PEST MANAGEMENT STRATEGIC PLAN

FOR

PAPAYA PRODUCTION IN HAWAIʻI

Workshop Summary
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Editors
Lynne N. Constantinides
John J. McHugh, Jr.

Contact: Cathy Tarutani
e-mail: cathy@hpirs.stjohn.hawaii.edu
(808) 956-2004

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WORKSHOP PARTICIPANTS AND CONTRIBUTORS

Lorey Andres	Tropical Hawaiian Products, Kea‘au, Hawai‘i Island
Alton Arakaki	County Extension Agent, Moloka‘i Extension Office, University of Hawai‘i Cooperative Extension Service
John Armstrong	Project Leader/Research Entomologist, Postharvest Tropical Commodities Research Unit, Pacific Basin Agriculture Research Center, USDA, Agricultural Research Service, Hilo, Hawai‘i Island
Luisa Castro	Assistant Coordinator, Water Quality Extension, Natural Resources and Environmental Management, University of Hawai‘i at Mānoa, Honolulu, O‘ahu
Pat Conant	Entomologist, Biocontrol Section, Hawai‘i Department of Agriculture, Hilo, Hawai‘i Island
Lynne Constantinides	Crop consultant, Crop Care Hawai‘i, LLC, Honolulu, O‘ahu
Joe DeFrank	Extension Weed Science Specialist, Department of Tropical Plant and Soil Sciences, University of Hawai‘i at Mānoa, Honolulu, O‘ahu
Mario Escobar	Grower, Hawai‘i Island
Dennis Gonsalves	Director, USDA Agricultural Research Service, Pacific Basin Agricultural Research Center, Hilo, Hawai‘i Island
Kenn Harada	Tropical Hawaiian Products, Kea‘au, Hawai‘i Island
Linda Herbst	Associate Director, Western IPM Center, University of California, Davis, California
Shinichi Ichimaru	Grower, SL Farm, Kea‘au, Hawai‘i Island
Eric Jang	Research Entomologist, USDA, Agricultural Research Service, Pacific Basin Agricultural Research Center, Hilo, Hawai‘i Island
Ken Kamiya	Papaya grower, Kamiya Farm, Inc., Hau‘ula, O‘ahu
Michael Kawate	Pesticide Registration Specialist, Department of Plant and Environmental Protection Sciences, University of Hawai‘i at Mānoa, Honolulu, O‘ahu

Emerson Llantero	Puna-Hawaii King Papaya Cooperative, Hilo, Hawai‘i Island
Mel Matsuda	Grower, Matsuda Fukuyama Farms, Kahuku, O‘ahu
John McHugh	Hawai‘i Farm Bureau Federation, Honolulu, O‘ahu
Danny Molina	Grower, Puna-Hawai‘i King Papaya Cooperative, Hilo, Hawai‘i Island
Scot Nelson	Plant Pathologist, Komohana Research and Extension Center, University of Hawai‘i at Mānoa, Hilo, Hawai‘i Island
Lou Nishida, Sr.	Grower, Kapa‘a, Kaua‘i
Kate Nishijima	USDA, Agricultural Research Service, Pacific Basin Agricultural Research Center, Hilo, Hawai‘i Island
Wayne Nishijima	Associate Dean, Cooperative Extension Service, College of Tropical Agriculture and Human Resources, University of Hawai‘i at Mānoa, Honolulu, O‘ahu
Melvin Nishina	County Extension Agent, Komohana Research and Extension Center, University of Hawai‘i at Mānoa, Hilo, Hawai‘i Island
Ken Ogawa	United Agricultural Products, Hilo, Hawai‘i Island
Kyle Onuma	Hawai‘i Department of Agriculture, Hilo, Hawai‘i Island
Delan Perry	Grower; Volcano Island Fruit Company, Inc., Pāhoa, Hawai‘i Island
Neil Reimer	Chief, Plant Pest Control Branch, Hawai‘i Department of Agriculture, Honolulu, O‘ahu
Derek Shigematsu	Hawai‘i Department of Agriculture, Pesticides Branch, Hilo, Hawai‘i Island
Rodolfo Sibucao	Grower; Kea‘au, Hawai‘i Island
Sabina Swift	Assistant Extension Specialist, Department of Plant and Environmental Sciences, University of Hawai‘i at Mānoa, Honolulu, O‘ahu
Cathy Tarutani	Educational Specialist, Department of Plant and Environmental Sciences, University of Hawai‘i at Mānoa, Honolulu, O‘ahu

Karen Umehara	Hawai‘i Papaya Industry Association, Hilo, Hawai‘i Island
Edward Uyeda	USDA, Animal Plant Health Inspection Service, Hilo, Hawai‘i Island
Roger Vargas	USDA, Agriculture Research Service, Pacific Basin Agricultural Research Center, Hilo, Hawai‘i Island
Mark Wright	Extension Specialist in Entomology, Department of Plant and Environmental Sciences, University of Hawai‘i at Mānoa, Honolulu, O‘ahu
Pueo Wright	Grower, organic papaya, Hana, Maui

EXECUTIVE SUMMARY

Commercial production of papaya occurs worldwide. Hawai‘i’s share worldwide is less than 1%. However, Hawai‘i is the global leader in research and knowledge of papayas. In some places, Hawai‘i is synonymous with the fruit. In Brazil, the Hawaiian Solo papaya is known as Mamão Hawaii. Because papaya is produced in tropical areas, the pest pressure on papaya is intense. Insects, mites, snails and slugs, nematodes, and diseases all contribute to making intensive pest management efforts necessary in papaya production. In the early- to mid-1990s, Hawai‘i nearly lost the majority of its papaya industry because of the spread of papaya ringspot virus (PRSV) to the main growing region, the Puna District of Hawai‘i Island (the Big Island). The solution for this disease was the use of the genetically-modified Rainbow papaya variety, which was developed through a partnership of the University of Hawai‘i at Mānoa, Cornell University, and the Hawai‘i Agriculture Research Center. The Rainbow papaya, though widely grown, has created controversy between organic and conventional farmers. The concern from organic farmers is that pollen from the transgenic papaya may cross-pollinate organically grown papayas and compromise their marketability.

Culture of papaya is unique to the situation in which it is grown. More than 90% of Hawai‘i’s papayas are grown without irrigation in the high rainfall areas of the state. Practices applicable to irrigated papaya fields may not be applicable to those grown without irrigation. Wherever possible, we have noted the differences between irrigated and non-irrigated papaya. Additionally, some pests of papaya can be found in certain regions but not others. This is especially true of diseases caused by *Phytophthora*. Insect, mite, and snail and slug outbreaks are also dependent on the microclimate of the area in which they are grown.

Continued successful commercial production of papaya in Hawai‘i is dependent on a well-defined Pest Management Strategic Plan that identifies the main pests of papaya and prioritizes them according to the impact felt by the growers. This document is a starting point for that process.

TOP PRIORITIES FOR HAWAI'I PAPAYA PRODUCTION

Research:

- Importation and establishment of effective white peach scale parasitoids
- Continuous research in transgenic resistance for papaya ringspot virus (PRSV) control
- Continued efforts on understanding the transmission of PRSV by aphids
- Ongoing plant breeding programs for disease and insect resistance
- Host specificity testing of papaya mealybug parasitoids
- Continued research on the efficacy of registered and nonregistered pesticides and on promising new pesticides
- Continuous and ongoing research on the aphid vector of PRSV
- Explore for egg parasitoids of Stevens leafhopper
- Use of radio frequency for postharvest disinfestations of fruit flies
- Postharvest management tools for disease pathogens
- Understanding the factors associated with cross-pollination of genetically-modified organisms (GMO) and non-GMO papaya
- Need to understand movement and distribution of aphids into papaya fields

Regulatory:

- Changing Provado pre-harvest interval (PHI) from 7 days to 1 day
- Single product certification for Vendex and other restricted use pesticides (RUP) where appropriate
- Stricter quarantine regulation and enforcement of inter-island movement and imports into state
- Streamline regulatory process for introduction of biocontrol agents
- Regulation to eradicate pest-infested plants in private properties (e.g., PRSV, mealybugs)

Education:

- Community and importer awareness of quarantine necessity and regulatory issues
- Develop strategies for GMO and non-GMO producers to coexist
- University of Hawai'i has an obligation to communicate and research GMO/conventional/organic interface
- Pest biology and timing of application for insecticide effectiveness
- Continuing education regarding safe handling and use of pesticides
- Understand the factors associated with cross-pollination of GMO and non-GMO papaya

BACKGROUND

Economic Importance

Hawai‘i leads the United States in papaya (*Carica papaya*) production. From 2001 through 2005, planted area averaged 2,384 acres with 1,590 harvested acres. Total papaya production in 2005 was 32,900,000 pounds, for an average of 22,200 pounds per harvested acre. Total farm value of the 2005 papaya crop was $11,241,000, with an average farm price of 36 cents per pound. The value of papaya production ranks ninth among the state's agricultural commodities. Of Hawai‘i's total papaya production acreage, 92% occurs on the island of Hawai‘i, 6% on O‘ahu, Moloka‘i, and Maui, and 2% on Kaua‘i. The main production region on Hawai‘i Island is in the Puna District, located on the east (windward) side of the island. Hawai‘i's fresh papaya crop goes to local and U.S. markets and is exported to Japan and Canada.

General Cropping Guidelines

Papaya is a tropical tree fruit crop that cannot tolerate freezing temperatures and does best at sea level to 500 feet elevation in Hawai‘i. Papaya is either direct-seeded or transplanted into newly prepared fields. In both cases, multiple seeds or transplants are planted into a single hole to increase the chances of producing a hermaphroditic plant with perfect flowers. Hawaiian Solo papaya varieties produce plants with flowers that are either female or hermaphroditic. The latter are preferred for commercial production. The ratio of hermaphroditic plants to female-only plants is approximately 2 to 1. After planting, papaya seedlings are thinned at the time of flowering to one hermaphroditic plant per planting hole. The time from planting to first harvest is nine months for red-fleshed varieties and 12–14 months for yellow-fleshed varieties. The time from flowering to harvest is 22 weeks in the warm "summer" (mid-April to mid-October with an average air temperature of 82°F) and as much as 26 weeks during the cooler "winter" season (mid-October to mid-April with an average air temperature of 77°F). Papaya fruit are borne on peduncles attached to the main trunk of the papaya tree and are clustered, starting a few feet above the ground and extending up to a foot below the top of the plant (see Photo 1 on page 10).

Photo 1. Papaya fruit clustered around main trunk.

Adequate water is essential to the uninterrupted growth and production of papaya fruit. Most of the papaya produced in Hawai‘i is in the Puna District on the east (windward) side of Hawai‘i Island. In the Puna District, rainfall averages more than 110 inches annually and is distributed mostly evenly throughout the year. The soil in the Puna District is also very rocky, which provides for adequate drainage of water in the high rainfall area. Because of the combination of elevation, drainage, and rainfall, papaya is not irrigated in Puna. Elsewhere on the island (where rainfall is less abundant and soils are not as well drained) and on the other islands, drip irrigation is supplied to papaya orchards. It is extremely important that soil drainage is adequate when establishing a new papaya orchard in order to minimize the potential for development of root diseases. A soil pH of 5.5 to 6.5 is optimal for papaya production.

Papaya plants and fruit require protection from wind for production of high quality fruit. Fruit can be scratched and scarred under windy conditions. Some wind and air movement within an orchard is desirable, because air movement minimizes the buildup of excessive free moisture and high humidity, which favor the development of papaya diseases. Care must be taken when constructing and planting windbreaks so that air movement is not stopped completely.

In the production of papaya, fertilizer schedules and practices differ between the porous rocky soil of Puna and the growing areas that have highly-developed deep clay soils. In general, the greater the drainage, the more frequently fertilizers need to be applied. Precise nutritional needs of papaya can be determined by tissue analysis and fertilizers applied accordingly. Because of high rainfall in Puna, fertilizer efficiency is

increased with smaller applications at shorter intervals. Generally in Puna, fertilizer is applied at 1½-month intervals from age 0 to 19 months and at 2-month intervals thereafter. When papaya is grown in soil, fertilizer is applied in the hole before transplanting and as a topdressing after planting.

The Kapoho Solo variety of papaya has dominated production in Hawai‘i because of its size, quality, and shipping ability. The Kapoho Solo papaya has largely been replaced by the genetically engineered variety known as Rainbow, which is the progeny of Kapoho Solo. The Rainbow variety has some of the same qualities and characteristics of the Solo papayas but is engineered to resist papaya ringspot virus. Other varieties grown in Hawai‘i include the Kamiya and the Sunrise and Sunset Solo types.

Papaya production requires extensive hand labor. Planting, thinning, fertilization, and harvesting tasks are all performed by hand. Pest control also requires hand labor, for example when herbicides are applied by backpack sprayers (a common practice for weed control in Hawaiian papaya fields). Papaya plantings can be maintained for up to 3 years or until they become too tall to harvest.

Major Pests of Papaya

The most economically important pest disorder affecting papaya is the papaya ringspot virus (PRSV). PRSV is transmitted by aphids and crippled the industry in the early 1990s.

The most important insect pest of papaya is the white peach scale (*Pseudaulacaspis pentagona*), a relatively recent introduction that is currently found only on the islands of Hawai‘i and Kaua‘i. White peach scale is a serious postharvest pest and can result in rejection of export shipments if found. Several species of mites—broad mite (*Polyphagotarsonemus latus*), flat mite (*Brevipalpus phoenicis*), spider mites (*Tetranychus cinnabarinus*, *Eutetranychus banksi*, and *Panonychus citri*), and leaf edgeroller mite (*Calacarus flagelliseta*)—occur on papaya and can continuously attack papaya, making them the most persistent arthropod pest control maintenance challenge. The papaya mealybug (*Paracoccus marginatus*) is an emerging insect pest that is currently found on the islands of Maui, Moloka‘i, and O‘ahu. The papaya mealybug can kill papaya plants under heavy infestation.

Two species of nematodes, reniform (*Rotylenchulus reniformis*) and root knot (*Meloidogyne incognita*) are economically important pests of papaya under irrigated papaya production. These microscopic roundworms attack the root systems of the plant and impair water and nutrient uptake. Heavy nematode infestations can cause wilting, stunting, decreased plant vigor, reduced yields, and shortening of the productive life of a papaya tree.

Anthracnose fruit rots are a major disease of papaya that results in poor quality fruit and reduced shelf life. Fruit, stem, and root rots caused by *Phytophthora palmivora* can result in the death of papaya trees and is especially challenging to control in clay or mineral soils. Powdery mildew (*Oidium caricae*) is a relatively constant fungal disease

that affects papaya leaves, causing them to turn yellow and drop and resulting in reduced fruit brix (sweetness).

Integrated Insect Pest Management in Papayas

In Hawai‘i papaya is attacked by a complex of pests and diseases that impact plant health, reduce yields, and pose phytosanitary risks. Brief notes on some of the most significant papaya pests are provided below.

The most significant insect pests are aphids (various species) that are vectors of papaya ringspot virus (PRSV), a non-persistent virus. PRSV causes massive losses in papaya production and almost extirpated papaya production in Hawai‘i. Genetically engineered (GE) varieties of papaya were developed that provide effective protection against PRSV. While many growers have implemented planting with GE papaya varieties and have had great success, there remain issues with export of GE to Japan. Also, organic farmers wishing to produce papaya cannot use GE varieties. Thus, while GE varieties provide an effective solution for a large part of the industry, there is a need for alternative approaches to managing PRSV and its vectors.

A recently established pest in Hawai‘i, the papaya mealybug (*Paracoccus marginatus*) is currently causing substantial damage on Maui, O‘ahu, and Moloka‘i and has become established in the Puna area where it is starting to spread within and among farms. Papaya mealybug attacks the foliage and fruit of papaya plants, causing the fruits to be unmarketable, and eventually kills plants completely if left unchecked. Biological control of *P. marginatus* can be very effective, but only one parasitoid is currently established on this insect in Hawai‘i. Insecticide control options include malathion, imidacloprid, and buprofezin, all of which have known non-target impacts on natural enemies.

White peach scale (*Pseudaulacaspis pentagona*) has been established on papaya in Hawai‘i since 1997 and was restricted to the Puna area until recently. In 2007, white peach scale was recorded on papaya on O‘ahu. A number of predatory Coccinellidae and some parasitoids attack white peach scale but do not suppress populations effectively. A classical biological control agent is currently in quarantine, and permission is being sought by the USDA-Agricultural Research Service Pacific Basin Agriculture Research Center (PBARC) for release of the parasitoid. Growers apply insecticides to suppress scales, and classical biological control is under investigation.

Stevens leafhopper (*Empoasca stevensi*) is a phloem-feeder that causes hopper burn, which can result in severe stunting of young plants. It has been observed (M. Nishina, personal communication) that imidacloprid applications made in efforts to control leafhoppers on papaya result in outbreaks of mites.

Insect pests receiving the most attention currently are papaya mealybug and white peach scale. Papaya mealybug biological control is being implemented through mass-rearing of *Anagyrus loecki* (Hymenoptera: Encyrtidae) at the University of Hawai‘i and redistribution of the wasps to various locations. Releases have been made in the Puna

area and on Molokaʻi and Oʻahu to date. Monitoring in these sites has shown that the wasps have become established, albeit at low densities initially, and that they appear to be dispersing among infested areas.

White peach scale monitoring was conducted during the past three years to determine current distribution of the pest in Hawaiʻi and to assess to what extent natural enemies were attacking populations. Although the surveys showed that Coccinellidae and Hymenoptera were attacking the scales, they did not suppress them effectively. PBARC researchers Peter Follett and Robert Hollingsworth have conducted research on a potential classical biological control agent, which is currently in quarantine in Hawaiʻi. Host specificity trials have been completed, and permission has been requested for releases to be made.

The Hawaiʻi Area-Wide Fruit Fly Program includes papaya production areas in its application. The program includes the use of trapping technology for fruit fly suppression, baits applied to surrounding vegetation, and in-field insectaries to enhance populations of tephritid biological control agents.

Many growers do not practice IPM as a conscious effort, but do apply a variety of pest suppression methods, often because of the dearth of labeled insecticide products or the costs associated with using insecticides. Sanitation (e.g. roguing PRSV infected plants and removal of unsaleable fruit) is an important IPM practice that is used extensively. Major issues that require attention in terms of insect IPM in papaya in Hawaiʻi include alternative management measures for vectors of PRSV; papaya mealybug management; white peach scale management; and integration of management options for leafhoppers and mites. The development of multiple-pest decision tools would be of great value to papaya growers in Hawaiʻi.

Emerging Pest Issues

Papaya mealybug. Since the workshop, papaya mealybug was found on Kauaʻi in August 2006, and in October 2006 it was found to be established on Hawaiʻi Island. Papaya mealybug infestations are widespread throughout the islands of Maui and Oʻahu. On Hawaiʻi Island, mealybug infestations have been found on the west side of the island, and in March 2007 they were found in lower Puna. On Kauaʻi, infestations have been found on the southern part of the island. Because effective chemical control of papaya mealybug is difficult to achieve, this may be one of the most important insect pests of papaya in Hawaiʻi. In addition to damage to the plants, mealybugs found on fruit can cause the fruit to be rejected at the packing plant.

Thrips. *Thrips parvispinus* has been found on papaya in the Puna District, and feeding symptoms appear to be correlated with foliar and fruit injury as well as flower drop. Further investigation is necessary to confirm this association. *T. parvispinus* is polyphagous (feeds on many different plants) and has been reported to occur on papaya in Malaysia.

Internal yellowing (IY). This bacterial disease of ripe papaya fruit that is caused by the enteric bacterium *Enterobacter cloacae* is not a new disease, but it is an emerging food safety concern. *E. cloacae*-infected fruit can affect the coliform bacterial counts of papaya cube products and may be the limiting factor in this emerging fresh-cut fruit or frozen products industry. Counts exceeding a product-specific food safety guideline limit for coliforms (less than 100 colony-forming units per gram) can result in product rejection.

OUTLINE OF PLAN

The following is a pest-by-pest analysis of the current pest management practices in papaya production in Hawai‘i. Nonchemical, cultural, and biological control measures are also discussed. A “Critical Needs” list for research, regulatory, and education needs is included with each pest analysis. Pests are presented in order of economic importance within each pest section. There is no attempt to prioritize importance between pest groups (e.g., insects and mites vs. nematodes, or nematodes vs. pathogens).

INSECT AND MITE PESTS

1. White peach scale (*Pseudaulacaspis pentagona*)

White peach scale is potentially the most destructive insect pest of papaya, because its presence can lead to the rejection of export shipments. Currently, white peach scale is found only on the islands of Hawai‘i and Kaua‘i. Under heavy infestation, colonies of white peach scale can progress up from the bottom of the tree trunk into the fruit, causing poor fruit quality and weakening the overall plant. The impact from this insect pest is most severe on older plants. Where this insect is found, it is a pest year-round and must be controlled throughout all stages of papaya growth and production.

Insecticides currently registered:

- Azadirachtin (Aza-Direct, Azatin, Azatrol, Ecozin)
  - Efficacy: not known
  - Advantages: safe; organically approved
  - Disadvantages: expensive; effectiveness is not known

- Imidacloprid (Admire Pro, Provado)
  - Efficacy: not known; seldom used; known to work well on similar insect pests on other crops
  - Limiting factors: Admire Pro has a 6-day PHI; Provado has a 7-day PHI
  - Advantages: safe for handlers; target-specific; soft on beneficials
  - Disadvantages: expensive; limited applications per year; Provado has been observed to cause an explosion of mite populations

- Malathion (Malathion 8 Aquamul, Malathion 5 EC, 5 lb. Malathion Spray)
  - Efficacy: reasonably efficacious, needs good coverage and repeated applications
  - Advantages: inexpensive; broad spectrum of control
  - Disadvantages: broad spectrum insecticide; hard on beneficials; strong smell; organophosphate compound; EC formulation can burn the leaves

- Neem oil (70% Neem oil, Agroneem, Bon-Neem, Trilogy)
  - Efficacy: not very effective
  - Advantages: safe; organically approved
  - Disadvantages: expensive

- Petroleum oil (BioCover UL)
  - Efficacy: reasonably efficacious; needs good coverage and repeated applications
  - Advantages: environmentally friendly; soft on beneficials; safe for handler; fungicidal activity; inexpensive
  - Disadvantages: do not spray on fruit (possible phytotoxicity)

Other pest management aids:

- Vapor heat treatment (postharvest) for harvested fruit
- Forced hot air treatment (postharvest)
- Irradiation (postharvest)

Natural enemies:

- Predator beetle, *Cybocephalus nipponicus*, found on Hawai‘i Island

Pipeline pest management tools:

- A parasitic wasp, *Encarsia berlesei*, is being targeted for importation by USDA-ARS
- Buprofezin (Applaud): Tolerance petition submitted to EPA, August 2005; 3-day PHI proposed

Critical needs list for white peach scale:

Research:

- Research effectiveness of registered pesticides
- Determine if there are any environmental factors that affect distribution

Regulatory:

- Register Buprofezin (Applaud)
- Allow for importation of natural enemies, especially parasitoids

Education:

- Timing of insecticide application relative to white peach scale biology

2. **Mites*:* broad mite** (*Polyphagotarsonemus latus*), **papaya leaf edgeroller mite** (*Calacarus flagelliseta*), **red and black flat mite** (*Brevipalpus phoenicis*), **Tuckerellid mites** (*Tuckerella ornata, T. pavoniformis*), **carmine spider mite** (*Tetranychus cinnabarinus*), **Texas citrus mite** (*Eutetranychus banksi*), **citrus red mite** (*Panonychus citri*)

In general, mites can be very serious pests when not controlled. Damage by mites includes fruit scarring, leaf drop, and loss of plant vigor. Heavy mite pressure can also reduce fruit quality by reducing fruit sugar. Mites can be found in all growing areas at various times of the year. Some mite species prefer hot and dry conditions, but others thrive in rainy growing areas such as the Puna District on Hawai‘i Island. Citrus red mite is the predominant mite pest on Hawai‘i Island. Broad mites tend to be the main mite pest species in cooler areas. The Sunrise variety of papaya is more susceptible to mites than other varieties. No formal economic thresholds for treatment have been developed.

Insecticides/miticides currently registered:

- Fenbutatin-oxide (Vendex 50WP)
  - Efficacy: good control with one application
  - Limiting factors: restricted use pesticide, PHI is 7 days
  - Advantages: long residual activity
  - Disadvantages: expensive; restriction on how much can be applied in one year; the development of resistance is likely if used frequently

- Sulfur (Kumulus DF, Sulfur 90W, Micro Sulf)
  - Efficacy: fair to good
  - Advantages: organically approved formulations; inexpensive
  - Disadvantages: strong smell; some handlers allergic to the product; can cause phytotoxicity when mixed with some surfactants and malathion (depending on formulation, do not mix with xylene-based malathion or any petroleum products); repeated applications required; corrosive to equipment; phytotoxicity is more likely if applied when air temperature is above 80°F

Other pest management aids:

- Biological control of spider mite by *Stethorus* beetle and other predatory mites/thrips
- Compost tea “microbe extract” used (organic)
- Maintain plant health to reduce susceptibility to mite attack
- Minimize malathion application to conserve natural enemies
- Full tree coverage when spraying with sulfur
- Provide a habitat for natural enemies

Pipeline pest management tools:

- Abamectin (Agri-mek): Residue study complete but on hold at IR-4; Florida project; 14-day PHI proposed
- Bifenazate (Acramite): Tolerance petition ready for submission to EPA; one application per season
- Fenpropathrin (Danitol): Using bridging data from avocado; final report completed, ready for submission to EPA; FL request; 3-day PHI proposed
- Pyridaben (Pyramite): Tolerance established September 2005; but use is for FL and Puerto Rico; PHI is 21 days, so not useful for Hawai‘i papaya growers; possible phytotoxicity to foliage

Critical needs list for mites:

Research:

- Need more non-restricted-use miticides
- In-field “insectaries” for natural enemies
- Development of non-pesticide control measures
- Develop papaya varieties that are mite-resistant
- Determine scouting and monitoring methods for early detection of mite infestation
- Determine treatment thresholds for mites

Regulatory:

- Reduce PHI for Vendex
- Allow importation of natural enemies
- Stricter quarantine regulations and enforcement
- Product-specific pesticide licensing
- Convince registrants to print pesticide labels in various languages

Education:

- Recognition of natural enemies by growers and the use of selective pesticides to conserve natural enemies
- More effective training so that farmers can pass the restricted use pesticide (RUP) exam
- Re-evaluate RUP exam so that growers can pass
- Continue grower education on control efforts that don’t require pesticides

3. Stevens leafhopper (*Empoasca stevensi*)

Stevens leafhopper can be a serious problem under dry conditions. The leafhopper can cause severe leaf edge chlorosis and necrosis as well as wrinkling and cupping of leaves and leaf drop and stunting of young plants. All of these symptoms, taken together, are known as hopper burn. Symptoms of hopper burn on papaya are similar to papaya ringspot virus (PRSV).

Insecticides currently registered:

- Azadirachtin (Aza-Direct, Azatin, Azatrol, Ecozin, Ornazin)
  - Efficacy: not known
  - Advantages: safe; organically approved
  - Disadvantages: expensive; effectiveness is not known

- Imidacloprid (Admire Pro, Provado)
  - Efficacy: good to very good; good spray coverage is required for Provado
  - Limiting factors: Admire Pro has a 6-day PHI; Provado has a 7-day PHI
  - Advantages: safe for handlers; target-specific; soft on beneficials
  - Disadvantages: expensive; limited applications per year; Provado has been observed to cause an explosion of mite populations

- Malathion (Malathion 8 Aquamul, Malathion 5 EC, 5 lb. Malathion Spray)
  - Efficacy: reasonably effective; good spray coverage required
  - Advantages: inexpensive; broad spectrum of control
  - Disadvantages: broad spectrum insecticide; hard on beneficials; strong smell; organophosphate compound; EC formulation can burn the leaves

- Neem oil (70% Neem oil, Agroneem, Bon Neem, Trilogy)
  - Efficacy: poor
  - Advantages: organically approved formulations; generally safe for the environment; soft on beneficials; some fungicidal activity similar to petroleum oil
  - Disadvantages: harmful to beneficial soil fungi; expensive

- Pyrethrins (Pyganic EC 1.4, Pyganic EC 5.0, Pyganic Pro, Pyrenone)
  - Efficacy: not known, not commonly used
  - Advantages: rapid knockdown; some formulations organically approved; broad spectrum insecticide; 12-hour PHI
  - Disadvantages: very short residual activity; hard on beneficials and natural enemies; skin irritant; expensive

- Pyrethrins + rotenone (Pyrellin)
  - Efficacy: not known; not commonly used

- Advantages: rapid knockdown; some formulations organically approved; broad spectrum insecticide; 12-hour PHI
- Disadvantages: very short residual activity; hard on beneficials and natural enemies; skin irritant; expensive

Other pest management aids:

- None

Pipeline pest management tools:

- Imidacloprid (Provado) residue study ongoing to change PHI from 7 days to 1 day

Critical needs list for Stevens leafhopper:

Research:

- Relationship between Provado use for control of Stevens leafhopper and exploding mite populations
- Determine effective egg parasitoids
- Determine efficacy of registered products

Regulatory:

- Reduce Provado PHI to 1 day

Education:

- Work with growers to determine efficacy of registered products

4. Fruit flies: Mediterranean fruit fly (*Ceratitis capitata*), **oriental fruit fly** (*Bactrocera dorsalis*), **melon fly** (*Dacus cucurbitae*)

Fruit flies can be a serious problem if fruit is harvested for local market after color break has occurred (green to yellow). If the fruit have been harvested before color break, and they are destined for local Hawai‘i markets, then fruit flies are a minor problem. The presence of fruit flies or fruit fly eggs is a very serious problem for export because of strict quarantine restrictions in target markets (e.g., California and Japan). Irradiation and vapor heat treatment are ways in which papaya can be “sterilized” for export sale. Fruit flies are found on all islands and in all growing areas in Hawai‘i. Some field management of fruit flies is necessary, but most control occurs postharvest.

Insecticides currently registered:

- Malathion (Malathion 8 Aquamul, Malathion 5 EC, 5 lb. Malathion Spray) + bait

- Efficacy: fair to good
- Limiting factors: only for use as a field border application
- Advantages: inexpensive
- Disadvantages: worker safety issues; strong smell; organophosphate compound

- Naled + lure (Dibrom + Cuelure, methyl eugenol)
  - Efficacy: good
  - Limiting factors: Special Local Needs registration allows for border treatment only
  - Advantages: inexpensive
  - Disadvantages: worker safety issues

- Spinosad (Success, GF-120)
  - Efficacy: very good
  - Limiting factors: short residual activity
  - Advantages: reduced risk to handlers; soft on beneficials; GF-120 is registered for use in organic farming
  - Disadvantages: expensive; washes off easily during rainy periods

Other pest management aids:

- Hawaii Areawide Fruit Fly Pest Management Program (includes attract-and-kill stations, field sanitation, biocontrol, and sterile male fly releases)
- Irradiation to kill or sterilize fruit fly larvae (acceptable in U.S. markets)
- Vapor heat treatment disinfestation procedure (acceptable by U.S. and Japan markets)
- Forced hot air treatment (acceptable by U.S. and New Zealand markets)
- Shipment to Canada without postharvest treatment is allowed

Pipeline pest management tools:

- Radio frequency as a potential postharvest quarantine treatment
- Sprayable formulation of methyl eugenol plus spinosad
- EPA is considering registration of different male annihilation products for field treatment

Critical needs list for fruit flies:

Research:

- Varietal resistance to fruit flies
- Feasibility of fruit fly-free zones
- Systems approaches for management and quarantine
- Economic impact of fruit flies on papaya

Regulatory:

- Creation of fruit fly-free zones
- Stricter quarantine regulation and enforcement for host material coming into Hawai‘i

Education:

- Community education for management (including public service announcements, commercials, etc.)
- Economic impact of fruit flies
- Educate policy makers about importance of quarantine and exclusion for fruit fly management

5. Papaya mealybug (*Paracoccus marginatus*)
(*Note*: This is an emerging issue, and changes have occurred since the workshop was held. Papaya mealybug was found on Kaua‘i in August 2006, and in October 2006 it was found to be established on Hawai‘i Island.)

Papaya mealybug is an extremely destructive pest in papaya and has been observed on the islands of Maui, O‘ahu, and Moloka‘i. During feeding, this mealybug injects a toxin that can cause leaf yellowing (chlorosis), premature leaf and fruit drop, stunting, deformation, and buildup of honeydew. Seedlings are more susceptible than trees to damage from the papaya mealybug, which can kill the plants under heavy infestation. When mealybugs are found on the fruit, the fruit can be rejected at the packing plant. The papaya mealybug has numerous alternate hosts, including plumeria, hibiscus, avocado, citrus, tomato, eggplant, beans, and many weed species, which increases the difficulty of control. Additionally, the role of ants in the movement of mealybugs may intensify the infestation of the papaya mealybug.

Insecticides currently registered:

- Azadirachtin (Aza-Direct, Azatin, Azatrol, Ecozin)
  - Efficacy: not known
  - Advantages: safe; organically approved
  - Disadvantages: expensive; effectiveness is not known

- Imidacloprid (Admire Pro, Provado)
  - Efficacy: Admire Pro efficacy is not known; Provado efficacy is good; good, thorough spray coverage required; limited use; known to work well on similar insect pests on other crops
  - Limiting factors: Admire Pro has a 6-day PHI; Provado has a 7-day PHI
  - Advantages: safe for handlers; target-specific; soft on beneficials
  - Disadvantages: expensive; limited applications per year; Provado has been observed to cause an explosion of mite populations

- Malathion (Malathion 8 Aquamul, Malathion 5 EC, 5 lb. Malathion Spray)
  - Efficacy: good; good, thorough spray coverage required
  - Advantages: inexpensive; broad spectrum of control
  - Disadvantages: broad spectrum insecticide; hard on beneficials; strong smell; organophosphate compound; EC formulation can burn the leaves

- Petroleum oil (BioCover UL)
  - Efficacy: not known
  - Advantages: environmentally friendly; soft on beneficials; safe for handler; fungicidal activity; inexpensive
  - Disadvantages: effectiveness is not known; do not spray on fruit because of possible phytotoxicity

Other pest management aids:

- A parasitoid observed on Maui but not identified

Pipeline pest management tools:

- Two parasitoid species in quarantine

Critical needs list for papaya mealybug:

Research:

- Control measures for little fire ant that can be attracted by the papaya mealybug and can be an irritant to harvesters
- Examine compatible tank mixes
- Determine efficacy of registered products

Regulatory:

- Streamline regulatory process to allow for speedier introduction of natural enemies
- Regulate the inter-island movement of pests and hosts
- Approve ant control products for use in papaya fields

Education:

- Grower and community outreach for identification and management of papaya mealybug

6. Aphids: green peach aphid (*Myzus persicae*), melon aphid (*Aphis gossypii*), potato aphid (*Microsiphum euphorbiae*)

Papaya is not a good host for aphids but is extremely susceptible to papaya ringspot virus (PRSV), which is transmitted by various species of aphids. The spread of PRSV cannot be controlled by spraying for aphids on papaya trees. Reduction of overall aphid pressure may be achieved by controlling aphids in fields abutting papaya orchards. Symptoms of PRSV are described in the section on Pathogens and Diseases.

Insecticides currently registered:

- Azadirachtin (Aza-Direct, Azatin, Azatrol, Ecozin)
  - Efficacy: not known
  - Advantages: safe; organically approved
  - Disadvantages: expensive; effectiveness is not known

- Imidacloprid (Admire Pro, Provado)
  - Efficacy: not known; seldom used; known to work well on similar insect pests on other crops
  - Limiting factors: Admire Pro has a 6-day PHI; Provado has a 7-day PHI
  - Advantages: safe for handlers; target-specific; soft on beneficials
  - Disadvantages: expensive; limited applications per year; Provado has been observed to cause an explosion of mite populations

- Malathion (Malathion 8 Aquamul, Malathion 5 EC, 5 lb. Malathion Spray)
  - Efficacy: reasonably effective if spray contacts insects; good spray coverage required
  - Advantages: inexpensive; broad spectrum of control
  - Disadvantages: broad spectrum insecticide; hard on beneficials; strong smell; organophosphate compound; EC formulation can burn the leaves

- Petroleum oil (BioCover UL)
  - Efficacy: not known
  - Advantages: environmentally friendly; soft on beneficials; safe for handler; fungicidal activity; inexpensive
  - Disadvantages: effectiveness is not known

Natural enemies:

- Several species of parasitoid wasps

Pipeline pest management tools:

- None

Critical needs list for aphids:

Research:

- Need to understand movement of aphids into papaya fields
- Identify species of aphids that specifically transmit PRSV

Regulatory:

- None

Education:

- Outreach to general community on impact of PRSV and the importance of removing diseased plants immediately

7. Thrips: *Thrips parvispinus*
(*Note*: This is an emerging issue that has arisen since the workshop was held. Therefore, there are no critical needs identified in this workshop summary document.)

Although not yet confirmed to be a pest, this thrips species has been identified in papaya in Puna and has been associated with characteristic foliar and fruit injury and flower drop.

Insecticides currently registered:

- Azadirachtin (Aza-Direct, Azatin, Azatrol, Ecozin)
  - Efficacy: not known
  - Advantages: safe; organically approved
  - Disadvantages: expensive; effectiveness is not known

- Imidacloprid (Admire Pro, Provado)
  - Efficacy: not known
  - Limiting factors: Admire Pro has a 6-day PHI; Provado has a 7-day PHI
  - Advantages: safe for handlers; target-specific; soft on beneficials
  - Disadvantages: expensive; limited applications per year; Provado has been observed to cause an explosion of mite populations

- Malathion (Malathion 8 Aquamul, Malathion 5 EC, 5 lb. Malathion Spray)
  - Efficacy: efficacy unknown; good spray coverage required
  - Advantages: inexpensive; broad spectrum of control
  - Disadvantages: broad spectrum insecticide; hard on beneficials; strong smell; organophosphate compound; EC formulation can burn the leaves

- Spinosad (Success, Entrust)
  - Efficacy: apparently good (anecdotal); known to work well on similar insect pests on other crops
  - Limiting factors: only two applications per year
  - Advantages: safe for handlers; target-specific; soft on beneficials; Entrust is organically approved formulation
  - Disadvantages: expensive; limited applications per year

NEMATODES

Reniform (*Rotylenchulus reniformis*) and **root knot** (*Meloidogyne incognita*)

Nematodes are microscopic parasitic worms of plant roots. Reniform nematodes reduce root mass, and root knot nematodes cause swelling and gall formation in the roots, which prevents water and nutrient uptake. Nematode populations can be high in papaya without producing symptoms. Heavy nematode infestations can cause wilting, stunting, decreased plant vigor, reduced yields, and shortening of the productive life of a papaya tree. Nematodes are present year-round and are more of a problem on mineral soils than rocky soils. Best control of nematodes is obtained by pre-plant treatment.

Nematicides currently registered:

- 1-3-dichloropropene (Telone)
  - Efficacy: excellent
  - Limiting factors: pre-plant fumigant only (need special equipment)
  - Advantages: reasonable cost; broad spectrum control of soil-borne pests
  - Disadvantages: predictable groundwater contaminant; restricted use pesticide, tricky to apply—requires specialized equipment; B2 carcinogen

- Azadirachtin (Ecozin)
  - Efficacy: not effective
  - Advantages: safe; organically approved; low non-target toxicity
  - Disadvantages: expensive; ineffective against soil-borne nematodes

- Metam-sodium (Vapam)
  - Efficacy: good
  - Advantages: broad spectrum control; readily available; cost-effective method to control tough annual weeds, reduce nematode populations, and control soil- borne pathogens prior to planting; versatile product used for more than three decades
  - Disadvantages: allergic contact dermatitis is possible; inconsistent efficacy

- *Myrothecium verrucaria* (DiTera**)**
  - Efficacy: reported as effective but is a new product; not fully tested
  - Advantages: environmentally friendly; may be registered for organic use; low non-target toxicity; easy to apply; can be used as a pre- or post-plant treatment
  - Disadvantages: high level of management required for proper application; expensive at labeled rates

Other pest management aids:

- Weed-free bare-ground fallow
- Cover crops
- Avoid fields formerly planted to pineapple
- Inoculation of soil with beneficial nematodes
- Improve drainage
- Rotation to non-host crops
- Composting and green manures

Pipeline pest management tools:

- None

Critical needs list for nematodes:

Research:

- Investigate cover crops (varieties, duration)
- Determine beneficial/predator nematode species found in Hawai‘i
- Resistance management strategies
- Develop nematode-resistant varieties

Regulatory:

- Address regulatory hurdles to importation of beneficial/predator nematodes
- Restrict movement of pest nematodes between islands

Education:

- Training on how to rear and conserve on-farm beneficial/predator nematodes

SNAILS AND SLUGS

African snail (*Achatina fulica*), **brown slug** (*Vaginulus plebeius*), **two-striped slug** (*Veronicella cubensis*, *Meghimatium striatum*), **semi-slug** (*Parmarion martensi*)

Snails and slugs are pests of newly planted papayas. Entire plants can be destroyed by the feeding of these pests. Snails and slugs are found on all islands and are most serious in locations with high rainfall and the presence of abundant plant litter within a papaya field. African snail has also been observed in the fruit clusters and in the growing point of mature (fruit-bearing) papaya trees.

Molluscicides currently registered:

- Metaldehyde (Deadline)
  - Efficacy: excellent
  - Advantages: cost-effective; easy to apply
  - Disadvantages: can be poisonous to non-target organisms; use on or in papaya scheduled for cancellation by EPA

Other pest management aids:

- Weed-free bare-ground fallow
- Field sanitation

Pipeline pest management tools:

- None

Critical needs list for snails and slugs:

Research:

- Research other control measures for snails and slugs

Regulatory:

- None

Education:

- None

DISEASES

1. Papaya Ringspot Virus

Papaya ringspot virus (PRSV) is the most serious disease problem of papaya in Hawai‘i. PRSV nearly destroyed the papaya industry in the 1990s. There is no naturally-occurring resistance to this disease, and the major management measure has been the production of genetically-modified papaya that has incorporated resistance to the disease into specific varieties. PRSV is spread by aphids and occurs on the islands of O‘ahu, Maui, and Hawai‘i. PRSV presence is year-round, which increases the likelihood of the disease developing resistance to the transgenic protection. Symptoms of PRSV infection are mottled fruit (circular patterns), yellow mosaic pattern on leaves, and “shoestring” leaves (Photo 2).

Photo 2. Severe symptoms of Papaya Ringspot Virus.

Pesticides currently registered:

Insecticides are registered for control of the aphid vector(s) of PRSV, but they do not control or prevent the transmission of the disease.

Other pest management aids:

- Transgenic resistance
- Surveying and roguing (infected trees cut down and destroyed)
- Genetically-resistant cultivars
- Large buffer areas between fields—isolation
- Windbreaks

Pipeline pest management tools:

- None

Critical needs list for PRSV:

Research:

- Variety development
- Resistance to new strains of virus (breeding)
- Study the (aphid) vector of this virus
- Traditional breeding for resistance

Regulatory:

- Regulation of any new transgenic cultivars
- Regulation for inter-island transfer of growing materials
- Change the regulations to allow eradication of backyard infected trees
- Stricter enforcement where quarantine regulation exists

Education:

- Community education—inform backyard growers about identification and destruction of infected trees
- Educate domestic and international consumers

2. Fruit and stem-end rots: anthracnose and chocolate spots (*Colletotrichum gloeosporioides*), **stem-end and body rots** (*Mycosphaerella caricae*, *Phoma caricae-papayae*, *Lasiodiplodia theobromae*, and *Phomopsis caricae-papayae*)

Most fruit rots occur as postharvest diseases and are not apparent at time of harvest. Anthracnose and chocolate spots, both caused by *Colletotrichum gloeosporioides*, become visible only when fruits ripen. (The fungus becomes established earlier but remains latent under the fruit cuticle.) Other fruit and stem-end rots occur when spores of fruit-rotting fungi residing on papaya fruit are provided entry points, such as mechanical or other injuries that occur during the harvesting, transporting, treating, and packing processes. Fruit-rotting organisms are found on all islands and in all growing regions.

Fungicides currently registered:

- Azoxystrobin (Abound)
  - Efficacy: good
  - Advantages: reduced risk; safe to handle; slightly systemic
  - Disadvantages: very expensive; not widely used (used when others fail); potential for resistance to develop

- Chlorothalonil (Bravo, Chloronil, Equus)
  - Efficacy: good
  - Limiting factors: phytotoxicity can occur on treated fruit when put through post- harvest heat treatment
  - Advantages: inexpensive
  - Disadvantages: can create burning when weather is hot; skin irritant; can cause spotting when treated with vapor heat

- Copper hydroxide (Champ—various formulations, Kocide—various formulations, Nu-Cop—various formulations)
  - Efficacy: fair
  - Limiting factors: EPA *might* limit number of applications as a result of the reregistration process
  - Advantages: relatively inexpensive; adheres to plant tissue; broad spectrum
  - Disadvantages: leaves blue residue on fruit; eye hazard; can kill beneficial fungi

- Mancozeb (Dithane, Mancozeb, Manex, Manzate, Penncozeb, Pentathlon)
  - Efficacy: good
  - Limiting factors: have to make frequent applications
  - Advantages: inexpensive; tank mixes well with other pesticides; very little resistance reported; controls other diseases
  - Disadvantages: strong smell; skin irritant

- Thiabendazole (TBZ)
  - Efficacy: good
  - Advantages: postharvest stem end rot treatment; TBZ is more effective when preceded by hot water spray or dip
  - Disadvantages: Japan will not accept papaya treated with TBZ; export limitations

Other pest management aids:

- Postharvest hot water dip treatment (120°F for 20 minutes)
- Field sanitation: remove diseased fruits
- Prune older, drooping leaves for better spray coverage of fruit column
- Selection and use of appropriate spray adjuvant (spreader/sticker)

Pipeline pest management tools:

- New packing materials to reduce injury and reduce humidity to extend postharvest fruit life
- Boscalid + pryaclostrobin (Pristine): Using bridging data from avocado; manufacturer and QA reviewing petition; need to conduct more local efficacy testing

- Cyprodinil + fludioxonil (Switch): Efficacy trials ongoing; tolerance *could* be covered by avocado; 0-day PHI
- Famoxadone + cymoxanil (Tanos): Efficacy trials ongoing; tolerance *could* be covered by avocado; 3-day PHI

Critical needs list for fruit rots—anthracnose and chocolate spots:

Research:

- Nonchemical treatments
- Chemical treatments, especially postharvest, that will inactivate latent infections of *Colletotrichum*
- Host plant resistance

Regulatory:

- Registration of pipeline products

Education:

- Timing of treatments for fruit rots (don't wait until symptoms appear)
- Postharvest handling of papaya fruits, e.g., management of temperature control

3. Phytophthora blight, stem rot, fruit rot, and root rot (*Phytophthora palmivora*)

Phytophthora blight and root rot are serious problems during the rainy season or in areas where rainfall is regular and frequent and soil drainage is poor. Phytophthora blight can kill trees and result in total loss of an orchard. Stem and fruit rot are also serious diseases caused by *Phytophthora palmivora*. Lesions on the trunk of the papaya tree, associated with white flecking on the bark, are symptomatic of *Phytophthora* invasion. The lesions advance to the core of the central trunk, eventually killing the tree. Fruit infected with *Phytophthora* develop white spores and rot. As with other Phytophthora diseases, the spores can become soilborne and quickly invade the root system under conditions favorable for the disease's development. Infection can occur during all stages of papaya tree growth, but it is especially critical to control it during the seedling stage. This disease is found on all islands and in all papaya growing areas.

Fungicides currently registered:

- Metalaxyl-M (mefenoxam) (Ridomil Gold)
  - Efficacy: very good
  - Limiting factors: prone to resistance developing
  - Advantages: very effective
  - Disadvantages: expensive

- Metalaxyl-M (mefenoxam/copper hydroxide) (Ridomil Gold Copper)
  - Efficacy: very good
  - Limiting factors: prone to resistance developing
  - Advantages: extended control range; foliar spray; very effective
  - Disadvantages: expensive

- Metam-sodium (Vapam)
  - Efficacy: good
    Limiting factors: pre-plant only
  - Advantages: broad spectrum control; readily available; cost-effective method to control tough annual weeds, reduce nematode populations, and control soil- borne pathogens prior to planting; versatile product used for more than three decades
  - Disadvantages: allergic contact dermatitis is possible; inconsistent efficacy

- Mono- and Di-Potassium Salts of Phosphorous Acid (Fosphite)
  - Efficacy: good
  - Advantages: systemic control
  - Disadvantages: prone to resistance development

Other pest management aids:

- Planting in "virgin" lands
- "Virgin" soil technique
- Liming to reach suitable soil pH
- Increase tree spacing

Pipeline pest management tools:

- Famoxadone + cymoxanil (Tanos): Efficacy trials ongoing; tolerance *could* be covered by avocado; 3-day PHI proposed

Critical needs list for Phytophthora:

Research:

- Need alternative management tools
- Develop resistant papaya variety
- Identify chemical alternatives

Regulatory:

- Registration of Tanos

Education:

- Remind growers about a management/control/spray program
- Update publications

4. Asperisporium black spot of papaya (*Asperisporium caricae*)

Asperisporium black spot of papaya is found on all islands and in all growing locations. It is present year-round but increases in intensity and pressure during the wet and cool "winter" (mid-October to mid-April) season in Hawai'i. Regular calendar fungicide sprays are required to maintain control of the disease. Spots occur on the lower surface of leaves and on fruit. If not controlled, leaf function is damaged and defoliation can occur, which reduces fruit sugar and quality. Red-fleshed varieties of papaya are most susceptible.

Fungicides currently registered:

- Azoxystrobin (Abound)
  - Efficacy: good
  - Advantages: reduced risk; safe to handle; slightly systemic
  - Disadvantages: very expensive; potential for resistance development, therefore must be used in rotation with fungicide with different mode of action

- Basic copper sulfate (Basic Copper)
  - Efficacy: fair
  - Limiting factors: EPA *might* limit number of applications as a result of the reregistration process
  - Advantages: inexpensive; broad spectrum; approved for organic production; kills/repels slugs and snails (indirectly);
  - Disadvantages: leaves blue-green residue on fruit; effectiveness is questionable; extreme eye hazard; can kill beneficial fungi

- Copper hydroxide (Champ—various formulations, Kocide—various formulations, Nu-Cop—various formulations)
  - Efficacy: fair
  - Limiting factors: EPA *might* limit number of applications as a result of the reregistration process
  - Advantages: relatively inexpensive; broad spectrum
  - Disadvantages: leaves blue residue on fruit; effectiveness is questionable; eye hazard; can kill beneficial fungi

- Copper oxide (Nordox)
  - Efficacy: fair

  Limiting factors: EPA *might* limit number of applications as a result of the reregistration process
  - Advantages: relatively inexpensive; broad spectrum
  - Disadvantages: leaves blue residue on fruit; effectiveness is questionable; can kill beneficial fungi

- Mancozeb (Dithane, Mancozeb, Manex, Manzate, Penncozeb, Pentathlon)
  - Efficacy: good
  - Limiting factors: current industry standard; protectant only; have to make frequent applications
  - Advantages: inexpensive; tank mixes well with other pesticides; very little resistance reported; controls other diseases
  - Disadvantages: strong smell; skin irritant

- Sulfur (Kumulus DF, Sulfur 90W, Micro Sulf)
  - Efficacy: good
  - Advantages: organically approved formulations; inexpensive
  - Disadvantages: strong smell; can cause phytotoxicity when mixed with some surfactants and malathion (depending on formulation, do not mix with xylene-based malathion or any petroleum products); corrosive to equipment; phytotoxicity is more likely if applied when air temperature is above 80°F.

Other pest management aids:

- Prune older droopy-leaved trees to increase air circulation and for better spray coverage on the fruit column
- Directed spray to leaves and fruit
- Thinning of fruit
- Beneficial fungal parasite that attacks the black spot fungus

Pipeline pest management tools:

- None

Critical needs list for Asperisporium black spot of papaya:

Research:

- Need alternative management tools
- Develop resistant papaya varieties
- Identify chemical/pesticide alternatives

Regulatory:

- Support registration of new pesticide products

Education:

- Remind growers about a good management/control/spray program
- Update publications

5. Powdery mildew (*Oidium caricae*)

Powdery mildew is a fungal disease that is present year-round but worse during periods of moderate temperatures (65–90°F) and humidity. If the disease is left untreated, severely infected leaves will dry and fall prematurely, causing loss in plant vigor and reduced brix and quality of fruit. Powdery mildew is mostly a problem in orchards on O‘ahu and Kaua‘i but has been observed on the other islands. Red-fleshed varieties (e.g., Sunrise) seem to be the most susceptible.

Fungicides currently registered:

- Azoxystrobin (Abound)
  - Efficacy: poor
  - Advantages: reduced risk; safe to handle; somewhat fewer sprays than with sulfur or carbonic acid
  - Disadvantages: very expensive; effectiveness is unknown; potential for resistance development; must be used in rotation with fungicide from a different class

- Potassium bicarbonate (Kaligreen)
  - Efficacy: not fully evaluated
  - Advantages: somewhat effective; safe to handle
  - Disadvantages: relatively expensive; frequent sprays needed in some locations

- Sulfur (Kumulus DF, Sulfur 90W, Micro Sulf)
  - Efficacy: fair to good
  - Advantages: organically approved formulations; inexpensive
  - Disadvantages: strong smell; some handlers allergic to the product; can cause phytotoxicity when mixed with some surfactants and malathion (depending on formulation, do not mix with xylene-based malathion or any petroleum products); repeated applications required; corrosive to equipment; phytotoxicity is more likely if applied when air temperature is above 80°F

Other pest management aids:

- Removal of old/fallen, diseased leaves (desirable but not practical)

Pipeline pest management tools:

- Myclobutanil (Rally): Tolerance petition submitted to EPA, March 2003; awaiting EPA's toxicological review of triazole fungicides
- Trifloxystrobin (Flint): All data received by IR-4 Headquarters; 0-day PHI proposed
- Triflumizole (Procure): Field residue trials ongoing

Critical needs list for powdery mildew:

Research:

- Need alternative management tools
- Develop resistant papaya varieties
- Identify chemical alternatives

Regulatory:

- Registration of pipeline products

Education:

- Remind growers about a good management/control/spray program
- Update Cooperative Extension Service publications

6. Pythium root rot

Pythium root rot is a significant problem when replanting a field previously planted to papaya. When conditions are favorable for its development Pythium can destroy papaya seedlings. Heavy extended infestations of Pythium can also debilitate and kill fruit-bearing papaya trees. Pythium is especially challenging during the cool, wet rainy season (mid-October to mid-April) and in locations where high amounts of rainfall are received. Control is needed during all crop stages where wet or soggy conditions prevail. The disease is found on all islands.

Fungicides currently registered:

- Metalaxyl-M (mefenoxam) (Ridomil Gold)
  - Efficacy: excellent
  - Limiting factors: disease resistance can be a problem with maintaining efficacy; can only be used on the non-bearing stage of the papaya tree
  - Advantages: prevents root rot
  - Disadvantages: expensive; hazardous to humans and domestic animals; toxic to aquatic invertebrates and wildlife; potential groundwater contaminant

- Metam-sodium (Vapam)
  - Efficacy: good
  - Limiting factors: pre-plant only
  - Advantages: broad spectrum control; readily available; cost-effective method to control tough annual weeds, reduce nematode populations, and control soil-borne pathogens prior to planting; versatile product used for more than three decades; has been shown to reduce competition, improve plant growth, and increase yields
  - Disadvantages: allergic contact dermatitis is possible; inconsistent effectiveness

Other pest management aids:

- Use of anti-penetrants
- "Virgin" soil technique
- Proper field selection and preparation to avoid low, poorly-drained areas or to provide good drainage
- Properly lime fields to insure pH is within recommended range

Pipeline pest management tools:

- None

Critical needs list for Pythium root rot:

Research:

- Develop resistant varieties
- Develop and/or test new chemical pesticides

Regulatory:

- Continue to work with EPA on registration of new control products

Education:

- Develop extension publication

7. Cercospora black spot (*Cercospora papayae*)

Cercospora black spot caused by *Cercospora papayae* is a minor disease of papaya that is easily controlled when spraying for Phytophthora or Asperisporium black leaf spot of papaya. Spotting mostly occurs on the leaves and is small, gray, and circular. Under heavy infection leaves turn yellow and may drop prematurely, affecting brix and quality

of the fruit. Damage to the fruit itself is mostly cosmetic, and fruit rot is not associated with this disease. Black spot is found throughout the islands.

Fungicides currently registered:

- Azoxystrobin (Abound)
  - Efficacy: good
  - Advantages: reduced risk; safe to handle; slightly systemic
  - Disadvantages: very expensive; must be rotated with fungicide with a different mode of action

- Basic copper sulfate (Basic Copper)
  - Efficacy: fair
  - Limiting factors: EPA *might* limit number of applications as a result of the reregistration process.
  - Advantages: inexpensive; broad spectrum; approved for organic production; kills slugs and snails (indirectly)
  - Disadvantages: leaves blue-green residue on fruit; effectiveness is questionable; extreme eye hazard; can kill beneficial fungi

- Copper hydroxide (Champ—various formulations, Kocide—various formulations, Nu-Cop—various formulations)
  - Efficacy: fair
  - Limiting factors: EPA *might* limit number of applications as a result of the reregistration process
  - Advantages: relatively inexpensive; broad spectrum
  - Disadvantages: leaves blue residue on fruit; effectiveness is questionable; eye hazard; can kill beneficial fungi

- Copper oxide (Nordox)
  - Efficacy: fair
  - Limiting factors: EPA *might* limit number of applications as a result of the reregistration process
  - Advantages: relatively inexpensive; broad spectrum
  - Disadvantages: leaves blue residue on fruit; effectiveness is questionable; can kill beneficial fungi

- Mancozeb (Dithane, Mancozeb, Manex, Manzate, Penncozeb, Pentathlon)
  - Efficacy: good
  - Limiting factors: have to make frequent applications
  - Advantages: inexpensive; tank mixes well with other pesticides; very little resistance reported; controls other diseases
  - Disadvantages: strong smell; skin irritant

Other pest management aids:

- Thin trees to increase air circulation
- Directed spray to leaves and fruit

Pipeline pest management tools:

- None

Critical needs list for Cercospora black spot:

Research:

- Need alternative management tools
- Develop resistant papaya varieties
- Identify chemical/pesticide alternatives

Regulatory:

- Support registration of new pesticide products

Education:

- Remind growers about a good management/control/spray program
- Update publications

8. Rhizopus soft rot (*Rhizopus stolonifer*)

Rhizopus stolonifer is an opportunistic fungal organism that colonizes wounds created during harvest/postharvest of papaya. Rhizopus soft rot is one of the most destructive postharvest fungal pathogens of papaya because of its ability to rapidly develop and spread. Dormant spores are heat-resistant, and hot water treatments for postharvest disease control can become ineffective if inoculum is allowed to accumulate. Disease outbreaks can be difficult to control because of time and expense involved. Disease symptoms are often not seen until after papayas are shipped and received at their destination. The disease is more serious during rainy weather or in wet growing areas. Rhizopus soft rot is found on all islands. Under extended rainy weather conditions, infected fruits may get through culling stations and get packed and shipped. High incidence of this rot can cause boxes to get wet and collapse and cause entire shipments to be rejected.

It is critical to control the disease during postharvest. The pathogen enters the fruit through any wounds, including the peduncle that is broken when harvesting the fruit. Unsanitary harvesting bags, bins, fruit-handling equipment, packing houses, boxes, and

anything that can harbor fruit debris can be colonized by the pathogen and produce spores that can infect the fruit.

Fungicides currently registered:

- None

Other pest management aids:

- Minimize wounding of fruit (use clean buckets during harvest and plastic liners for field bins)
- Sanitation in and around packing area (e.g., equipment, tanks, field bins, ripening rooms)
- Vapor heat treatment for quarantine is somewhat effective if implemented along with sanitation measures that prevent the buildup of dormant spores that are heat-resistant
- Minimize moisture in chambers when ripening fruit

Pipeline pest management tools:

- None

Critical needs list for Rhizopus soft rot:

Research:

- Chemical control. Specifically confirm the effectiveness of the fungicide iprodione (Rovral) for postharvest use

Regulatory:

- Register additional fungicides for Rhizopus control

Education:

- Stress the importance of constant sanitation of field bins and packinghouse facilities and equipment to prevent disease outbreak and the buildup of heat-resistant dormant spores

9. Fruit spots (*Alternaria* sp., *Stemphylium* sp., *Guignardia* sp., and *Fusarium* spp.)

A number of pathogenic organisms cause rots and spots in papaya fruit. One of these (*Guignardia* sp.) is prevalent when fruits are damaged from excessive quarantine heat treatment; others (*Alternaria* sp. and *Stemphylium*) when a large inoculum source is present. Temperatures below 50°F for extended periods of time (15–30 days) predispose

fruit to most of these pathogens. Presence of spots and rots can lead to rejection of fruit by the market and can ultimately lower the value of the crop. Mismanagement of stored temperature settings or quarantine heat treatment protocols can lead to postharvest expression of the disease. Fruit spots can be a problem at any time of the year on all islands and in all growing regions. Fruit spots can be controlled with fungicides used for preventing fruit rots.

Fungicides currently registered:

- Azoxystrobin (Abound)
  - Efficacy: good
  - Advantages: reduced risk; safe to handle; slightly systemic
  - Disadvantages: very expensive; not widely used (used when others fail); potential for resistance development, therefore must be used in rotation with fungicides with different modes of action

- Chlorothalonil (Bravo, Chloronil, Equus)
  - Efficacy: good
  - Limiting factors: phytotoxicity can occur on treated fruit when put through postharvest heat treatment
  - Advantages: inexpensive
  - Disadvantages: can create burning when weather is hot; skin irritant

- Copper hydroxide (Champ—various formulations, Kocide—various formulations, Nu-Cop—various formulations)
  - Efficacy: fair
  - Limiting factors: EPA *might* limit number of applications as a result of the reregistration process
  - Advantages: relatively inexpensive; adheres to plant tissue; broad spectrum
  - Disadvantages: leaves blue residue on fruit; eye hazard; can kill beneficial fungi

- Mancozeb (Dithane, Mancozeb, Manex, Manzate, Penncozeb, Pentathlon)
  - Efficacy: good
  - Limiting factors: have to make frequent applications
  - Advantages: inexpensive; tank mixes well with other pesticides; very little resistance reported; controls other diseases
  - Disadvantages: strong smell; skin irritant

- Thiabendazole (TBZ)
  - Efficacy: good
  - Advantages: postharvest stem end rot treatment; TBZ is more effective when preceded by hot water spray or dip
  - Disadvantages: Japan will not accept papaya treated with TBZ; export limitations

Other pest management aids:

- Rapid turnover of fruit so that transit time from refrigerator to consumer is minimized
- Postharvest management of temperature can contribute to management of these diseases

Pipeline pest management tools:

- None

Critical needs list for fruit spots:

Research:

- Nonchemical treatments
- Chemical treatments
- Host plant resistance

Regulatory:

- Register new products

Education:

- Postharvest management of temperature control

10. Internal smut/internal blight (*Cladosporium* sp., *Penicillium* sp., *Fusarium* spp.)

Internal smut fills the fruit cavity with mold. This results because of incomplete closure of the blossom end of the fruit. Premature yellowing of the papaya fruit can occur if infected. The disorder can be found on all islands and is a minor "disease" of papaya. The condition cannot be treated in the field.

Fungicides currently registered:

- None

Other pest management aids:

- Incomplete closure of blossom end of fruit is genetically controlled; therefore, careful selection of seed from trees that do not express the trait can reduce and/or eliminate the problem
- Field sanitation is helpful by removing infected fruit and potential inoculum

Pipeline pest management tools:

- None

Critical needs list for internal smut/internal blight:

- None identified

11. Internal yellowing (*Enterobacter cloacae*)

(*Note*: This is an emerging issue that has arisen since the workshop was held. Therefore, there are no critical needs identified in this workshop summary document.)

Internal yellowing (IY) is a bacterial disease of ripe papaya fruit that is caused by the enteric bacterium *Enterobacter cloacae*. IY is not a new disease, but it is an emerging food safety concern. *E. cloacae*-infected fruit can affect the coliform bacterial counts of papaya cube products and may be the limiting factor in this emerging fresh-cut fruit or frozen products industry. Counts exceeding a product-specific food safety guideline limit for coliforms (less than 100 colony-forming units per gram) can result in product rejection.

Fungicides currently registered:

- None

Other pest management aids:

- Use resistant cultivars (e.g., Rainbow, Sunrise, SunUp) in papaya cube products

Needs list for internal yellowing:

Note: This is an emerging issue that has arisen since the workshop was held. Therefore, there are no critical needs identified in this workshop summary document. However, there are no yellow-fleshed, non-GMO cultivars that are resistant to IY. Breeding for such cultivars would be a potential area for research.

WEEDS

Weed control is critical to successful establishment of a papaya orchard. Weeds compete for water and nutrition and are especially competitive because of the shallow nature of the roots of the papaya plant, which spread laterally just below the surface of the soil. Cultivation is not an option because of the possibility of damaging the root system of the papaya tree. Heavy weed pressure reduces yields, affects harvest efficiency, and serves as a host for diseases, insects, and nematodes. Weeds are a problem year-round and include sedges, grasses, and broadleaf types. Weed management strategies vary depending on whether papaya is grown on rocky lava "soil" or clay mineral soils. Pre-emergence herbicides cannot be used on rocky lava because of the potential for burning papaya seedlings. Weed control is critical during the crop establishment phase and then is continuous throughout the cropping cycle of a papaya orchard. As the papaya orchard canopy develops, weed pressure subsides.

Pre-plant herbicides registered (herbicides used for field preparation prior to planting):

- Glyphosate (Roundup and various other formulations)
  - Efficacy: excellent on grasses; good to excellent on sedges; good on broadleaves
  - Limiting factors: some reports of grassy weed resistance (grower report on Oʻahu)
  - Advantages: cheaper now that glyphosate is off patent; safe for workers and no soil activity
  - Disadvantages: drift; slow rate of kill; better on grasses than broadleaf weeds; papaya is very susceptible to drift whenever green stems are contacted by the spray; requires minimum of 6 hours of drying time for optimum effectiveness

- Paraquat dichloride (Gramoxone Max)
  - Efficacy: good on grasses and broadleaves; fair to good on sedges
  - Advantages: rapid burndown; inexpensive; good in high rainfall areas; increased effectiveness in low-light areas; no soil residual
  - Disadvantages: hazardous to applicator; no antidote; restricted use pesticide

- Pelargonic (nonanoic) acid (Scythe)
  - Efficacy: fair on weeds smaller than six inches tall
  - Limiting factors: only works on small weeds
  - Advantages: approved for organic farming; shows results in 2 to 4 hours
  - Disadvantages: strong smell (like rancid oil), and its smell could make some workers uncomfortable or even sick

Pre- and post-emergence herbicides registered (used in established plantings only):

- Diuron (Direx, Diuron, Karmex)

- Efficacy: good on grasses and broadleaves on papaya in soil; poor on sedges
- Advantages: inexpensive; has both pre- and post-emergent activity when used with a wetting agent; persistent
- Disadvantages: potential groundwater contaminant; affects papaya grown in rocky conditions; Special Local Needs registration that allowed for use of diuron within 1 year of planting was canceled

- Oxyfluorfen (Goal)
  - Efficacy: good to excellent for grasses and broadleaves on papaya in soil; poor on sedges
  - Advantages: good control of guinea grass seedlings; reasonable cost; very good activity as a pre-emergence herbicide with adequate rainfall or irrigation for activation; primarily a pre-emergence herbicide but can have improved post-emergence activity with the addition of a surfactant
  - Disadvantages: 2XL formulation can be phytotoxic to a young crop; can get a buildup of Spanish needle (*Bidens pilosa*) with continued use; application on a hot day followed by rainfall causes steam to rise from treated area and vapor drift to papaya canopy, which can cause burning of succulent new foliage; affects papaya grown in rocky conditions; a new formulation, GoalTender, might be less phytotoxic

Pre-emergence herbicides registered:

- Oryzalin (Surflan)
  - Efficacy: good
  - Advantages: safe around young papaya plants but should not be applied to green stems; makes a good tank mix with oxyfluorfen for wide spectrum weed control; no vapor action against papaya foliage
  - Disadvantages: no contact burn on weeds; needs to be mixed with contact herbicide when living weeds are present

Post-emergence herbicides registered (used to control weeds after they've sprouted and orchard is established; used as a shielded spray):

- Glyphosate (Roundup and various other formulations)
  - Efficacy: excellent on grasses; good to excellent on sedges; good on broadleaves
  - Limiting factors: some reports of grassy weed resistance (grower report on O'ahu)
  - Advantages: cheaper now that glyphosate is off patent; safe for workers and no soil activity
  - Disadvantages: drift; slow rate of kill; better on grasses than broadleaf weeds; papaya is very susceptible to drift whenever green stems are

contacted by the spray; requires minimum of 6 hours of drying time for optimum effectiveness

- Paraquat dichloride (Gramoxone Max)
  - Efficacy: good on grasses and broadleaves; fair to good on sedges
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  - Disadvantages: hazardous to applicator; no antidote; restricted use pesticide

- Pelargonic (nonanoic) acid (Scythe)
  - Efficacy: fair on weeds smaller than six inches tall
  - Limiting factors: only works on small weeds
  - Advantages: approved for organic farming; shows results in 2 to 4 hours
  - Disadvantages: strong smell (like rancid oil), and its smell could make some workers uncomfortable or even sick

Other pest management aids:

- Leguminous cover crops/green manures
- Mowing
- Directed burning

Pipeline pest management tools:

- None

Critical needs list for weeds:

Research:

- Mow and blow system for new plantings: use of sudex grass that is heavily fertilized. Top growth mowed and directed to future papaya crop row. At 4–6 inches of mulch, tender papaya seedlings can be transplanted. Mulch will delay need for herbicides by 2–4 months. By the time the mulch breaks down, papaya is hardy enough to use post-emergence herbicide sprays.

Regulatory:

- Registering additional herbicides

Education:

- Convince papaya growers that weed control begins with site preparation prior to planting the crop. Crop rows should be purged of weed seeds prior to planting with pre-plant irrigation followed by weed flush followed by kill with herbicides. Two or more cycles can reduce weed pressure by 85%.

- Growers forced to replant old papaya field need to come up with an improved system of restoring soil health before the next crop is planted. Continuous cropping without a planned rotation leads to a decline in crop vigor and increased susceptibility to diseases and insects. An aggressive groundcover management cycle between papaya crops can alleviate many of the soil-borne problems like diseases, nematodes, and weeds.

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Table 1. Registered Pesticides for Papaya in Hawai'i

Active Ingredient	Trade name	Company
INSECTICIDES		
azadirachtin	Agroneem Plus	Agro Logistics Systems, Inc.
	Aza-Direct Biological Insecticide	Gowan Company, LLC
	Azatin XL Biological Insecticide	OHP, Inc.
	Azatrol EC Insecticide	PBI/Gordon Corp.
	Ecozin 3% EC Botanical Insecticide	AMVAC Chemical Corp.
Bacillus thuringiensis subsp. *aizawai* (6403)	Xentari Biological Insecticide Dry Flowable	Valent Biosciences Corp.
Bacillus thuringiensis subsp. *kurstaki* (6402)	DiPel DF Biological Insecticide Dry Flowable	Valent Biosciences Corp.
Bacillus thuringiensis subsp. *kurstaki*, strain EG7841 Lepidopteran active toxin (6453)	Crymax Bioinsecticide	Certis USA, LLC
clarified hydrophobic extract of neem oil	Trilogy	Certis USA, LLC
hydramethylnon	Amdro Pro	BASF Corp.
imidacloprid	Admire 2 Flowable Insecticide	Bayer CropScience LP
	Admire Pro Systemic Protectant	Bayer CropScience LP
	Provado	Bayer CropScience LP
malathion	Drexel Malathion 5EC Insecticide/Miticide	Drexel Chemical Company
	Malathion 8 Aquamul (supplemental labeling)	Loveland Products Inc.
	Micro Flo Malathion 5EC	Micro Flo Company LLC
	Prentox 5 Lb. Malathion Spray	Prentiss Inc.
naled (EPA SLN No. HI-000005, expiration 2/5/2011)	Dibrom Concentrate (not for use within production fields)	AMVAC Chemical Corp.

Active Ingredient	Trade name	Company
petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil	BioCover UL	Loveland Products, Inc.
	BioCover MLT	Loveland Products, Inc.
	Glacial Spray Fluid	Loveland Products, Inc.
	PureSpray Green	Petro-Canada
potassium salts of fatty acids	Bon-Neem Insecticidal Soap Concentrate	Bonide Products, Inc.
pyrethrins	Pyganic Crop Protection EC 1.4 II	McLaughlin Gormley King Company
	Pyganic Crop Protection EC 5.0 II	McLaughlin Gormley King Company
pyrethrins + piperonyl butoxide	Pyrenone Crop Spray	Bayer Environmental Science
	Prentox Pyronyl Crop Spray	Prentiss Inc.
pyrethrins + rotenone	Pyrellin E.C.	Webb Wright Corp.
spinosad	Success	Dow AgroSciences LLC
	Entrust	Dow AgroSciences LLC
sulfur	Drexel Sulfur 90W	Drexel Chemical Company
	Kumulus DF	Micro Flo Company LLC
	Micro Sulf	Nufarm Americas Inc., Agriculture Division
FUNGICIDES		
azoxystrobin	Abound Flowable Fungicide	Syngenta Crop Protection, Inc.
basic cupric sulfate	Basic Copper 53	Albaugh Inc.
	Basicop Basic Copper Sulfate Wettable Powder Fungicide/Bactericide	Griffin LLC
	Micro Flo Basic Copper 53	Micro Flo Company LLC
carbonic acid	Kaligreen Potassium Bicarbonate Soluble Powder	Toagosei Co., LTD c/o Arysta LifeScience

Active Ingredient	Trade name	Company
chlorothalonil	Bravo Ultrex Agricultural Fungicide	Syngenta Crop Protection, Inc.
	Bravo Weatherstik Agricultural Fungicide	Syngenta Crop Protection, Inc.
	Equus 720 Fungicide Flowable	
	Initiate 720	Loveland Products, Inc.
	Applause 720	Loveland Products, Inc.
copper hydroxide	Champ Formula 2 Flowable Agricultural Fungicide/Bactericide	Nufarm Americas Inc.
	Champion Wettable Powder Agricultural Fungicide	Nufarm Americas, Inc.
	Griffin Kocide 101 Fungicide Wettable Powder	Griffin LLC
	Griffin Kocide 4.5LF Fungicide/Bactericide	Griffin LLC
	Griffin Kocide 2000 Fungicide/Bactericide	Griffin LLC
	Griffin Kocide LF Fungicide/Bactericide	Griffin LLC
	Nu-Cop 3L	Albaugh, Inc.
	Nu-Cop 50DF	Albaugh, Inc.
	Nu-Cop 50WP	Albaugh, Inc.
	Nu-Cop HB	Albaugh, Inc.
	Nu-Cop 50WP	Micro Flo Company LLC
copper hydroxide + mancozeb	ManKocide Fungicide/Bactericide	E.I. du Pont de Nemours and Company
copper hydroxide + metalaxyl-M	Ridomil Gold Copper	Syngenta Crop Protection, Inc.
copper oxide	Nordox 75WG	Monterey Chemical Company

Active Ingredient	Trade name	Company
mancozeb	Dithane 75DF Rainshield	Dow AgroSciences LLC
	Dithane DF Rainshield Fungicide	Dow AgroSciences LLC
	Dithane F-45 Rainshield Fungicide	Dow AgroSciences LLC
	Dithane M45 Fungicide	Dow AgroSciences LLC
	DuPont Manzate Flowable Fungicide	E.I. du Pont de Nemours and Company
	DuPont Manzate Pro-Stick Fungicide	E.I. du Pont de Nemours and Company
	Griffin Manzate 75DF Fungicide	Griffin LLC
	Griffin Manzate Flowable Fungicide	Griffin LLC
	Penncozeb 75DF Dry Flowable Fungicide	Cerexagri-Nisso LLC
	Penncozeb 80WP Fungicide	Cerexagri-Nisso LLC
maneb	DuPont Manex Fungicide	E.I. du Pont de Nemours and Company
	Griffin Manex Fungicide Flowable with Zinc	Griffin LLC
	Maneb 75DF Dry Flowable Fungicide	Cerexagri-Nisso LLC
	Maneb 80WP Fungicide	Cerexagri-Nisso LLC
metalaxyl-M (mefenoxam)	Axle 2E Fungicide	Syngenta Crop Protection, Inc.
	Ridomil Gold EC Fungicide	Syngenta Crop Protection, Inc.
metam-sodium	Metam CLR 42%	Taminco, Inc.
	Clean Crop Nemasol 42%	Platte Chemical Co.
	Sectagon 42	Tessenderlo Kerley, Inc.
	Vapam	AMVAC Chemical Corp.
	Vapam HL Soil Fumigant	AMVAC Chemical Corp.

Active Ingredient	Trade name	Company
mono- & di-potassium salts of phosphorous acid	Fosphite Fungicide	JH Biotech, Inc.
	Fungi-phite	Plant Protectants, LLC
	Rampart	Loveland Products, Inc.
petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil	BioCover UL	Loveland Products, Inc.
	BioCover MLT	Loveland Products, Inc.
	Glacial Spray Fluid	Loveland Products, Inc.
	PureSpray Green	Petro-Canada
Postharvest:		
thiabendazole	Decco Salt No. 19	Decco Cerexagri Inc.
HERBICIDES		
Pre-emergence:		
diuron	Diuron 80 WDG Weed Killer	Loveland Products, Inc.
	Drexel Diuron 4L Herbicide	Drexel Chemical Company
	DuPont Direx 4L Herbicide	E.I. du Pont de Nemours and Company
	DuPont Karmex XP Herbicide	E.I. du Pont de Nemours and Company
	DuPont Karmex DF Herbicide	E.I. du Pont de Nemours and Company
	Griffin Direx 4L Herbicide	Griffin LLC
	Griffin Direx 80DF Herbicide	Griffin LLC
	Griffin Karmex DF Herbicide	Griffin LLC

Active Ingredient	Trade name	Company
oryzalin	Farmsaver.com Oryzalin 4 A.S.	Farmsaver.com, LLC
	Oryza Ag Herbicide	AgValue, Inc.
	Surflan AS Specialty Herbicide	United Phosphorus, Inc.
oxyfluorfen	Goal 2XL Specialty Herbicide	Dow AgroSciences LLC
	Goal 4F	Dow AgroSciences LLC
	GoalTender Herbicide	Dow AgroSciences LLC
Post-emergence:		
N-(phosphonomethyl)glycine - potassium salt	Roundup Weathermax Herbicide	Monsanto Company
	Roundup Original Max Herbicide	Monsanto Company
glyphosate	Buccaneer Herbicide	Tenkoz Inc.
	Buccaneer Glyphosate Herbicide	Tenkoz Inc.
	Buccaneer Plus Herbicide	Tenkoz Inc.
	Buccaneer Plus Glyphosate Herbicide	Tenkoz Inc.
	ClearOut 41	Chemical Products Technologies, Inc.
	ClearOut 41 Plus	Chemical Products Technologies, Inc.
	Glyfos X-tra Herbicide	Cheminova, Inc.
	Glyphomax Herbicide	Dow AgroSciences LLC
	Glyphomax Plus Herbicide	Dow AgroSciences LLC
	Gly Star Plus	Albaugh, Inc.
	Griffin Glyphosate Original Herbicide	Griffin LLC
	Helosate Plus	Helm Agro US, Inc.

Active Ingredient	Trade name	Company
glyphosate (continued)	Hi-Yield Super Concentrate Killzall	Voluntary Purchasing Groups, Inc.
	Honcho Herbicide	Monsanto Company
	Honcho Plus Herbicide	Monsanto Company
	Mad Dog	Loveland Products, Inc.
	Mad Dog Plus	Loveland Products, Inc.
	Makaze	Loveland Products, Inc.
	Micro Flo Gly-Flo Herbicide	Micro Flo Company LLC
	Mirage	Loveland Products, Inc.
	Mirage Plus Herbicide	Loveland Products, Inc.
	Nufarm Credit Systemic Extra Herbicide	Nufarm, Inc.
	Rascal Herbicide	Monsanto Company
	Roundup Original Herbicide	Monsanto Company
	Roundup Original II Herbicide	Monsanto Company
	Roundup Ultradry Herbicide	Monsanto Company
	Roundup Ultramax Herbicide	Monsanto Company
	Superstate Herbicide	Loveland Products, Inc.
	Touchdown Herbicide	Syngenta Crop Protection, Inc.
	Touchdown HiTech	Syngenta Crop Protection, Inc.
	Touchdown Total Herbicide	Syngenta Crop Protection, Inc.
	Wise Up Plus	Mey Corporation

Active Ingredient	Trade name	Company
pelargonic acid (nonanoic acid)	Scythe Herbicide	Dow AgroSciences LLC
paraquat dichloride	Gramoxone Max Herbicide	Syngenta Crop Protection, Inc.
	Gramoxone Inteon	Syngenta Crop Protection, Inc.
BAITS/REPELLANTS		
spinosad	GF-120 NF Naturalyte Fruit Fly Bait	Dow AgroSciences LLC
	LURES	
1,2-dimethoxy-4-allylbenzene	Methyl Eugenol	Yasho Industries PVT., Ltd.
4-[p-Acetoxyphenyl]-2-butanone	Cuelure	CCA Biochemical Co., Ltd.
Hydrolysed corn gluten meal	Nu-Lure Insect Bait	Miller Chemical and Fertilizer Corp.
MITICIDES		
fenbutatin-oxide	Vendex 50WP	E.I. du Pont de Nemours and Company
	Griffin Vendex 50WP Miticide	Griffin LLC
petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil	BioCover UL	Loveland Products, Inc.
	BioCover MLT	Loveland Products, Inc.
	Glacial Spray Fluid	Loveland Products, Inc.
	PureSpray Green	Petro-Canada
sulfur	Drexel Sulfur 90W	Drexel Chemical Company
	Micro Sulf	Nufarm Americas Inc., Agriculture Division

Active Ingredient	Trade name	Company
MOLLUSCICIDES		
metaldehyde	Deadline Bullets	Pace International LLC
	Deadline M-PS Mini Pellets	Pace International LLC
NEMATICIDES		
1,3-dichloropropene	Telone II	Dow AgroSciences LLC
	Telone EC	Dow AgroSciences LLC
	Telone C-35	Dow AgroSciences LLC
	Telone C-15	Trical, Inc.
	Telone C-17	Dow AgroSciences LLC
azadirachtin	Ecozin 3% EC Botanical Insecticide	AMVAC Chemical Corp.
metam-sodium	Metam CLR 42%	Taminco, Inc.
	Clean Crop Nemasol 42%	Platte Chemical Company
	Sectagon 42	Tessenderlo Kerley, Inc.
	Vapam	AMVAC ChemIcal Corp.
	Vapam HL Soil Fumigant	AMVAC Chemical Corp.

Table 2. Unregistered Pesticides Tested on Papaya in Hawai'i

Insecticides	Insects Tested	
	Stevens Leafhopper	White Peach Scale
buprofezin		E
imidacloprid	E	?

Fungicides	Diseases Tested			
	Anthracnose	Phytophthora	Powdery Mildew	Black Spot (*Asperisporium*)
boscalid + pyraclostrobin	*			G
pyraclostrobin	*			G
cyprodinil + fludioxonil	*			F
famoxadone + cymoxanil	*	*		
zoxamide		*		
myclobutanil			E	
trifloxystrobin			E	
triflumizole			E	

Miticides	Mites tested					
	Broad Mite	Carmine Spider Mite	Citrus Red Spider Mite	Flat Mite	Leaf Edgeroller Mite	Texas Citrus Mite
abamectin	E	E	E	E	E	E
bifenazate	?	E	E	?	?	?
fenpropathrin	E	E	E	E	E	E
pyridaben	?	G	?	?	G	?

Efficacy rating symbols: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (<70% control), ? = no data but successful on related organisms; - = not applicable and/or not used; * = efficacy studies ongoing.

Table 3. Description of Pests and Pathogens of Papaya in Hawai'i

Pest/Pathogen	Symptoms
INSECT PESTS	
Aphids: Green peach aphid (*Myzus persicae*) Melon aphid (*Aphis gossypii*) Potato aphid (*Microsiphum euphorbiae*)	Aphids rarely occur on papaya and would not be considered a major pest except for the transmission of papaya ringspot virus—P strain (PRSV). PRSV is the most serious papaya disease in Hawai'i. The virus cannot be successfully controlled by controlling the aphid vector.
Fruit Flies: Mediterranean fruit fly (*Ceratitis capitata*) Melon fly (*Dacus cucurbitae)* Oriental fruit fly (*Bactrocera dorsalis*)	Fruit flies can be a serious problem if fruit is harvested for local market after color change has occurred (green to yellow). If the fruit have been harvested before color change and are destined for local Hawai'i markets, then fruit flies are a minor problem. The presence of fruit flies or fruit fly eggs is a very serious problem for export because of strict quarantine restrictions in target markets (e.g. California, Japan). Irradiation and vapor heat treatment are ways in which papaya can be "sterilized" for export sale. Fruit flies are found on all islands and in all growing areas of Hawai'i. Some field management of fruit flies is necessary, but most control occurs postharvest.
Papaya mealybug (*Paracoccus marginatus*)	Papaya mealybug is an extremely destructive pest in papaya and has been observed on the islands of Maui, O'ahu, Moloka'i, Kaua'i, and Hawai'i. During feeding, this mealybug injects a toxin that can cause leaf yellowing (chlorosis), premature leaf and fruit drop, stunting, deformation, and buildup of honeydew. Seedlings are more susceptible than trees to damage from the papaya mealybug, which can kill the plants under heavy infestation. When found on the fruit, mealybugs can lead to rejection at the packing plant. The papaya mealybug has numerous alternate hosts, including plumeria, hibiscus, avocado, citrus, tomato, eggplant, beans, etc., increasing the difficulty of control. Additionally, the role of ants in the movement of mealybugs may intensify the infestation of the papaya mealybug.

Pest/Pathogen	Symptoms
INSECT PESTS *(continued)*	
Stevens leafhopper (*Empoasca stevensi*)	Stevens leafhopper can cause severe leaf edge chlorosis and necrosis as well as wrinkling and cupping of leaves and leaf drop and stunting of young plants. All of these symptoms, taken together, are known as hopper burn. Symptoms of hopper burn on papaya are similar to papaya ringspot virus (PRSV).
Thrips (*Thrips parvispinus*)	(Note: This is an emerging issue that has arisen since the workshop was held.) Although not yet confirmed to be a pest, this thrips species has been identified in papaya in Puna and has been associated with characteristic foliar and fruit injury and flower drop.
White peach scale (*Pseudaulacaspis pentagona*)	White peach scale is potentially among the most destructive insect pests of papaya, because its presence can lead to the rejection of export shipments. Currently, white peach scale is found only on the islands of Hawai'i and Kaua'i. Under heavy infestation, colonies of white peach scale can progress up from the bottom of the tree trunk onto the fruit, causing poor fruit quality and weakening the overall plant. Where this insect is found it is a pest year-round and must be controlled throughout all stages of papaya growth and production.
NEMATODES	
Reniform nematode (*Rotylenchulus reniformis*) **Root knot nematode** (*Meloidogyne incognita*)	Nematodes are microscopic parasitic worms of plant roots. Reniform nematodes reduce root mass, and root knot nematodes cause swelling and gall formation in the roots, preventing water and nutrient uptake. Nematode populations can be high in papaya without producing symptoms. Heavy nematode infestations can cause wilting, stunting, decreased plant vigor, reduced yields, and shortening of the productive life of a papaya tree. Nematodes are present year-round and are more of a problem on mineral soils than rocky soils. Best control of nematodes is obtained by pre-plant treatment.

Pest/Pathogen	Symptoms
OTHER INVERTEBRATE PESTS	
Mites: Broad mite (*Polyphagotarsonemus latus*) Flat mite (*Brevipalpus phoenicis*) Leaf edgeroller mite (*Calacarus flagelliseta*) Spider mites: Carmine spider mite (*Tetranychus cinnabarinus*) Citrus red mite (*Panonychus citri*) Texas citrus mite (*Eutetranychus banksi*)	In general, mites can be very serious pests when not controlled. Damage by mites includes fruit scarring, leaf drop, and loss of plant vigor. Heavy mite pressure can also reduce fruit quality by reducing fruit sugar. Mites can be found in all growing areas at various times of the year. Some mite species prefer dry conditions, but others thrive in rainy growing areas such as the Puna District on Hawai'i Island. The 'Sunrise' variety of papaya is more susceptible to mites than other varieties.
Snails and Slugs: African snail (*Achatina fulica*) Brown slug (*Vaginulus plebeius*) Semi slug (*Parmarion martensi*) Two striped slug (*Veronicella cubensis*)	Snails and slugs are pests of newly planted papayas. Entire plants can be destroyed by the feeding of these pests. Snails and slugs are found on all islands and are most serious in locations with high rainfall and the presence of abundant plant litter within a papaya field.

Pest/Pathogen	Symptoms
PATHOGENS	
Anthracnose and chocolate spots (*Colletotrichum gloeosporioides*)	Anthracnose and chocolate spot are among the most important postharvest diseases of papaya wherever papayas are grown and during all growing seasons. Spores of the fungus infect the fruit at all stages of development, but the fungus remains "latent" immediately under the cuticle until the fruit begins to ripen. The grower, therefore, rarely sees the disease, because the fruits are typically harvested before the development of symptoms. The primary infection site is the fruit. Lesions of anthracnose begin small and become sunken when they are about two to four millimeters in diameter. At advanced stages the pathogen sporulates abundantly with salmon-colored conidial masses. Chocolate spot is caused by the same pathogen but begins as a chocolate-colored discoloration up to about 10 millimeters in diameter. As chocolate spot develops, lesions become sunken and begin to sporulate, with an appearance similar to anthracnose. Infected fruits are not salable and may serve as points of infection for other fungi (such as *Phomopsis* and *Rhizopus*) that cannot penetrate intact cuticle themselves. Dry conditions reduce infection, but preventive field sprays are important management tools. Hot water dips (15 minutes at 120°F) are effective in inactivating many of the latent infections.
Black spot (*Asperisporium caricae*)	Black spot, caused by *Asperisporium caricae,* is a relatively new disease in papaya in Hawai'i and was first observed in 2001. Irregular dark brown to black spots are found on the lower leaf surface, with corresponding yellow to tan sunken spots on the upper leaf surface. When infection is heavy, fruit will also be affected, but fruit rot is not associated with this disease.

Pest/Pathogen	Symptoms
PATHOGENS *(continued)*	
Black spot (*Cercospora papayae*)	Another black spot disease is caused by *Cercospora papayae.* Leaf spots are gray, circular, and small. Under heavy infection, leaves turn yellow and may drop early. Fruit can also be affected, but fruit rot is not associated with this disease. Fruit damage is mainly cosmetic. Cercospora black spot on fruits is not controlled by hot water treatment.
Fruit spots: *Alternaria alternata*, *Stemphylium lycopersici*	Lesions are usually sunken, with obvious mycelial growth, and are relatively slow to increase in size. Lesions are dark brown to black due to the dark mycelia and fruiting structures. Symptoms may occur in the field but usually do not appear except when a large inoculum source is present and fruits are stored or shipped under refrigeration (15–30 days at temperatures below 50°F). Because of the relatively low occurrence, no specific control measures are used to control these fungi. Control measures for the other fruit diseases also should reduce or minimize diseases caused by these two fungi.
Fusarium fruit rot (*Fusarium solani*)	*Fusarium* is not an aggressive pathogen on papaya. It occurs typically when fruits are stored under refrigeration for extended periods and when there are abundant fruit spots caused by other fungi. Lesions are characterized by being slightly sunken, having abundant sporulation, and having white mycelial growth.

Pest/Pathogen	Symptoms
PATHOGENS *(continued)*	
Fruit spots (continued): Guignaridia spot (*Guignaridia* sp.)	This disease is caused by an unidentified *Guignardia* sp. occurring only on papaya in Hawai'i. Ascospores of *Guignardia citricarpa* Kiely are found in the airspora of papaya orchards year-round in Hawai'i; however, it is unknown whether this species is the cause of this disorder. The disease is characterized by usually numerous, circular to oval, sunken greenish-black lesions up to about 15 millimeters in diameter. Lesions expand in diameter very slowly, but the fungus may grow deep into the flesh, causing a black, firm discoloration. Occurrence of the disease has been sporadic, but heat stress from postharvest quarantine treatments has been implicated as a predisposing factor. The disease was most common on fruits that were treated twice with hot water, using the original schedule of 40 minutes at 42°C (107.6°F) followed by 20 minutes at 49°C (120.2°F). Its occurrence was drastically reduced when the first-stage treatment time was reduced to 30 minutes. The disease occasionally occurs when the time between the second hot water dip and the tap water shower to cool fruits to near ambient temperature is delayed longer than 3 minutes. Control of this disease requires close monitoring and accurate control of postharvest quarantine heat treatments. If the fruits are overheated they become predisposed to this disease.
Internal Blight/Internal Smut (*Cladosporium sp.* *Alternaria* sp., *Fusarium* sp., *Penicillium* sp.)	Massive mold development in the seed cavity of fruit is most commonly associated with *Cladosporium* sp., but *Alternaria*, *Fusarium*, and *Penicillium* can be present. Premature yellowing of the papaya fruit can occur if infected. This problem is mainly due to the incomplete closure of the blossom end of the fruit.

Pest/Pathogen	Symptoms
PATHOGENS *(continued)*	
Papaya ringspot virus	Papaya ringspot virus (PRSV) is the most severe disease of papaya, often limiting production worldwide. PRSV is found in tropical and temperate regions throughout the world. Symptoms of PRSV infection are mottled fruit (circular patterns), yellow mosaic pattern on leaves, and "shoestring" leaves. In Hawai'i, O'ahu was the island with the highest papaya production in the 1950s. The spread of PRSV caused most of the farms to move to the Puna district in the 1960s. In 1992, PRSV invaded the island of Hawai'i and began to spread in the Puna District, resulting in a significant decrease in the state's production. In 1997, two transgenic cultivars, 'UH Sun Up' and 'UH Rainbow' (also referred to as 'Sun Up' and 'Rainbow') were approved for production and sale. PRSV can be avoided by planting these two genetically-resistant cultivars. Resistance management is an important component of the terms of use for the resistant cultivars. PRSV is present year-round, which increases the likelihood of the disease developing resistance to the transgenic protection. While Hawaiian papaya varieties are resistant to PRSV strains found in Hawai'i, neither of the cultivars is resistant to strains found in Asia. PRSV is spread by aphids and occurs on the islands of O'ahu, Maui, and Hawai'i.
Phytophthora blight, stem rot, fruit rot, and root rot (*Phytophthora palmivora*)	Phytophthora blight and root rot is one of the major diseases of papaya. Under ideal weather conditions for the disease (continuous rain), the pathogen has the potential to kill entire fields. Typically, daily and continuous rain for two weeks is required before the pathogen becomes established in the orchard. The disease is found on all islands but is most prevalent in wet areas and especially during and following continuous rains. Fruit infection is usually the first evidence of the disease, with older fruit being more susceptible. Small, water-soaked, discolored spots may occur anywhere on the stem, around the fruit or leaf scars, especially during fruit production. These infected areas enlarge and often completely encircle stems of young trees. Green fruits are resistant to

Pest/Pathogen	Symptoms
PATHOGENS *(continued)*	
Phytophthora blight, stem rot, fruit rot, and root rot (*Phytophthora palmivora*) (continued)	infection but can be invaded through the wound or through the peduncle from the stem cankers. Infected mature fruits that hang on the tree shrivel as disease progresses, turn dark brown, become mummified, and fall to the ground. Mummified fruits become reservoirs for fungus and a source of infection. Removal of rotting fruits from the tree can help to control this disease, as these serve as reservoirs of spores, which are carried by rain or wind to healthy parts of plants. These spores may infect non-injured leaf tissue, stems, or fruit. Good drainage conditions reduce infection, and use of protectant spray fungicides limits extent of injury. There are variety differences in resistance to the fungus. Phytophthora stem and fruit rot are continuing problems. During severe epidemics, high incidence of advanced Phytophthora infections (more than 24 hours old but less than 48 hours old) escape visual examination at packing plants. These advanced infections are not adequately controlled by the standard hot water treatment. Epidemiological studies on Kauaʻi and Hawaiʻi Island suggest that establishment and spread of Phytophthora blight require about 1 inch of weekly rainfall on Kauaʻi and about 2 inches of weekly rainfall on Hawaiʻi. Phytophthora blight is one of the most severe diseases in Hawaiʻi. Ongoing grower education about the disease and how it can be spread are needed.
Powdery mildew (*Oidium caricae*)	Powdery mildew is present in orchards on Oʻahu and Kauaʻi. Humid and moderate temperature conditions (65–90°F) favor the development of the disease. If left untreated, powdery mildew causes significant leaf drop, thus reducing tree vigor and fruit brix. Red-fleshed varieties (e.g., Sunrise) appear to be more susceptible.

Pest/Pathogen	Symptoms
PATHOGENS *(continued)*	
Pythium root rot (*Pythium* spp.)	Pythium root rot is usually associated with poorly drained soils and excess soil moisture. It's a problem mostly of seedlings and young plants up to about six months of age. Damage occurs on the fine roots. Plants are stunted and appear weak, often showing nutrient deficiencies and chlorosis, and often leaning. Heavy, extended infestations of *Pythium* can also debilitate and kill fruit-bearing papaya trees. Pythium root rot is a significant problem when replanting a field previously planted to papaya.
Rhizopus soft rot (*Rhizopus stolonifer*)	Rhizopus soft rot is a postharvest disease caused by an opportunistic fungus that colonizes wounds created during harvest and postharvest handling. *Rhizopus stolonifer* is one of the most destructive postharvest fungal pathogens of papaya because of its ability to rapidly develop and spread. High moisture and warm temperature enhance disease development. Dormant spores are heat-resistant, and hot water treatments for postharvest disease control can allow inoculum to accumulate. The disease is more serious during rainy weather or in wet growing areas. Under extended rainy weather conditions, infected fruits may get through the culling stations and be packed and shipped. High incidence of this rot can cause boxes to get wet and collapse and can cause entire shipments to be rejected.

Pest/Pathogen	Symptoms
PATHOGENS *(continued)*	
Stem-end and body rots (*Lasiodiplodia theobromae*, *Mycosphaerella caricae*, *Phoma caricae-papayae*)	Stem-end rots caused by these fungi and others can be serious postharvest diseases in Hawai'i and wherever papayas are grown. The fungus becomes established earlier but remains latent under the fruit cuticle. Rots occur when spores of fruit-rotting fungi residing on papaya fruit are provided entry points, such as mechanical or other injuries that occur during harvest, transport, treatment, and packing processes (e.g., the broken peduncle from when the fruit is harvested). Stem-end rots can also be caused by a number of other fungi. Under typical conditions, it is not unusual for 75–100% of the fruits to become infected by one or more fungi. Hot water dips (15 minutes at 120°F) is an excellent control measure. Thiabendazole sprays or dips directed at the stem-end are also an effective control measure, but fruits destined for Japan are not allowed to be treated with this fungicide. Vapor heat treatment, especially when the final stage is done at a saturated atmosphere, is effective in controlling stem-end rots. When the relative humidity is reduced to 90%, control is not as good.
Wet fruit rot (*Phomopsis* sp.)	Phomopsis is a ubiquitous fungus that affects many fruits and plants. It is primarily a postharvest disease that is rarely seen in the field. It frequently infects through the broken peduncle, but it also infects through wounds or scratches on the body of the fruit. This pathogen lacks the enzyme cutinase, so it can only infect through a break in the cuticle. Once it infects a fruit, lesion expansion is very rapid. It causes a soft rot that yields to gentle pressure. The infected area often is "shriveled," with many dark-colored fruiting bodies (pycnidia).

Table 4. Advantages and Disadvantages of Pesticides for Papaya in Hawai'i

Active Ingredient	Disease/Pest	Advantages/Disadvantages
INSECTICIDES		
azadirachtin	Aphids Papaya mealybug	● safe ● possibly organic versions ● not fully evaluated
Bacillus thuringiensis subsp. aizawai (6403)		● soft on beneficials ● safe for the environment
Bacillus thuringiensis subsp. kurstaki (6402)		● soft on beneficials ● safe for the environment
Bacillus thuringiensis subsp. kurstaki, strain EG7841 Lepidopteran active toxin		● soft on beneficials ● safe for the environment
clarified hydrophobic neem oil	Aphids Stevens leafhopper White peach scale	● soft on beneficials ● organic ● safe for the environment ● some fungicidal activity ● could kill beneficial soil fungi ● expensive ● relatively ineffective
hydramethylnon		● relatively safe to use ● long residual activity ● narrow range of control
imidacloprid	Aphids Papaya mealybug Stevens leafhopper White peach scale	● safe for handlers ● target-specific ● controls aphids and leafhoppers ● soft on beneficials ● not fully evaluated ● 7-day PHI ● expensive ● limited applications per year ● very effective against leafhoppers but results in explosion of mite populations

Active Ingredient	Disease/Pest	Advantages/Disadvantages
INSECTICIDES *(continued)*		
malathion	Aphids Melon fly Mediterranean fruit fly Oriental fruit fly Papaya mealybug White peach scale	● inexpensive ● broad spectrum ● not fully evaluated ● hard on beneficials ● worker safety issue ● strong smell
naled + lure/bait	Melon fly Mediterranean fruit fly Oriental fruit fly	● inexpensive ● worker safety issue
petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil	Aphids Papaya mealybug White peach scale	● environmentally friendly ● soft on beneficials ● very safe ● fungicidal activity ● inexpensive ● not fully evaluated
potassium salts of fatty acids	Aphids White peach scale	● expensive
pyrethrins	Aphids Stevens leafhopper	● rapid knockdown ● possibly organic versions ● broad spectrum ● short 12-hour PHI ● short residual ● hard on beneficials ● skin sensitivity
pyrethrins + piperonyl butoxide	Aphids Stevens leafhopper	● enhanced activity ● rapid degradation ● hard on beneficials
pyrethrins + rotenone	Aphids Stevens leafhopper	● rapid knock down ● possible organic use ● broad spectrum ● short 12-hour PHI ● expensive ● hard on beneficials ● skin sensitivity ● short residual

Active Ingredient	Disease/Pest	Advantages/Disadvantages
INSECTICIDES *(continued)*		
pyriproxyfen	White peach scale	● hard on beneficials ● long PHI ● relatively expensive
spinosad	Melon fly Mediterranean fruit fly Oriental fruit fly	● effective ● reduced-risk ● soft on beneficials ● certified organic compatible ● expensive ● washes off easily ● short residual period
FUNGICIDES		
azoxystrobin	Anthracnose/chocolate spot Black spot Fusarium fruit rot	● reduced risk ● slightly systemic ● works on root disease like Pythium ● very expensive
basic cupric sulfate	Anthracnose/chocolate spot Black spot Fusarium fruit rot	● adheres to plant tissue ● cheap ● broad spectrum ● organic ● kills slugs and snails ● some questions about efficacy ● more expensive than copper ● residue on fruit ● eye hazard ● can kill beneficial fungi
carbonic acid		● unknown effectiveness

Active Ingredient	Disease/Pest	Advantages/Disadvantages
FUNGICIDES *(continued)*		
chlorothalonil	Anthracnose/chocolate spot Fusarium fruit rot	● inexpensive ● when weather is hot can be phytotoxic to fruit on tree ● skin irritation ● phytotoxicity can occur on treated fruit when put through heat treatment
copper hydroxide	Anthracnose/chocolate spot Black spot Fusarium fruit rot	● adheres to plant tissue ● cheap ● broad spectrum ● organic ● kills slugs and snails ● some questions about efficacy ● more expensive than copper ● residue on fruit ● eye hazard ● can kill beneficial fungi
copper oxide	Anthracnose/chocolate spot Black spot Fusarium fruit rot	● adheres to plant tissue ● cheap ● broad spectrum ● organic ● kills slugs and snails ● some questions about efficacy ● more expensive than copper ● residue on fruit ● eye hazard ● can kill beneficial fungi
mancozeb	Anthracnose/chocolate spot Black spot Fusarium fruit rot	● cheap ● controls other diseases ● little resistance ● easy to use in tank mixes ● adheres to plant tissue ● frequent application necessary ● smelly ● skin irritant ● more expensive that copper ● residue on fruit

Active Ingredient	Disease/Pest	Advantages/Disadvantages
FUNGICIDES *(continued)*		
maneb		● inexpensive ● broad spectrum ● tank mixes well ● frequent application required
metalaxyl-M	Pythium root rot Phytophtora blight and root rot	● effective ● prevents root rot phase ● used for blight phase ● only registered for nonbearing ● expensive ● easy to develop resistance
mono- and di-potassium salts of phosphorous acid	Phytophtora blight and root rot	● good systemic product
petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil		● unknown effectiveness ● can be costly
sulfur		● works well to control powdery mildew ● expensive ● corrosive to equipment
thiabendazole	Anthracnose/chocolate spot Fusarium fruit rot	● postharvest stem end rot treatment ● more effective when preceded by hot water spray or dip ● Japan will not accept treated papaya ● export limitation

Active Ingredient	Disease/Pest	Advantages/Disadvantages
MITICIDES		
fenbutatin-oxide	Broad mite Flat mite Carmine spider mite Citrus red mite Leaf edgeroller mite Texas citrus mite	● good control with one application ● good residual ● restricted use pesticide ● restriction on amount that can be applied per 12-month season ● 7-day PHI too long ● expensive
petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, paraffinic oil	Broad mite Carmine spider mite Citrus red mite Flat mite Leaf edgeroller mite Texas citrus mite	● unknown effectiveness ● environmentally friendly ● potentially expensive
sulfur	Broad mite Carmine spider mite Citrus red mite Flat mite Leaf edgeroller mite Texas citrus mite	● relatively inexpensive ● organically compatible ● adequate efficacy ● also controls powdery mildew ● may have an effect on black spot and other fungal diseases ● strong smell ● use of surfactant is necessary ● some surfactants phytotoxic ● can be phytotoxic if mixed with EC/xylene-based malathion or petroleum product ● may cause phytotoxicity if applied when temperature is greater than 80°F ● corrosive to equipment
MOLLUSCICIDES		
metaldehyde	African snail Black slug Semi-slug Two line brown slug	● very effective ● easy to apply ● relatively long residual

Active Ingredient	Disease/Pest	Advantages/Disadvantages
NEMATICIDES		
1,3-dichloropropene	Nematodes (root knot, reniform)	● highly toxic biocide ● very effective
azadirachtin	Nematodes (root knot, reniform)	● effectiveness unknown ● may be used in organics ● expensive
kaolin	Nematodes (root knot, reniform)	● very expensive ● effectiveness unknown ● relatively safe
metam-sodium	Nematodes (root knot, reniform)	● toxic biocide ● expensive ● very effective
HERBICIDES		
diuron	Grassy and broadleaf weeds	● good control ● poor control of sedges ● inexpensive ● persistent ● potential groundwater contaminant ● affects papaya grown in rocky conditions
N-(phosphonomethyl)glycine -potassium salt		● broad control ● papaya sensitive to drift
glyphosate		● cheaper (off patent) ● safe for workers ● no soil activity ● slow rate of kill ● better against grasses than broadleaf weeds ● papaya very susceptible to drift ● minimum 6 hours of drying time for optimum effectiveness
pelargonic acid (nonanoic acid)		● approved for organic farming ● shows results in 2–4 hours ● strong smell can affect workers

Active Ingredient	Disease/Pest	Advantages/Disadvantages
HERBICIDES *(continued)*		
oryzalin		● safe around young papaya plants but should not be applied to green stems ● makes a good tank mix with oxyfluorfen for wide spectrum weed control ● no vapor action against papaya foliage ● no contact burn on weeds
oxyfluorfen	Grassy and broadleaf weeds	● good control for papaya in soil ● reasonable cost ● very good as a pre-emergence with adequate rainfall or irrigation ● can have improved post-emergence activity with the addition of a surfactant ● poor sedge control ● 2XL formulation can be phytotoxic to a young crop (A new formulation, GoalTender, might be less phytotoxic.) ● can get a buildup of Spanish needle (*Bidens pilosa*) with continued use ● application under certain conditions causes vapor drift to papaya canopy, which can burn succulent new foliage
paraquat dichloride	Grassy and broadleaf weeds	● good control ● rapid burndown ● inexpensive ● good in high rainfall areas ● increased effectiveness in low-light areas ● no soil residual ● hazardous to applicator ● no antidote ● restricted use pesticide

Table 5. Efficacy of Pest Management Tools for Control of Insects and other Invertebrate Pests on Papaya in Hawai'i

	Pest																		
Management Tool:	**African Snail**	**Aphids[1]**	**Brown Slug**	**Semi-Slug**	**Two-Striped Slug**	**Aphids[1] (Papaya Ringspot Virus)**	**Broad Mite**	**Carmine Spider Mite**	**Citrus Red Spider Mite**	**Flat Mite**	**Leaf Edgeroller Mite**	**Texas Citrus Mite**	**Mediterranean Fruit Fly**	**Melon Fly**	**Oriental Fruit Fly**	**Papaya Mealybug**	**Stevens Leafhopper**	**Thrips**	**White Peach Scale**
Registered Pesticides																			
azadirachtin (Aza-Direct Biological Insecticide, Azatin XL Biological Insecticide, Azatrol EC Insecticide, Ecozin 3% EC Botanical Insecticide)	-	P - F	-	-	-	P - F	*	*	*	*	*	*	*	*	*	P	P	*	P
Bacillus thuringiensis subsp. *aizawai* (6403) (Xentari Biological Insecticide Dry Flowable)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
Bacillus thuringiensis subsp. *kurstaki* (6402) (DiPel DF Biological Insecticide Dry Flowable)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
Bacillus thuringiensis subsp. *kurstaki*, strain EG7841 Lepidopteran active toxin (6453) (Crymax Bioinsecticide)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
clarified hydrophobic extract of neem oil (Trilogy)	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	*	*		*
copper oxid (Nordox)	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
fenbutatin-oxide (Griffin Vendex 50WP Miticide)	-	-	-	-	-	-	G	G	G	G	G	+	-	-	-	-	-		-

	Pest																		
Management Tool:	**African Snail**	**Aphids[1]**	**Brown Slug**	**Semi-Slug**	**Two-Striped Slug**	**Aphids[1] (Papaya Ringspot Virus)**	**Broad Mite**	**Carmine Spider Mite**	**Citrus Red Spider Mite**	**Flat Mite**	**Leaf Edgeroller Mite**	**Texas Citrus Mite**	**Mediterranean Fruit Fly**	**Melon Fly**	**Oriental Fruit Fly**	**Papaya Mealybug**	**Stevens Leafhopper**	**Thrips**	**White Peach Scale**
hydramethylnon (Amdro Pro)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
imidacloprid (Admire Pro Systemic Protectant, Provado)	-	E	-	-	-	G	-	-	-	-	-	-	-	-	-	F	G - E	*	F
malathion (Drexel Malathion 5EC Insecticide/Miticide, Malathion 8 Aquamul, Micro Flo Malathion 5EC, Prentox 5 Lb. Malathion Spray)	-	G	-	-	-	G	-	-	-	-	-	-	-	-	-	P	G	*	P
metaldehyde (Deadline M-PS Mini Pellets)	E	-	E	E	E	-	-	-	-	-	-	-	-	-	-	-	-		-
naled (Dibrom Concentrate)	-	-	-	-	-	-	-	-	-	-	-	-	G	G	G	-	-		-
petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil (Biocover UL, Biocover MLT)	-	G	-	-	*	P	-	*	*	*	*	*	-	-	-	P	P		F
potassium salts of fatty acids (Bon-Neem Insecticidal Soap Concentrate)	-	F	-	-	-	P	-	*	*	*	*	*	-	-	-	F	P		F
pyrethrins (Pyganic Crop Protection EC 1.4 II, Pyganic Crop Protection EC 5.0 II,	-	P	-	-	-	P	-	-	-	-	-	-	-	-	-	*	*		*
pyrethrins + piperonyl butoxide (Pyrenone Crop Spray, Prentox Pyronyl Crop Spray)	-	P	-	-	-	P	-	-	-	-	-	-	-	-	-	*	*		*

	Pest																		
Management Tool:	**African Snail**	**Aphids[1]**	**Brown Slug**	**Semi-Slug**	**Two-Striped Slug**	**Aphids[1] (Papaya Ringspot Virus)**	**Broad Mite**	**Carmine Spider Mite**	**Citrus Red Spider Mite**	**Flat Mite**	**Leaf Edgeroller Mite**	**Texas Citrus Mite**	**Mediterranean Fruit Fly**	**Melon Fly**	**Oriental Fruit Fly**	**Papaya Mealybug**	**Stevens Leafhopper**	**Thrips**	**White Peach Scale**
pyrethrins + rotenone (Pyrellin E.C.)	-	P	-	-	-	P	-	-	-	-	-	-	-	-	-	*	*		*
pyriproxyfen (Esteem 35 WP Insect Growth Regulator)	-	P	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-		-
spinosad (Success, Entrust, GF-120 NF Naturalyte Fruit Fly Bait)	-	P	-	-	-	G	-	-	-	-	-	-	G	G	G	-	-	+	-
sulfur (Drexel Sulfur 90W, Micro Sulf)	-	P	-	-	-	F	G	G	G	G	G	G	-	-	-	P	P		P
Cancelled Pesticide																			
permethrin (Ambush)—previously registered as a 24(c) in Hawaii, but growers did not use the product and the registration was allowed to expire in December, 2002. The registrant no longer supports this use. Remaining label is for use in Florida only.	-	G	-	-	-	G	-	G	-	P	P	P	P	F	P	P	-		-
Pipeline Pest Management Tools																			
abamectin	-	-	-	-	-	-	G	G	G	G	G	G	-	-	-	-	-		-
bifenazate	-	-	-	-	-	-	+	G	G	+	+	+	-	-	-	-	-		-

	Pest																		
Management Tool:	**African Snail**	**Aphids[1]**	**Brown Slug**	**Semi-Slug**	**Two-Striped Slug**	**Aphids[1] (Papaya Ringspot Virus)**	**Broad Mite**	**Carmine Spider Mite**	**Citrus Red Spider Mite**	**Flat Mite**	**Leaf Edgeroller Mite**	**Texas Citrus Mite**	**Mediterranean Fruit Fly**	**Melon Fly**	**Oriental Fruit Fly**	**Papaya Mealybug**	**Stevens Leafhopper**	**Thrips**	**White Peach Scale**
buprofezin	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+		E
change of Provado PHI to 1 day	-	E	-	-	-	G	-	-	-	-	-	-	-	-	-	F	G - E		F
fenpropathrin	-	-	-	-	-	-	+	+	+	+	+	+	-	-	-	+	+		+
parasitoid (*Encarsia berlesei*) targeted for importation by USDA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		*
pyridaben	-	+	-	-	-	+	+	G	+	+	G	+	-	-	-	-	-		-
radio frequency as a quarantine treatment	-	*	-	-	-	*	*	*	*	*	*	*	*	*	*	*	*		*
registration of male annihilation end products by EPA	-	-	-	-	-	-	-	-	-	-	-	-	F	F	F	-	-		-
sprayable formulation of methyl eugenol and spinosad	-	-	-	-	-	-	-	-	-	-	-	-	G	G	G	-	-		-
two species of parasitoids in quarantine	-	-	-	-	-	-	-	-	-	-	-	-	G	G	G	-	-		-
Cultural/Nonchemical Controls																			
biological control by *Stethorus* beetle	-	-	-	-	-	-	+	G	G	+	+	G	-	-	-	-	-		-

	Pest																		
Management Tool:	**African Snail**	**Aphids[1]**	**Brown Slug**	**Semi-Slug**	**Two-Striped Slug**	**Aphids[1] (Papaya Ringspot Virus)**	**Broad Mite**	**Carmine Spider Mite**	**Citrus Red Spider Mite**	**Flat Mite**	**Leaf Edgeroller Mite**	**Texas Citrus Mite**	**Mediterranean Fruit Fly**	**Melon Fly**	**Oriental Fruit Fly**	**Papaya Mealybug**	**Stevens Leafhopper**	**Thrips**	**White Peach Scale**
compost tea "microbe extract" (organic)	*	-	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*
field sanitation	G	P	G	G	G	P	-	-	-	-	-	-	G	G	G	G	P		F
full spray coverage	-	+	-	-	-	G	G	G	G	G	G	G	-	-	-	+	+		+
harvest timing and heat	-	*	-	-	-	*	*	*	-	*	*	*	*	*	*	*	*		*
Hawai'i Area-Wide Fly-PM Program	-	-	-	-	-	-	-	-	-	-	-	-	G	G	G	-	-		-
irradiation	-	-	-	-	-	*	*	*	*	*	*	*	*	*	*	*	*		*
irradiation to kill/sterilize fruit fly (postharvest)	-	*	-	-	-	-	-	-	-	-	-	-	E	E	E	-	-		-
maintain plant health	-	*	-	-	-	-	+	+	+	+	+	+	-	-	-	-	-		-
microwave (postharvest)	-	*	-	-	-	*	*	*	*	*	*	*	*	*	*	*	*		*
minimize malathion appplication to conserve natural enemies	-	*	-	-	-	-	+	G	G	+	+	G	P	P	P	-	-		-
other parasites	-	*	-	-	-	F	-	-	-	-	-	-	F	F	F	G	+		G
predator mites	-	-	-	-	-	P	+	G	G	+	+	G	-	-	-	-	-		-
predator thrips	-	*	-	-	-	P	+	+	+	+	+	+	-	-	-	-	-		-

TABLE 5. EFFICACY OF PEST MANAGEMENT TOOLS FOR CONTROL OF INSECTS AND OTHER INVERTEBRATE PESTS ON PAPAYA IN HAWAI'I

	Pest																		
Management Tool:	**African Snail**	**Aphids[1]**	**Brown Slug**	**Semi-Slug**	**Two-Striped Slug**	**Aphids[1] (Papaya Ringspot Virus)**	**Broad Mite**	**Carmine Spider Mite**	**Citrus Red Spider Mite**	**Flat Mite**	**Leaf Edgeroller Mite**	**Texas Citrus Mite**	**Mediterranean Fruit Fly**	**Melon Fly**	**Oriental Fruit Fly**	**Papaya Mealybug**	**Stevens Leafhopper**	**Thrips**	**White Peach Scale**
parasitoid observed in Maui fields	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-		-
predatory beetle (*Cybocephalus nipponicus*)	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	P	-		G
provide habitat for natural enemies	-	*	-	-	-	?	?	?	?	?	?	?	?	?	?	?	?		?
vapor heat treatment disinfestation procedure	-	-	-	-	-	-	*	*	*	*	*	*	G	G	G	*	*		*
vapor heat treatment for harvested fruit	-	*	-	-	-	*	*	*	*	*	*	*	*	*	*	*	*		*

Efficacy rating scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (<70% control); ? = no data, more research needed; - = not applicable or not used; + = no data, but successful on other related organisms; * = not enough experience to rate.

[1]Aphids are not a primary pest of papaya but do vector Papaya Ringspot Virus (PRSV). Control of PRSV by controlling aphids is not effective.

Table 6. Efficacy of Pest Management Tools for Control of Disease and Nematode Pests on Papaya in Hawai'i

	Pest																
Management Tool:	**Anthracnose/ Chocolate Spot**	**Black Spot**	**Fruit Spot**	**Fusarium Fruit Rot**	**Guignardia Spot**	**Internal Blight/Internal Smut**	**Papaya Ringspot Virus**	**Pythium Root Rot**	**Phytophthora Blight/ Root Rot**	**Phytophthora Canker/ Fruit Rot**	**Powdery Mildew**	**Replant Decline**	**Root Knot Nematode**	**Reniform Nematode**	**Rhizopus Soft Rot**	**Stem-endlbody Rot**	**Wet Fruit Rot**
Registered Materials																	
1,3-dichloropropene (Telone II, Telone EC, Telone C-35, Telone C-15)													E	E			
azoxystrobin (Abound Flowable Fungicide)	G	G	G	G	G						P					G	
azadirachtin (Ecozin 3% EC Botanical Insecticide)													P	P			
basic cupric sulfate (Basic Copper 53, Basicop Basic Copper Sulfate Wettable Powder Fungicide/ Bactericide, Micro Flo Basic Copper 53)		F															
carbonic acid (Kaligreen Potassium Bicarbonate Soluble Powder)											?						
chlorothalonil (Bravo Ultrex Agricultural Fungicide, Bravo Weatherstik Agricultural Fungicide, Equus DF Fungicide, Equus 720 Fungicide Flowable)	G		G	G	G											G	

	Pest																
Management Tool:	**Anthracnose/ Chocolate Spot**	**Black Spot**	**Fruit Spot**	**Fusarium Fruit Rot**	**Guignardia Spot**	**Internal Blight/Internal Smut**	**Papaya Ringspot Virus**	**Pythium Root Rot**	**Phytophthora Blight/ Root Rot**	**Phytophthora Canker/ Fruit Rot**	**Powdery Mildew**	**Replant Decline**	**Root Knot Nematode**	**Reniform Nematode**	**Rhizopus Soft Rot**	**Stem-end\body Rot**	**Wet Fruit Rot**
copper hydroxide (Champ Formula 2 Flowable Agricultural Fungicide/Bactericide, Champion Wettable Powder Agricultural Fungicide, Griffin Kocide 101 Fungicide Wettable Powder, Griffin Kocide 4.5LF Fungicide/Bactericide, Griffin Kocide 2000 Fungicide/Bactericide, Griffin Kocide LF Fungicide/Bactericide, Nu-Cop 50DF, Nu-Cop 50WP)	F	F	F	F	F											F	
copper oxide (Nordox 75WG)		F															
kaolin (Surround WP Crop Protectant)																	
mancozeb (Clean Crop Mancozeb 80WP Fungicide, Dithane 45C Rainshield, Dithane 75DF Rainshield, Dithane DF Rainshield Fungicide, Dithane F-45 Rainshield Fungicide, Dithane M45 Fungicide, Griffin Manzate 75DF Fungicide, Griffin Manzate Flowable Fungicide, Lesco 4 Flowable Mancozeb, Penncozeb 75DF Dry Flowable Fungicide, Penncozeb 80WP Fungicide)	G	G	G	G	G											G	

	Pest																
Management Tool:	**Anthracnose/ Chocolate Spot**	**Black Spot**	**Fruit Spot**	**Fusarium Fruit Rot**	**Guignardia Spot**	**Internal Blight/Internal Smut**	**Papaya Ringspot Virus**	**Pythium Root Rot**	**Phytophthora Blight/ Root Rot**	**Phytophthora Canker/ Fruit Rot**	**Powdery Mildew**	**Replant Decline**	**Root Knot Nematode**	**Reniform Nematode**	**Rhizopus Soft Rot**	**Stem-end\body Rot**	**Wet Fruit Rot**
maneb (Griffin Manex Fungicide Flowable with Zinc, Maneb 75DF Dry Flowable Fungicide, Maneb 80WP Fungicide)			+														
metalaxyl-M (mefenoxam) (Ridomil Gold Copper Fungicide, Ridomil Gold EC Fungicide)								E	G - E	G - E							
metam-sodium (Metam CLR 42%, Clean Crop Metam Sodium, Clean Crop Nemasol 42%, Sectagon 42, Vapam, Vapam HL Soil Fumigant)								G	G				G	G			
mono- & di-potassium salts of phosphorous acid (Fosphite Fungicide)									G	G							
Myrothecium verrucaria (DiTera)													+	+			
petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil (BioCover UL, Biocover MLT)																	

	Pest																
Management Tool:	**Anthracnose/ Chocolate Spot**	**Black Spot**	**Fruit Spot**	**Fusarium Fruit Rot**	**Guignardia Spot**	**Internal Blight/Internal Smut**	**Papaya Ringspot Virus**	**Pythium Root Rot**	**Phytophthora Blight/ Root Rot**	**Phytophthora Canker/ Fruit Rot**	**Powdery Mildew**	**Replant Decline**	**Root Knot Nematode**	**Reniform Nematode**	**Rhizopus Soft Rot**	**Stem-endlbody Rot**	**Wet Fruit Rot**
sulfur (Kumulus DF, Drexel Sulfur 90W, Micro Sulf)		G									G						
thiabendazole (Decco Salt No. 19)	G		G	G	G											G	
Pipeline Pest Management Tools																	
boscalid + pyraclostrobin	+	E															
cyprodinil + fludioxonil	+																
famoxadone + cymoxanil									+	+							
myclobutanil											E						
New packing materials to extend post-harvest life of fruit																	
trifloxystrobin											E						
triflumizole		G									E						
Cultural/Non-chemical Controls																	
"virgin" soil technique								X	X								

	Pest																
Management Tool:	**Anthracnose/ Chocolate Spot**	**Black Spot**	**Fruit Spot**	**Fusarium Fruit Rot**	**Guignardia Spot**	**Internal Blight/Internal Smut**	**Papaya Ringspot Virus**	**Pythium Root Rot**	**Phytophthora Blight/ Root Rot**	**Phytophthora Canker/ Fruit Rot**	**Powdery Mildew**	**Replant Decline**	**Root Knot Nematode**	**Reniform Nematode**	**Rhizopus Soft Rot**	**Stem-endlbody Rot**	**Wet Fruit Rot**
beneficial nematodes													?	?			
adjusting soil pH								X	X								
anti-penetrants								?									
avoid planting in fields formerly planted to pineapple													X	X			
composting and green manures													X	X			
control of aphid vector of disease							P										
cover crop/weed-free non-host fallow													?	?			
directed fungicide spray		X															
drainage, improve or maintain													X	X			
genetic selection of seed to reduce/eliminate expression of incomplete closure of blossom end of fruit						E											
genetically resistant cultivars							E										

	Pest																
Management Tool:	**Anthracnose/ Chocolate Spot**	**Black Spot**	**Fruit Spot**	**Fusarium Fruit Rot**	**Guignardia Spot**	**Internal Blight/Internal Smut**	**Papaya Ringspot Virus**	**Pythium Root Rot**	**Phytophthora Blight/ Root Rot**	**Phytophthora Canker/ Fruit Rot**	**Powdery Mildew**	**Replant Decline**	**Root Knot Nematode**	**Reniform Nematode**	**Rhizopus Soft Rot**	**Stem-endlbody Rot**	**Wet Fruit Rot**
heat treatment for quarantine somewhat effective	G		G	G											F		G
hot water dip treatment (120°F for 20 minutes)	G		G	G						G						G	G
large buffer areas between fields—isolation							X										
minimize wounding of fruit															E		
planting in "virgin" lands								G	G								
postharvest management of temperature can contribute to management of this disease			G	G	E												
postharvest management of moisture															X		
pruning older, drooping leaves	X	X	X													X	
rapid turnover of fruits so that transit time from refrigerator to consumer is minimized	G		G	G	G											G	
regular fertilization																	
sanitation in the field	X		X			X										X	

TABLE 6. EFFICACY OF PEST MANAGEMENT TOOLS FOR CONTROL OF DISEASE AND NEMATODE PESTS ON PAPAYA IN HAWAI'I

	Pest																
Management Tool:	**Anthracnose/ Chocolate Spot**	**Black Spot**	**Fruit Spot**	**Fusarium Fruit Rot**	**Guignardia Spot**	**Internal Blight/Internal Smut**	**Papaya Ringspot Virus**	**Pythium Root Rot**	**Phytophthora Blight/ Root Rot**	**Phytophthora Canker/ Fruit Rot**	**Powdery Mildew**	**Replant Decline**	**Root Knot Nematode**	**Reniform Nematode**	**Rhizopus Soft Rot**	**Stem-endlbody Rot**	**Wet Fruit Rot**
sanitation in packing area															G		
spray adjuvant	X		X													X	
surveying and roguing (infested trees cut down and destroyed)			X				X										
thinning fruit		X															
tree spacing, thinning trees to increase air circulation									X	X							
windbreaks							X										

Rating Scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (<70% control); ? = no data/more research needed; + = no data, but successful on other related organisms; X = This control is used and is believed to have some efficacy against this pest but may not be stand-alone method; + = no data, but successful on other related organisms.

Table 7. Efficacy of Pest Management Tools for Control of Weed Pests in Papaya in Hawai'i

	Pest		
Management Tool:	**Grasses**	**Broadleaves**	**Sedges**
Registered Materials			
Pre-emergence:			
diuron (Diuron 80 WDG Weed Killer, Drexel Diuron 4L Herbicide, Griffin Direx 4L Herbicide, Griffin Direx 80DF Herbicide, Griffin Karmex DF Herbicide)	E (on papayas in soil)	G (on papayas in soil)	P
oryzalin (Farmsaver.com Oryzalin 4 A.S., Oryza Ag Herbicide, Surflan AS Specialty Herbicide)	E	F	P
oxyfluorfen (Goal 2XL Specialty Herbicide, Goal 4F, GoalTender Herbicide)	E (on papayas in soil)	E (on papayas in soil)	P
Post-emergence:			
N-(phosphonomethyl)glycine - potassium salt (Roundup Weathermax Herbicide, Roundup Original Max Herbicide)	E	G	F
glyphosate (Buccaneer Herbicide, Buccaneer Glyphosate Herbicide, Buccaneer Plus Herbicide, Buccaneer Plus Glyphosate Herbcide, ClearOut 41, ClearOut 41 Plus, Glyfos X-tra Herbicide, Glyphomax Herbicide, Glyphomax Plus Herbicide, Gly Star Plus, Griffin Glyphosate Original Herbicide, Helosate Plus, Honcho Herbicide, Honcho Plus Herbicide, Micro Flo Gly-Flo Herbicide, Mirage, Mirage Plus Herbicide, Nufarm Credit Systemic Extra Herbicide, Rascal Herbicide, Roundup Original Herbicide, Roundup Original II Herbicide, Roundup Ultradry Herbicide, Roundup Ultramax Herbicide, Superstate Herbicide, Touchdown Herbicide)	E	G	F
pelargonic acid/nonanoic acid (Scythe Herbicide)	P	P	P
paraquat dichloride (Gramoxone Max Herbicide)	G	G	F - G

	Pest		
Management Tool:	**Grasses**	**Broadleaves**	**Sedges**
Cultural/Nonchemical Controls			
cover crop	F	G	F
crop residue	P	P	P
fallow (bareground with shallow cultivation)	F	G	P
plant spacing/density	P	P	P

Rating Scale: E = excellent (90–100% control); G = good (80–90% control); F = fair (70–80% control); P = poor (<70% control); - = not applicable or not used.

Table 8. Toxicity of Pest Management Tools to Beneficials in Papaya in Hawai'i

	Beneficial								
Management Tool:	***Stethorus* beetle for mites**	**Predator mites for pest mites**	**Predator thrips for pest mites**	**Parasitic wasps for fruit flies**	***Cybocephalus nipponicus* for White Peach Scale**	***Encarsia berlesei* for White Peach Scale**	***Encarsia diaspidicola* for White peach Scale**	**Other predators**	**Other parasites**
Registered Materials									
Insecticides/Miticides:									
Azadirachtin/Neem oil (various products)	1	1	2	1	1	1	1	1	1
Bacillus thuringiensis subsp. *aizawai* (6403) (Xentari Biological Insecticide Dry Flowable)	0	0	0	0	0	0	0	0	0
Bacillus thuringiensis subsp. *kurstaki* (6402) (DiPel DF Biological Insecticide Dry Flowable)	0	0	0	0	0	0	0	0	0
Bacillus thuringiensis subsp. *kurstaki*, strain EG7841 Lepidopteran active toxin (6453) (Crymax Bioinsecticide)	0	0	0	0	0	0	0	0	0
Fenbutatin-oxide (Griffin Vendex 50WP Miticide)	?	?	?	?	?	?	?	?	?
Hydramethylnon (Amdro Pro)	?	?	?	?	?	?	?	?	?
Imidacloprid (Provado)	1	1	1	1	1	1	1	1	1
Malathion (various products)	4	2	4	4	4	4	4	4	4
Metaldehyde (Deadline M-PS Mini Pellets)	?	?	?	?	?	?	?	?	?
Naled (Dibrom Concentrate)	5	?	?	5	5	5	5	5	5

	Beneficial								
Management Tool:	***Stethorus* beetle for mites**	**Predator mites for pest mites**	**Predator thrips for pest mites**	**Parasitic wasps for fruit flies**	***Cybocephalus nipponicus* for White Peach Scale**	***Encarsia berlesei* for White Peach Scale**	***Encarsia diaspidicola* for White peach Scale**	**Other predators**	**Other parasites**
Petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil (BioCover UL, BioCover MLT)	1	2	2	1	1	1	1	1	1
Potassium salts of fatty acids (Bon-Neem Insecticidal Soap Concentrate)	1	1	2	1	1	1	1	1	1
Pyrethrins (Pyganic Crop Protection EC 1.4 II, Pyganic Crop Protection EC 5.0 II)	3	3	3	3	3	3	3	3	3
Pyrethrins + piperonyl butoxide (Pyrenone Crop Spray, Prentox Pyronyl Crop Spray)	3	3	3	3	3	3	3	3	3
Pyrethrins + rotenone (Pyrellin E.C.)	4	4	4	4	4	4	4	4	4
Pyriproxyfen (Knack Insect Growth Regulator)	?	?	?	?	?	?	?	?	?
Spinosad (Success, Entrust, GF-120 NF Naturalyte Fruit Fly Bait)	2*	1*	4*	3	3	3	3	?	?
Sulfur (Drexel Sulfur 90W, Micro Sulf)	2	3	3	2	2	2	2	2	2
Cancelled Insecticide:									
Permethrin	4	3	4	4	4	4	4	4	4
Fungicides/Nematicides:									
1,3--dichloropropene (Telone II, Telone EC, Telone C-35, Telone C-15)	?	?	?	?	?	?	?	?	?
Azoxystrobin (Abound Flowable Fungicide)	?	?	?	?	?	?	?	?	?

	Beneficial								
Management Tool:	***Stethorus* beetle for mites**	**Predator mites for pest mites**	**Predator thrips for pest mites**	**Parasitic wasps for fruit flies**	***Cybocephalus nipponicus* for White Peach Scale**	***Encarsia berlesei* for White Peach Scale**	***Encarsia diaspidicola* for White peach Scale**	**Other predators**	**Other parasites**
Basic cupric sulfate (Basic Copper 53, Basicop Basic Copper Sulfate Wettable Powder Fungicide/Bactericide, Micro Flo Basic Copper 53)	?	?	?	?	?	?	?	?	?
Carbonic acid (Kaligreen Potassium Bicarbonate Soluble Powder)	?	?	?	?	?	?	?	?	?
Chlorothalonil (various products)	?	?	?	?	?	?	?	?	?
Copper hydroxide (various products)	?	?	?	?	?	?	?	?	?
Copper oxide (Nordox 75WG)	?	?	?	?	?	?	?	?	?
Kaolin (Surround WP Crop Protectant)	?	?	?	?	?	?	?	?	?
Mancozeb (various products)	?	?	?	?	?	?	?	?	?
maneb (Griffin Manex Fungicide Flowable with Zinc, Maneb 75DF Dry Flowable Fungicide, Maneb 80WP Fungicide)	?	?	?	?	?	?	?	?	?
Metalaxyl-M (Ridomil Gold Copper Fungicide, Ridomil Gold EC Fungicide)	?	?	?	?	?	?	?	?	?
Metam-sodium (Metam CLR 42%, Clean Crop Metam Sodium, Clean Crop Nemasol 42%, Sectagon 42, Vapam, Vapam HL Soil Fumigant)	?	?	?	?	?	?	?	?	?
Mono- & di-potassium salts of phosphorous acid (Fosphite Fungicide)	?	?	?	?	?	?	?	?	?

	Beneficial								
Management Tool:	***Stethorus* beetle for mites**	**Predator mites for pest mites**	**Predator thrips for pest mites**	**Parasitic wasps for fruit flies**	***Cybocephalus nipponicus* for White Peach Scale**	***Encarsia berlesei* for White Peach Scale**	***Encarsia diaspidicola* for White peach Scale**	**Other predators**	**Other parasites**
Thiabendazole (Decco Salt No. 19)	?	?	?	?	?	?	?	?	?
Herbicides									
Diuron (Diuron 80 WDG Weed Killer, Drexel Diuron 4L Herbicide, Griffin Direx 4L Herbicide, Griffin Direx 80DF Herbicide, Griffin Karmex DF Herbicide)	?	?	?	?	?	?	?	?	?
Oryzalin (Farmsaver.com Oryzalin 4 A.S., Oryza Ag Herbicide, Surflan AS Specialty Herbicide)	?	?	?	?	?	?	?	?	?
Oxyfluorfen (Goal 2XL Specialty Herbicide, Goal 4F, GoalTender Herbicide)	?	?	?	?	?	?	?	?	?
N-(phosphonomethyl)glycine - potassium salt (Roundup Weathermax Herbicide, Roundup Original Max Herbicide)	?	?	?	?	?	?	?	?	?
Glyphosate (various products)	?	?	?	?	?	?	?	?	?
Pelargonic acid/nonanoic acid/ (Scythe Herbicide)	?	?	?	?	?	?	?	?	?
Paraquat dichloride (Gramoxone Max Herbicide)	?	?	?	?	?	?	?	?	?
Pipeline Pest Management Tools:									
Abamectin (Agri-mek 0.15 EC)	?	4	2	?	?	?	?	?	?
Bifenazate (Acramite)	?	3	?	?	?	?	?	?	?
Boscalid + pyraclostrobin (Pristine)	?	?	?	?	?	?	?	?	?

	Beneficial								
Management Tool:	***Stethorus* beetle for mites**	**Predator mites for pest mites**	**Predator thrips for pest mites**	**Parasitic wasps for fruit flies**	***Cybocephalus nipponicus* for White Peach Scale**	***Encarsia berlesei* for White Peach Scale**	***Encarsia diaspidicola* for White peach Scale**	**Other predators**	**Other parasites**
Buprofezin (Applaud)	1	1	1	1	1	1	1	1	1
Cyprodinil + fludioxonil (Switch)	?	?	?	?	?	?	?	?	?
Famoxadone + cymoxanil (Tanos)	?	?	?	?	?	?	?	?	?
Fenpropathrin (Danitol)	4	4	4	4	4	4	4	4	4
Myclobutanil (Rally)	?	?	?	?	?	?	?	?	?
Pyridaben (Pyramite)	?	2	?	?	?	?	?	?	?
Trifloxystrobin (Flint)	?	?	?	?	?	?	?	?	?
Triflumizole (Procure)	?	?	?	?	?	?	?	?	?
Cultural/Nonchemical Controls									
Adjusting soil pH	‡	‡	‡	‡	‡	‡	‡	‡	‡
Anti-penetrants	‡	‡	‡	‡	‡	‡	‡	‡	‡
Avoid planting in fields formerly planted to pineapple	0	0	0	0	0	0	0	0	0
Biological control by *Stethorus* beetle	‡	‡	‡	‡	‡	‡	‡	‡	‡
Compost tea "microbe extract" (organic)	‡	‡	‡	‡	‡	‡	‡	‡	‡
Cover crop	0	0	0	0	0	0	0	0	0
Cover crop/weed-free non-host fallow	0	0	0	0	0	0	0	0	0

	Beneficial								
Management Tool:	***Stethorus* beetle for mites**	**Predator mites for pest mites**	**Predator thrips for pest mites**	**Parasitic wasps for fruit flies**	***Cybocephalus nipponicus* for White Peach Scale**	***Encarsia berlesei* for White Peach Scale**	***Encarsia diaspidicola* for White peach Scale**	**Other predators**	**Other parasites**
Crop residue	‡	‡	‡	‡	‡	‡	‡	‡	‡
Directed fungicide spray	‡	‡	‡	‡	‡	‡	‡	‡	‡
Fallow (bareground with shallow cultivation)	0	0	0	0	0	0	0	0	0
Field sanitation	0	0	0	2	0	0	0	0	0
Forced hot air treatment	0	0	0	0	0	0	0	0	0
Full spray coverage	‡	‡	‡	‡	‡	‡	‡	‡	‡
Genetically resistant cultivars	‡	‡	‡	‡	‡	‡	‡	‡	‡
Hand weeding	‡	‡	‡	‡	‡	‡	‡	‡	‡
Hawai'i Areawide Pest Management Program	‡	‡	‡	‡	‡	‡	‡	‡	‡
Harvest timing and heat	‡	‡	‡	‡	‡	‡	‡	‡	‡
Heat treatment for quarantine	0	0	0	0	0	0	0	0	0
Hot water dip treatment (120°F for 20 minutes)	0	0	0	0	0	0	0	0	0
Irradiation	0	0	0	0	0	0	0	0	0
Irradiation to kill/sterilize fruit fly	‡	‡	‡	‡	‡	‡	‡	‡	‡
Large buffer areas between fields—isolation	‡	‡	‡	‡	‡	‡	‡	‡	‡
Maintain plant health	‡	‡	‡	‡	‡	‡	‡	‡	‡

	Beneficial								
Management Tool:	***Stethorus* beetle for mites**	**Predator mites for pest mites**	**Predator thrips for pest mites**	**Parasitic wasps for fruit flies**	***Cybocephalus nipponicus* for White Peach Scale**	***Encarsia berlesei* for White Peach Scale**	***Encarsia diaspidicola* for White peach Scale**	**Other predators**	**Other parasites**
Microwave	0	0	0	0	0	0	0	0	0
Minimize malathion appplication to conserve natural enemies	‡	‡	‡	‡	‡	‡	‡	‡	‡
Parasitic/parasitoid wasps	0	0	0	0	0	0	0	0	0
Parasitoid observed in Maui fields	‡	‡	‡	‡	‡	‡	‡	‡	‡
Plant spacing/density	‡	‡	‡	‡	‡	‡	‡	‡	‡
Planting in "virgin" lands	?	‡	‡	‡	‡	‡	‡	‡	‡
Predatory beetle (*Cybocephalus nipponicus*)	0	1*	0	0	0	0	0	0	0
Predator mites and thrips	0	0	0	0	0	0	0	0	0
Other predators	‡	‡	‡	‡	‡	‡	‡	‡	‡
Provide habitat for natural enemies	‡	‡	‡	‡	‡	‡	‡	‡	‡
Regular fertilization	‡	‡	‡	‡	‡	‡	‡	‡	‡
Sanitation	0	0	0	1	0	0	0	0	0
Sanitation in packing area	‡	‡	‡	‡	‡	‡	‡	‡	‡
Sterile male fruit fly	0	0	0	1	0	0	0	0	0
Surveying and roguing (infested trees cut down and destroyed)	0	0	0	0	0	0	0	0	0
Thinning fruit	‡	‡	‡	‡	‡	‡	‡	‡	‡
Tree spacing, thinning trees to increase air circulation	‡	‡	‡	‡	‡	‡	‡	‡	‡

	Beneficial								
Management Tool:	***Stethorus* beetle for mites**	**Predator mites for pest mites**	**Predator thrips for pest mites**	**Parasitic wasps for fruit flies**	***Cybocephalus nipponicus* for White Peach Scale**	***Encarsia berlesei* for White Peach Scale**	***Encarsia diaspidicola* for White peach Scale**	**Other predators**	**Other parasites**
Use of different papaya varieties	‡	‡	‡	‡	‡	‡	‡	‡	‡
Vapor heat treatment for harvested fruit	0	0	0	0	0	0	0	0	0
"Virgin" soil technique	0	0	0	0	0	0	0	0	0
Windbreaks	‡	‡	‡	‡	‡	‡	‡	‡	‡

Rating Scale: 1 = low impact to 5 = severe impact; 0 = no impact; ? = no data, more research needed; * = more research needed to refine rating; ‡ = no data or not applicable.

Table 9. Papaya Crop Stages, Field Actions, and Worker Activities

Crop Stage	Action(s)	Worker Activity
Pre-plant	• Non-crop fallow for 3–5 years (NI)* • Land clearing (I, NI) • Shank or rip soil in lava rock (I, NI) • Establish windbreaks (I, NI) • Start seedlings for transplant. • Pest management in seedling nursery • Soil testing for fertility, pests • Apply soil amendments • Inoculate with soil microbes for organic production (I, NI) • Install irrigation (I) • Stale seed bed weed control (I, NI) • Install plastic mulch (I) • Apply pre-plant fumigant (I) • Incorporate "virgin" soil for papaya replant fields (NI)	• Sterilize machinery (to minimize nematode and disease spread) • Equipment operation for land clearing, field shanking/ripping, harrowing, and disking • Collect soil samples for testing • Apply and incorporate soil amendments including soil microbe inoculants • Plant seedlings for transplant • Control pests on seedlings prior to transplant • Stale seed bed weed control spraying • Installation of irrigation and plastic mulch materials • Apply pre-plant soil fumigant • Placement of "virgin" soil in papaya replant fields
Planting/Transplant	• Direct seed • Transplant seedlings • Starter fertilizer • Snail and slug control	• Mark planting rows • Apply starter fertilizer • Plant seeds or transplants • Apply Deadline for snail and slug control
Plant to 1st thinning before flowering (direct seed only)	• Irrigation • Fertilization • Pest control • Thinning to reduce competition	• Apply fertilizers • Irrigate • Spray for pest control • Hand thin to 3 to 6 plants (varies by variety)
Thinning at flowering (for direct seed and transplant)	• Thin to 1 hermaphroditic plant (practice called "mama solo")	• Identify and hand cull male only and female only plants
Post sexing to harvest	• Irrigation • Fertilization • Pest control	• Apply fertilizers • Irrigate • Spray for pest control

Harvest to end of crop life (begin at 22–26 weeks after "mama solo," end at 3 years after planting)	• Irrigation • Fertilization • Pest control • Fruit thinning • Field sanitation • Testing leaves and seeds for organic certification	• Apply fertilizers • Irrigate • Spray for pest control • Thin fruit column for marketable fruit size • Remove unmarketable fruit from field • Collect leaves and fruits for organic certification
Postharvest	• Prepare for shipment	• Quarantine treatments for shipping/export

*NI = Nonirrigated fields; I = Irrigated fields.

Table 10. Pest Control Measures by Papaya Crop Stage

	Crop Stage						
Pest/ Control Measure	**Pre-plant**	**Planting/ Transplant**	**Plant to 1st Thinning Before Flowering**	**Thinning at Flowering**	**Post-Sexing to Harvest**	**Harvest to End of Crop**	**Post-Harvest**
Insects							
Aphids							
Azadirachtin	✓		✓		✓	✓	
Clarified hydrophobic extract of neem oil	✓		✓		✓	✓	
Imidacloprid	✓		✓		✓	✓	
Malathion	✓		✓		✓	✓	
Minimize malathion appplication to conserve natural enemies	✓		✓		✓	✓	
Parasites	✓		✓		✓	✓	
Predators	✓		✓		✓	✓	
Petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil	✓		✓		✓	✓	
Potassium salts of fatty acids	✓		✓		✓	✓	
Provide habitat for natural enemies	✓		✓		✓	✓	
Pyrethrins	✓		✓		✓	✓	
Pyrethrins + piperonyl butoxide	✓		✓		✓	✓	
Pyrethrins + rotenone	✓		✓		✓	✓	
Fruit Flies							
Forced hot air treatment							✓
Hawai‘i Areawide Pest Management Program					✓	✓	

	Crop Stage						
Pest/ Control Measure	**Pre-plant**	**Planting/ Transplant**	**Plant to 1st Thinning Before Flowering**	**Thinning at Flowering**	**Post-Sexing to Harvest**	**Harvest to End of Crop**	**Post-Harvest**
Irradiation to kill/sterilize fruit fly							✓
Malathion					✓	✓	
Naled					✓	✓	
Spinosad					✓	✓	
Vapor heat treatment disinfestation procedure							✓
Papaya Mealybug							
Azadirachtin					✓	✓	
Imidacloprid					✓	✓	
Malathion					✓	✓	
Parasitoid observed in Maui fields					✓	✓	
Other parasites					✓	✓	
Petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil					✓	✓	
Stevens Leafhopper							
Clarified hydrophobic extract of neem oil	✓		✓		✓	✓	
Imidacloprid	✓		✓		✓	✓	
Pyrethrins	✓		✓		✓	✓	
Pyrethrins + piperonyl butoxide	✓		✓		✓	✓	
Pyrethrins + rotenone	✓		✓		✓	✓	

	Crop Stage						
Pest/ Control Measure	**Pre-plant**	**Planting/ Transplant**	**Plant to 1st Thinning Before Flowering**	**Thinning at Flowering**	**Post-Sexing to Harvest**	**Harvest to End of Crop**	**Post-Harvest**
White Peach Scale							
Clarified hydrophobic extract of neem oil	✓		✓		✓	✓	
Forced hot air treatment							✓
Imidacloprid	✓		✓		✓	✓	
Irradiation							✓
Malathion	✓		✓		✓	✓	
Petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil	✓		✓		✓	✓	
Potassium salts of fatty acids	✓		✓		✓	✓	
Predatory beetle (*Cybocephalus nipponicus*)	✓		✓		✓	✓	
Pyriproxyfen	✓		✓		✓	✓	
Vapor heat treatment for harvested fruit							✓
Mites							
Stethorus beetle			✓		✓	✓	
Compost tea "microbe extract" (organic)			✓		✓	✓	
Fenbutatin-oxide			✓		✓	✓	
Full spray coverage			✓		✓	✓	
Maintain plant health			✓		✓	✓	
Minimize malathion application to conserve natural enemies			✓		✓	✓	

	Crop Stage						
Pest/ Control Measure	**Pre-plant**	**Planting/ Transplant**	**Plant to 1st Thinning Before Flowering**	**Thinning at Flowering**	**Post-Sexing to Harvest**	**Harvest to End of Crop**	**Post-Harvest**
Petroleum distillate, oils, solvents, or hydrocarbons; also parrafinic hydrocarbons, aliphatic hydrocarbons, parrafinic oil			✓		✓	✓	
Provide habitat for natural enemies			✓		✓	✓	
Sulfur			✓		✓	✓	
Nematodes							
1,3-dichloropropene	✓						
Azadirachtin	✓						
Cover crop/weed-free non-host fallow	✓						
Metam-sodium	✓						
Slugs/Snails							
Metaldehyde		✓	✓				
Diseases / Pathogens							
Anthracnose/Chocolate Spot							
Azoxystrobin					✓	✓	
Basic cupric sulfate					✓	✓	
Chlorothalonil					✓	✓	
Copper hydroxide					✓	✓	
Copper oxide					✓	✓	
Hot water dip treatment (120°F for 20 minutes)							✓

	Crop Stage						
Pest/ Control Measure	**Pre-plant**	**Planting/ Transplant**	**Plant to 1st Thinning Before Flowering**	**Thinning at Flowering**	**Post-Sexing to Harvest**	**Harvest to End of Crop**	**Post-Harvest**
Mancozeb					✓	✓	
Thiabendazole							✓
Black Spot							
Azoxystrobin					✓	✓	
Basic cupric sulfate					✓	✓	
Copper hydroxide					✓	✓	
Copper oxide					✓	✓	
Mancozeb					✓	✓	
Thinning fruit					✓	✓	
Tree spacing, thinning trees to increase air circulation					✓	✓	
Fruit Spots (*Alternaria* sp., *Stemphylium* sp., *Guignardia* spp., and *Fusarium* spp.)							
Azoxystrobin					✓	✓	
Basic cupric sulfate					✓	✓	
Copper hydroxide					✓	✓	
Copper oxide					✓	✓	
Mancozeb					✓	✓	
Thiabendazole							✓
Postharvest management of temperature can contribute to management of this disease							✓

	Crop Stage						
Pest/ Control Measure	**Pre-plant**	**Planting/ Transplant**	**Plant to 1st Thinning Before Flowering**	**Thinning at Flowering**	**Post-Sexing to Harvest**	**Harvest to End of Crop**	**Post-Harvest**
Rapid turnover of fruits so that transit time from refrigerator to consumer is minimized							✓
Internal Blight/Internal Smut							
Field sanitation					✓	✓	
Genetic selection of seed to reduce/eliminate expression of incomplete closure of blossom end of fruit	✓						
Papaya Ringspot Virus							
Genetically resistant cultivars	✓						
Large buffer areas between fields—isolation	✓						
Surveying and roguing (infested trees cut down and destroyed)		✓	✓		✓	✓	
Windbreaks	✓						
Pythium Root Rot							
"Virgin" soil technique	✓						
Adjusting soil pH	✓						
Anti-penetrants		✓					
Metalaxyl-M		✓					
Metam-sodium	✓						
Phytophthora Blight, Canker, and Root Rot							
"Virgin" soil technique	✓						

	Crop Stage						
Pest/ Control Measure	**Pre-plant**	**Planting/ Transplant**	**Plant to 1st Thinning Before Flowering**	**Thinning at Flowering**	**Post-Sexing to Harvest**	**Harvest to End of Crop**	**Post-Harvest**
Metalaxyl-M	✓						
Metam-sodium		✓					
Mono- & di-potassium salts of phosphorous acid		✓					
Planting in "virgin" lands	✓						
Tree spacing, thinning trees to increase air circulation		✓					
Powdery Mildew							
Azoxystrobin					✓	✓	
Carbonic acid					✓	✓	
Myclobutanil					✓	✓	
Sulfur					✓	✓	
Trifloxystrobin					✓	✓	
Triflumizole					✓	✓	
Rhizopus Soft Rot							
Heat treatment for quarantine							✓
Minimize wounding of fruit							✓
Minimize moisture in ripening chambers							✓
Sanitation in packing area							✓

Pest/ Control Measure	Crop Stage						
	Pre-plant	Planting/ Transplant	Plant to 1st Thinning Before Flowering	Thinning at Flowering	Post-Sexing to Harvest	Harvest to End of Crop	Post-Harvest
Weeds							
Cover crop	✓						
Crop residue						✓	
Diuron		✓					
Fallow (bareground with shallow cultivation)	✓						
N-(phosphonomethyl)glycine - potassium salt	✓		✓		✓	✓	
Glyphosate	✓		✓		✓	✓	
Pelargonic acid/nonanoic acid	✓		✓		✓	✓	
Oryzalin		✓					
Oxyfluorfen		✓					
Paraquat dichloride	✓		✓		✓	✓	
Plant spacing/density		✓	✓		✓	✓	