

History of Hawaiian Pomology: Introduction to the Workshop

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The Hawaiian Islands were colonized by waves of Polynesian settlers perhaps as early as 300 CE. Fruit culture at that time was based on banana, breadfruit, candlenut, coconut, mountain apple, and pandanus. The first documented contact with Europe was the encounter of Hawaii by British explorer James Cook in 1778. Subsequent settlement by European and American planters brought in numerous fruit crops, including avocado, citrus, coffee, macadamia, mango, papaya, passionfruit, and pineapple, with varying success. The present workshop, History of Hawaiian Pomology, sponsored by the History of Horticultural Science and Pomology Working Groups, explored three famous fruit and nut crops of Hawaii: pineapple (oral presentation by Johnny Lopez), papaya (oral presentation by Richard Manshardt), and macadamia (oral presentation by David Rietow), each with very different stories and outcomes.

The first paper, entitled "Pineapple: The Rise and Fall of an Industry" by Duane P. Bartholomew, Richard A. Hawkins, and Johnny Lopez, reviews the Hawaiian history of one of the world's most famous tropical fruits. The industry was based on processing and export and reached its peak in terms of production in 1972. The spectacular ascent and precipitous decline of the pineapple area in Hawaii underscores the fact that horticulture is more than a science and an art but is an industry whose success depends on many factors, including climate and biotic factors but principally economics. As a result of labor costs, and foreign competition initiated by Hawaii-based companies (!), the Hawaiian pineapple industry that once covered almost 74,000 acres (30,000 ha) declined precipitously and essentially disappeared. However, breeding advances carried out in Hawaii by the Pineapple Research Institute culminating in the development of the 'MD-2' clone (Fig. 1) have led to a world resurgence in fresh pineapple but the impact has proved to be greatest outside of the islands.

The presentation "Papaya in Hawaii" by Richard Manshardt reviews the origins of one

of the great success stories of Hawaiian horticulture, a drama that continues to unfold. Papaya was introduced to the islands \approx 1820 and initially considered an inauspicious crop.

Since the early 20th century, breeding and the development of cultural techniques have been the backbone of the industry as demonstrated by the successful development and

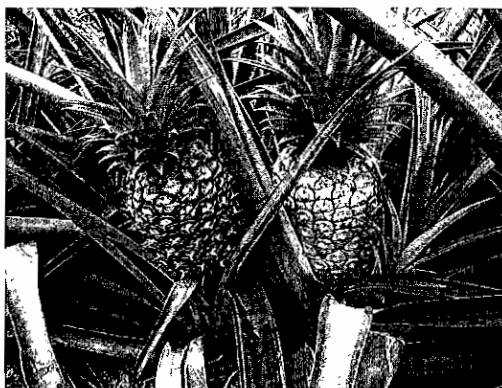


Fig. 1. The famous 'MD-2' pineapple developed in Hawaii at the Pineapple Research Institute has revitalized the world market for fresh pineapple.



Fig. 2. The transgenic 'SunUp' papaya developed in Hawaii with resistance to the papaya ringspot virus has resurrected the Hawaiian papaya industry.

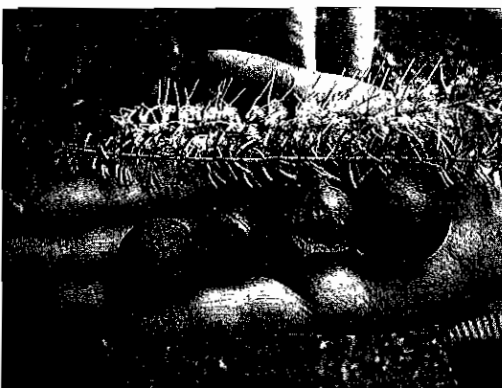


Fig. 3. Flowers and fruit of macadamia.

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production of the high-quality solo papaya types. However, from the 1950s, the papaya ringspot virus threatened to destroy the industry and nearly wiped it out. Salvation came as a result of developments in molecular biology carried out by collaborating researchers at Cornell University, the University of Hawaii, and the USDA Sugarcane Research Laboratory. The incorporation of transgenic resistance in two cultivars, SunUp (Fig. 2) and Rainbow, has enabled the

resurrection of the industry in Hawaii and elsewhere. Although the industry continues to struggle as a result of competition from Central and South America, acceptance of transgenic papaya in Asia is expected to revive the industry.

The last presentation by David Rietow, entitled "Macadamia: A Hard Nut to Crack," chronicles the development of an industry by Hawaiian pomologists from importation of a little known Australian species to its

development and commercialization. The macadamia tree produces a nut with an extremely hard shell with a deliciously flavored kernel high in lipid content (Fig. 3). It is fair to say that the macadamia world industry is an innovation that owes its success to research and development carried out in Hawaii. However, the success of the Hawaiian macadamia industry has led to an expanding world production that has provided challenges to Hawaiian growers who are now battling to survive.

Hawaii Pineapple: The Rise and Fall of an Industry

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Abstract. The date pineapple (*Ananas comosus* var. *comosus*) was introduced to Hawaii is not known, but its presence was first recorded in 1813. When American missionaries first arrived in Hawaii in 1820, pineapple was found growing wild and in gardens and small plots. The pineapple canning industry began in Baltimore in the mid-1860s and used fruit imported from the Caribbean. The export-based Hawaii pineapple industry was developed by an entrepreneurial group of California migrants who arrived in Hawaii in 1898 and the well-connected James D. Dole who arrived in 1899. The first profitable lot of canned pineapples was produced by Dole's Hawaiian Pineapple Company in 1903 and the industry grew rapidly from there. Difficulties encountered in production and processing as the industry grew included low yields resulting from severe iron chlorosis and the use of low plant populations, mealybug wilt that devastated whole fields, inadequate machinery that limited cannery capacity, and lack of or poorly developed markets for the industry's canned fruit. The major production problems were solved by public- and industry-funded research and innovation in the field and in the cannery. An industry association and industry-funded cooperative marketing efforts, initially led by James Dole, helped to expand the market for canned pineapple. Industry innovations were many and included: selection of 'Smooth Cayenne' pineapple as the most productive cultivar with the best quality fruit for canning; identification of the cause of manganese-induced iron chlorosis and its control with biweekly iron sulphate sprays; the use of mulch paper and the mechanization of its application, which increased yields by more than 20 t ha⁻¹; and the invention of the Ginaca peeler-corer machine, which greatly sped cannery throughput. Nematodes were also a serious problem for the industry, which resulted in the discovery and development of nematicides in the 1930s. As a result, by 1930 Hawaii led the world in the production of canned pineapple and had the world's largest canneries. Production and sale of canned pineapple fell sharply during the world depression that began in 1929. However, the formation of an industry cartel to control output and marketing of canned pineapple, aggressive industry-funded marketing programs, and rapid growth in the volume of canned juice after 1933 restored industry profitability. Although the industry supported the world's largest pineapple breeding program from 1914 until 1986, no cultivars emerged that replaced 'Smooth Cayenne' for canning. The lack of success was attributed in part to the superiority of 'Smooth Cayenne' in the field and the cannery, but also to the difficulty in producing defect-free progeny from crosses between highly heterozygous parents that were self-incompatible. Production of canned pineapple peaked in 1957, but the stage was set for the decline of the Hawaii industry when Del Monte, one of Hawaii's largest canners, established the Philippine Packing Corporation (PPC) in the Philippines in the 1930s. The expansion of the PPC after World War II, followed by the establishment of plantations and canneries by Castle and Cooke's Dole division in the Philippines in 1964 and in Thailand in 1972, sped the decline. The decline occurred mainly because foreign-based canneries had labor costs approximately one-tenth those in Hawaii. As the Hawaii canneries closed, the industry gradually shifted to the production of fresh pineapples. During that transition, the pineapple breeding program of the Pineapple Research Institute of Hawaii produced the MD-2 pineapple cultivar, now the world's pre-eminent fresh fruit cultivar. However, the first and major beneficiary of that cultivar was Costa Rica where Del Monte had established a fresh fruit plantation in the late 1970s. Dole Food Co. and Maui Gold Pineapple Co. continue to produce fresh pineapples in Hawaii, mostly for the local market. All of the canneries eventually closed, the last one on Maui in 2007.

The history of the Hawaiian pineapple (*Ananas comosus* var. *comosus*) industry is richly documented, but until the recent books of Hawkins (2011) and Larsen and Marks (2010), much of the information was in documents and publications of more limited

scope or having limited availability (Auehter, 1946, 1951; Dole, 1929; Dole and Porteus, 1990; Kehlor, 1992; Ten Bruggencate, 2004; Oelun, University of Hawaii'i at Manoa Library, Hawaiian Collection, 1953). The profusely illustrated book by Larsen and Marks (2010) provides comprehensive coverage of the canning industry and includes considerable oral history of that industry. Larsen spent more than 20 years at Dole and the book contains extensive interviews with industry workers and leaders. The book lacks an index, a limitation given the wealth of information it contains.

In this article, we provide an overview of the rise and decline of the industry as a whole and highlight some of the events that promoted its development and were responsible for its decline. Although the focus of this article is on pineapple production and canned product, Larsen and Marks (2010) devote an

entire chapter to pineapple juice, which became an important byproduct of the industry after 1933 and eventually exceeded 13 million cases in 1955. One thing made clear from the wealth of information included in these references is that we can only touch on the array of issues and events that resulted in the rise and fall of the Hawaiian pineapple industry in this article.

PINEAPPLE IN THE UNITED STATES AND HAWAII—19TH CENTURY

The date that pineapple was introduced into Hawaii is lost in history, but the first record of pineapple in Hawaii was a 21 Jan. 1813 note in Don Francisco de Paula Marín's diary stating "This day I planted pineapples and an orange tree" (Collins, 1960). Collins (1960) asserts that the note indicated an ordinary

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event and so likely was not the date of first introduction. Larsen and Marks (2010) conclude that pineapple was well established in Hawaii in both wild and cultivated states before missionaries arrived from New England in 1820 and suggest multiple possibilities by which pineapple could have arrived in the islands. However, Marin's note is the first verifiable record of its presence. Pineapple was not again noteworthy until 1849 to 1851 when some 21,000 fruits were transported from the Kona area of Hawaii to Honolulu and then to California after gold was discovered there (Gortner et al., 1963). Spoilage during shipment was a serious problem and losses were high because refrigerated shipping did not exist. As a result, there were infrequent small shipments of fresh pineapples from Hawaii to California between 1851 and 1903 (Gortner et al., 1963).

From \approx 1815 until 1900, when Hawaii was incorporated as a U.S. Territory, the principal agricultural commodity exported from Hawaii was sugar. The profitability of agriculture exports from Hawaii during this period was determined mainly by land availability and tenure, availability of labor, and U.S. tariff regulations. For sugar, the land tenure issue was solved by the Great Mahele, a land redistribution act proposed by King Kamehameha III in 1830, enacted in 1848, and amended in 1850 that allowed foreigners to buy and lease land. Tariffs and duties on exports to the United States were eliminated by the Reciprocity Treaty of 1875. The factors impacting the profitability of fresh pineapple shipments were similar to those of sugar but included a lack of refrigerated transport, which did not exist until the early 1880s. Its appearance about coincided with the development of improved methods of canning, in particular the invention of the double-seamed tinned steel can.

Nicholas Appert published the methods for preserving meats, vegetables, and fruits in glass jars in 1810. A British patent on the preservation of foods in tinplated cans and glass jars was issued to Peter Durand, a colleague of Appert, in 1810 and gave rise to the name "canning" (Larsen and Marks, 2010, p. 30). A canning industry was established in Baltimore in 1819 and by 1850, five canning companies existed that mainly processed oysters (Hawkins, 1995). However, until relatively late in the 19th century, canned commodities remained beyond the reach of all but the wealthy and government troops on campaigns, e.g., the American Civil War.

Baltimore became the canning center of America. Pineapple, initially imported from the Bahamas and later also from Cuba, was first canned there in 1865 (Hawkins, 1995). The fruits were of poor quality because they were picked green to reduce rotting during the 25- to 30-d sailing trip from the Bahamas. However, green pineapples "degreen," but the quality and flavor only diminish with storage time. Initially, the Baltimore pineapple canning industry was small because all work was done by hand. Machinery developed between \approx 1870 and 1900 that could core,

slice, and shred pineapples helped the industry to grow. The ring-shaped slices so characteristic of premium canned pineapple originated in the Baltimore canneries and mechanical slicers were particularly popular with canners. A contour peeler that could peel four pineapples per minute was developed and patented in 1893 (Hawkins, 1995), but it was not particularly successful so much of the peeling work continued to be done by hand. Some 70 years later the Dole division of Castle and Cooke developed and patented a contour pineapple peeler. It too was not successful, in part as a result of the difficulty in keeping the knives sharp (Larsen and Marks, 2010, p. 236).

Duties and tariffs imposed in 1894 and 1897 by the United States at the instigation of pineapple growers in Florida, and an additional tariff passed in 1909, were largely responsible for the decrease in shipments of pineapples from the Bahamas to Baltimore and thus for the demise of the Baltimore pineapple canning industry (Hawkins, 1995). Coincident with, but unrelated to, the demise of the Baltimore pineapple canning industry was the rise of the Hawaii industry after the annexation of the Republic of Hawaii by the United States in 1898.

The earliest record of pineapple being canned in Hawaii was when the Kona Fruit Preserving Co., founded in 1882 in North Kona by John Douglas Aekerman and Waldemar Muller, sent samples of canned pineapple to Honolulu. The fruit was reported to be of excellent flavor. However, the business apparently was unprofitable and only survived a few months (Hawkins, 2011; Larsen and Marks, 2010, p. 51).

The basis for the modern Hawaii industry was begun when John Kidwell, a trained horticulturist, arrived in Honolulu from San Francisco in 1882 and established a nursery in Manoa Valley. Kidwell was encouraged by Charles Henson, a local horticulturist and fruit broker, to grow pineapples because he liked to include a few fresh pineapples in his banana shipments to the U.S. mainland (Auchter, 1951). In 1885, Kidwell started a pineapple farm with locally available plants, but their fruit was of poor quality (Hawkins, 1997). That prompted him to search for better cultivars. A report in *The Florida Agriculturist* about 'Smooth Cayenne', a pre-Columbian cultivar first collected in French Guyana (Coppens d'Eeckenbrugge et al., 2011), prompted the importation of 12 plants. An additional 1000 plants were obtained from Jamaica in 1886, and an additional 31 cultivars, including 'Smooth Cayenne', were imported from various locations around the world. 'Smooth Cayenne' was reported to be the best of the introductions and, at the time of Henson's premature death from tuberculosis in 1886 (Anonymous, 1886), Kidwell had 4.05 ha (10 acres) of pineapple under cultivation. R.W. Jordan shipped an additional one million 'Smooth Cayenne' plants obtained in Australia to his brother's nursery in Honolulu in 1896 (Auchter, 1951). The pineapple cultivar that would form the foundation

of the future Hawaii industry had become well established in the islands, presumably because it was vigorous, productive, tolerant of most pests and diseases, and had fruit of good quality that canned well.

RISE OF THE COMMERCIAL HAWAIIAN PINEAPPLE INDUSTRY—20TH CENTURY

The commercial Hawaiian pineapple canning industry began in 1889 when Kidwell's business associate, John Emmeluth, a Honolulu hardware merchant and plumber, produced commercial quantities of canned pineapple. Emmeluth refined his pineapple canning process between 1889 and 1891 and in \approx 1891 packed and shipped 50 dozen cans of pineapple to Boston, 80 dozen to New York, and 250 dozen to San Francisco. The test product was well received, but the profit margin was slim and he lost money because of the 35% duty on processed fruit imports to the United States (Larsen and Marks, 2010, p. 53). Kidwell and Emmeluth established the Hawaii Fruit and Packing Company in 1892 and built a small cannery. The business was closed and the cannery was sold to the Pearl City Fruit Company after the 1898 season because the crushing tariffs and high shipping costs made the venture unprofitable. In 1893 there were 13 pineapple growers, mostly on Oahu, with almost 400,000 plants in the ground and most fruits went to the fresh market. In 1897, almost 158,000 fruits were exported to the U.S. mainland. Production declined after 1897 and by 1901 no data on pineapple fresh fruit exports were collected (Larsen and Marks, 2010, p. 57).

Several events occurred in 1898 that facilitated the development of the new pineapple canning industry. First, the annexation of Hawaii in that year resulted in the revocation of the 35% duty on Hawaiian canned pineapple. Second, the Republic of Hawaii legislature passed a law that made some 526.3 ha (1300 acres) of government land near Wahiawa available for homesteading once a pasture lease expired. Lastly, Byron O. Clark, Territorial Commissioner of the Board of Agriculture and Forestry, helped bring 13 southern California families to Wahiawa to homestead the land made available under the new law. These early migrants and James Dole, who arrived in 1899, formed the nucleus of what would eventually become the largest pineapple industry in the world (Auchter, 1951; Larsen and Marks, 2010, p. 68–69). Dole quickly established relationships with prominent citizens in Hawaii, including Governor Sanford B. Dole, his second cousin. These relationships helped to assure that his venture into pineapple growing and canning was not starved for capital (Larsen and Marks, 2010, p. 80).

Although sugarcane was "king" in Hawaii, untilled government land was in pasture rather than sugarcane because it was too dry for un-irrigated sugarcane and the elevation was too high for irrigated cane (Higgins, 1912). Sugarcane on Oahu was irrigated with groundwater

and pumping costs made irrigation unprofitable above ≈ 183 m (600 ft) elevation (Wadsworth, 1933). Even when the Wahiawa dam at an elevation of ≈ 260 m was completed in 1907, the water collected in the reservoir was almost all distributed to sugar plantations at lower elevations (Wadsworth, 1933).

It may have been fortuitous that the elevation of Wahiawa was ≈ 60 m too high for sugarcane because it is now common knowledge that the best pineapples in terms of sugar content and sugar-acid balance come from areas in Hawaii with an elevation of ≈ 300 m. As the industry expanded on Oahu, most pineapple plantations were established at elevations above 180 m. Lands at lower elevation were already planted to sugarcane because their shallower slopes made them easier to irrigate.

The recently arrived homesteaders cleared land, built homes, and at first planted food and fodder crops. Byron O. Clark had obtained a small pineapple farm planted with 'Smooth Cayenne' plants near Pearl City in 1898 before the prospective homesteaders had left California. Clark's farm provided the first pineapple plants grown on the homesteaded lands near Wahiawa and they grew so well that other homesteaders followed suit (Auchter, 1951). James Dole established the Hawaiian Pineapple Company (HPC) in 1901 and is "usually considered to have produced the first commercial pack of 1,893 cases of canned pineapple in 1903" (Auchter, 1951).

The pineapple plantation concept quickly spread to Kauai and Maui, perhaps because the already well-established sugar industry provided the near-ideal plantation model for those to whom it was not initially obvious. As the industry expanded, the cases of canned pineapple grew steadily while the number of canneries fluctuated (Fig. 1) (Auchter, 1951; Ten Bruggencate, 2004). By ≈ 1930 , after multiple reorganizations and consolidations, four companies came to dominate the Hawaii pineapple canning industry and all survived at least into the 1960s. These survivors were HPC; Libby McNeil & Libby (LML), a major continental U.S. canner based in Chicago that became established in Hawaii in 1910; the California Fruit Canners Association, which acquired a Hawaiian pineapple canning company in 1911 [in 1916 it merged with three other U.S. West Coast canners to form California Packing Corporation (Calpak)]; and a group of companies affiliated with the sugar factor Alexander & Baldwin that eventually became Mani Pineapple Co. (MPC) (Hawkins, 2011).

The first pineapple company on the island of Kauai was established in 1906. Over the years several additional companies were organized there, some by citizens of Japanese ancestry. Of the Kauai companies, only Hawaiian Fruit Packers (HFP), which was formed in 1937 by the reorganization of a company initially started by a group of ethnic Japanese growers, survived into the 1960s. Stokeley-Van Camp bought stock in the company in 1939 and became the exclusive distributor for its entire production (Auchter,

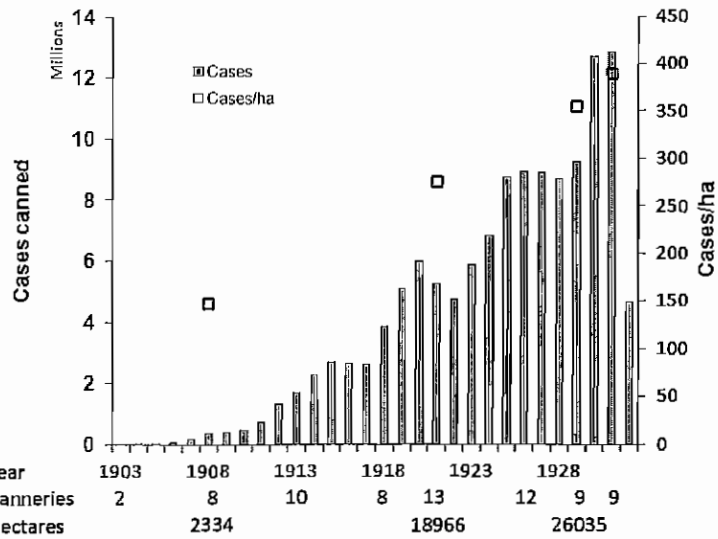


Fig. 1. Cases of pineapple canned, cases per hectare, operating canneries and selected data on area in crop in Hawaii from 1903 to 1932 (Auchter, 1951; Hawkins, 2011; Larsen and Marks, 2010).

1951). Ethnic Japanese also established pineapple farms on Oahu and Maui (Hawkins, 2011).

Japanese men were brought to Hawaii between 1885 and 1908 as indentured laborers for the sugar industry. Once their period of indenture was completed, many left to work in the pineapple industry because of easier working conditions, more freedom, and greater opportunity for advancement (Hawkins, 2011). In 1908, $\approx 7.5\%$ of the pineapple lands were controlled by growers of Japanese ancestry (Hawkins, 2011). A number of the farms operated by ethnic Japanese supplied pineapples to larger companies that grew as well as canned pineapple. In 1913, the greatest number of ethnic Japanese growers were on Oahu and 220 of those growers formed the Oahu Island Pineapple Growers Cooperative with over 2966 ha (7325 acres) under cultivation (Hawkins, 2011). In 1920, 87.7% of the small pineapple farms were owned or operated by ethnic Japanese (Hawkins, 2011). As the pineapple industry consolidated, the number of the small farms run by ethnic Japanese gradually declined. However, Mani Pineapple Co. bought pineapples from a grower of Japanese ancestry for the canneries until it closed in 2007 and then purchased reduced volumes of fresh fruits through the end of 2009. The last large group of Asian immigrants came to Hawaii from the Philippines. By 1920 Filipinos comprised a significant segment of the plantation workforce and that remains the situation to this day.

Initially, pineapple yields, expressed as cases/ha, were very low. In 1908, pineapples occupied fewer than 2429 ha (6000 acres) (Hawkins, 2011); only $\approx 344,000$ 21.8-kg (48 lb) cases of canned product were produced (Larsen and Marks, 2010), and yields were less than 150 cases/ha (Fig. 1). Can size details were not available until the 1932–33 year. In that year and for many years afterward, there were nine can sizes. The various packs included slices, the most valuable of

the canned products, as well as chunks, crushed or shredded, and juice (Auchter, 1951). Yields were low because planting densities were less than half the densities that became common by the 1930s (Larsen and Marks, 2010).

The new industry encountered a number of problems. The first that limited expansion of the planted area was a severe chlorosis that was observed in ≈ 1900 (Auchter, 1951). The chlorosis occurred on large areas of so-called black soils that were high in manganese. The problem was not encountered in soils at higher elevations where rainfall was higher and soils were more highly leached and had lower pH values. The disorder was described and associated with manganese levels in soil (Kelley, 1909). Some years later Johnson (1916) discovered that high manganese rendered soil iron unavailable to pineapple plants and reported that sprays of iron sulphate would cure the problem. Johnson may have discovered the cure independently or he may have read of a similar lime-induced chlorosis problem of pineapple in Puerto Rico that was cured with iron sulphate sprays (Gile, 1911). Hoyt, an HPC employee, developed a rule-drawn sprayer to apply the iron sulphate solution and this ushered in the era of foliar fertilization of pineapple (Larsen and Marks, 2010, p. 150). With the chlorosis problem solved, the area planted to pineapple reached 18,966 ha by 1921. Foliar sprays with iron sulphate and other innovations developed by the industry or the Hawaii Agricultural Experiment Station (HAES), which included increasing planting densities to 24,700 plants/ha or more, had improved yields such that cases per hectare reached 277 in 1921 (Fig. 1).

The "Banker's Panic" of 1907 caused pineapple sales to drop sharply and by early 1909, 70% of the 1908 production of over 343,000 cases was still in cannery warehouses. The Hawaiian Pineapple Growers' Association (HPGA), which included HPC

and six other pineapple companies, was formed in 1908 to deal with the problem (Auchter, 1951). A marketing study showed only limited sales in many large U.S. mainland cities, so salesmen were sent to such areas to market the glut of canned pineapple. Some success was achieved, but it was an advertising campaign, launched at a cost of \$50,000, that caused demand to surge (Larsen and Marks, 2010, p. 140). The advertising campaign was supported by grower assessments based on the size of their canned pack. It was the first generic (not label or company-specific) advertising campaign in the U.S. food processing industry, preceding a similar campaign by the California orange industry by a few months (Hawkins, 2011).

The HPGA was disbanded in December of 1912 and was immediately replaced by the Hawaiian Pineapple Packers' Association (HPPA) with James Dole elected as president (Auchter, 1951). The bylaws of the organization covered the main issues confronting the new industry and included: 1) promote the common interests of the pineapple packers of the Territory of Hawaii; 2) undertake and encourage the scientific development of pineapple culture; 3) maintain a sufficient labor supply; 4) improve packing methods and equipment; 5) maintain and advance high standards for all products of the pineapple packing industry; 6) advertise and increase the demand for Hawaiian pineapple products; 7) seek the passage of laws beneficial to the pineapple industry; and 8) obtain the best possible transportation terms and facilities.

The HPPA began funding research at the experiment station of the Hawaiian Sugar Planters Association (HSPA) in 1914 to supplement the work of the HAES. The HSPA experiment station was established in 1895, more than five years before the HAES existed, to carry out research on sugarcane. The joint research program included the breeding of pineapple to attempt to develop a Smooth Cayenne cultivar that was resistant to mealybug wilt (Lyon, 1915). In 1917 the Trustees of the HPPA leased 0.8 ha (2 acres) of land for the planting of seedlings produced by the program and additional land was leased in 1919 (Auchter, 1951). 'Smooth Cayenne' clones with partial resistance to mealybug wilt were found but breeding and selection for mealybug wilt resistance was not pursued because the resistance was insufficient (Rohrbach et al., 1988). By 1930, the wilt problem had become so serious that some growers considered establishing plantations outside of Hawaii (Rohrbach et al., 1988). Research showed that ants moved the mealybugs into the field so research focused on a way to keep ants out of the field. It was found in 1925 that ant fences bordering fields and sprayed with petroleum products would keep the ants out of the fields. Research by Calpak showed that pineapple border guard beds planted perpendicular to rows in the field would achieve the same result because ants preferred to move down rows rather than across them. The Calpak technique remained in use in some fields into the 1950s (Rohrbach et al., 1988);

however, once effective insecticides became available, they replaced the physical controls (Rohrbach and Johnson, 2003).

The industry association name was changed in 1922 to Association of Hawaiian Pineapple Canners (AHPC) and cooperative marketing continued to be done periodically, but few other organizational changes were made. Despite the name change, the major objectives of AHPC remained research, a forum for the industry, industry publicity and oversight, worldwide data collection, and interaction with governmental agencies (Hawkins, 2011; Larsen and Marks, 2010, p. 142).

The cooperative research program with the HSPA was replaced in 1924 by a large research facility supported by self-imposed levies on pineapple production (TenBruggencate, 2004). Both the HSPA and pineapple research programs were relatively unique in American agriculture because they were funded primarily by grower assessments rather than by government. The new pineapple research program was housed in buildings adjacent to the University of Hawaii campus. In the 1926-27 University of Hawaii catalog, the AHPC research program supported 13 staff, two of whom had PhDs. The 1929-30 catalog listed five faculty in agriculture employed by the University of Hawaii, whereas the AHPC-supported program had grown to 28 total staff, 22 scientific staff, seven with doctorates, five with Master's, and the remainder with Bachelor's degrees.

Consistent with the social order of the time, the large plantations had a male-dominant all-white management hierarchy. Jung (2006) suggests that the business oligarchy in interwar Hawaii actively discouraged the middle class ambitions of Hawaii's non-white communities to maximize the number of potential plantation laborers. However, the AHPC research program apparently had a more liberal social outlook because Helene Morita, B.S., Assistant Nematologist, was among the staff in 1926-27. This probably reflected the fact that the University of Hawaii, as a public university, endeavored to uphold "democratic principles within the University" regarding race (Kamins and Potter, 1998). By 1929-30 the professional staff was remarkably diverse in terms of ethnicity as well as sex and included Morita; Assistant Physiologists Beatrice Krauss, B.S., and Eichi Masunaga, B.S.; Shizuo Harada, B.S., Assistant; Mary Kann, B.S., Assistant Pathologist; and Carl A. Farden, B.S., Assistant Chemist; Farden was an ethnic Hawaiian. The senior scientific staff also supported the University of Hawaii's College of Agriculture by teaching classes and serving on graduate thesis committees.

An important innovation developed by Charles F. Eckart of the HSPA in 1914 was asphalt-impregnated paper mulch for weed control. John Whitmore of the HPC saw the value of the mulch, which increased pineapple plant growth rates, whereas yields were 22.4 to 33.7 t·ha⁻¹ (10 to 15 tons/acre) greater (Hawkins, 2011). HPC bought the rights to the mulch for \$50,000 and patented its use for

pineapple and the application of the mulch was soon mechanized (Lyon, 1922). By 1932, HPC had collected royalties on the patent from other Hawaii pineapple growers totaling \$735,186 and James Dole considered this one of his more valuable contributions to the company (Larsen and Marks, 2010, p. 188). Paper mulch was eventually superseded by plastic and all pineapples grown by plantations in Hawaii were and are planted through mulch. In addition to helping to control weeds, the soil temperature was higher under the mulch. Planting was seasonal, mostly in the fall, so raising soil temperatures during the cooler months of the year resulted in large increases in plant growth (Auchter, 1951).

As the industry grew in size, innovations in the cannery were essential to increased cannery throughput and reduced labor costs. A major advance resulted when HPC hired Henry Ginaca in 1911 and charged him with developing a machine that produced fruit cylinders at a much higher rate. While developing the final model of the improved machine, Ginaca patented 11 innovations, all of which were assigned to HPC. By 1913 the improved machine could process up to 100 fruits per minute (Hawkins, 2011) and by 1918, HPC was selling Ginaca machines to processors for between \$3500 and \$4200 (Larsen and Marks, 2010, p. 92).

HPC became the largest pineapple producer in the world when the company purchased most of the island of Lanai in 1923. Fruit produced there was barged to Honolulu for processing. By 1931, pineapple production exceeded 12 million cases as a result of both expansion and improvements in productivity. Cases per hectare had increased from 277 in 1921 to 389 where it remained until 1949 (Figs. 1-2). The total area devoted to pineapple production peaked at 36,032 ha (89,000 acres) in 1936 (Hawkins, 2011) and when data were again available in 1947, the area in pineapple had decreased by 8097 ha (Fig. 2). However, the decline in planted area was more than offset by increased yields. As a result of improvements made by the industry and its successful research program, productivity had increased to 500 cases/ha in 1949.

Early in the 20th century significant quantities of canned pineapple were being produced outside of Hawaii, mostly in British Malaya. In 1911 over 700,000 cases were packed in Singapore, a pack similar in size to that of the Hawaii industry of the time. However, most of the pack went to the United Kingdom. By 1940 Japanese canners in Taiwan packed over two million cases but only a small fraction entered the United States (Hawkins, 1989). In-shippments of canned pineapple from foreign sources to the United States were small during the first 30 years of the industry and averaged only 70,000 cases between 1924 and 1927, whereas more than eight million cases were shipped in annually from Hawaii (Hawkins, 2011). By 1940, ≈15% of the canned pineapple sold in the United States was produced outside of Hawaii (Hawkins, 2011). However, between 1930 and

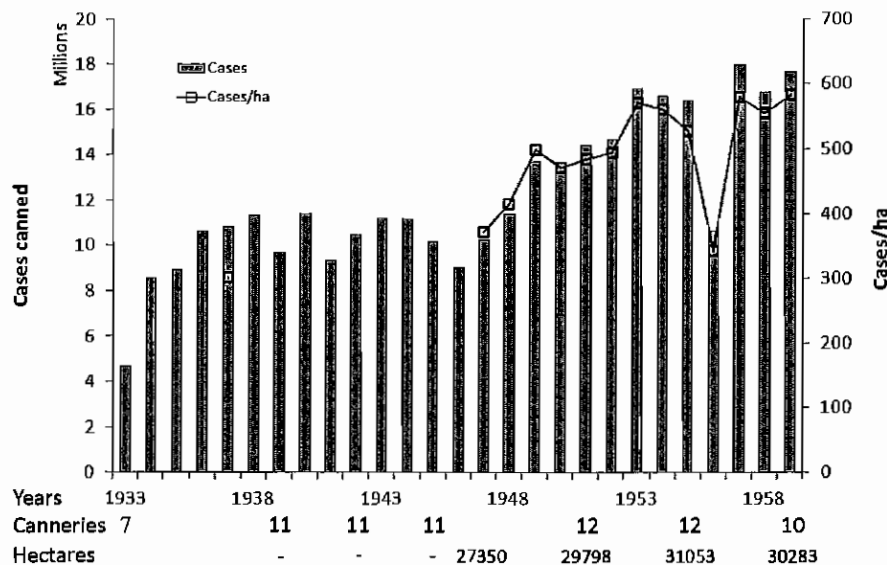


Fig. 2. Cases of pineapple canned and cases per hectare and selected data on canneries and, when available, land area planted to pineapple in Hawaii from 1933 to 1959 (Auehter, 1951; Larsen and Marks, 2010). Dashes indicate no data available.

1940, no foreign pineapple canner posed a serious threat to the dominant position held by Hawaii canners in the U.S. marketplace.

The world depression that began in 1929 did not seriously impact the Hawaii pineapple industry until 1931 (Hawkins, 1989). By 1932, mostly as a result of severe financial difficulties caused as a result of selling canned pineapple at a loss, cases produced plummeted (Fig. 1). HPC became financially overextended and, under pressure from its board to reorganize, James Dole, a pinnacle of the industry for over 30 years, was forced to resign as president of the company in 1932. The AHPC was superseded in 1933 by the Pineapple Producers Cooperative Association (PPCA). The PPCA was replaced by the Pineapple Growers Association of Hawaii in 1944 and that organization survived until early in the 21st century. The Pineapple Research Institute of Hawaii (PRI) was a department of the PPCA until 1944 when it was established as a separate industry-funded non-profit research institute (Auehter, 1951).

The PPCA incorporated the additional function of a production pool or cartel that controlled the output and marketing of canned pineapples (Hawkins, 1989); legal advice obtained in the late 1930s suggested the cartel was illegal. In addition to controlling supply, the PPCA embarked on an extensive marketing campaign that specifically targeted the upper segment of the American market for food products (Hawkins, 2009). In November of 1932, the PPCA launched a \$1 million marketing campaign. That was followed by additional advertising campaigns in 1933 and 1934. By 1934, exports to the U.S. mainland had recovered to 12 million cases (Hawkins, 1989; note that there is not always correspondence between production and exports).

The recovery of the Hawaii pineapple industry was also aided when the HPC developed the technology to produce a high-quality

pineapple juice. Juice production increased from 6,000 cases in 1933 to 700,000 in 1934 and had reached 7.5 million cases by 1936 (Hawkins, 1989). Juice production provided an outlet for the overproduction of fruit and significantly increased industry profitability (Hawkins, 1989). By 1941, juice exports reached a pre-war peak of 13.2 million cases, whereas industry receipts increased from \$1000 in 1933 to \$21.3 million in 1941.

During the period from \approx 1925 through 1940, innovations in the Hawaiian pineapple industry developed by individual companies or by their cooperative research organization led to a high degree of mechanization on the plantations and in the canneries. The major innovations included the laying of mulch paper by machines that also injected fumigant. Iron chlorosis was controlled by bi-weekly sprays of iron sulphate solution using boom sprayers, some with double booms that covered blocks 121 m (300 ft) wide (Larsen and Marks, 2010). Ammonium sulphate was used quite widely as a sidedressing by 1912, but other improvements in fertilization practices also occurred on individual plantations. However, Auehter (1951) found no published records of how such improvements were adopted over the years. Zinc was found to be lacking in soils in some areas and was eliminated, either by soil application of zinc sulphate or by a foliar spray that included zinc. Plant calcium deficiency was also identified and rectified by liming, mainly to supply lime rather than to increase soil pH. Adjustment of soil pH was not practiced because pH levels below 5.0 helped suppress *Phytophthora* sp. root and heart rot. Although iron was already being applied as a foliar spray, most other fertilizers were applied to the soil or into the plant leaf axils. In the early 1930s, researchers at the PPCA discovered that plants responded more quickly to sprays of dilute liquid nutrient solutions than to dry

applications (Auehter, 1951) and that discovery eventually led to the foliar application of nitrogen with iron sulphate. The concept of crop logging for the measurement of plant growth and assessment of plant nutrient status was introduced in the 1940s (Nightingale, 1942a, 1942b) and was in widespread use by the 1950s (Sanford, 1962). By the 1950s, all the large plantations were applying foliar sprays that included iron sulphate and nitrogen, usually as urea, at biweekly intervals.

The technique of forced induction of flowering of pineapple using smoke was accidentally discovered in the latter part of the 19th century in the Azores Islands where pineapples were being grown in greenhouses (Collins, 1960). Rodriguez (1932) found that the active ingredient in smoke was ethylene and a technique was developed for its application to pineapple (Kerns and Collins, 1937). Later research showed that 1-naphthaleneacetic acid could also force pineapple (Clark and Kerus, 1942). However, forced induction of flowering, which peaked harvests and increased labor productivity, did not come into widespread use until after World War II (WWII). Now forced flowering is an essential cultural practice in the production of fresh pineapple because it allows fruit to be produced throughout the year.

Pesticide use also expanded after the war, resulting in improved control of mealybugs, nematodes, and weeds. Soil fumigation was used to control root knot and reniform nematodes, initially with chloropicrin (Johnson and Godfrey, 1932), later with a mixture of 1,3-dichloropropene-1,2-dichloropropane (Carter, 1943), and still later with ethylene dibromide (EDB) and dibromochloropropane (DBCP). Fumigation preserved the mother-plant root system, making the harvesting of a second or ratoon crop from the mother plant a viable option and a common practice. Up to three ratoons could be harvested before the plants were destroyed by disking, after which fields were prepared for replanting. Multiple passes with the disk were essential for the complete destruction of plants. Incomplete destruction, particularly of the desiccation-resistant pineapple stems, resulted in pineapple becoming a serious weed pest in succeeding crops.

EDB and DBCP were particularly valuable for post-planting control of nematodes. With the adoption of fumigation to control nematodes, retention of a volatile fumigant was an additional important benefit of paper, and later plastic, mulch. Another benefit of mulch was improved water distribution (Ekern, 1964), which helped speed plant establishment. Insecticides were used to control mealybugs, the most important insect pest of pineapple in Hawaii, or the ants that protected them.

Pesticides were not without their problems. After a number of years of use, it was discovered that EDB and DBCP did not readily degrade in soil and gradually percolated to groundwater. That contamination resulted in the need to use activated carbon filters to clean up water supplied to the new

town of Mililani, which was being developed by Castle and Cooke on lands formerly planted to pineapple. A large DBCP spill at Del Monte (Calpak was renamed Del Monte in 1967) required major remediation (EPA, 2011; Oki and Giambelluca, 1987). Another pesticide contamination problem that garnered national publicity was the discovery that milk from cows and nursing mothers was contaminated with above-tolerance levels of heptachlor, a persistent chlorinated hydrocarbon insecticide applied to pineapple for ant control (Larsen and Marks, 2010, p. 330; Smith, 1982). The heptachlor in the milk came from green-chopped pineapple fed to dairy cattle. Residue analysis of pineapple leaves showed there was no detectable heptachlor in that tissue. However, the company that produced the green-chopped pineapple saw an opportunity to increase yields by lowering the cutting head to also chop the stems. Later analysis showed that the source of the heptachlor in milk was from an accumulation of the insecticide in the leaf axils adjacent to the stem.

Planting was done by hand, as it still is for the most part, although Larsen and Marks (2010) enumerate multiple efforts to develop pineapple planting machines, some of almost unbelievable complexity. These machines were in use for a few years, but all had shortcomings that caused them to eventually end up in plantation "bone yards." Fruit was being harvested into lug boxes that were loaded onto trucks for transport to the cannery until near the end of WWII. In 1944, MPC developed a conveyor boom that transported fruits picked by workers to bins on a truck (Larsen and Marks, 2010). That and other innovations that took place in the industry increased worker productivity and likely helped keep the price of canned pineapple within the range of that for canned peaches, the main competitor of Hawaiian canned pineapple in U.S. markets (Hawkins, 2011). Up through \approx 1960, the Hawaiian pineapple industry set the world standards for pineapple culture, processing, quality control, and marketing. As the pineapple canning industry expanded outside of Hawaii after WWII, much of the technology developed in Hawaii was adopted by foreign producers of canned product.

Interest in overseas expansion of the pineapple industry began in 1913 when HPC explored possibilities in various parts of the world. These early explorations and a later trial in Fiji in 1929 were subsequently abandoned and the company did not establish a successful overseas plantation until the early 1960s. A trial begun by LML in Kenya in 1930 was also later abandoned (Hawkins, 2011). Calpak was the first Hawaii company to establish a foreign plantation, which Hawkins (2011) suggests was because of the lack of land for expansion in Hawaii. However, Ten Bruggencate (2004), a LML manager for many years, asserts that HPC, Calpak, and LML explored options overseas because of the devastating mealybug wilt. Once methods were developed to control the wilt, initial

attempts to establish foreign ventures ceased. Only Calpak persisted in its efforts to establish an overseas plantation and began with exploratory plantings in Mindanao in 1925. A suitable site eventually was located in Bukidnon, Philippines, at an elevation of \approx 600 m. The climate was similar to, but wetter than, the area around Wahiawa, HI. The Hawaiian 'Smooth Cayenne' clones grew well there and the fruit quality was comparable to that of fruits produced in Hawaii. Calpak formed the PPC in 1928 and by 1930 a cannery had been built at Bugo on the coast to process the first harvest. By 1940, production had increased to 919,000 cases (Hawkins, 2011). The PPC cannery and the well-established canning industries in British Malaya and Taiwan were all shut down or destroyed by the war.

DECLINE OF THE PINEAPPLE INDUSTRY IN HAWAII

Atherton Richards, a HPC board member, saw the potential for loss of the U.S. market to foreign competition initiated by Hawaii-based companies, principally Calpak. Richards testified as an individual in support of legislation submitted to the 1941 Hawaii legislature that would ban the export of pineapple planting material that could be used to start plantations in the Philippines or South America (Larsen and Marks, 2010, p. 201). The bill passed the legislature but was killed by Governor Poindexter's pocket veto. Then WWII intervened and the status quo was maintained until after the war.

The production of Hawaiian canned pineapple was sustained throughout the war (Fig. 2) but finding sufficient labor to keep the industry going was difficult because 30% or more of the workers in the industry left for the military or for defense industry jobs (Auchter, 1951). After the war, the PPC was restarted. HPC made unsuccessful forays into Cuba in 1947 and Mexico in 1948 (Larsen and Marks, 2010, p. 208), but the land area in pineapple also grew at home (Fig. 2).

Foreshadowing of the decline of the industry began in the 1960s, mainly as a result of competition from canned packs produced in the Philippines and Thailand. By 1950, PPC had recovered to the extent that more of the Pineapple Growers Association fruit allocation to Calpak came from the Philippines than from Hawaii. Production was also growing elsewhere with 3.82 million cases produced in 1950 in Taiwan, Malaya/Singapore, Okinawa, South Africa, Australia, Côte d'Ivoire, and "all other" areas; by 1969, production in those countries totaled 24.1 million cases, whereas Hawaii's production had only increased from 11.95 to 12.85 million cases (Anonymous, 1972). The report (Anonymous, 1972) also noted that labor represented half of Hawaii's cost of production and that Hawaii's hourly labor costs ranged from \$2.64 to \$3.69, whereas the labor cost for growers in the Philippines and Taiwan ranged from \$0.08 to \$0.24 per hour.

Shipping and labor strikes in 1971 highlighted the competitive problems confronting the Hawaii pineapple industry and Malcolm McNaughton, president of Castle and Cooke, spoke pessimistically about the future of corporate agriculture in Hawaii (Larsen and Marks, 2010, p. 500).

Several of the smaller Kauai and Maui pineapple companies closed in the late 1960s and in 1969, HFP on Kauai, the last cannery remaining there, announced plans to cease planting in 1969. The cannery was closed in Oct. 1973. In Apr. 1973, the U.S. Tariff Commission received a petition from Local 142 of the International Longshore and Warehouse Union requesting assistance on behalf of the workers on the presumption that Stokely-Van Camp Inc., the sole marketer of HFP pineapple, was importing pineapple into the United States in quantities that caused unemployment or underemployment of union workers. The Commission succinctly summed up the competitive issues confronting the Hawaii pineapple industry in their findings. These included shipping costs from Hawaii to the mainland that exceeded the costs from the Philippines and Thailand as a result of the Jones Act, the termination of regular ocean shipping service to Gulf and East Coast ports in 1968, and price competition from domestic fruits and juices. However, the Commission found that the primary factor contributing to the higher cost of Hawaiian canned pineapple was unit labor costs, which accounted for half of production costs and were 90% greater in 1972 than they had been in 1960 (Larsen and Marks, 2010, p. 429–430). Larsen and Marks (2010, p. 430) also noted that land costs were high in Hawaii and observed that a 0.5% gross income tax on products and the cost of pineapple research also contributed to the higher costs in the Hawaii industry.

Although some were pessimistic about the future of pineapple in Hawaii, MPC set new profit records between 1976 and 1984 (Larsen and Marks, 2010, p. 204). During those years, only the fresh fruit segment of the industry experienced growth (Fig. 3). As the Hawaii industry declined, expansion overseas by Hawaii companies continued as Castle and Cooke established a plantation and cannery, DoleFil, in 1964 in the Cotabato area of Mindanao. By the mid-1980s DoleFil was producing 202,429 t of pineapple with 26,315 t marketed fresh in Japan (Larsen and Marks, 2010, p. 636). However, the Hawaii pineapple industry was not the only one to decline. Industrialization in Taiwan eliminated that country as a significant competitor by 1980 (Table 1), but the development of the 33,000-ha PT Great Giant Pineapple Co. (PTGG) plantation in Sumatra in 1979 introduced another large and low-cost competitor. MPC (renamed Maui Land and Pineapple Co. in 1969 as more resources were committed to resort development) formed a strategic alliance with, and provided advice to, PTGG as it developed. In return, PTGG provided MPC with low-cost canned pineapple, thus providing MPC access to the non-premium

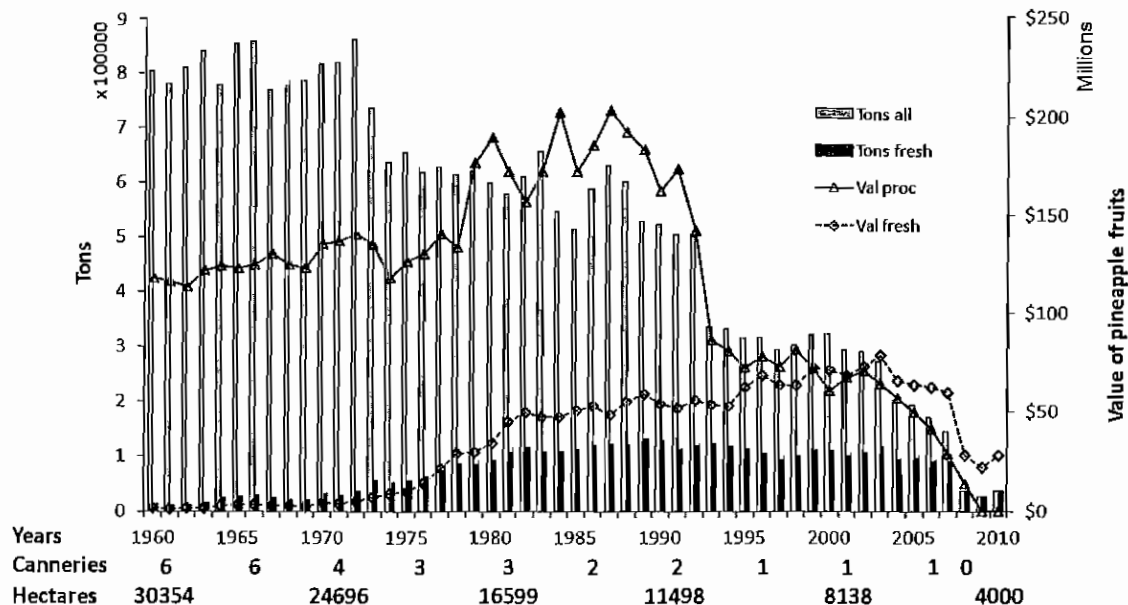


Fig. 3. Total tons pineapple produced in Hawaii (Tons-all), tons sold fresh (Tons fresh), farm gate value of pineapple sold, value of tons sold fresh, and selected data on canneries and land in pineapple. (Anonymous, 1961–1997; Hidano and Nakasono, 2007; Martin and Osaki, 1998–2006; values from 2008 to 2010 are the authors' best estimates.)

Table 1. Percentage of world production of canned (C) and canned plus fresh (CF) pineapples exported from countries that produced 10 or more percent of either category for the period shown (data from Ten Bruggencate, 2004).

Location	1942		1950		1960		1970		1980		1990		2000	
	C	CF	C	CF	C	CF	C	CF	C	CF	C	CF	C	CF
Hawaii	83	83	74	51	55	36	37	16	16	6	1	5	0	2
Philippines	War	War	4	4	7	5	10	4	22	9	19	10	25	11
Thailand	0	0	0	0	6	9	10	4	32	34	43	17	44	17
Taiwan	8	8	5	3	9	6	10	5	4	—	—	—	—	—
Indonesia	0	0	0	0	0	0	4	1	5	2	5	3	13	3

canned pineapple market (Larsen and Marks, 2010, p. 516).

Hawaii companies continued to expand overseas with DM purchasing Kenya Canners Ltd. in 1968. In 1972, Castle and Cooke purchased a small canning company near Hua Hin, Thailand. A few years after the purchase, the Dole plantation had reduced pineapple production in Hawaii from 522,727 to 318,181 t by reducing production at Wahiawa and Lanai. By 1991, only two canneries remained and the area in pineapple had also decreased (Fig. 3). When Castle and Cooke closed the Lanai plantation in 1992, the land in pineapple dropped further. By 1992 DoleThai was operating the third largest pineapple cannery in the world with PPC ranked first and DoleFil second (Larsen and Marks, 2010, p. 647).

As the cannery business was becoming less profitable, there was a gradual shift to fresh fruit production (Fig. 3), which about coincided with greatly expanded consumption of fresh fruits and vegetables in the developed world. Unlike most fruits grown in Hawaii, no quarantine restrictions were placed on fresh pineapple fruits imported into the U.S. mainland because cultivars with 50% or more 'Smooth Cayenne' parentage were not fruit fly hosts (Armstrong et al., 1979). However,

as long as pineapples were still being canned, only 'Smooth Cayenne' fruits were shipped fresh out of Hawaii. It had long been recognized that 'Smooth Cayenne' was not the ideal fresh fruit because quality was poor in the winter as a result of high fruit acidity (Gortner et al., 1963). The few alternative cultivars, but primarily 'Queen', had small fruits, low yields, spiny leaves, and were prone to internal browning when refrigerated. However, as long as the canneries remained in operation, the plantation grew fruit for the cannery and the fresh market was a small side business. As the canneries closed, Dole and DM shifted to the production of fresh fruit. From 1960 until 2007, there was a gradual decline in tons of fruit produced and, coincidentally, a gradual increase in the proportion of tons of fruit sold fresh (Fig. 3). After MPC closed its cannery in 2007, all fruit produced was sold fresh. The early increases in fresh pineapple shipments from Hawaii were based entirely on 'Smooth Cayenne' clones, but that all changed after 1996.

GLOBAL RISE OF FRESH 'MD-2' PINEAPPLE PRODUCTION

The lack of good-quality fresh fruit cultivars that were also capable of producing high

yields was at least in part the result of an industry focus on 'Smooth Cayenne' fruit. The poor quality of 'Smooth Cayenne' fruit produced in the winter was not a problem for the cannery because most of the fruit destined for processing was harvested during the summer when fruit quality was best and seasonal labor was more readily available. The industry focus on canning directed the PRI pineapple breeding program (Williams and Fleisch, 1993), which even in 1964 had as its primary objective the development of cultivars suitable for canning that would out-yield 'Smooth Cayenne' (Johannessen and Kerns, 1964). Breeding of new pineapple cultivars is difficult because parents are highly heterozygous, self-incompatibility prevents the development of inbreds, and selection involves a multiplicity of characteristics (Williams and Fleisch, 1993). As a result of the poor success of the PRI pineapple breeding program, no crosses were made after 1972, the PRI physical plant was closed in 1975, and the remaining seedlings were shipped to Maui for further evaluation (Williams and Fleisch, 1993).

Castle and Cooke left the PRI in 1971 and received a 60% share of those seedlings. The remaining seedlings were jointly owned by MPC and DM, and the best selections were distributed to the two companies in ~1980. In the late 1970s, DM established a plantation in Costa Rica to provide a source of fresh fruit for the eastern United States and Europe. The company's 'Smooth Cayenne' clone, Champa 153, did not perform satisfactorily in the Costa Rican environment. In the mid-1980s DM shipped plants of PRI hybrid 73-114, named 'MD-2' after manager Frank Dillard's wife Millie, from Hawaii to Costa Rica (Bartholomew, 2009). The hybrid grew well in the Costa Rican environment and test marketing showed it to be preferred by consumers.

'MD-2' pineapples, trademarked Del Monte Gold, were officially introduced to U.S. and European markets in 1996. Del Monte was purchased by R.J. Reynolds in 1979 and the fresh fruit business was sold in 1989 by what was then RJR Nabisco and renamed Fresh Del Monte Produce (FDMP). By 2002, FDMP's pineapple sales, presumably all 'MD-2', had grown to over \$400 million and boxes of the fruit sold for a premium in the European and U.S. markets (Frank, 2003). By early 2000, 'MD-2' fruit had almost completely replaced 'Smooth Cayenne' in the rapidly growing markets for fresh pineapples in the United States and Europe and devastated the 'Smooth Cayenne'-based fresh pineapple industries of Ghana and Côte d'Ivoire (Bartholomew, 2009).

In 2010, the 'MD-2' pineapple was named the American Society for Horticultural Science's 2010 Outstanding Fruit Cultivar (Anonymous, 2010). 'MD-2' was one of only two commercially successful pineapple cultivars produced by the world's largest pineapple breeding program. The other cultivar, PRI hybrid 73-50, named 'MD-1' by DM, was later patented by DM as 'CO-2' (Bartholomew et al., 2010). Both 'MD-2' and 'CO-2' have slightly higher Brix than 'Smooth Cayenne', but their superiority as fresh fruits was the result of significantly lower acidity, especially during winter, and greatly improved storability. 'Smooth Cayenne' fruits develop quite severe internal browning, a chilling injury, when refrigerated, a defect that is not present in 'MD-2', and 'CO-2' is much less susceptible to the disorder than is 'Smooth Cayenne'. 'CO-2' achieved some success at MPC as Maui Gold® and is also grown by Dole (Castle Cooke was renamed Dole Food Company, Inc. in 1991) on Oahu and in the Philippines. The hybrid also is one of the main fresh fruit cultivars in Australia (G. Sanewski, personal communication).

With the success of 'MD-2' assured, FDMP began to rapidly convert their Hawaii plantation to 'MD-2' by importing planting material from Costa Rica to Hawaii in 2001. The Hawaii division shipped fresh and fresh-cut fruit to the U.S. West Coast until FDMP abruptly closed the plantation in 2007. The Dole division in Hawaii introduced a low-acid pineapple in early 2000 but the quality was poor and it was replaced as quickly as possible with a Dole selection of 'MD-2' named MG3. 'MD-2' planting material became widely available after the "pineapple war" over rights to the cultivar were resolved (Frank, 2003; Greig, 2004; Janick, 2003). As a result of the market shift from 'Smooth Cayenne' to 'MD-2', independent growers in Ghana and the Ivory Coast quite rapidly abandoned 'Smooth Cayenne' and rapidly expanded the area planted to 'MD-2' as did independent growers in Costa Rica, Ecuador, and the Philippines. As a result of this rapid expansion in the supply of 'MD-2' fruits, fresh pineapple has become cheaper, resulting in "heterogeneous quality" (Loeillet et al., 2011).

The pineapple business of MPC closed in 2009 and a new company, Maui Gold

Pineapple Co., began growing Maui Gold® ('CO-2') in 2010 on ≈400 ha of land leased from Maui Land and Pineapple Co. The newly formed corporation hopes its flatter organizational structure will help assure its success. Dole continues to grow fresh fruit on Oahu, primarily for the Oahu and tourist markets with ≈15% of their pack going to West Coast markets when shortages in the company's Central American supply occur.

The industry that dominated the U.S. canned pineapple market for 60 years now exists primarily to supply local markets with fresh pineapples and to keep lands owned by Maui Land and Pineapple Company and Dole Food Company in agriculture to take advantage of the favorable tax base such lands enjoy. The industry grew and survived as a result of innovations in culture, mechanization of production in the field and cannery, a focus on product quality, and market-leading advertising campaigns. The circumstances that brought about the fall of the Hawaii industry are no different from those that have caused the demise of many industries in developed countries. The globalization of the international economy allowed companies in developed countries to relocate production to developing countries to take advantage of lower labor costs together with cheaper resources such as land and water. The systematic reduction of tariffs by developed countries since WWII accentuated this trend.

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The Papaya in Hawai'i

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Abstract. Dioecious papayas were introduced shortly after Cook's 1778 discovery of Hawai'i but were supplanted for commercial uses by the gynodioecious solo papaya brought from the Caribbean in 1911. Growth of a local papaya industry based on hermaphrodite plants was enabled by research allowing prediction of seedling sex segregation and by development of cultivars with high quality, symmetrical fruits free of stamen carpelody, and carpel abortion. The industry expanded into export markets after 1940 by providing an alternative use for land and expertise abandoned by declining sugar plantations, adopting a cultivar capable of tolerating long-distance shipping, developing postharvest technology to overcome fruit fly quarantine restrictions, capitalizing on a growing tourism industry for marketing and air freight logistics, and forming an organization to support industry growth. In recent years, the industry has withstood pest and disease challenges by adopting innovative technologies that have allowed high-quality solo papayas to continue to participate in an increasingly competitive export market.

The papaya (*Carica papaya*) is a member of the Caricaceae, which consists of five New World genera and one African genus. In 2000, the genus *Carica* was split to better reflect molecular and morphological differences between a group of ≈21 predominantly South American species, now assigned to genus *Vasconcellea*, and the single remaining *Carica* species, *C. papaya*, which has a native range restricted to Central America (Badillo, 2000, 2001). Although there is at least one Peruvian archaeological ceramic pot from ≈300 CE (Common Era) that is said to resemble (not very convincingly) a papaya fruit (Wikimedia Commons, 2009), the homeland of the typical wild papaya is limited to the region extending from southern Mexico to perhaps as far south as northern Costa Rica (Manshardt and Zee, 1994). Wild papayas are dioecious, and the fruits borne on pistillate plants are small (less than 100 g) and seedy with very little edible flesh. Human selection for self-pollinating hermaphrodite mutations and larger fruit size has produced gynodioecious cultivars and genotypes that yield succulent fleshy fruits weighing as much as several kilograms. Fruit quality varies considerably within the species, and many genotypes have fruits with low total soluble solids (TSS) and/or objectionable flavor or texture. However, all papayas are predisposed to travel, because they are derived from opportunistic wild types that are pioneer species in disturbed habitats (Bartlett, 1937; Lundell, 1936). Characteristics that have facilitated the rapid movement of papaya around the tropical regions of the world include their

continuous bearing habit, the attractive and abundant fruits, and plentiful seeds of long viability.

EARLY HISTORY IN HAWAII

Arrival and characteristics. Papaya is a relatively recent introduction in Hawai'i. Its arrival is usually dated at ≈1820 and attributed to Don Francisco de Paula Marin, the Spanish adventurer turned horticulturist who was given land on O'ahu in payment for services rendered to Kamehameha I. However, many crop introductions connected with this legendary figure are poorly documented. For 250 years (1550–1800) before Don Marin's activities, the Spanish court had operated a lucrative trade route between Acapulco, Mexico, and Manila in the Philippines (Hayes, 2001). Although there is no record of contact with Hawai'i during that period, legends of visitors arriving in Hawai'i in large boats before Captain Cook (1778) suggest that there may have been opportunity for earlier introductions (Kane, 1996). Regardless of which Spaniard made the initial introduction, the first papayas were probably large-fruited dioecious types from the west coast of Mexico. These are the types commonly illustrated in Hawaiian publications from the early 1900s, among which was the important bulletin entitled "The Papaya in Hawai'i," authored by J. Edgar Higgins and Valentine Holt, horticulturists at the Hawai'i Agricultural Experiment Station (HAES) in Honolulu in 1914. They noted that dioecious papayas were more common than gynodioecious and that there were no real papaya cultivars in Hawai'i in the sense that seed could not be depended on to yield plants with predictable characteristics.

The prevailing notion at that time in Hawai'i was that papaya fruits were fit only for hog feed (Crawford, 1937), but there existed sufficient demand for the fruit on the U.S. mainland to merit investigation of export potential. Higgins and Holt described successful shipping experiments of color-break fruit under refrigeration to Portland, Seattle, and Vancouver and indicated that the

long cylindrical shape of the hermaphrodite fruits was better for packing in single-tier wooden crates than the more spherical fruit shape of pistillate plants. Interestingly, even at this early stage of export development, shipments to California were restricted as a result of Mediterranean fruit fly quarantine! Fields planted with gynodioecious lines were also noted to be more productive than those planted with dioecious lines, because nearly every tree produced fruit as a result of the absence of male plants. Consequently, Higgins and Holt bent their efforts toward selecting improved gynodioecious lines, beginning a trend that eventually displaced dioecious papayas from commercial fields.

The solo papaya. Three years before Higgins and Holt published their papaya research, an event happened that would accelerate the trend toward gynodioecious cultivars and determine the future of the papaya industry in Hawai'i. In 1911, Gerrit P. Wilder, a scion of an old *kama'aina* family and an amateur horticulturist, who later was appointed botanist at the Bishop Museum in Honolulu (University of Hawai'i at Mānoa, Botany Department, 2012), collected seeds of a single small papaya from Barbados in the Caribbean and brought it back to Hawai'i (Storey, 1941). This was the introduction of the solo papaya, a small-fruited, high-quality gynodioecious line, the descendants of which, over the subsequent 25 years, accomplished Higgins and Holt's objective of replacing the dioecious types originally introduced into Hawai'i in the 1800s. Today, dioecious lines are rare under cultivation but still exist because feral populations escaped from agriculture in numerous locations in the islands such as Kualoa Beach Park on Kāne'ohe Bay, O'ahu, and in the region around Captain Cook above Kealahou Bay in the South Kona District of Hawai'i Island.

Solo is not the name of a specific cultivar; rather, it refers to the general class of export-quality, gynodioecious papayas having pear-shaped fruits weighing ≈450 to 675 g, yellow or red flesh color, TSS in the 12% to 15% range, and superior flavor characteristics. The name was given by J.E. Higgins (HAES, 1920) and was said to derive from HAES

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personnel of Puerto Rican descent, who differentiated the small-fruited papayas that could be consumed by a single person (solo) from the large "watermelon" types that could feed a group. Small fruit size was as important as the excellent flavor and texture traits in establishing the solo as the export standard, because it kept the cost of individual fruits, sold on a cost/lb basis, acceptable in mainland U.S. markets.

Genetics of sex determination. With the adoption of gynodioecious solo lines as the preferred commercial production model came several significant production problems. The occurrence of both pistillate and hermaphrodite sexes among seedling progenies of gynodioecious lines and the inability to distinguish these using purely vegetative characters led growers to question how to establish a field of seedlings with the maximum number of commercially desirable hermaphrodite plants.

The phenomenon of sex segregation in papaya had been noted by all early researchers, including Higgins and Holt (1914), Earley V. Wilcox (1916), and Willard Pope (1930), who published "Papaya Culture in Hawai'i". However, it was William B. Storey who first provided experimental evidence to explain papaya sex segregation. Storey was born in Hawai'i and was educated at Cornell University. He returned to become a horticulturist at the University of Hawai'i (UH). Over a period of 10 years from 1936 to 1945, Storey (1938b) and J.D.J. Hofmeyr (1938), who worked independently on the same topic in South Africa, published a series of articles that showed that sex segregation was controlled by a single Mendelian locus with three alleles (Table 1). The male and hermaphrodite states are determined by different dominant alleles (M_m and M_h , respectively), and these sexes are genetically heterozygous, sharing the locus with the recessive allele (m) that in homozygous condition determines the female state. A sex-linked lethal gene prevents the formation of homozygous M_m/M_m or M_h/M_h , or M_m/M_h genotypes. With this genetic model, Storey worked out the expected segregation ratios for various matings of the different sexes. The theoretical sex segregation ratios allowed efficient and predictable establishment of commercial papaya

Table 1. Single-locus model with multiple alleles for sex determination in papaya (Storey, 1941).

Scheme for sex determination in *Carica papaya*

M_1 = dominant factor for maleness
 M_2 = dominant factor for hermaphroditism
 m = recessive factor for femaleness

M_1m = the male or staminate tree; form D
 M_2m = the hermaphrodite tree; forms B and C
 mm = the female or pistillate tree; form A

1. $mm \times M_1m \rightarrow 1 mm : 1 M_1m$
2. $mm \times M_2m \rightarrow 1 mm : 1 M_2m$
3. M_1m selfed $\rightarrow 1 mm : 2 M_1m : (1 M_1M_1)$
4. M_2m selfed $\rightarrow 1 mm : 2 M_2m : (1 M_2M_2)$
5. $M_2m \times M_2m \rightarrow 1 mm : 2 M_2m : (1 M_2M_2)$
6. $M_2m \times M_1m \rightarrow 1 mm : 1 M_2m : 1 M_1m : (1 M_2M_1)$

fields based on calculations of the minimum number of seedlings required per planting hole to achieve any desired probability of sex uniformity in the field (Jones and Storey, 1941). The standard planting procedure now involves planting each hole with three seedlings from a self-pollinated hermaphrodite parent followed several months later at flowering time by roguing of females and extra hermaphrodites to yield a field with hermaphrodites in $\approx 96\%$ of the holes.

Fruit carpelody. A second production problem that accompanied the commercial exploitation of gynodioecious lines was the sensitivity of many hermaphrodite genotypes to fruit deformity caused by stamen carpelody. This is a genetic proclivity affecting floral development in hermaphrodites such that stamens become carpel-like and attach to the ovary in irregular or occasionally symmetrical lobes (Storey, 1938a, 1941), particularly during the cool, wet season. This causes distorted growth resulting in production of unattractive and unmarketable fruit. The opposite tendency toward abortion of carpels from the ovary in some hermaphrodite genotypes results in fruits with mango or banana shapes or total loss of the ovary leading to unproductive zones in the fruit column. Carpel abortion is usually most pronounced under warm, dry conditions. These environmental influences on fruit morphology are unique to hermaphrodites, but the tendencies are under genetic control, and it is possible to select effectively against these negative characteristics.

Early improvement objectives. An early description of papaya production in the United States, focusing primarily on Florida, listed six named cultivars there, including Hawaiian solo (Traub et al., 1942). Writing in Hawaii at the same time, Storey (1941) echoed the observations of Higgins and Holt 25 years earlier that there were no true-breeding cultivars in Hawai'i as a result of the tendency to outcross among types unless grown in isolation or intentionally self-pollinated. Named types were usually descriptive of economically important morphologies such as the small pyriform-fruited "solo" or large red-fleshed "watermelon" papayas or they were named after the farmer that produced them. Storey pointed out the desirability of a more uniform and predictable crop and set about developing such by stabilizing the genetics through inbreeding selected hermaphrodites with good fruit qualities and production characteristics. The objectives that he and subsequent breeders have generally identified for improvement included fruit weight of 450 to 675 g, high TSS in the range of 12% to 15%, good flavor and texture, minimal seasonal variation in fruit shape caused by stamen carpelody or carpel abortion, and early flowering leading to fruit production low on the trunk. Working primarily at the Waimānalo Experiment Station on windward O'ahu, he released Line 5 in 1948 and Line 8 in 1953. Line 8 is a yellow-fleshed cultivar with excellent flavor, but fruits are too soft for export. It was still grown to a limited extent on O'ahu until the early 1990s.

DEVELOPMENT OF EXPORT POTENTIAL

By the mid-1950s, papaya production reached 4.5 million kilograms annually and became the largest component of the diversified crops sector (crops other than sugar and pineapple) in terms of gross production, and it was third in value behind coffee and tomatoes (HAES, 1958). However, papaya was nearly exclusively marketed locally. The large growth in the industry over the subsequent 25 years was the result of development of export markets in North America and Japan. The shift in marketing was made possible by several advances, which overcame technical problems or allowed improvements in logistical capacity.

Fruit fly disinfection. The initial barrier to papaya shipments to California was the quarantine restriction imposed in 1914 to exclude fruit flies. Although color-break papaya fruits are not a major host for fruit flies, compliance with quarantine regulations required a disinfection procedure. An existing vapor heat treatment was modified for papaya by UH plant physiologists (Jones, 1940a), and subsequent experimental shipping and testing in mainland markets led to the first commercial shipments in 1940. That same year, methyl bromide was approved for fruit fly disinfection (Jones, 1940b) followed by ethylene dibromide (EDB) in 1951. EDB treatment became the standard disinfection method until 1984 as a result of its relative low cost and freedom from adverse effects on fruit quality.

'Kapoho' papaya. Another step in the evolution of the papaya industry toward export markets resulted from the confluence of several factors that effectively moved the major production areas from O'ahu to Hawai'i Island. Increasing urbanization and rising land values in the 1950s and 1960s, combined with repeated outbreaks of *Papaya ringspot virus* (PRSV), served to make papaya production increasingly problematic on O'ahu. The area of the state with cheap land available for agriculture was the Puna District in East Hawai'i. The chief agricultural employer of the area, Puna Sugar Company, was in decline through the 1970s and closed in 1982, gifting laid-off workers with 5-acre land parcels and creating a pool of new farmers looking for profitable crops (University of Hawai'i at Mānoa Library, Hawaiian Collection, 2006). This region became the new center of the papaya industry. Puna has abundant rainfall, well distributed throughout the year, but it is a volcanically active region with geologically young lava substrate and little soil development. It was not clear that papaya could be grown successfully under Puna conditions, but in fact a cultivar specifically adapted to Puna had been under selection in the region for several decades. Hanichi Masumoto was a farmer with land near Hilo, who requested seed from the Cooperative Extension Service to grow papayas. He was initially given "pig food" papaya seed, because the extension agent handling the request knew that Masumoto raised pigs, and he

assumed that was the intended use for the fruit. Anecdotal information suggests that Masumoto, on discovering the poor quality of the fruits, made his displeasure abundantly clear and was quickly provided with solo papaya seed, from which he gradually refined his selection. It was initially known as 'Masumoto' solo but was renamed 'Kapoho' as it became more widely planted in the Puna District (Hamilton and Ito, 1986).

'Kapoho' has several characteristics that destined it for success as the standard export cultivar from Hawai'i. Fruit quality is excellent, and it is free of carpelody and carpel abortion. 'Kapoho' fruits remain firm after harvest, which makes them well suited for packing and shipment to distant export markets. Under the high rainfall conditions in Puna, the fruit size is the preferred 450 kg, but grown anywhere else, the combination of different soil and climatic factors tend to produce very tall trees and fruits that are too small for export. For this reason, Puna is the only area of the state that can benefit from the other desirable qualities of 'Kapoho'. The combination of land availability, unique environmental conditions, and a papaya cultivar adapted to those conditions conspired to favor the Puna District as the new home of the Hawai'i papaya industry after its decline on O'ahu during the decades of the 1950s and 1960s (Loudat et al., 1987).

Tourism connection. Another factor contributing to and enabling the growth of papaya as an export crop was the concurrent development of the tourism industry in Hawai'i. In the years after World War II, increasing numbers of visitors from the mainland and later from Japan traveled to Hawai'i for their first encounter with tropical environments. Exposure to papaya in restaurants and in produce sections of local groceries amounted to free advertising for the industry and resulted in a growing demand for the fruit in temperate regions when tourists returned to their homes. Moreover, tourists increasingly arrived in the Islands by air, so that starting in the 1960s, air freight provided an alternative to sea shipment with an accompanying improvement in quality at market destinations. The growth in papaya exports from 1960 to 1986 closely tracked the increase in air traffic from the mainland to Hawai'i (Fig. 1), and in 1969, the first air shipments to Japan commenced (Loudat et al., 1987).

Cultivar development. New cultivars were developed and introduced in the 1960s and 1970s by breeders at the UH College of Tropical Agriculture and Human Resources (CTAHR). All earlier commercial releases had produced yellow- or orange-fleshed fruits, including the industry standard cultivar Kapoho. In 1963, Richard A. Hamilton and Philip Ito selected the red-fleshed cultivar Sunrise derived from a cross between the red-fleshed Line 9 and a yellow-fleshed solo breeding line called 'Kariya' (Hamilton and Ito, 1968). 'Sunrise' is a high-quality papaya with fruit weights greater than 'Kapoho' under the same growing conditions. It is free of carpelody and usually has only a brief sterile period resulting

from carpel abortion in warm weather. 'Sunrise' flesh softens to a greater extent than that of 'Kapoho' and is not as well suited for export from Hawai'i, although it became the basis of Brazil's European export industry in the 1980s and seems to be adaptable to a broader range of environments than 'Kapoho' (Hamilton and Ito, 1986). Since its release, 'Sunrise' has been popular among breeders as a parental line in the development of papaya F1 hybrid cultivars, including 'Tainung No. 2' from Taiwan and 'Exotica' from Malaysia, because of its high TSS, excellent flavor, red flesh color, and lack of carpelody. A sib line of the same parental cross was released later under the name 'Sunset', but its characteristics are very similar to 'Sunrise' (Hamilton et al., 1993). 'Sunset' has been planted extensively in Brazil and to some extent has replaced 'Sunrise' there as the chief export cultivar.

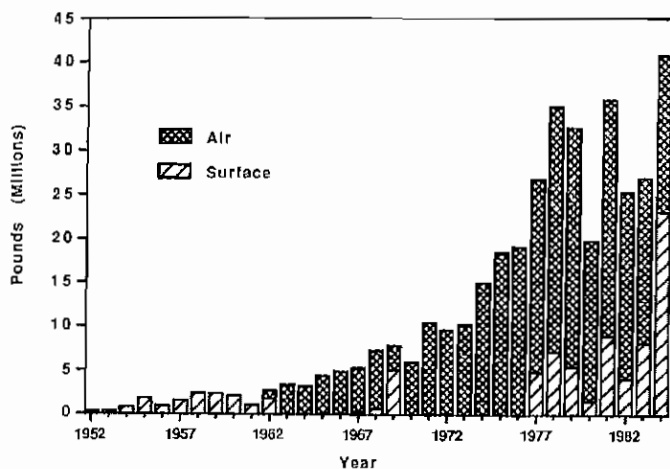
About the same time, the experimental line X-77 was released by CTAHR horticulturist Henry Y. Nakasone as the papaya cultivar Waimanalo (Nakasone et al., 1972). This cultivar was derived from a cross made in 1948 between solo Line 5 and a dwarf line from Florida called 'Betty' with the intent to create a high-quality papaya with a precocious, low-bearing habit. 'Waimanalo' produces larger yellow-fleshed fruits weighing 675 to 900 g and of a more spherical shape than 'Kapoho' or 'Sunrise'/'Sunset', and it is modestly lower-bearing than either. It is notable for its relative resistance to the serious fungal pathogen *Phytophthora palmivora* and has served as a parent in breeding programs to improve *Phytophthora* resistance in other lines. On the negative side, it has a rather narrow adaptation to conditions on windward O'ahu and tends to be subject to fruit disfigurement as a result of stamen carpelody in other locations. A selection from 'Waimanalo' called 'Kamiiya' was made by Ken Kamiiya, a farmer on O'ahu's windward coast. It is very similar to the parent line and has been popular in Honolulu markets.

PROBLEMS IN PARADISE

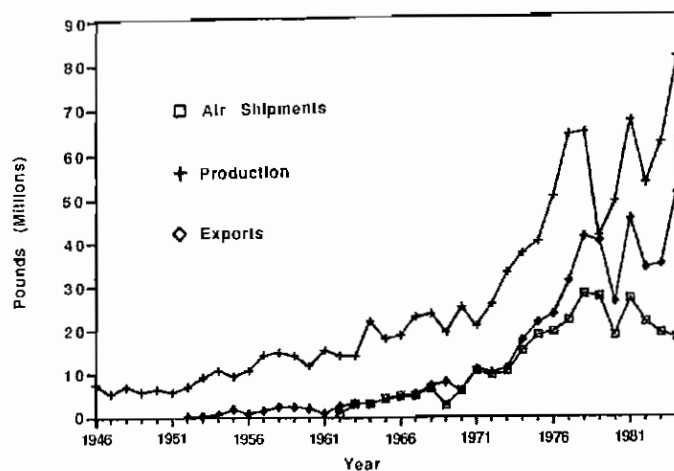
Production and postharvest problems. Production and postharvest problems with fungal diseases received attention from UH and U.S. Department of Agriculture (USDA) researchers during the 1960s. Description and identification of the major postharvest pathogens affecting papayas in shipment to mainland and Japanese markets was the work of plant pathologists at UH at Mānoa, particularly Anne Alvarez and Wayne Nishijima (1987). Stricter controls on fungicide use imposed by the Food and Drug Administration in 1963 led to the initiation of hot water dipping as a control measure for postharvest fruit rots. The hot water treatment, developed by Ernest Akamine at UH during the 1950s (Akamine and Arisumi, 1953) and uniformly implemented in the industry by 1972, was effective in controlling postharvest infections and had the added benefit that it improved the efficacy of EDB treatment for fruit fly disinfection (Loudat et al., 1987). In wet

windward production fields, *Phytophthora palmivora* and *Pythium aphanidermatum* extracted high tolls on papaya seedlings, particularly when fields were replanted repeatedly (Trujillo and Hine, 1965). This so-called "replant problem" was addressed by Wen-Ho Ko of the UH Plant Pathology Dept. Ko found that the competitive effect of the microbial flora in native soils obtained from non-agricultural areas provided effective protection in the root zone of young papaya seedlings during the critical early stages of development. His "virgin soil" technique involved placing several gallons of soil not previously used for papaya production at each planting site in the field and planting the seedlings in that (Ko, 1982). This approach was used successfully in areas without adequate land available for crop rotation. *Phytophthora* is also a serious problem on ripening fruits on the trunk, and it is controlled by frequent applications of dihydrocarbamate fungicides, which were evaluated and cleared for use with papayas in the 1970s.

In the early 1980s, the Environmental Protection Agency gave notice that the use of EDB for fruit fly disinfection would be curtailed, and this initiated a switch from chemical to physical postharvest treatments that evolved through multiple steps over several decades. The task of finding a replacement treatment to maintain exports of papaya fruit to the mainland originally fell mainly on the USDA Agricultural Research Service (ARS), Tropical Fruit and Vegetable Research Laboratory in Hilo, Hawai'i. By the federal deadline for ending EDB use in 1984, Mel Couey and coworkers had devised a "double-dip" hot water treatment that met quarantine requirements for fruit fly control. However, this procedure impaired fruit ripening, resulting in lumpy or "hard shell" fruits that failed to soften normally, particularly when harvested at less than the one-fourth-ripe maturity stage (Paull et al., 1997). Quick modifications of the double-dip procedure produced better results and a crisis was averted, but over the next decade, the double-dip procedure was replaced by a vapor heat treatment using modern equipment manufactured in Japan or by a high-temperature forced-air treatment developed by Jack Armstrong of the ARS Tropical Fruit and Vegetable Research Laboratory in Hilo and engineered by Michael Williamson at the UH Agricultural Engineering Department. Important contributions to understanding how all three heat treatments impacted fruit ripening were made by Robert Paull, Postharvest Physiologist, and Ms. Catharine Cavaletto, quality evaluation specialist, both of CTAHR (Paull et al., 1997). The vapor heat and high-temperature forced-air treatments were determined to have less negative effect on fruit quality and also heated the fruit uniformly to the central cavity rather than just the outer regions. This latter feature became crucial when it was discovered that a morphological abnormality called "blossom-end defect" made a small percentage of papaya fruits vulnerable to fruit fly oviposition directly into the central seed cavity, where



Source: Statistics of Hawaiian Agriculture 1964.



Source: Statistics of Hawaiian Agriculture 1983.

Fig. 1. Growth in papaya export shipments by air was closely linked with development of tourism industry in Hawai'i (Loudat et al., 1987).

eggs and larvae were unaffected by the double-dip treatment. Mainland exports were interrupted several times in 1987 when live fruit fly larvae were discovered in papaya shipments by California quarantine inspectors, precipitating an urgent re-examination of the quarantine protocol. Francis Zee, curator of the newly opened USDA National Clonal Germplasm Repository in Hilo, made the observation that carpels at the style end of the ovary occasionally fail to fuse completely, allowing a route for ovipositing fruit flies to bypass the double-dip treatment (Zee et al., 1989). Papaya packing houses had to undertake careful monitoring to eliminate fruits with abnormal morphology in the years leading up to 1990 when the replacement high-temperature forced-air disinfection protocols became available. During the interval, Zee produced a cross between 'Kapoho', which manifested the problem most often, and 'Sunrise', which had a more elliptical fruit shape with better carpel fusion, and offered these hybrids to the industry to reduce the probability of blossom-end defects. This marked the first use of a hybrid cultivar in Hawai'i, and the new hybrid and derived lines were used for some years by Diamond Head packing company. Vapor heat and forced-air dry-heat treatment chambers were unchallenged as disinfection protocols during the decade of the 1990s, but in 2000, a particle beam irradiator was built in Hilo by a private group, Hawai'i Pride LLC, headed by local businessman Eric Weinert and mainland investor John Clark. Staunch local opposition in the 1980s and 1990s to irradiation based on radioactive isotopes had prevented development of a disinfection facility for fresh export commodities, but concerns were finally overcome by using an X-ray machine employing a electron beam accelerator technology. The ability to turn off the beam when not in use mitigated most public concerns about the dangers of ionizing radiation that accompany radioactive sources.

Hawai'i Papaya Industry Association. The Hawai'i Papaya Industry Association

was organized in 1965 through the UH Cooperative Extension Service (CES) to provide a forum for industry communications among growers, packers, and state agencies, including the UH (Loudat et al., 1987). This goal was facilitated by annual meetings organized by UH CES and attended by growers, packers, marketers, agricultural suppliers, and researchers. The CES liaison for over 25 years was C.L. Chia, who organized meetings and edited the program proceedings for publication by the CES. The proceedings serve as a valuable historical record of the growth of the industry. A secondary goal was to provide a statewide papaya marketing cooperative to address erratic swings in production and pricing. This was achieved in 1971 by creation of the Papaya Administrative Committee (PAC), a federally authorized structure to enforce the marketing order. The PAC had the authority to levy an assessment on growers and packers, which was used to promote sales through generic marketing and occasionally to fund research on problems of high priority to the industry.

Papaya ringspot virus. Two other battles affecting the Hawai'i papaya industry were fought during the 1990s, one biological and the other political. In 1992, the perennial problem of PRSV arrived at the main production areas in Puna, ≈ 30 years after it had destroyed most of the state's production, at that time, on O'ahu. The geographical isolation that had protected production fields in eastern Puna from PRSV introduced years earlier near the city of Hilo had been breached over this time period by the growth of intervening housing developments and their associated backyard papaya plants. The damage started slowly enough, but by 1998, papaya production in Puna had dropped by 50% from levels of the late 1980s and early 1990s (National Agricultural Statistics Service, 1999). Research to solve the PRSV problem had been ongoing since the 1970s and 1980s involving screening papaya germplasm for resistant lines, using cross-protective mild-symptom virus strains (Mau

et al., 1989; Yeh and Gonsalves, 1984), and investigating wide crosses with PRSV-resistant wild relatives (Manshardt and Wenslaff, 1989; Mekako and Nakasone, 1975). None of these approaches proved successful in delivering economical protection or a resistant cultivar. By the mid-1980s, genetic engineering technology had advanced to the point that it was possible to conceive a plan to provide Hawai'i's papaya cultivars with PRSV resistance by this approach. Beginning in 1987, a team of scientists under the leadership of a Cornell University virologist, Dennis Gonsalves, provided the needed skills to accomplish the task. Gonsalves, who was born in Hawai'i and was familiar with the PRSV problem, identified and isolated the resistance gene from the PRSV genome itself. Jerry Slightom of the Upjohn Company engineered the gene into a functional transformation vector. Maureen Fitch of the USDA's Sugarcane Research Laboratory in Aiea, O'ahu, developed the tissue cultures for transformation and regeneration of the genetically engineered plants as part of her doctoral research at UH at Mānoa. Confirmation of the efficacy of PRSV resistance under field conditions in Hawai'i was the contribution of Richard Manshardt and Stephen Ferreira of UH at Mānoa aided by cooperating growers Delan and Jenny Perry of Kapoho, Hawai'i (Ferreira et al., 2002). Ironically, 'SunUp', the first "transgenic" papaya with successful PRSV resistance (Fitch et al., 1992), was rejected by the papaya industry, because it was the wrong color. Marketing of Hawaiian papayas was based on the yellow flesh color of the standard Kapoho cultivar and 'SunUp', a genetically engineered version of the existing Sunset cultivar was pink-fleshed. This impediment was overcome by a conventional sexual cross between 'Kapoho' and 'SunUp' to yield the yellow-fleshed, PRSV-resistant F1 hybrid named 'Rainbow' (Manshardt, 1998). These names were suggested provisionally by UH Horticulture Department chair H.C. Bittcbeuder as symbolically hopeful for papaya growers after the PRSV "storm," and

they stuck, becoming the official cultivar appellations. In addition to its resistance to PRSV, the resulting hybrid was more highly productive and more widely adapted to microclimatic variation than its 'Kapoho' parent but also somewhat more susceptible to *Phytophthora* fruit rot, stem canker, and root rot. When released in 1998, 'Rainbow' and 'SunUp' became the world's first genetically engineered tree fruit cultivars to reach commercial production and the first transgenic cultivars to be released by public institutions in the United States (Gonsalves, 1998). 'Rainbow' was rapidly adopted by growers in the Puna District, and by 2009, plantings of 'Rainbow' accounted for $\approx 75\%$ of commercial papaya acreage in Hawai'i (National Agricultural Statistics Service, 2009) (Fig. 2). Several other PRSV-resistant papaya hybrids have been produced by conventional crosses with the transgenic cultivars after their 1998 release. The most important of these, released by USDA plant physiologist Maurcen Fitch in 2002, is the cross of 'Kamiya' with a transgenic inbred derived from 'Rainbow'. The resulting hybrid, called 'Laie Gold', is a high-quality, yellow-fleshed fruit that is popular with growers along the windward eastern coast of O'ahu.

Control of the Papaya Administrative Committee. The other major battle in the Hawai'i papaya industry in the 1990s involved competition for control of the PAC between groups with differing points of view. Several contentious changes of management ensued, and turmoil centering on the burden of PAC assessments on growers during a period of falling fruit prices led growers in 2002 to vote out the papaya marketing order and abolish the PAC. These events resulted in an industry organization with fewer resources and a less cohesive membership.

FUTURE PROSPECTS

The industry today is leaner than in the last decades of the 20th century. Market share in the U.S. mainland was lost to international competitors in Central and South America during the drop in Hawaiian production caused by PRSV in the 1990s, and that loss was not regained after introduction of PRSV-resistant varieties (Figs. 3 and 4). Imports of the large Mexican 'Maradol' papayas into the United States have risen dramatically since 1990 but are less damaging competition for Hawai'i than other producers of solo papayas such as Belize and Brazil. Reductions also occurred in lucrative exports to Japan as a result of Japanese quarantine restrictions against shipments of transgenic papaya cultivars. Statistics from the late 1980s indicate that more than 300 papaya farms statewide harvested ≈ 975 ha of papaya, compared with 177 farms and 535 ha in 2009 (National Agricultural Statistics Service, 2009). In recent years, Hawai'i has produced ≈ 13.5 million kilograms of fruit annually for fresh consumption, approximately half the amount produced in the mid- to late 1980s, and annual crop value has averaged $\approx \$14$ million.

PAPAYA: Total Acreage, Varietal Distribution, State of Hawaii, 2000-2009

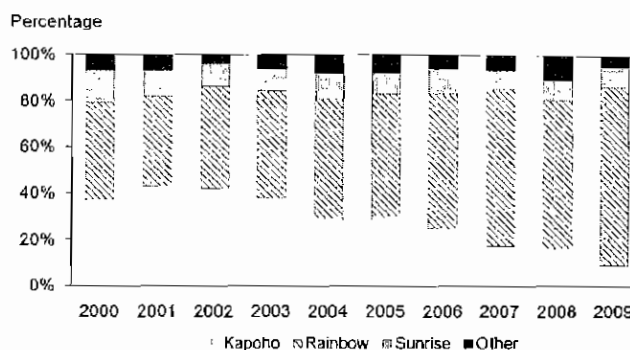


Fig. 2. 'Rainbow' was an immediate success when introduced in 1998 as a result of its resistance to *Papaya ringspot virus* (National Agricultural Statistics Service, 2009).

PAPAYA: Fresh Utilization and Price, State of Hawaii, 1955-2008

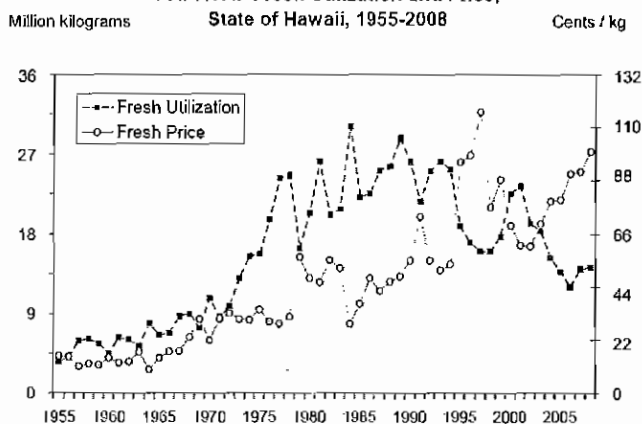


Fig. 3. Growth of papaya industry and recent decline resulting from foreign competition in traditional export markets (National Agricultural Statistics Service, 2009).

Origin & Magnitude of Papaya Imports into Mainland US (1990 - 2009)

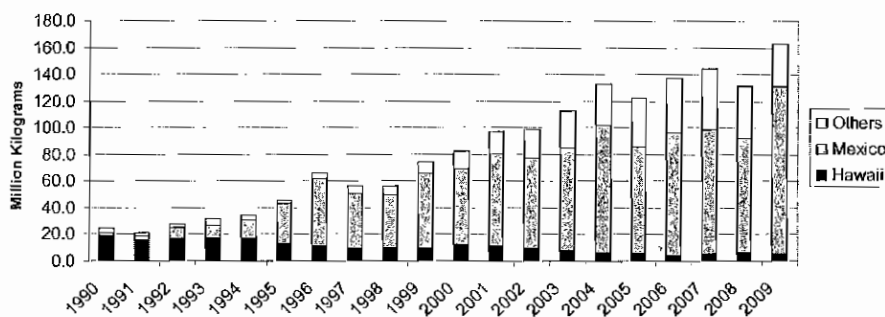


Fig. 4. Hawai'i's market share on the U.S. mainland has declined as a result of *Papaya ringspot virus* (1994-99) and to increased competition from foreign producers of solo papayas (Belize and Brazil) (National Agricultural Statistics Service. Hawaii Papayas. U.S. Imports of fresh papaya, by country, 1990-2009).

Papaya genome sequenced. Although competition has caused a contraction in the papaya industry, advances in technology in the present decade and the potential for acceptance of transgenic fruits in overseas markets provide some hope for a more positive outlook. In 2008, an international team of researchers based in Hawai'i published a draft sequence for the papaya genome of 327 million bps (Ming et al., 2008). Hawai'i

principals in this effort were Ray Ming, formerly of the Hawai'i Agriculture Research Center in Aiea, O'ahu, Maqsood Alam of the UH at the Mānoa genomics center, and Dennis Gonsalves, currently Director of the USDA Pacific Basin Agriculture Research Center in Hilo, along with an international group of collaborators including a number of faculty and graduate students at UH. This project is informing research in

papaya improvement that will favorably impact the industry in the future. The first genome sequence has already benefitted papaya breeding efforts by making available a broad assortment of DNA markers, potentially linked with important economic traits, for marker-assisted selection. In the near future, it may allow dissection of the genetic control of sex in papaya and enable development of homozygous hermaphrodite genotypes that will eliminate the current necessity of roguing females from segregating seed-propagated plantings. Like a book of deep knowledge that reveals its meaning in proportion to our ability to comprehend, the genome sequence will provide understanding in measure with our ability to reinterpret it in the light of new experience.

International acceptance of 'Rainbow'. In addition, a decade-long effort has recently succeeded in gaining approval in Japan for export of transgenic 'Rainbow', and the first fruits were shipped from Hawai'i in early 2012. The production of data and documents to satisfy the exacting requirements of Japanese regulatory agencies was the work of many researchers, whose efforts were tenaciously motivated and coordinated by Dennis Gonsalves. Gonsalves is also leading a similar project to open markets for 'Rainbow' in China.

In 1914, Higgins and Holt wrote: "Excepting the banana, there is no fruit grown in the Hawaiian Islands that means more to the people of this Territory than the papaya, if measured in terms of the comfort and enjoyment furnished to the people as a whole." A century later, their words apply more than ever. In Hawai'i, a combination of progressive growers and modern horticultural research moved papaya from "pig feed" status to iconic tropical delicacy. The prosperity of the Hawaiian papaya industry has been the result of its success in extending that appeal to other countries and peoples of the world. With new markets opening overseas for virus-resistant solo papayas, there is new hope that papaya will remain an important Hawaiian commodity.

Looking back over the century of papaya history that separates us from the time of Higgins and Holt, it seems true to say that the little fruit from the Caribbean has found a favored home in the middle of the Pacific Ocean.

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A Hard Nut to Crack: Macadamia in Hawaii

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Abstract. The macadamia nut (*Macadamia integrifolia*) was introduced to Kapulena on the Hamakua Coast of Hawaii from Australia in 1881 by William Purvis. The first commercial plantation was established in Oahu but the commercial industry moved to Hawaii, the Big Island. By 1950, the largest producer was the Honakaa Sngar Company with 450 acres (182 ha). The development of new technology, including the selection of cultivars on grafted trees, resulted in an expansion of the industry. The Manna Loa Company is now the world's largest grower, processor, and marketer of macadamia nuts with over 10,000 acres (4047 ha). The industry now consists of ~500 to 600 growers that are connected by ownership or contract to the two largest processor/marketers, Manna Loa and Mac Farms. The Hawaiian macadamia industry is now relatively static. Crop area peaked in 1990 at 22,600 acres (9146 ha) and then gradually dropped to 17,000 acres (6880 ha) in 2006 where it has remained. In-shell nut production during the same period ranged from a low of 40 million pounds (18,148 t) in this past crop year (2010–11) to a high of 58 million pounds (26,315 t) in 2006–07. Competition among Hawaii, Australia, and Africa is now intense.

The year was 1881. Kalakaua was king and Hawaii was still a peaceful monarchy. A man named William Purvis arrived from Australia on a steamship that year bringing with him the first macadamia tree to Hawaii. At that time, Purvis was a 23-year-old avid plant collector and sugar plantation manager on the island of Hawaii. He planted the tree in the sleepy plantation town of Kapulena on the island's Hamakua Coast. Many years ago when I was farming macadamia orchards at Kapulena, I went with a local resident who knew where the tree was planted to see it for myself. I believe that it is still there today.

The macadamia was first classified and described in 1858 by Baron Sir Ferdinand Jakob Heinrich von Mueller, director of Australia's Melbourne Botanical Gardens, and Walter Hill, superintendent of Brisbane's Botanical Gardens. The nut was named in honor of Mueller's good friend, John Macadam, a prominent scientist, philosopher, and politician.

The macadamia tree, a subtropical evergreen of the Proteaceae (Hardner et al., 2009; Nagao, 2008), has two species that produce edible nuts: *Macadamia integrifolia* and *Macadamia tetraphylla*. Both have dark green holly-like leaves and can reach a height of 40 ft or more.

Macadamia integrifolia, known as smooth-shell macadamia, has proved suitable for commercial production. *Macadamia tetraphylla*, the rough-shell macadamia, has proved unsuitable and produces nuts of inconsistent quality.

The first commercial planting of macadamia is credited to Ernest Shelton van Tassel. He planted the first macadamia plantation on 75 acres of land on Tantalus, Oahu, and founded the Hawaiian Macadamia Nut

Company. Oahu Island was not to be the future home of Hawaii's macadamia industry, rather Hawaii Island with its vast land mass suitable for an orchard crop such as macadamia would ultimately become the center of production. van Tassel chose Keauhou, Kona, on the leeward side of the island to expand his business. In 1924 he leased ~100 acres (40 ha) in Keauhou and planted 7000 trees. To market his product, he established a commercial processing facility in Honolulu and sold his macadamia nuts, in glass jars, to selected shops on the U.S. mainland. During the same timeframe, Walter Naquin began planting macadamia trees on the other side of the island near Honokaa. By 1950, his employer, Honokaa Sugar Company, was the largest producer of macadamia nuts in the territory of Hawaii with ~450 acres (182 ha) of trees planted.

DEVELOPMENT OF THE HAWAIIAN INDUSTRY

As the industry began to mature, it became evident that trees planted from seed-produced trees varied greatly, including variable nut production and kernel quality. Great contributions to the industry were made by the University of Hawaii's College of Agriculture and the Hawaii Agricultural Experiment Station (Hamilton and Fukunaga, 1959; Moltzan and Ripperton, 1939; Shigenra and Ooka, 1984). The resulting plant breeding program established by the University of Hawaii developed the cultivars that are currently used in the industry today. Grafted trees replaced seedlings and both orchard yield and kernel quality improved dramatically.

With the development of reliable grafted tree cultivars and increased marketing efforts that promoted the awareness of the macadamia as the "perfect nut," Hawaii's larger agricultural companies began to look at diversifying and macadamia was the obvious choice. In 1948, Castle & Cooke, Inc. planted 1000 acres (405 ha) in Keaan and marketed their product under the Royal Hawaiian label. C. Brewer & Company followed Castle & Cooke into the macadamia business, eventually purchasing Castle & Cooke's macadamia

interests, and established Mauna Loa Macadamia Nut Company. Mauna Loa became the world's largest grower, processor, and marketer of macadamia nuts with over 10,000 acres (4047 ha) of macadamia, all on the island of Hawaii. Other companies soon followed.

Hawaiian Holiday Macadamia Nut Company. Paul DeDominico of Hawaiian Holiday Macadamia Nut Company established large orchards in both Kohala and Keaan through a series of limited partnerships. Paul and his wife, Anita, were pioneers in product development and marketing. The company eventually went bankrupt and sold its processing and manufacturing equipment to Hamakua Macadamia Nut Company.

Mac Farms of Hawaii. In 1960, Willis Jennings leased 4200 acres in South Kona from the Bishop Estate and through limited partnerships established a macadamia orchard under the management of Kona Property Management, Inc. The orchards and the management company were sold in 1977 to Mac Farms of Hawaii, Inc. Under Mac Farms, the operation became fully integrated with the establishment of processing, manufacturing, and marketing functions. The product was sold under the Mac Farms label. Mac Farms was the first to use the pouch, rather than a jar or can, as a container. The significance of the pouch was reduced materials shipping cost because all packing materials came from the U.S. mainland.

Hawaiian Host Candies. The company developed a loyal grower following on both sides of the Hawaii Island and built receiving stations along with small processing facilities that produce kernel for their manufacturing plant in Honolulu. They are currently the leader in combining macadamia nuts with chocolate to produce many tasty retail products.

Island Princess. The company is comprised of a 1000-acre orchard and processing facility in Keaan. The manufacturing facility and corporate office are in Honolulu.

Hamakua Macadamia Nut Company. The company is located in Kawaihae, buys nuts from growers around Hawaii Island, and processes and manufactures the nuts into both bulk kernel and retail products. The company

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sells its retail products under the Hamakua Plantations label.

The importance of a stable processor/ marketer community is that it provides the necessary vehicle for the small macadamia grower to exist and prosper during most years. As the result, the Hawaiian industry has, at any one time, between 550 and 600 growers that range in size from several acres to thousands of acres (Table 1). The larger orchards are connected by ownership or contract to the two largest processor/marketers, Mauna Loa and Mac Farms. The independent orchards contract with the processor of their choice, generally based on the price and location.

Another important component of the industry is the ownership of these key processor/marketers. During the industry's development and through the early 1980s, the companies that were planting the orchards and developing the processing and marketing facilities had their roots in Hawaii. As macadamia became a global commodity and many companies worldwide were diversifying, corporate entities from both the U.S. mainland and foreign countries became interested in macadamia from Hawaii. This interest resulted in two significant changes in the industry: consolidation and reorganization.

CONSOLIDATION AND REORGANIZATION OF THE INDUSTRY

The first consolidation of the macadamia industry was the sale of Mac Farms of Hawaii to CSR of Sydney, Australia, in 1981. Mac Farms has had a series of owners after the CSR acquisition, which include Blue Diamond (almond cooperative) and Campbell Soup through an Australian subsidiary. Mac Farms is currently Australian-owned.

The second was the reorganization of Mauna Loa Macadamia Nut Company into two separate business entities, an orchard company and a processing/marketing company. In 1986 Mauna Loa Partners (the orchard company) became a publicly traded limited partnership. It would eventually be renamed ML Macadamia Orchards L.P. In 2000, Mauna Loa (the processing/marketing company) was sold to The Shansby Group, a private equity group from San Francisco. In 2004, Shansby sold Mauna Loa to The Hershey Company.

The result of these transactions was to place the ownership of the industry's two largest processors under "foreign" ownership. This changed the dynamics of the industry's relationship between the growers and the major processors. There was no synergistic relationship where each needed the other to be economically successful. The growers were

still dependent on the processor, but the processor had the option of purchasing kernel from other parts of the world. Loyalty to the Hawaiian macadamia industry as well as the promotion of the Hawaiian nut was on its way out.

In the period that followed these significant changes in the structure of the industry, the small grower suffered financially from the vagaries of a worldwide commodity market. They became a captive audience to the direction the Hawaiian industry was taking. A casualty of this shift was the Hawaii Macadamia Nut Association. Its mandate was to provide industry members with a forum to discuss and create solutions for problems as well as create a unified direction for the Hawaiian macadamia industry. The major areas to be addressed by the association were 1) cultivation research and development to include a cultivar improvement program; 2) farm equipment design with emphasis on mechanical harvesting; 3) processing equipment innovation; and 4) generic promotion of the Hawaiian macadamia nut.

To accomplish these goals, the association was the industry's partner in getting grants, working with the University of Hawaii and the USDA's Pacific Basin Agricultural Research Center (PBARC) to manage research and development projects. Industry funding came from a voluntary assessment program in which annual contributions were made to the association by its members based on the amount of crop harvested and processed.

This voluntary assessment program worked while all of the industry was represented by local ownership. As soon as the ownership of Mac Farms and Mauna Loa changed, the majority of the funding ceased and the association did not have adequate funding to continue with its projects. Most projects required a funding ratio of 1:1 between the industry and the entity providing the grant. The Hawaii Macadamia Nut Association is currently inactive.

MACADAMIA CULTIVATION AND PRODUCTION

The water requirement for macadamia is 60 inches (152 cm) of rainfall or the equivalent irrigation. It is generally planted at between 500 (152 m) and 1000 ft (305 m) in elevation and needs relatively dry weather during flowering and nut set to prevent abortion resulting from fungus organisms.

The most common spacing is 30 ft (9.1 m) between rows, 15 ft (4.5 m) between trees in a row, which provides for 96 trees/acre (237 trees/ha). Older orchards in Hawaii were planted at 30 ft by 30 ft, providing for 48 trees/acre (119 trees/ha).

The most common cultivation operations for macadamia in Hawaii are as follows: mowing, herbicide spraying (glyphosate) under the tree rows, fertilizing four times per year, irrigation (where required), pruning and leaf blowing to assist with harvesting, pest control (primarily rats), and leaf tissue

analysis to monitor nutrient uptake, which assists with fertilizer determination.

The macadamia is very similar to other orchard nut crops. The tree produces a nut that is generally allowed to mature on the tree and fall to the ground where it is harvested either by hand or by machine. Processing of the nut entails removing the outer husk, removing most of the moisture from the in-shell nut through a drying process, cracking the dry in-shell nut, separating the shell from the kernel, roasting and grading followed by bulk packaging. The manufacturing process begins with one or more grades of bulk kernel and ends with a retail product. Some of the smaller grades will be used in other products as an ingredient. Some examples of this are ice cream, cookies, and cakes. Macadamia oil is made from unusable nuts and nut pieces.

Orchard production and kernel recovery, in very general terms, are outlined subsequently. Production will vary with tree age and location. Quality will vary from orchard to orchard depending on climate, cultivar, and cultivation practices.

- A mature orchard will yield between 4000 and 6000 lb of nut-in-shell/acre (4500 and 6700 kg·ha⁻¹).
- One hundred pounds (45.3 kg) of nut-in-husk harvested will yield 50 lb (22.6 kg) of nut-in-shell at field moisture (20%).
- Fifty pounds of nut-in-shell (22.6 kg) at field moisture will yield 41 lb (18.6 kg) of dry-in-shell (1.5% moisture).
- Forty-one pounds of dry-in-shell nuts (18.6 kg) will yield 10 lb (4.5 kg) of kernel.

The nutritional content of the macadamia kernel is as follows: protein (9.2%), fat (78.2%), carbohydrate (10.0%), and vitamins and minerals (2.6%). The fatty acid profile of the macadamia kernel is as follows: monounsaturated (82.5%), saturated (15.7%), and polyunsaturated (1.8%)

CURRENT VALUE OF THE INDUSTRY

The macadamia industry in Hawaii currently has 570 growers farming 17,000 acres (6882 ha) that produce 40 million pounds (18,148 t) of in-shell nuts valued at \$30 million. The industry value is understated statistically because in-shell nuts are not generally sold in either the industrial or retail markets. The nut is sold to industrial markets in the form of bulk kernels, usually packaged in 25-lb (11.3 kg) foil-lined boxes. In retail markets, kernel is sold in a variety of products that include roasted and salted, candy or chocolate-coated, in various packages, cans or jars. Therefore, the industry value based on kernel sales alone is significantly undervalued.

If some general assumptions are made, the kernel value of the industry can be calculated. First the in-shell nut is dried from field moisture at 20% to 1.5% moisture at which point the nut is cracked. The shell is then removed leaving the edible kernel. The recovery of

Table 1. Distribution of growers by crop area.

Size (acres)	Grower distribution (%)	Total area (%)
≤ 1	30	1
2-5	45	7
6-19	19	7
≥ 20	6	85

kernel to the in-shell nut averages $\approx 28\%$. So the 40 million pounds of in-shell nuts would lose 18.5% of its weight to moisture then weigh 32.6 million pounds. The edible kernel at 28% recovery would weigh 9.1 million pounds. If the average sales price for the kernel is \$6.00/pound, then the annual macadamia production is worth \$54.6 million rather than the reported \$30 million. The retail value of the industry, depending on the ratio of retail products sold to industrial sales of bulk kernel, is somewhere in excess of \$100 million.

It is interesting to note that processing of the macadamia nut makes very efficient use of both kernel and byproducts.

- All grades (sizes) of kernel, even kernel dust, are sold as either a retail macadamia product or for industrial use as an ingredient of another product (used in ice cream and cookies as an example).
- Cull kernel is pressed for macadamia oil. The oil has high flash point and a mild taste making it excellent for cooking.
- The outer husk of the macadamia is used for compost.
- The shell is burned in a furnace to produce heat for drying the incoming nut-in-shell. Larger processors also used the steam produced by the furnace to produce electricity. A new company on the island of Hawaii is buying macadamia shell and converting it to activated charcoal.

THE FUTURE

The macadamia industry in Hawaii today is comprised of five major processors and they are, in order of size:

- Mauna Loa Macadamia Nut Company. Mauna Loa retail product. Contract processes the Kirkland labeled products for Costco.
- Mac Farms of Hawaii. Mac Farms retail product. Sells bulk kernel into the U.S. industrial market.
- Hamakua Macadamia Nut Company. Hamakua Plantations retail product.
- Hawaiian Host. Hawaiian Host retail product. Sells both roasted salted macadamia and chocolate-covered retail product.
- Island Princess. Island Princess retail product.

Mauna Loa and Island Princess are on the east side of the island of Hawaii. Mac Farms and Hamakua Macadamia Nut Company are located on the west side. Hawaiian Host has two small processing facilities on the island, one on the east side and one on the west side. There are several smaller regional processors as well.

If one looks at statistics, the Hawaiian macadamia industry has been relatively static. The in-crop area in 1984 was 17,500 acres (7082 ha). The crop area peaked in 1990 at 22,600 acres (9146 ha) and then gradually dropped to 17,000 acres (6880 ha) in 2006

where it has remained. Net in-shell production during the same period ranges from a low of 40 million pounds (18,148 t) in this past crop year (July 2010 to June 2011) to a high of 58 million pounds (26,314 t) in the 2006–07 crop year.

Statistics are valuable, but they become an afterthought when it comes to what drives an industry to either prosper or decline. From the grower standpoint, it is a combination of weather and the farm price for nut-in-shell. As we know from the current weather trends on the U.S. mainland, weather to the farmer can be everything but it is not something we can control. In Hawaii, we have the Pacific Ocean as a buffer and therefore do not have the wide changes in weather that farmers on the U.S. mainland are currently experiencing. Hawaii's macadamia production fluctuations resulting from weather are within the range of $\pm 10\%$.

The most significant impact on the macadamia grower is the nut-in-shell price. There is a "bottom" price for each grower at which farming is not economically viable and the industry seems to fall into this price range on a relatively consistent cycle of about five to six years. It is very difficult to sustain a farming business under this cyclic pricing and this is probably why the Hawaiian industry has been relatively static over the past 25 years or so.

So what causes this cyclic fluctuation? The change in the macadamia from a cottage market product of the Hawaiian macadamia nuts to a world commodity is one. In the mid-1970s, Hawaii produced $\approx 95\%$ of the world's macadamia kernel. Today Africa is the number one producer followed by Australia (Table 2). Hawaii is the third largest producer with $\approx 16\%$ of world kernel production. The change in ownership of the two largest brands, Mauna Loa and Mac Farms, is another. With international ownership and a world supply of kernel, price became the driver.

What has happened over time is that both Australia and Africa have continued to plant macadamia orchards and Hawaii has not. When production is good in these continents, world production tends to exceed demand and the world price of kernel goes down. When weather conditions in either or both of the top-producing regions negatively impact production, the price goes up.

The other market driver is consumption. The primary market for the macadamia nut is the United States followed by Europe and then Asia. During years of high production, the kernel price is relatively low, inducing manufacturers to use macadamia kernel in retail product lines or in mixed nut products. This increased consumption does not dissipate during low nut production years. The resulting competition for kernel by the manufacturers equates to higher nut-in-shell prices to the grower.

What are possible solutions to providing for a more stable economic environment from the Hawaiian industry point of view?

1. Reduce the cost of farming. This is difficult with the continued rise in the

Table 2. World kernel production in 2011.

Region	Kernel (tonnes)	Percent
Hawaii	3,890	14.1
Australia	9,914	36.0
Africa	10,916	39.6
Latin America	2,854	10.4
Total	27,574	100.0

cost of petroleum-related items such as fertilizer, pesticides, and equipment, but there is an opportunity in harvesting. Harvesting is a significant cost of macadamia production primarily as a result of lack of mechanization of the process by the smaller grower. Australian pinwheel harvesting technology has made it possible for the small grower to become mechanized with a low capital investment.

2. Plant improvement. The University of Hawaii's cultivar research program has fallen by the wayside as a result of cuts in funding and the industry is unable to fund the program on its own. However, new cultivars that provide for higher production and recovery as well as disease resistance would effectively reduce the cost of production per unit area.
3. Manufacturing innovation. Current robotics technology and computerized production lines would reduce the cost of processing and manufacturing. New manufacturing technology is beginning to see its way into the industry's processing and manufacturing facilities. A good example of this is the optic sorter that removes shell from kernel.
4. Balanced marketing (sales). A balance between high margin retail sales and lower margin industrial sales that provides the manufacturer with an overall higher net price per kernel pound would allow for a higher price paid to the grower for nut-in-shell. The basis for a healthy Hawaiian macadamia industry is a financially healthy grower base.

Hawaii may not have "invented" the macadamia tree, but it became the home of an industry that has provided the "perfect nut" to many people worldwide. We are proud of our contribution.

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