

Taro and cassava are two of the most important root crops of the tropics. Taro (*Colocasia esculenta*) was one of the earliest cultivated plants of Hawaii, having been introduced with the original immigrants (Neal, 1965). A large assortment of taro varieties was brought into Hawaii, and the Hawaiians derived many clones from these (Whitney et al., 1939). However, there has been no modern plant breeding or systematic yield trials of these taro cultivars. Cassava (*Manihot esculenta*) has similarly been introduced and grown widely throughout the State without systematic evaluative and selection studies. Such studies have recently been initiated by the HAES on Kauai (de la Peña, unpublished).

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PINEAPPLE

Ron Terry
Formerly Assistant Director, Maui Land Pineapple Company

Hawaiian pineapple has a preprocessing value of approximately $38 million each year. This equals 20 percent of the State's income from agriculture. However, on a processed value basis, it is worth approximately $135 million per year. The industry employs about 6,000 people year-round, with an additional 12,000 during the summer harvest season. The industry payroll amounts to about $50 million annually. Hawaii's pineapple acreage accounts for over one-third of total world production.

The pineapple industry has been going through a period of rapidly spiraling costs for the past 10 years, and agronomic problems are increasing due in part to the monoculture practice. Labor accounts for two-thirds of pineapple production costs. Planting and harvesting are by hand and, in most instances, pineapple slices are placed into the can one at a time. The industry is trying to farm with the highest-paid agricultural worker in the world, yet still use large, highly specialized, and often highly inefficient, equipment.

Active pineapple breeding was carried out for about 60 years at the Pineapple Research Institute in Hawaii. Despite the development of many new varieties, production is still based entirely on the clone 'Smooth Cayenne' (Collins, 1960). The adaptability of this variety is unique in agriculture; it is essentially the only pineapple variety raised commercially throughout the world. The pineapple is reproduced entirely by vegetative propagation. Seeds occur only when two different varieties are outcrossed, due to self-incompatibility (Brewbaker and Gorrez, 1967), and the development of new varieties requires absolute suppression of any self-fertility of the fruits. All the wild relatives of the pineapple are self-fertile.

Major concerns of the pineapple breeder have been fruit size and shape, adapting the fruit to the demands of the cannery. Other important characteristics include internal fruit color, porosity, density, brix (sweetness), acid, aroma, and off-flavors. Several species have entered the breeding studies, including the long-fruited *Ananas ananassoides* and the large-fruited *A. bracteatus*, and some varieties with extraordinary quality and productivity have been obtained. However, only two of these have appeared with commercial possibilities. These have been in production only because they are extremely resistant to *Phytophthora* heart and root rots. They have limited production potential since the fruits are not as large or flavorful as 'Cayenne'. One of these, however, has excellent quality in cooler winter weather, when the 'Cayenne' tends to become low in brix and high in acids. It appears that pineapple breeding is a very frustrating job, and the odds of success are very small.

Major improvements in pineapple have come not through breeding, but through improved production and engineering technology, with special advances in control of nematodes and fruit diseases and in flowering physiology (Nakasone, 1976). An area of major research emphasis is that of plant hormone manipulation. It is now possible with the hormone ethrel to manipulate flowering more accurately than with previously used agents, such as ethylene and naphthalene acetate salts. Applying ethrel to fruits 2 to 3 weeks before natural ripening causes the fruit to ripen artificially. This should have a significant impact on harvesting costs. Presently, the period of ripening is spread over a 4- to 6-week period, requiring weekly harvesting. Ethrel applications promise great reduction in this labor.

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