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Papaya Production in Hawaii

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Site selection

The three major environmental factors to consider in selecting a site to grow papayas are temperature, moisture (rainfall and soil drainage), and wind. The hermaphrodite papaya plant preferred for commercial orchards is more sensitive to the growing environment than the female papaya plant, and therefore selection of a suitable site is critical. Another condition to consider is the amount of sunlight the site receives to support plant growth and fruit production. Insufficient sunlight results in low yields and fruits with inadequate sugar and encourages plant diseases affecting papaya production.

Temperature

The temperature of the site is the most important factor. Commercial papaya production in Hawaii is generally limited to low-elevation areas where the minimum temperature is above 60°F. Temperatures below 60°F cause carpeloidy, which results in "cat-face" deformity when floral stamens develop abnormally into fleshy, carpel-like structures. Even at low elevations, fruits formed during cool winter months can express carpeloidy. Cool growing conditions also cause reduced sugar content and delay in fruit maturity. Thus, commercial operations are generally limited to elevations under 500 feet and to higher elevations only on the leeward sides of the islands, such as the Kona region of the island of Hawaii. High temperatures (90–95°F) may induce "female sterility," in which normally hermaphroditic papaya plants produce male flowers, resulting in poor fruit set and production.

Moisture

A minimum monthly rainfall of 4 inches (100 mm) and an average relative humidity of 66 percent are suggested as "ideal" for papaya growth and production. In low-rainfall areas irrigation should be provided via drip-type or mini-sprinkler irrigation systems.

Papaya requires good soil drainage. Where soil drainage is restricted, papaya is susceptible to fungal root diseases. The plants are severely affected by waterlogging and can be killed when subjected to puddled conditions for even a few hours. The Puna area is well suited to commercial papaya production because its *ʻaʻā* lava soils are extremely porous. Elsewhere in Hawaii on mineral soils, papaya requires either good soil drainage or low rainfall to allow for proper soil moisture management.

Wind

Papaya plants must be protected from wind. Plants exposed to constant wind develop deformed, crinkled leaves. When wind stress damage is excessive, the plants have reduced growth, fruit set, fruit quality, and productivity. Wind-blown dust can cause sap bleeding that harms fruit appearance. In coastal regions, salt spray carried by wind can desiccate leaves and kill papaya plants. Winds of 40 mph (64 km/hr) can uproot papaya trees growing in mineral soils, especially when accompanied

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by heavy rain. Windbreaks should be established well in advance of planting a papaya crop.

On the other hand, adequate air movement is important in reducing incidence of fungal diseases such as phytophthora and anthracnose; these diseases can become severe when there is excessive free moisture and high humidity around the plants.

Land preparation

After existing vegetation is cleared, soil samples should be collected and analyzed to determine if there are any problems. Soil samples can be analyzed by the CTAHR Agricultural Diagnostic Service Center (ADSC) or commercial laboratories that are familiar with Hawaii's soil conditions. Based on analysis results, recommendations are provided on adjusting soil pH and the amounts of soil amendments required to correct any deficiencies. For details on sampling technique, see CTAHR publication AS-4, *Testing your soil—why and how to take a soil-test sample*.

Papaya grows well at a soil pH between 5.5 and 6.5. In some of Hawaii's soils, pH below the optimum range results in high levels of soluble aluminum in the soil solution, which severely reduces root development. Additions of agricultural lime to raise the soil pH to 5.5 or higher reduces aluminum solubility and eliminates this problem. In some soils, high levels of manganese (Mn) can be toxic to plants, and liming to pH 6 is necessary to reduce Mn toxicity. The lime should be mixed into the soil as thoroughly as possible in order to affect soil pH throughout the root zone. For more information, see CTAHR publication AS-1, *Liming acid soils of Hawaii*.

Lime also provides calcium, which is essential in preventing maturing fruits from developing a condition known as "soft fruit" that is related to the ratio of calcium to potassium. Regardless of the calcium source, it is important that it be well mixed with the soil, because the neutralizing effect of liming materials is restricted to a short distance from the point of application. Applications of calcium to the soil surface will correct the pH at the soil surface but will have limited effect in correcting soil pH in the root zone.

Like lime, phosphorus (P) also must be mixed well into the soil. Most of Hawaii's soils originated from volcanic ash and have the ability to retain ("fix") P. Depending on the type of clay, the soil may hold on to this fixed P very strongly. Some soils can fix large amounts of P, and for good crop growth on those soils you must add enough phosphate fertilizer to satisfy the soil's P-fixation capacity before any of the P applied becomes available to plants. Contact your local Cooperative Extension Service agent or the CTAHR Agricultural Diagnostic Service Center for assistance in determining the recommended P fertilizer application level for your soil. For more information, see CTAHR publication AS-2, *Predicting phosphorus requirements of some Hawaii soils*.

Fields to be planted with papaya should be "shanked" ("subsoiled") with a reaper blade to a depth of 24–36 inches to break up any hardpan and ensure proper root development. Shanking is also important in *ʻaʻā* soils to break up the underlying *pāhoehoe* lava. In *ʻaʻā* fields, it is common to shank only the planting row. Shanked rows are 11 feet apart where tractors are part of the operation and 10 feet apart where only small pickup trucks are used. Under *ʻaʻā* lava conditions, plant spacing in the row is 5–6 feet apart, while under mineral soil conditions the spacing is 6–7 feet. The number of plants in various spacings is shown in Table 1.

Cultivars

All commercially grown Hawaii papaya cultivars are called "solo" types because they are usually small enough to be eaten by one person alone. Hawaii's solo papayas have 1–3-pound fruits with flesh that is either "red" or "yellow." Cultivars with red flesh are 'Sunrise', 'Sunset', and 'UH SunUp' (a genetically transformed 'Sunset'). Yellow-fleshed cultivars are 'Waimanalo', 'Kapoho', and 'UH Rainbow', which is a cross (F_1 hybrid) between 'Kapoho' and 'UH SunUp'. The red-

Table 1. Planting density for various papaya plant spacings.

Plant spacing (feet)	Row spacing (feet)	Density (plants/acre)
5	10	871
6	10	726
7	10	622
5	11	792
6	11	660
7	11	566

fleshed cultivars are adapted to a wide range of climatic conditions, while the yellow-fleshed cultivars have more exact climatic requirements. For example, 'Waimanalo' is adapted to hot, dry locations and when grown in cooler locations has low brix (a measure of sugar content) and a high incidence of fruit carpeloidy during winter. 'Kapoho' requires uniform, mild temperature and rainfall and produces small fruits when grown under hot, dry conditions. 'UH SunUp' and 'UH Rainbow' were developed to resist infection by papaya ringspot virus, which is highly prevalent in the major papaya producing areas on the islands of Oahu and Hawaii.

The cultivars 'Sunrise', 'Sunset', 'Waimanalo', and 'Kapoho' have been inbred for many generations and are genetically stable, reproducing true to type from seed.

The cultivars 'UH SunUp' and 'UH Rainbow' can be planted only with seed obtained under a license agreement with the Papaya Administrative Committee (PAC). Farmers wishing to receive certification training for this license should contact the PAC or the nearest CTAHR Cooperative Extension Service office. Special precautions are needed with these two cultivars to maintain the virus resistance, as described in CTAHR publication NPH-2, *Production requirements of the transgenic papayas 'UH Rainbow' and 'UH SunUp'*.

These commercial cultivars produce harvestable fruits about 10–12 months after planting, with the exception of 'Kapoho', which takes about 14 months. 'Sunrise' has the shortest shelf life and must be marketed in a timely manner. 'Kapoho' and 'Sunset' have the best shelf life, and 'Waimanalo' is intermediate in this character. Fruits of most commercial papaya cultivars are typically harvested at the "color-break" stage, but harvest of 'Sunset' and 'UH SunUp' should be delayed until the quarter-ripe to half-ripe stage because brix development is slower in these cultivars.

Seedling production

Papaya can be either seeded directly or transplanted into the new field. Direct seeding is practiced in the Puna area because of the porous nature of the *'a'ā* soil, which has few fine particles, resulting in poor moisture-holding and nutrient-holding capacity. The seeds are planted in a trench approximately 6 inches long dug parallel to the planting row. About 15–20 seeds are placed in this trench and covered with ½–1 inch of soil. The use of a trench allows separation of seedlings in the hole and reduces plant competition. Germination occurs 10–21 days after sowing.

In soil areas, transplanting allows growers to place a larger plant (4–8 inches tall) into the field. Seeds are direct-seeded into individual cells (2 x 2 inches) placed in full sunlight. The potting media should be sterile and well drained to minimize root rot. Seedlings are transplanted into the field at about 6 weeks of age after being "hardened" in the nursery to minimize transplant shock.

Planting

Planting in "virgin" lands or fields in which papaya has not been grown before is preferred because of low disease and insect pressure. It is becoming increasingly difficult to find such fields.

"Replant" fields in which papaya has recently been grown generally have high levels of *Phytophthora palmivora* spores due to the decomposition of infected papaya fruit, trunk, and root residues. In replant fields in Puna, it is essential that the "virgin soil" technique is practiced. The technique requires the use of ½ cubic foot of "virgin" soil (soil not previously planted with papaya) placed in each planting hole. This soil allows the seedling roots to grow in a fungus-free environment until the seedlings are old enough to withstand fungal infection as the roots extend beyond the "virgin soil" zone. Because *'a'ā* lava fields are so porous, soil fumigation is impractical, and these fields require a fallow period of 3–5 years before planting another papaya crop.

In fields with mineral soils, residual fungi and nematodes can be controlled with soil fumigants. The fumigant is injected under plastic mulch before planting and allowed to volatilize for 2–3 weeks to ensure that seedlings are not damaged when transplanted. Fumigation reduces the population of nematodes and residual fungi and allows young roots to grow free of pathogenic organisms.

In fields that are infested with *Phytophthora*, an approved fungicide may be used to drench the soil in which the seeds or seedlings are planted.

Seeds planted into the ground or flats are prone to damage by mice and rats. Rodent damage can be detected by looking for signs of digging in the soil surface and by the presence of seed remnants. Cutworms, snails, and slugs often attack papaya seedlings.

Plant sex selection

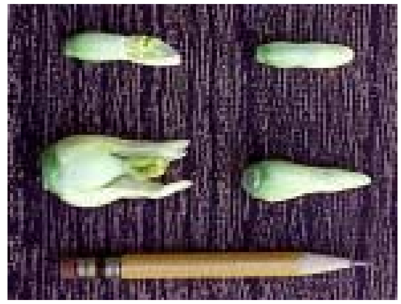
Seeds from solo varieties produce plants of two reproductive types: female and hermaphrodite. Although there is no difference in the eating quality of fruits from these two types, the commercial market prefers the pear-shaped fruits produced by hermaphrodite plants over the rounder fruits of the female plants. Female plants require cross pollination to produce fruit, and there can be gaps in production when pollination does not occur.

All four standard cultivars ('Kapoho', 'Waimanalo', 'Sunrise', and 'Sunset') and the two transgenic cultivars ('UH Rainbow' and 'UH SunUp') produce either only female or only hermaphroditic flowers on any one plant. The tendency to produce plants with male flowers has been bred out of the UH solo cultivars. However, male plants may occur in non-UH varieties, such as the large-fruited types often grown for green-papaya use. The presence of male papaya plants in commercial fields is an indication that out-crossing with a non-solo variety has occurred.

The desired hermaphroditic plants have flowers that contain both an ovary (female organ) and pollen sacs (male organ); they are self-pollinating. Hermaphroditic flowers are more uniformly tubular than female flowers, which are bulbous at the base and pointed at the end (see illustration). Female flowers contain an ovary but lack pollen sacs, and they need to be pollinated.

Thinning

Thinning is done to reduce competition while retaining enough plants to ensure that a hermaphrodite plant is finally obtained. In direct-seeded fields, the plants are thinned three times. First, one month after germination, the number of seedlings is reduced to 6–10 per hole. Second, at three months after germination, the number of seedlings is further reduced to three plants for the standard commercial solo cultivars, which have a sex segregation ratio of 2:1 (two hermaphrodite plants for each female plant), ensuring a 97 percent chance of retaining one hermaphroditic plant. For the transgenic 'UH Rainbow' hybrid, which has a sex segregation ratio of 1:1 (one hermaphrodite to one female plant), five plants should be left in each hole. The third thinning is done at flowering, when one hermaphrodite plant is kept. Commercial cultivars begin to flower at approximately 6 months, with the exception of 'Kapoho', which flowers at about 8 months of age.



Hermaphrodite
fairly uniform thickness; contains both ovary and pollen; self-fertile.

Female
bulbous at base; contains ovary but no pollen; not fertile—must be pollinated.

Hawaiian solo papaya varieties produce plants with flowers that are either female or hermaphroditic; the latter are prefered for commercial production.

Fertilizer

'A'ā lava conditions

Fertilizer practices for the porous *'a'ā* lands of Puna differ from those for papaya-growing areas that have developed soils. Table 2 gives a generalized fertilizer schedule used by most Puna growers.

Due to the porous nature of the *'a'ā* land and the high rainfall in the Puna area, fertilizer efficiency is increased with smaller applications at shorter intervals. From nine months of age, 0.3% boron (B) is added to the fertilizer application at six-month intervals. Boron deficiency is expressed as a distortion of the fruit surface ("bumpy" fruit) and is most prevalent during long periods of moisture stress. Fruit damage occurs early in the fruit development stage and is characterized by latex exuding from the surface of the developing fruits.

Soil conditions

When papaya is grown in soil, the soil should be sampled in advance of planting to allow for incorporation of any amendments needed. The results will determine the form and application rate of liming material required to adjust the soil pH to the 5.5–6.5 range. Preplant rates of phosphorus application are also determined by the analysis. The need for application of minor elements can be indicated by analysis of index tissues from previous crops. A general-composition minor-element fertilizer blend is recommended in the absence of prior crop information.

Soil should be analyzed annually to determine if current practices are sufficient for maintaining production. If deficiencies are found, recommendations will be given by the soil testing laboratory.

Table 2. A typical fertilizer schedule for papaya grown on *‘a‘ā* lands in Puna.

Age (months)	Fertilizer analysis	Application (lb/acre)	Notes
0	0-46-0	100	Treble superphosphate
0	Dolomite	400	Ag 65®
0	14-14-14	25	Osmocote®
1.5	“	25	Osmocote®
3	“	200	granular
4.5	“	300	granular
6	“	300	granular + 0.3% B
7.5	“	300	granular
9	“	300	granular
10.5	“	300	granular
12	“	300	granular + 0.3% B
13.5	16-5-16	300	granular
15	14-14-14	300	granular
16.5	16-5-16	300	granular
18	14-14-14	300	granular + 0.3% B
19.5	16-5-16	200	granular
21	14-14-14	200	granular
23	16-5-16	200	granular
25	14-14-14	200	granular

Continue applications every two months, alternating 16-5-16 and 14-14-14.

A mixture of treble superphosphate (0-45-0, at ½ lb/tree), and minor elements is applied in the hole before transplanting. After planting, top-dress with about ⅒ lb/tree of a complete fertilizer such as 16-16-16. Double this application amount each month until flowering (recommended in an unpublished report by D. Ikehara and R. Yamakawa). After flowering, apply nitrogen at 40–50 lb/acre/month to maintain the N:K ratio in the index tissue between 1:1 and 1:1.5. When applying fertilizer in the irrigation water (“fertigating”), apply weekly to reduce the occurrence of soft fruits.

Plant tissue analysis

Papaya is grown under many different environmental and soil conditions, and therefore it is difficult to have any one fertilizer practice that fits all conditions. Plant tissue analysis is useful in determining the nutritional status of growing plants at different stages of development. This permits modification of fertilizer programs to maximize yield and improve fertilizer use efficiency.

Tissue sampling should be initiated after the plants begin to set fruit. The petiole under the most recently set fruit is collected from five representative plants within a uniform production area. Samples should be taken every two to three months, two weeks after a fertilizer application. Six samplings are usually enough to develop a fertilizer program for a site. Fertilizer program modifications are made by comparing tissue analysis data with “critical” levels developed from research (Table 3). This comparison should be considered in relation to the field’s yield data and observations of fruit size and fruit column length.

Table 3. Critical nutrient levels in papaya petiole tissue under conditions of Puna, Hawaii.

	%		ppm
Nitrogen	1.20 – 1.38	Iron	20 – 100
Phosphorus	0.17 – 0.21	Manganese	20 – 150
Potassium	2.70 – 3.40	Zinc	14 – 40
Calcium	1.00 – 3.00	Copper	4 – 10
Magnesium	0.40 – 1.20	Boron	20 – 50
Sulfur	0.30 – 0.80		

Weed control
Weed control is a major cost in papaya production, particular in young fields. In "virgin fields," the initial weed population may be low, requiring minimal hand weeding. The use of fumigation or the "virgin soil" technique reduces the need for hand weeding in replant fields. Before planting, irrigate fields to germinate weed seeds and then spray the weeds with a systemic herbicide (e.g., Roundup®). If this is done twice, most weed seeds in the surface soil will be eliminated. After planting, hand weeding is recommended around the young seedlings. Herbicides should be used with caution. Contact herbicides are preferred over systemic herbicides at this stage, although both may damage the papaya plants.

It is advisable to shield the young plants when spraying. Older papaya plants with woody trunks are more tolerant of glyphosate-based systemic herbicides such as Roundup, but care in herbicide application should be emphasized. Herbicide applications are usually limited to a bimonthly or quarterly interval in mature orchards, where shading reduces weed growth.

Leaf trimming
Leaves of bearing plants should be trimmed to facilitate application of fungicide to the fruit column and minimize fruit scarring from petioles rubbing against the fruits. It is important to retain as many leaves as possible, because they produce the energy that supports the developing fruits. Trim only leaves with petioles that angle below horizontal. Trimming should be kept to a minimum in winter. Petioles should be cut at the halfway point between the leaf blade and base to minimize fungal infection.

Harvesting
Fruit development is directly related to climatic conditions. During summer, fruits take 22 weeks to mature, and 26 weeks are needed during winter. Fruits are typically harvested weekly at color-break, but harvest may be increased to twice weekly during summer. Fruits are harvested by hand or with the aid of a cut-off "plumber's helper" attached to a pole for hard-to-reach fruits. It is imperative that fruits be handled with minimal bruising or abrasion. The fruit quality in the retail market is directly related to the handling and care during harvesting and packing.

Pest management
Papaya crops are affected by various disease, insect, and mite problems. Becoming aware of potentially injurious organisms and taking appropriate management measures are important for success. The following sections present a brief overview of the major pests of papaya.

Diseases
The diseases of papaya include those caused by a virus, fungi, and nematodes. The papaya ringspot virus (PRV) is the most severe papaya disease and is often the limiting factor in papaya production throughout the world. PRV is widespread on Oahu. On the island of Hawaii, PRV is found throughout the island, including the important papaya production area of Puna. Both Kauai and Maui are presently declared free of PRV, and the virus has not been observed on Lanai or Molokai. Papaya plants infected with PRV must be destroyed to minimize spread of the virus. Virus problems can be avoided by planting genetically resistant cultivars.

PRV is not transmitted via seeds, but it can be spread to areas where it is not present by transporting infected seedlings. To avoid introductions of the virus, do not transport papaya seedlings between islands. On islands where PRV is already present, raise seedlings in nurseries close to the planting site to minimize the possibility of spreading the virus further.

Fungal diseases are a major problem in papaya production. The strategy for fungal disease management is prevention through the application of fungicides at regular intervals. Proper timing, deposition, and coverage of the pesticide application is critical for effective control. Once the disease is established, the fungicides have minimal impact on control. Under high-rainfall conditions, high-volume sprays (75–100 gallons per acre) are required at 2–3 week intervals. Under drier conditions, low-volume sprays (40–50 gallons per acre) at 3–4 week intervals are adequate to protect the exposed fruit surfaces. The use of a surfactant is important to ensure good distribution and adherence of the fungicide spray. Currently, the most effective fungicide for protecting fruits is mancozeb, which can be used in combination with a copper product to increase efficacy.

Powdery mildew can cause premature loss of foliage, resulting in reduced fruit quality and yield. Wettable sulfur is effective for powdery mildew control but only when thorough coverage of the foliage is achieved.

Nematodes can be controlled by fumigating the soil before planting. For more information on nematodes, see CTAHR publication PD-15, *Plant-parasitic nematodes and their management*.

Papaya diseases

Papaya ringspot virus (formerly called papaya mosaic)
Anthracnose and chocolate spot, *Colletotrichum gloeosporioides* (fruit, petiole, leaf)
Phytophthora, *Phytophthora palmivora* (fruit, stem, roots)
Powdery mildew, *Oidium caricae* (leaves)
Black spot, *Cercospora papayae* (fruit)
Damping off, *Pythium, Phytophthora,* and *Rhizoctonia* spp. (seedlings)
Wet rot, *Phomopsis* sp. (fruit)
Dry rot, *Mycosphaerella* sp. (fruit)
Watery fruit rot, *Rhizopus stolonifer*
Stem-end rot, *Botryodiplodia theobromae*, *Mycosphaerella* sp., *Rhizopus stolonifer*, *Phomopsis* sp. (mature fruit)
Reniform nematode, *Rotylenchulus reniformis*
Root-knot nematode, *Meloidogyne* spp.

Insects

Insects can be a major problem in papaya production. The Stevens leafhopper can be a serious problem when its populations build to high levels, which can occur under dry conditions. Infestation is recognized by the yellowing of terminal leaves and the exudate from feeding wounds on petioles. The phytotoxic reaction of the plant, termed "hopper burn," is characterized by the browning (or "firing") of leaf tips and edges.

The white peach scale is a recent introduction to Hawaii. The insects can form large populations at the base of the trunk, giving it a whitewashed appearance. They may move up the trunk and invade the fruit column. If this pest is on fruit intended for export, it becomes a quarantine concern.

Fruit flies are primarily a problem in fruits allowed to ripen on the tree; they are not a major problem when fruits are harvested mature-green for export sale. Papaya fruits for export need to be subjected to approved disinfestation procedures. Treatments currently approved when conducted in accordance with USDA-PPQ specifications are the vapor-heat, irradiation, and high-temperature forced-air treatments.

Mealybugs and white peach scale are occasional pests on the fruits and may lead to rejection at the packing plant. Thorough spray coverage is important in mealybug control, especially at the stem end of the fruit, near the trunk.

Papaya insect pests

Green peach aphid, *Myzus persicae*
Onion thrips, *Thrips tabaci*
Stevens leafhopper, *Empoasca stevensi*
Mediterranean fruit fly, *Ceratitis capitata*
Melon fly, *Dacus cucurbitae*
Oriental fruit fly, *Dacus dorsalis*
White peach scale, *Pseudaulacaspis pentagona*
Mealybugs
Ants
Whitefly

Mites

Mite infestation can affect both the fruit and foliage. It becomes a significant problem under hot, dry conditions. Mites usually feed on the underside of leaves and on young, developing tissues. Miticides generally kill only adults and nymphs and have little effect on eggs. Timely chemical applications are necessary to control the emerging young, which can become egg-laying adults in 7–14 days. Proper spray coverage is essential to prevent "escapes" from reestablishing their population to destructive levels.

Papaya mite pests

Broad mite, *Polyphagotarsonemus latus* (seedlings, young plants, lower surface of young leaves)
Papaya leaf edgeroller, *Calacarus brionesae*
Red and black flat mite, *Brevipalpua phoenicis* (fruit)
Truckerellid mites, *Tuckerella ornata*, *T. pavoniformis* (trunks of old plants)
Carmine spider mite, *Tetranychus cinnabarinus* (lower surface of mature leaves)
Citrus red mite, *Panonychus citri* (upper surface of mature leaves)
Texas citrus mite, *Eutetranychus banksi* (upper surface of mature leaves)

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