



**Plant Biotechnology:
Current and Potential Impact
For Improving Pest Management
In U.S. Agriculture
An Analysis of 40 Case Studies**
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Viral Resistant Papaya

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1. PAPAYA

Viral Resistant

Production

Papaya is a tropical fruit that normally is consumed fresh. Papaya is valued as a health food because of its richness in vitamins C and A [5]. Papaya also has a high sugar content (20%).

Papaya is a short-lived perennial, growing to 30 feet high. Papaya, a fast growing tree fruit, is grown from seed and comes into production within 9 to 12 months. Trees bear fruit throughout the year. The plants continue to bear fruit for many years, but yields usually decline as the trees age. In commercial production, fields usually are replanted or abandoned after three years.

U.S. production of papayas is located in Hawaii. In recent years, papayas were grown on 1,600 acres in Hawaii with annual production of 53 million pounds and an associated value of \$17 million. (See Table 1.1) Typically, 35-40% of Hawaii's harvest is sold to Japan [7].

In recent years the U.S. has imported approximately 123 million pounds of papayas – mostly from Mexico [2].

Aphid/Virus Transmission

Aphids feed by sucking sap from their host. Aphids vector many plant diseases that cause substantially greater losses than damage caused by direct feeding injury. Virus transmission occurs when the virus is taken up into the aphid's mouth while it feeds on an infected plant, and transferred to a healthy plant during the next feeding or probing by mouthparts. For some aphid/virus combinations, this process may require less than a minute. The virus reproduces in the plant, and the aphids simply aid in transporting the virus.

Since winters in Hawaii are mild, aphids there do not need an overwintering egg stage. Aphid reproduction in Hawaii, therefore, does not include mating and egg laying. Hawaiian aphid populations are composed solely of females and there are no males present. Female aphids give birth to live female nymphs. Adult females produce 8 to 22 young nymphs per day [1]. As a

consequence of this type of reproduction, there are many aphid generations throughout the year in Hawaii.

Papaya ringspot, caused by papaya ringspot virus (PRSV), is the most important disease of papayas worldwide. These viruses typically have long, flexuous, rod-shaped particles. Papaya ringspot virus can be spread rapidly by several aphid species. Earliest symptoms appear as yellowing of younger leaves. A prominent yellow mottling of the leaves follows. One or more lobes of infected leaves may become severely distorted and narrow. The disease was named because of the striking symptoms that appear on the fruit. These consist of circles and C-shaped markings that are darker green than the background fruit color. Later these markings may become gray and crusty in texture. Ringspot on the fruit is usually evident only after infection has been present for an extended period of time. Infected plants exhibit growth reduction. There is reduced fruit set and quality, with flavor especially adversely affected. Attempts to reduce disease levels by applying insecticides to kill the aphids have not been successful. No naturally occurring genes with PRSV resistance have been found in papayas for traditional plant breeding.

Once PRSV occurs in an area, it cannot be eradicated because secondary hosts harbor the disease but do not exhibit symptoms. Transmission of the virus from aphid to papaya is almost instantaneous. If a papaya seedling is heavily infected, it will die. If infection occurs in an older plant, the plant may live for a while as a source of infection for other plants. Growers are advised that when disease appears, all affected plants and near-by ground plants should be burned, and all papayas within a wide surrounding area should be destroyed.

PRSV was discovered in Hawaii in the 1940's and virtually eliminated large papaya production on Oahu island in the 1950's, causing the papaya industry to relocate to Puna district on Hawaii island in the early 1960's. The papaya industry thrived in Puna because of ideal rainfall conditions, availability of land, and, most importantly, because Puna was free of PRSV. Even though PRSV was only 19 miles away from Puna, geographic isolation and diligent surveillance and rouging efforts had kept the virus out of the district. Consequently, by the 1980's 95% of Hawaii's papaya was being produced in Puna [5].

Arrival of PRSV into the Puna district was observed in May 1992. PRSV spread very rapidly in Puna. By late 1994, nearly one-half of Puna's acreage was infected, and a number of farmers went out of business [5]. The entire Puna area became infected within a five-year period. Hawaii's production of papaya was reduced by half. (See Table 1.A.1.)

Transgenic Papaya

In 1987, researchers at the University of Hawaii (UH) and Cornell University in New York had begun trying to create a transgenic papaya with virus resistance. The Cornell researchers had selected papaya as a model system to develop the technology for engineering virus resistance into fruit crops, such as apples and grapes. Young embryos from papaya seeds of the commercial Hawaiian cultivar "Sunset" were transformed with the coat protein gene of a PRSV isolate from Hawaii [5]. Researchers isolated the virus's coat protein gene and modified it for expression in plants. In 1989, copies of the modified gene were "shot" into cultured papaya tissue using a "gene gun" [3]. UH researchers developed a tissue-culture system needed to grow out the genetically engineered plants from the bombarded plant materials. In 1991, the first transformed plant that appeared to have PRSV resistance was observed.

The modified virus gene transferred to papaya encodes the information needed to produce the viral coat protein, making the plant virus resistant. However, virus resistance is not dependent on the production of coat protein. Expression of the foreign transgene above some threshold level appears to trigger a plant cellular mechanism that selectively destroys the transgene message before any protein is produced [4]. When the virus pathogen invades the plant, this same plant mechanism recognizes the virus coat protein gene and renders it non-functional. This is done at very little energy cost to the papaya cell.

At UH, researchers used traditional plant breeding techniques to crossbreed the resistant plant with a non-transgenic plant, producing a true-breeding, red-fleshed transgenic cultivar that was named "UH SunUp" (also referred to as "SunUp"). Because the papaya industry wanted a yellow-fleshed fruit, "SunUp" was crossed with "Kapoho" to produce a yellow-fleshed transgenic hybrid that was named "UH Rainbow" (also called "Rainbow") [3].

A small-scale field trial of the transgenic line was established on Oahu Island in April 1992. The field trial showed that the transgenic line was highly resistant to PRSV. While all control plants became infected within 77 days, the transformed plants remained resistant to PRSV. Fruit quality and plant growth characteristics of the transgenic line were similar to “Sunset” [5].

Hawaii’s Papaya Administrative Committee (PAC) assumed the task of obtaining license agreements with owners of the patented genetic engineering technology, while the UH and Cornell scientists prepared and submitted the documents required by the U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the Food and Drug Administration (FDA). In September 1997, the federal regulatory agencies completed their review and approved the transgenic papaya for production and sale. PAC successfully negotiated use licenses with Monsanto Company, Asgrow Seed Company, Cambia Biosystems L.L.C., and the Massachusetts Institute of Technology [3].

The licenses negotiated with the four companies include limitations-of-use and compliance provisions. There are five provisions, common to all of the licenses, which growers must follow to be in compliance with the contracts, as follows [3]:

- Transgenic papaya can only be planted in the state of Hawaii
- Only PAC can sell seeds of “Rainbow” and “SunUp”
- Fruits can be sold only in countries that have accepted genetically engineered papayas as safe for commercialization
- Producers must attend an educational session that covers the requirements of the licenses and PRV resistance management
- Producers are required to sign an agreement with the PAC to purchase seed

PAC funded a program to produce seeds of “UH SunUp” and “UH Rainbow” so that there would be available seed near the time that the transgenic papaya was commercialized. All license agreements were completed by April 1998, and distribution of transgenic papaya seeds to Hawaiian papaya growers was started in May 1998 [5]. The seed was given to growers at no charge.

Estimated Impacts

The development of transgenic papaya varieties allows papayas to be grown on PRSV infected acres on Oahu and Hawaii.

A survey in 2000 determined that the two transgenic papaya varieties (Rainbow and Sun Up) comprise 53% of the bearing acreage of papayas in Hawaii [6]. A 33% increase in Hawaiian papaya production occurred from 1999 to 2000. (See Table 1.) The increase is attributed to the planting of transgenic varieties. Genetically engineered papaya plants are being credited with saving the Hawaiian papaya industry [7].

It is estimated that transgenic papaya will soon be planted on 90% of Hawaii's acreage, and that this adoption can be credited with preventing the loss of 53 million pounds of production with an annual value of \$17 million.

TABLE 1.1: Papaya Production: Hawaii

<u>Year</u>	<u>Acreage Harvested</u>	<u>Production (000 Lbs)</u>	<u>Value (Millions \$)</u>
2000	1,600	53,000	17.3
1999	1,940	42,400	15.9
1998	2,120	39,900	12.6
1997	1,985	38,800	18.9
1996	1,835	41,800	17.0
1995	2,435	50,800	18.5
1994	2,200	62,000	13.8
1993	2,555	63,700	13.7
1992	2,415	71,300	14.4

Source: [8]

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