Diseases of Papaya *(Carica papaya* L.*)* in Hawaii

R. B. Hine
O. V. Holtzmann
R. D. Raabe

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WARNING

The chemicals listed for control of papaya diseases should be considered dangerous. The manufacturers' recommendations for application and handling should be strictly adhered to. The United States Department of Health, Education, and Welfare, under the provisions of the Pesticide Chemicals Amendment to the Federal Food, Drug, and Cosmetic Act, has established criteria to govern the use of each chemical to which clearance for use has been given. Before using any pesticide, growers should always check its current status with their county agent or the local representative of the U.S.H.E.W., Food and Drug Administration.

PHOTOGRAPHS ON COVER: LEFT: *Top,* **Powdery mildew on the undersurface of a papaya leaf;** *bottom,* **Papaya fruit infected with** *Phytophthora parasitica,* **laboratory inoculation. RIGHT: Papaya fruit infected with** *Phytophthora parasitica,* **natural infection.**

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THE AUTHORS

DR. R. B. HINE is Associate Plant Pathologist at the Hawaii Agricultural Experiment Station; Chairman, Department of Plant Pathology, College of Tropical Agriculture; and Associate Professor of Plant Pathology, University of Hawaii.

DR. O. V. HOLTZMANN is Assistant Plant Pathologist at the Hawaii Agricultural Experiment Station and Assistant Professor of Plant Pathology, University of Hawaii.

DR. R. D. RAABE was formerly Plant Pathologist at the Hawaii Agricultural Experiment Station. He is now Associate Plant Pathologist at the University of California, Berkeley, California.

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INTRODUCTION

Diseases have been shown to be very important factors in reducing yield and marketability of papaya. It is the purpose of this bulletin to describe the symptoms, epidemiology, and control measures for the diseases of papaya that occur in Hawaii.

Papaya (*Carica papaya* L.) is grown in all tropical countries and in some subtropical regions as far north and south as 32 degrees of latitude. Of the 40 or more species of *Carica,* only a few are cultivated and only *C. papaya* has become of economic importance. Of the many variations among the types of papaya grown in Hawaii, the only type considered to be of variety rank is the so-called Solo papaya. This papaya typically has small, pyriform fruits borne on hermaphroditic trees. Fruits borne on female trees are spherical in shape. The trees are usually single-stemmed and reach bearing maturity in 12 to 14 months after planting of seed. This bulletin will discuss the diseases of economic importance on the Solo variety.

Many of the parasitic diseases of papaya from other parts of the world *(1, 4, 5, 22, 24, 27)* do not occur in Hawaii. Possible explanations for the lack of many known diseases in Hawaii are:

1) Isolation of Hawaii from other papaya-producing areas of the world.
2) Strict and efficient quarantine laws.
3) No seed-borne virus diseases of papaya are known and Hawaiian introductions have been from seed.

NONPARASITIC DISEASES

There are a number of diseases not caused by infectious organisms. The most common nonparasitic problem associated with papaya production is the susceptibility of the plant to poor soil aeration and drainage. Mature trees may be killed if

they are exposed to water-saturated soils for 24 hours. After exposure to excess soil moisture, trees wilt rapidly, their leaves yellow, and the trees soon die. Therefore, poorly drained planting sites should be avoided.

Little is known of symptoms associated with nutritional deficiencies in papaya. However, nitrogen deficiency results in small, yellow leaves with short petioles. Phosphorus deficiency causes the leaves to become dark green with a purplish-red coloration on the veins and petioles.

Unisexual trees with functional ovaries but no stamens (females) frequently do not set fruit. If not pollinated the ovaries do not develop and soon fall from the tree. The only solution is to eliminate these trees from the plantings or to hand-pollinate the flowers.

PARASITIC DISEASES

Virus Diseases

Although viruses as causes of diseases in plants have been known since the turn of the century, the first virus disease in papaya was not described until 1929 from Jamaica *(23)*. Since that time, papaya virus diseases have been reported from many papaya-producing areas in the world and appear at present to be the most common limiting factor for production *(1, 3, 7)*. In Hawaii, the first virus disease on papaya was described from Waialua and Lualualei, on the island of Oahu, in 1937 *(17)*. This disease was prevalent in the Waialua area from 1938 to 1941, but incidence steadily declined in the field

FIGURE 1. Commercial papaya orchard severely affected with papaya mosaic disease.

and the disease has not been found since about 1951. The so-called Waialua disease caused the leaves to fall in 4 to 6 weeks after the first symptoms appeared, leaving the stem bare except for a few stunted, distorted leaves at the apex. Presently, there are two virus diseases known to occur in Hawaii: papaya mosaic and papaya ringspot.

Papaya Mosaic

An outbreak of the papaya mosaic virus disease was first encountered in 1959 in Waimanalo Valley on the windward side of the island of Oahu *(9)*. By 1961, it had spread rapidly and had restricted papaya-growing in a number of commercial orchards (fig. 1). The mosaic disease is very destructive; losses ranging from 5 to 20 percent are common in many orchards but losses as high as 75 percent have occurred. In 1962, papaya mosaic was found in the Puna district of the island of Hawaii.

Symptoms

Leaves. Initially, the leaves develop a rugose appearance. The underside of the leaves shows thin, irregular, dark-green lines which appear to etch the borders of cleared areas along the veins. Younger leaves of the crown are generally stunted and severely chlorotic with vein-banding (fig. 2) or transparent oily areas scattered over the leaf or along the leaf veins. In mature leaves, the chlorotic pattern frequently is expressed as extensive vein-clearing, and numerous small rings (fig. 3) develop which are transparent and yellow to tan in color. In severely affected

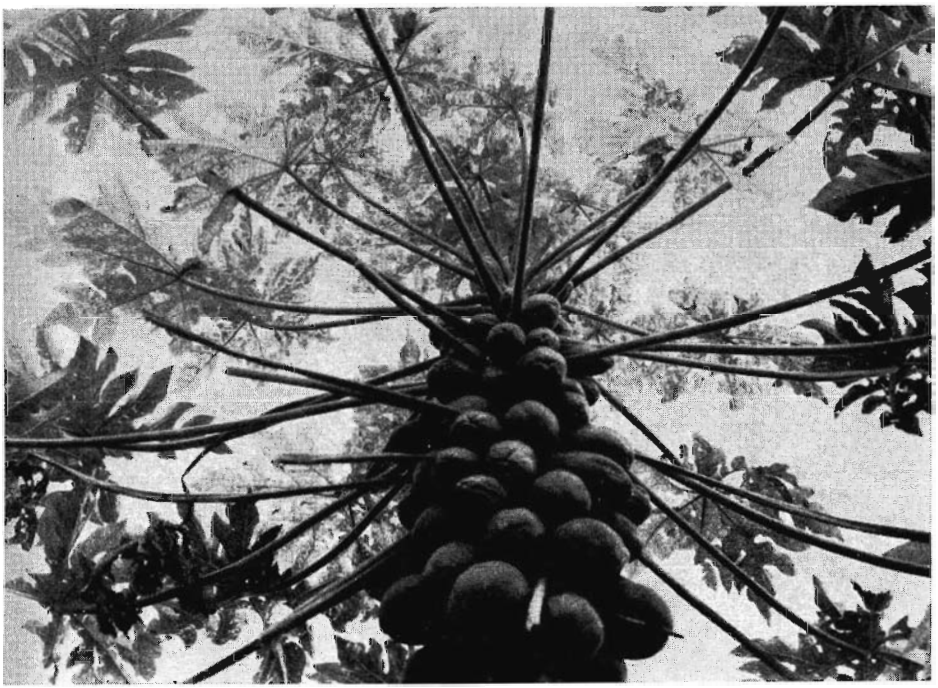


FIGURE 2. Typical symptoms of papaya mosaic disease. Note the marked chlorosis and vein-clearing of crown leaves.

FIGURE 3. Typical small-ring patterns on mature papaya leaf, caused by papaya mosaic virus.

trees, defoliation progresses upward until only a small tuft of leaves remains at the crown. Leaf symptoms for papaya mosaic contrast with the more mild and diffuse mosaic pattern of the papaya ringspot disease. However, stunting of all parts occurs in trees affected with the papaya ringspot virus under adverse environmental stress.

Stem and petiole. On the stems of infected plants are found pinpoint-size spots. As the infection progresses, these spots may develop into linear or, in some instances, distinct concentric ring patterns (fig. 4) which become more intense in color and larger in size. On the petioles, the spots are more irregular in distribution, linear in shape, and at times more elliptical than on the stems. They are also generally lighter in color than those of the stem. In severe infections, petioles are stunted and may bend downward.

Fruit. On the fruit, symptoms may be manifested in all stages of maturity. Small, dark-green ringspots, $\frac{1}{16}$ inch in diameter, have been observed on fruits as young as 2 weeks old. Typically, rings initially show either on the stem end or blossom end. The rings at first may be incompletely closed and irregular, but as the fruit develops, targetlike spots will increase in diameter from $\frac{1}{16}$ inch, consisting of only 1 ring, to about 1 inch with approximately 8 distinct, slightly raised, concentric, brownish rings with a green outside ring (fig. 5). On ripe fruit, there is no mottling of colors as found in papaya ringspot disease (fig. 6).

Transmission

The papaya mosaic disease is readily transmitted either mechanically or by several aphid species, including the green peach aphid, *Myzus persicae.* Attempts to transmit the virus to 56 species of plants representing 15 plant families have been unsuccessful, except for papaya and species in the family Cucurbitaceae *(16).* Although squash, pumpkin, and cantaloupe are susceptible to the virus, watermelon is the best source-plant, followed by cucumber, then papaya. Only one aphid is required to infect a plant. An aphid is able to acquire the virus from a diseased plant during a 10-second feeding period and to infect a healthy plant in a feeding period of the same duration. After acquisition of the virus, the aphid rapidly loses its ability to transmit and within an hour little or no transmission occurs. Symptoms normally appear 18 to 24 days after inoculation.

FIGURE 4. Close-up of papaya stem infected with papaya mosaic showing extensive water-soaked pimples on stem.

FIGURE 5. Green papaya fruit showing characteristic ring formation associated with papaya mosaic virus.

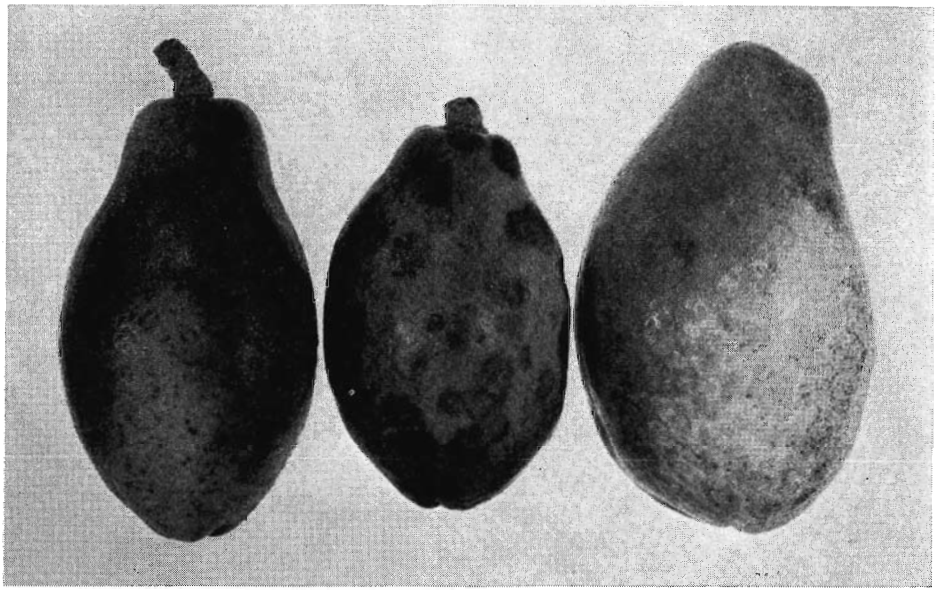


FIGURE 6. Comparative symptoms of ripe papaya fruits affected by papaya mosaic virus *(center)* and papaya ringspot virus *(right)*. Healthy fruit *(left)* with the so-called freckles condition. The cause of these frecklelike blemishes is unknown.

Control

At present, the only satisfactory way of controlling mosaic is by destroying the source of the virus. Once infected, a tree will always remain infected. Complete recovery from the disease does not occur. Partial recovery is only apparent and temporary. A roguing program with the following specific steps is necessary for control of this disease:

1) Spray all infected trees with an insecticide so that aphid carriers are destroyed.
2) Cut and remove from the growing area of papaya and cucurbitaceous plants all infected trees, so that the disease cannot spread and all infected plant parts will dry out and die.
3) Avoid nearby cultivation of all cucurbitaceous plants, as the virus is found naturally in several species in this plant family.
4) Control aphids with pesticides, since they are the disease carriers.

Papaya Ringspot

Papaya ringspot is found at times in epidemic proportions in Waianae on the dry, leeward side of the island of Oahu. Papaya ringspot was the second virus disease to be described on papaya from Hawaii *(13)*, but at the present time it causes little damage to papaya under the cultural environment where it is found and does not materially affect commercial production.

Symptoms

The symptoms of papaya ringspot disease are exhibited on the foliage, fruit, and main stem of the plant. The first evidence of the disease in plants inoculated with ringspot virus is a puckering or bulging of the leaf tissue between the veinlets on the upper surface of the young leaves. Affected leaves on field trees show a distinct tendency to roll upward along the margins and are lighter green than healthy leaves. The time necessary for plants to show leaf symptoms after inoculation varies from 9 to 39 days and depends upon the climate. Plants inoculated during early summer do not develop even mild symptoms until 3 months after inoculation. During the winter months, however, symptoms are produced about 6 weeks after inoculation.

The main stem of papaya plants growing at the time of infection frequently develops dark-green spots and streaks of an oily appearance. These are usually most common on the middle two-thirds of the stem. This symptom is characterized first by the development of a number of distinct round spots approximately $\frac{1}{16}$ inch in diameter. When the disease is severe, the spots coalesce to form larger areas which frequently appear as elongated streaks.

The symptoms on mature green fruits provide the most striking and reliable symptoms of the disease. They consist of yellow spots and yellow rings with green centers (fig. 6). The size of the spots ranges from approximately $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter; whereas, the rings vary in size from $\frac{1}{8}$ to $\frac{3}{4}$ inch in diameter. The number of spots or rings on a single fruit may vary from a few to more than 150.

The effect of papaya ringspot virus on plant growth and vigor varies considerably, depending on environmental conditions for growth. Adverse environmental conditions such as seasonal drought or poor fertilization practices affect ringspot-infected trees more severely than noninfected trees. Trees that are fertilized and irrigated regularly grow moderately well and produce fruit despite the presence of the disease. Stunting of all parts occurs in trees affected with the papaya ringspot virus under adverse environmental stress. Stem and petiole symptoms described for papaya ringspot disease are similar to, but generally milder than, those of mosaic. Concentric ring patterns on the stem have not been observed on trees affected with ringspot disease.

Transmission

The disease is transmitted by aphids as well as by mechanical means. The green peach aphid, the most common insect on papaya in Hawaii, is the major insect vector of the ringspot virus. The melon aphid *(Aphis gossypii)*, the bean aphid *(A. medicaginis)*, and *A. rumicis* are also vectors of the disease *(10)*, but they are not as important as the green peach aphid *(Myzus persicae)*. A healthy green peach aphid may acquire the virus from diseased papaya plants in a feeding time of 2 minutes and may then infect healthy trees after feeding on them for as little time as 5 minutes. The virus is not retained by the aphid beyond the first healthy plant fed upon after transfer from a diseased plant. The virus has a limited host-range and, as far as is known, only papaya can become infected.

Control

Crop-free periods, theoretically possible for the ringspot virus because the virus attacks only papaya, do not seem to be practical because the host is grown as a short-lived perennial in overlapping succession. It would be necessary for growers to omit successive plantings for a time long enough to provide a wholly crop-free

period. Varieties immune to either virus are not known at present. Removal of diseased trees, as discussed in Papaya Mosaic, is the best method of controlling the disease. Insect control as a means of virus control, as described in Papaya Mosaic, is possible but difficult because the aphid vectors breed on many plant species and tend to reinfest papaya soon after treatment.

Fungus Diseases

Anthracnose

Anthracnose, if uncontrolled, is the most important disease affecting papaya in Hawaii. The causal fungus, *Colletotrichum gloeosporioides,* attacks not only the fruit, where it causes the most damage, but also attacks the petioles of the lower leaves as they begin to die. The fungus is a common pathogen of many plants in Hawaii including anthurium, avocado, banana, mango, and plumeria. It has recently been demonstrated that isolates from papaya and mango readily cross-inoculate, whereas the isolates from avocado and plumeria do so weakly or not at all *(20).*

FIGURE 7. Papaya fruit showing symptoms of anthracnose caused by the fungus, *Colletotrichum gloeosporioides.*

Symptoms

The first symptoms usually appear as small, round, dark areas on the ripening portions of the fruits. As the fruits ripen, these spots enlarge rapidly, forming circular, slightly sunken lesions (fig. 7). Due to the continuous picking of the partially ripened fruits, the lesions in the field rarely are much larger than ¾ inch in diameter. However, the lesions enlarge as the fruits mature and may reach a size of as much as 2 inches in diameter. Frequently, many infections may be found on a fruit, and as the lesions enlarge they may converge, covering a large portion of the fruit. As the lesions enlarge, the margins appear dark in color while the central portion of the lesion turns brown or black. As the fungus develops, it frequently produces large masses of spores in the central portions of the lesions causing them to turn light orange or pink. The spores sometimes are produced in concentric rings, giving the lesion the appearance of a bull's-eye. In addition to producing a lesion on the surface, the fungus also advances into the fruit, producing a rot of the affected tissues, causing the tissues to become soft and somewhat darker in color. Although the affected areas of the fruit may become fairly large, the infection eventually becomes walled off by the host. Following this, the in-

fected tissues can be lifted free of the fruits, or if such fruits fall to the ground the infected areas frequently fall out.

Although the disease usually appears on the ripening portions of the fruit, occasionally green portions of the fruit may become infected. The disease appears first as small lesions, but soon after penetration by the fungus the latex from the fruit oozes out in sticky mounds or horns. The lesions enlarge very slowly and rarely become larger than ½ inch in diameter as long as the fruit remains green.

The fungus which causes anthracnose also attacks the petioles of the lower leaves as they begin to die and are shed from the plant. Though probably of no importance in the process of the dropping of these leaves, the infection of these petioles is of importance in that these infections may act as a source of potential inoculum for the infection of the fruits.

"Chocolate spot" is the name given to a disease resulting from infection by a physiological strain of *C. gloeosporioides,* the causal agent of anthracnose. Though not as prevalent or as damaging as anthracnose, its presence will prevent the marketing of infected fruits. The disease appears on the ripening portions of the fruit as small, chocolate-brown lesions which usually do not become sunken. They also differ from the regular anthracnose lesions in that they tend to be angular rather than circular and they do not become as large.

Control

Control of these fruit-spotting diseases can only be achieved through a thorough and continuing spray program. The intervals between spraying depend upon the amount of disease present and the weather conditions. Ten-day intervals usually give good control but during periods favorable for disease development, i.e., high temperatures coupled with high rainfall, it may be necessary to reduce the spray intervals to 7 days. Recent tests in Puna, Hawaii, have shown that Dithane M-45, recently cleared by the Food and Drug Administration for use on papaya, gives excellent control of anthracnose fruit spot when put on at 10-day intervals. This fungicide has increased the average number and weight of fruits produced per tree by a factor of 3 when compared with the unsprayed check plots. A spreader-sticker, such as Triton B-1956, should be added to the spray. Post-harvest storage decay can be materially reduced by treating fruit with hot water at temperatures of 110° to 120°F for 20 minutes *(2).*

Black Spot of Papaya

Black spot of papaya, caused by *Cercospora papayae,* was first noticed in Hawaii as a serious fruit- and leaf-spot disease of papaya in the winter of 1952–1953.

Symptoms

The leaf spots are grayish-white, subcircular to irregular, $\frac{1}{16}$ to ¼ inch in diameter. Heavily infected leaves turn yellow and dry up. The fruit spots start as tiny spots which turn black and enlarge to $\frac{1}{32}$ to ⅛ inch in diameter (fig. 8). The tissue just beneath the epidermis of the fruit becomes corky; the spot does not develop into a fruit rot.

As a defoliating disease there is undoubtedly a significant reduction in yield. The fruit-spot phase, even when the incidence is high, does very little damage to the fruit. However, it detracts from the appearance and thereby the marketability of the fruit.

Control

Unlike anthracnose, black spot of papaya fruit cannot be controlled by hot-

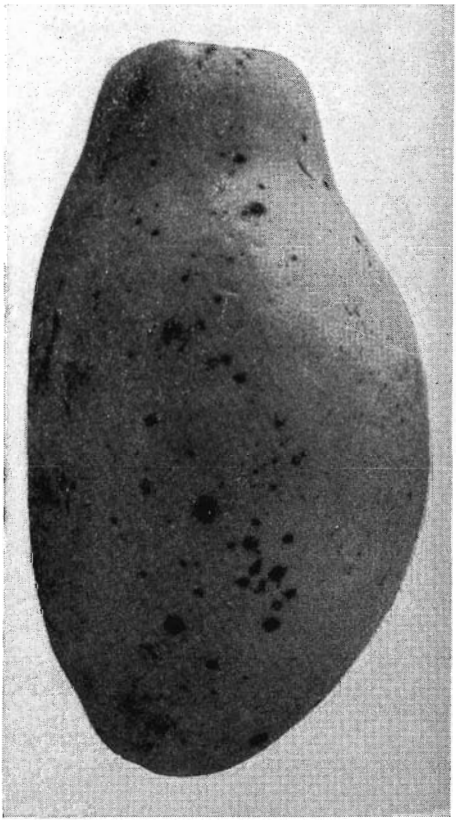


FIGURE 8. Black spot of papaya fruit caused by *Cercospora papayae.*

water dips at 120°F. Thus, good field control must be obtained. Spray tests have shown that zineb, maneb, captan, and basic copper sulfate give excellent control of the disease.

Damping-off of Seedlings

A number of fungi, including *Pythium aphanidermatum, P. ultimum, Phytophthora parasitica,* and *Rhizoctonia* sp., can cause damping-off of papaya seedlings. These fungi live in the soil and attack young seedlings. The disease is particularly severe in warm, wet weather and is more severe under crowded conditions. *P. aphanidermatum* is a serious problem only when the soil reaches a temperature of 85°F or higher. The other fungi can often be a problem at soil temperatures below this. Damping-off consists of a relatively rapid water-soaking and collapse of the stem tissues at the soil line due to the growth of the fungus in these tissues. These parasitized, emerging young seedlings wilt rapidly, dry out, and die. Young seedlings are very susceptible but become resistant to this disease as they become older.

Control

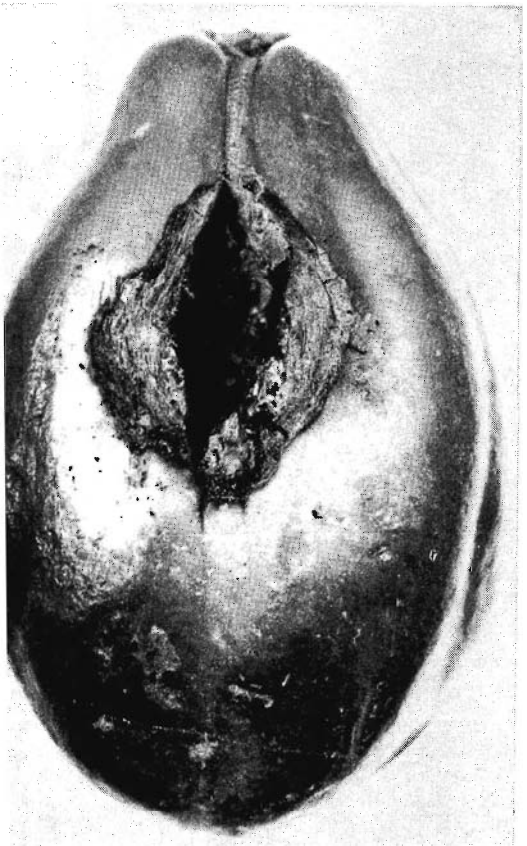
It is important to know that these pathogens are found in most soils and that the disease is favored by certain conditions. Several of these have already been mentioned, i.e., high temperatures and wet weather. Other factors favorable for disease development include wet soils, poor drainage, deep-planting of seeds, thick-planting of seeds, poor aeration, and high levels of available nitrogen. Any cultural practice which will help to correct these conditions will help to give control. Once damping-off has started in a bed, little can be done to save the infected plants. Treatment of the soil prior to planting is an effective way of ridding the soil of the fungi which cause damping-off. The materials and means of application used in soil treatments are discussed elsewhere (see section under Nematodes). It should be remembered that soils treated with certain of these chemicals, i.e., chloropicrin, formaldehyde, methyl bromide, vapam, and mylone, are comparatively free of soil fungi and bacteria but are rapidly invaded as soon as the chemicals disappear. If the reinvading organisms are disease-producing organisms, serious problems will result. Therefore, a great deal of caution and sanitation should be practiced in order to

prevent contamination of treated soil by using contaminated equipment and tools.

Dry Rot and Stem-end Rot

The dry rot disease is associated with mechanical injuries to the fruit and frequently arises where fruits rub on branches or on other fruits. The injury allows the entrance of fungi which normally do not attack healthy fruits, but once inside an injured fruit, these fungi invade the tissues and produce a large, somewhat sunken lesion (fig. 9). This lesion, usually found on the shoulders on the underside of the fruit, is circular and may be as large as 1½ inches in diameter. The fungus produces a tan or brown dry rot which extends into the fruit. The rotted area dries out, causing deep cracks in the infected tissues. No control

FIGURE 9. Papaya fruit showing typical symptoms associated with dry rot.



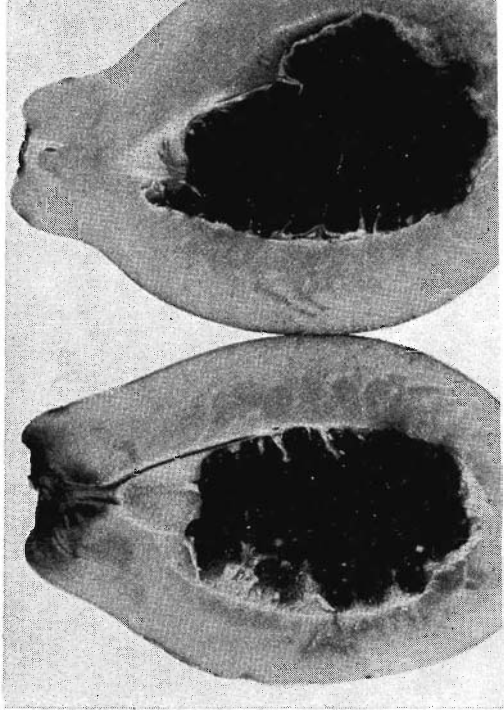


FIGURE 10. Typical stem-end rot symptoms caused by the fungus, *Ascochyta (bottom)*, and healthy fruit *(top)*.

measures have been found for this disease.

Stem-end rot is a disease of senescent, mature fruit. It usually occurs after picking rather than in the field and is, therefore, primarily a post-harvest problem. A dry, firm, dark rot extends internally into the fruit from the stem end (fig. 10). *Ascochyta* sp. has recently been demonstrated to be the cause of the disease. Control measures to date other than hot-water fruit dips (as discussed under Anthracnose) have been unsuccessful, but it has been observed that fruits picked with part of the peduncle remaining do not become diseased. Further studies are in progress on the usefulness of this method of picking as a control measure.

Internal Blight

Internal blight disease, caused by *Cladosporium* sp., is not too prevalent but is of importance in that infected fruits

cannot be marketed. The fungus gains entrance through the flower end of the fruit. Once inside, the fungus grows through the tissues surrounding the seeds, digesting the mucilaginous coating from many of the seeds. Cutting open an infected fruit reveals not only the unsightly presence of the dark fungus strands and spores, but also the seeds without their mucilaginous covering. Infected fruits fail to ripen, the external coloring does not develop normally, and because of this such fruits usually can be detected in the sorting process. Control measures have not been worked out for this disease, but a good spray program for controlling fruit rots should give adequate control.

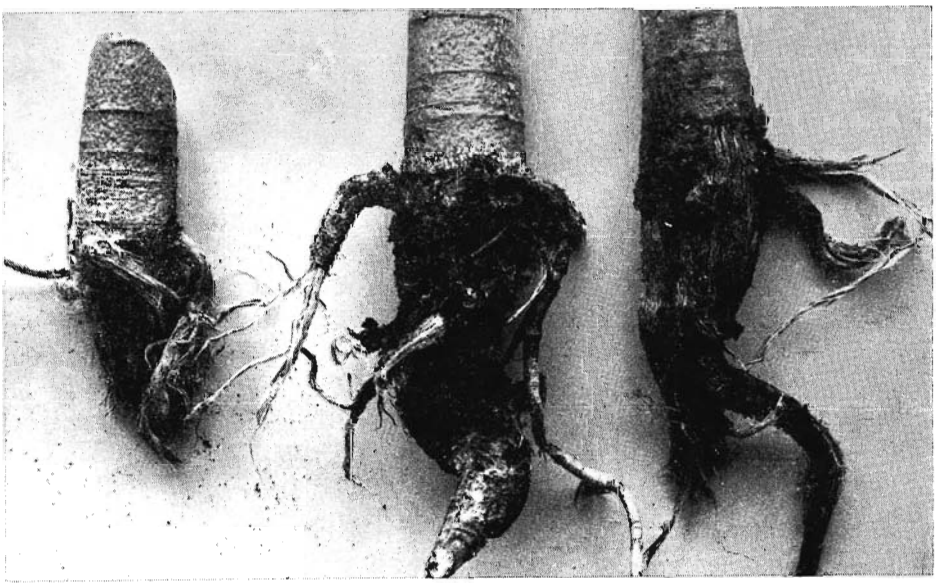
Phytophthora Blight

Species of the fungus genus *Phytophthora* are some of the most virulent of known plant pathogens. The most common and serious pathogen of this group in Hawaii is *P. parasitica.* This pathogen, which is common in the tropics, is known to parasitize a large number of plants in Hawaii including carnation, hibiscus, parsley, pineapple, tomato, watermelon, and papaya. In papaya, *Phytophthora* blight caused by *P. parasitica* was first identified as a serious fruit- and stem-rotting disease in Hawaii in 1940 *(19).* Today, this wet-weather disease can be a serious problem in all of the papaya-producing areas in Hawaii. The fungus commonly parasitizes the above-ground portion of the papaya plant but also causes root rot, damping-off of young seedlings, and cankers of the stem at the soil line (fig. 11).

Symptoms

The most common symptoms associated with *Phytophthora* blight are found on the stems and fruit. Small discolored spots occur around fruit or leaf scars or

FIGURE 11. Root rot of papaya caused by *Phytophthora parasitica.* This disease is more severe when the fungus colonizes papaya residue and reaches high populations in the soil.



any location on the stem, but primarily in the region of fruit production. These infected areas enlarge and often completely girdle the stem of young trees. When the stem is completely girdled, the top of the plant wilts and eventually dies. Some lesions, particularly in older trees, may not completely girdle the stem but so weaken the tree that the plant may be broken off in the wind. These decapitated plants may put out new growth which remains healthy if the weather remains dry, or they may die during wet weather.

Fruit of any age may become infected as it hangs on the tree (figs. 12, 13). As the disease progresses, the fruit shrivels, turns dark brown, and falls to the ground where further shrivelling takes place. Mummified fruits ultimately become brownish-black, light in weight, and stone-like in texture. These mummified fruits are a reservoir for the fungus and constitute a source of inoculum for further infection.

FIGURE 12. Papaya fruit infected under natural conditions in the field with *Phytophthora parasitica*.

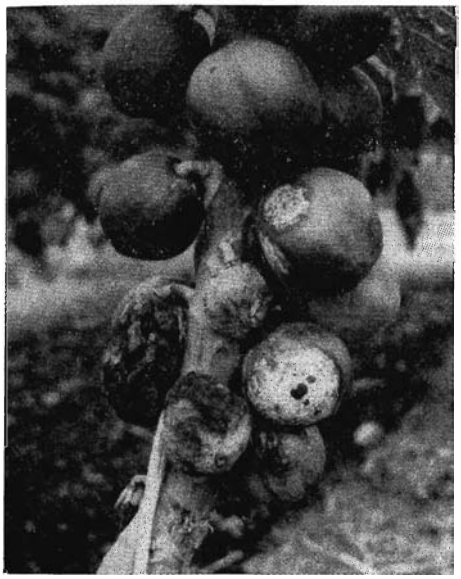


FIGURE 13. Stem-end rot of papaya caused by *Phytophthora parasitica*.

Dissemination and infection

Although many plants in Hawaii are susceptible to infection by *P. parasitica*, it has been experimentally demonstrated that isolates from other hosts will not parasitize papaya, and only isolates obtained from papaya have the capacity to cause disease in papaya *(8)*. The tomato blight fungus, for instance, does not cause disease in papaya. The fungus produces a whitish fungal mass (figs. 12, 13) on rotting fruit and stems, in which large quantities of sporangia (fig. 14) are found. These sporangia are carried by splattering rain or wind to healthy parts of the plant where they germinate, only in the presence of water, to produce large numbers of motile swimming zoospores which infect the plant and initiate the disease. These zoospores may invade un-

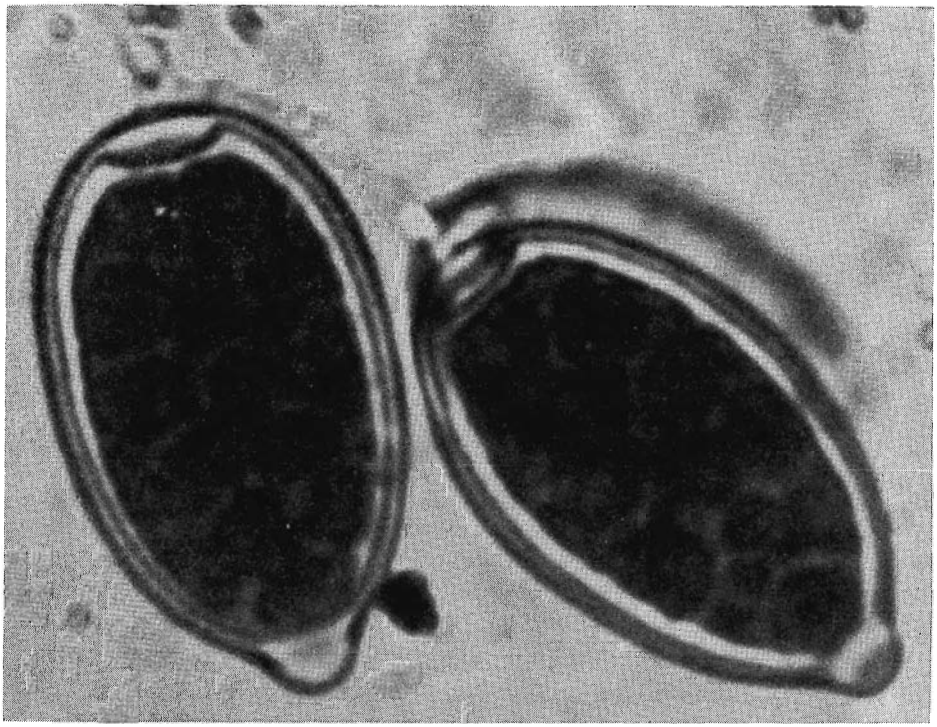


FIGURE 14. Sporangia of *Phytophthora parasitica.* These sporangia (magnified approximately 3000×) germinate in water to produce zoospores which are motile and infect the plant.

injured leaf tissue, stems, or fruit. As the fungus grows through the tissue, it causes death of the host cells and the typical water-soaking rot, or so-called blight, occurs. Temperature has been experimentally demonstrated to play an important role in this disease. Optimum temperature for leaf-blight development is 82°F with no disease development at 60°F or below, or 93°F or above *(6).*

Control

Prompt and complete removal and destruction of infected plants and fruits from the orchard will aid in control of this disease.

Protectant sprays of 2 to 4 pounds of basic copper sulfate per 100 gallons of water during the wet seasons will help reduce the incidence of this disease. Care must be exercised in that excessive copper residue will injure the fruit. Dithane M-45, as discussed under Anthracnose, may also be used for control.

Powdery Mildew

Powdery mildew of papaya is caused by a fungus, *Oidium caricae.* The fungus grows superficially on the undersurface of the leaves (see photo on cover, top left), withdrawing nutrients from the cells of the leaf surface by specialized absorbing structures, known as haustoria. The disease is widespread and common in Hawaii.

Symptoms

On the underside of diseased leaves are found patches of whitish powdery material, which is the main body of the fungus, and is the reason the disease is called powdery mildew. On the upper surface, leaves at the infection site show blotches of yellow or pale green usually near the veins, surrounded by normally colored tissue. Early, less conspicuous symptoms consist of tiny, pale yellow spots near the veins. The fungal mycelium growing on the undersurface of the papaya leaf produces chains of spores which are carried by wind to healthy leaves. These spores germinate, send haustoria into the leaf, develop a fungus vegetative body, and reproduce the disease cycle. They are the only known stage of the fungus under Hawaiian conditions. The fungus does not have a saprophytic stage and only produces spores when growing on living papaya plants. The fungus has not been found in recent years as a fruit parasite in Hawaii, although this phase of the disease is evidently fairly common in other parts of the world. Occasionally, the fungus may attack the stem of young seedlings when grown under reduced light conditions. The typical powdery growth is found on the stem of the plant, and under severe attacks the top portion of the seedling may die.

Control

The disease may be controlled by wettable sulfur at 6 pounds per 100 gallons of water. Lower rates known to be effective for control of mites have often not given adequate mildew control. However, caution should be taken in hot weather as sulfur may injure papaya if temperatures rise above 90°F.

Replant Problem

Repeated planting of papayas in the same field has been customary in Hawaii because of short-lived economic productivity and unavailability of arable land. Replanted papayas may become established satisfactorily in the field but characteristically grow slowly and attain less size than nonreplanted papayas grown in the same type of soil under similar growing conditions. After coming into bearing, such replanted papayas may decline slowly and soon reach a stage where it is not economically feasible to maintain them as a commercial orchard planting. The difficulty in producing satisfactory plant growth and economic crops of papaya on old papaya land has been loosely termed "the papaya-replant problem."

Symptoms of the replant problem on papaya seedlings include yellowing of leaves, premature defoliation, and stunting of the plant. The root systems show varying degrees of root rot. Experimental data have recently been collected that implicate soil fungi such as *Pythium aphanidermatum* and *Phytophthora parasitica* as one of the causes of the problem. Incorporation of papaya tissues into field soils containing these fungi results in a marked increase in root rot and mortality of seedlings. Incorporation of papaya tissues in soils free of these pathogens causes no effect on normal growth of the plants. Studies on the pathogenicity of *P. aphanidermatum* and *P. parasitica* on papaya seedlings have demonstrated that damping-off and root rot of papaya are more serious when the inoculum density of both pathogens is increased by incorporating papaya residues into soil *(26)*. Experimentation in greenhouse soil-temperature tanks has demonstrated that *P. aphanidermatum* is a more serious root parasite at soil temperatures of 85°F or above. Papaya tissues buried in field soil are colonized by both pathogens in less than 48 hours.

Extracts from both fresh and decaying papaya residue in soil have inhibited pa-

paya seedling growth in laboratory experiments *(15)*. The possible role of inhibitory substances on the growth of papaya under field conditions is presently under investigation.

Control

The effectiveness of corrective measures on soils where the replant problem exists varies with location and soil type; therefore, it is apparently likely that the primary cause of the replant problem varies from locale to locale, necessitating different control measures. In well-drained soils where nematodes were a contributing factor, a number of nematocides such as 1,2-dibromo-3-chloropropane at 35 to 70 pounds per acre, or 1,3-dichloropropene and 1,2-dichloropropane at 200 pounds per acre, or high rates of methyl bromide, gave good responses *(11)*. In areas where *P. aphanidermatum* and *P. parasitica* are major contributing causes, a number of fungicidal materials have been shown to be effective in stimulating the growth of papaya in replanted orchards. These include methyl bromide-chloropicrin mixtures, vapam, and mylone. Fumigation with Dowfume MC-33 at 250 to 450 pounds per acre reduced papaya root rot *(26)*.

FIGURE 15. Rot of an injured mature papaya fruit caused by *Rhizopus stolonifer*.

Rhizopus Fruit Rot

The fruit rot caused by the fungus, *Rhizopus stolonifer,* differs markedly from that due to the fruit-rot fungus, *P. parasitica. Rhizopus* causes a soft, watery rot and produces masses of macroscopically observable black sporangia under conditions of high relative humidity (fig. 15). The sporangia of *P. parasitica* produced on the rotting fruit are not visible except with a microscope. The rot caused by *Phytophthora* is firm and there is no leakage of cell fluids from the rotting fruit as is common with *Rhizopus* infection. *Rhizopus* invades primarily injured mature fruit and usually does not cause rot in sound, uninjured, immature fruit. *Phytophthora* has the ability to invade and cause disease in uninjured as well as injured fruit tissue of all ages.

Control

Great caution should be used during picking, transporting, and packing operations so as not to bruise or otherwise injure the fruit. Uninjured fruit is un-

affected by this disease. Hot-water dip at 120°F for 20 minutes, used to control *Phytophthora* blight and anthracnose, has been shown to be effective in eliminating the fungus from early infection sites. Sporangia of the fungus are killed at this water temperature. Rotting fruit in the packing sheds should be removed and destroyed as it is a source of spores which are wind-blown and initiate infection in healthy fruit.

Nematode Diseases

Nematode diseases of papaya are either serious or potentially serious in all papaya-growing regions. Presently, the two nematodes which are recognized as pathogens of papaya are the root-knot nematode (*Meloidogyne* sp.) and the reniform nematode *(Rotylenchulus reniformis).*

Root-knot Nematode

Severe stunting of papaya has been reported in Australia *(24)* and Florida *(25)* by the root-knot nematode. This pest is presently not of much consequence in papaya production in Hawaii. It is most severe in light soils.

Symptoms

Roots are the only part of the plant which is attacked. Small to large swellings (galls), which are produced as a result of the feeding process of the nematode, interfere with the proper functioning of the roots. Severe attacks of this nature cause retarded root growth and a subsequent reduced root system for the plant. Secondary symptoms which may be seen in the above-ground portion of the tree are like those associated with trees suffering from malnutrition or lack of water. The leaves of infected plants are generally light green to yellowish and may fall prematurely. Infected plants are sensitive to slight moisture stresses and wilt more readily than noninfected ones. Fruits produced are smaller than normal and may be slightly insipid.

Causal agent and life history

Meloidogyne incognita acrita (18, 21) has been reported attacking roots of papaya in Hawaii. This nematode attacks a wide range of plants and is generally distributed in Hawaii. It is commonly found on cultivated plants as well as weed hosts. Another of the *Meloidogyne* species, *M. hapla,* has also been found galling roots of papaya; however, it is not as widely spread nor does it have as large a number of hosts as the afore-mentioned species.

The larvae of the root-knot nematode are microscopic worms which are able to move short distances in undisturbed soil; cultivation and surface water aid the distribution in the field and from field to field. Penetration by the larvae occurs most frequently near the tip of the root. When the female larva begins feeding in the central cylinder region, root cells may increase in size and number, resulting in the distorted, massive enlargements known as knots or galls. During the process of gall formation the sedentary female undergoes several moults until her body is "flask- or pear-shaped." When the gall is cut open, the glassy, pear-shaped females may be seen embedded in the tissue. Eggs are laid in a gelatinous matrix (egg-mass) which may be embedded in the root tissue or exposed on the root surface. A single female deposits an average of 350 eggs in the egg-mass. Under subtropical and tropical conditions as many as 14 to 17 generations are possible in one year's time.

Control

Avoid fields heavily infested with root-knot nematodes. However, some control can be realized by treating each planting

site prior to planting. First, allow adequate time for the breakdown of heavily galled roots, then drench on vapam at the rate of 200 pounds (actual) per acre. The soil should be dry enough so that the solution will penetrate to a depth of 6 inches. Allow 2 weeks to elapse between the time of treating and planting. A longer period may be required if the soil is cold and wet (below 60°F) for a prolonged period after the application. Nematocides containing halogenated hydrocarbons presently are not cleared by the Food and Drug Administration for use on papaya (see Reniform Nematode Control).

Papaya should be seeded and/or potted in soil which has been treated to kill nematodes as well as other soil organisms such as *Phytophthora parasitica, Pythium aphanidermatum, P. ultimum,* and *Rhizoctonia* spp. Soil can be treated with methyl bromide at the rate of 2 pounds per 100 square feet. Expose the soil to fumigation for 48 hours under a gas-proof cover. Aerate for 3 days before seeding or 7 days before setting transplants. If loose soil is used, treat it at the rate of 1 pound per cubic yard under a gas-proof cover for 24 hours. Aerate for 3 days before seeding or 6 days before setting transplants.

The deleterious effect of root-knot infections in the field may be partially compensated for by close observance of optimum moisture and fertilizer requirements for papaya.

Reniform Nematode

The reniform nematode has been found to be a serious pest where papaya is grown on soil rather than in lava culture. It is possible that this nematode has not as yet been introduced into the lava areas. Stunting of the trees as well as yield reduction has been noted in the field *(12).*

Symptoms

Unlike the feeding of the root-knot nematode, the feeding of the reniform nematode does not cause swelling or retardation of the root. Presence of the nematode in the root may be detected by observing the small grains of sandlike bodies which remain attached when the root system is carefully washed. However, microscopic examinations are necessary to make qualitative as well as quantitative determinations.

In heavy infections, the above-ground symptoms are similar to those described for root-knot nematode on papaya.

Causal agent and life history

Nearly 100 host species for the reniform nematode *(Rotylenchulus reniformis)* have been reported. Many cultivated plants as well as weeds are hosts for this worm. The means of movement in the soil are the same as for the root-knot nematode.

Larvae of the reniform nematode are less than 1/50 inch long. The young females penetrate the cortex of the root and then become sedentary. The portion of the body which remains outside the root enlarges until it resembles a kidney (fig. 16). After the female matures, she secretes a gelatinous substance about her body in which she lays about 100 eggs. A complete life cycle is possible in about 25 days.

Control

Control which is economically feasible has been obtained by using 1,2-dibromo-3-chloropropane (Fumazone or Nemagon) at 35 to 70 pounds per acre, a mixture of dichloropropane and dichloropropene (D-D) at 200 pounds per acre, dichloropropene (Telone) at 200 pounds per acre, and ethylene dibromide (EDB) at 72 to 96 pounds per acre *(12).* Presently, none of the above nematocides

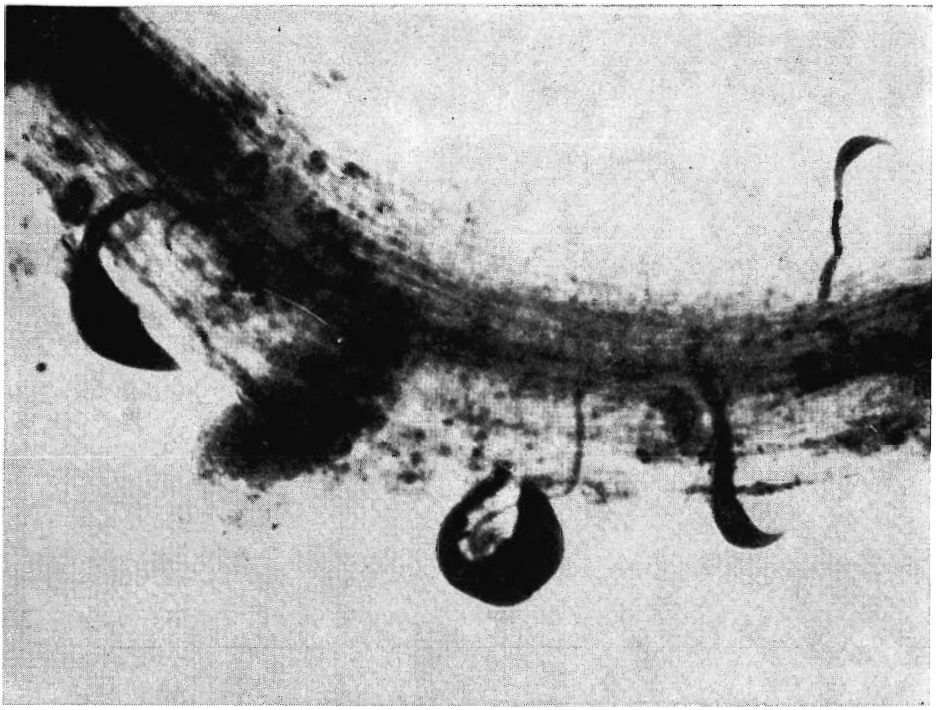


FIGURE 16. Photomicrograph of developing reniform nematodes parasitizing a papaya root.

have been cleared by the Food and Drug Administration for use on papaya.

For field and potting soil-fumigation, see Control for Root-knot Nematode. However, it is not necessary to allow time for root breakdown in that the female reniform nematode is seldom embedded in the tissue.

DISEASES OF UNKNOWN CAUSE

There are two diseases of papaya which occur in Hawaii for which neither a parasitic nor a nonparasitic cause has been ascribed. They are referred to locally as "freckles" *(9)* and "lumpy" fruit *(14)*. These two diseases manifest their symptoms on the fruit.

Freckles

The freckles disease consists of superficial dark or gray spots with water-soaked margins on the fruit (fig. 6). These spots are apparently associated with stomates. The spots may initially appear when the fruit is half developed. As the fruit matures, these spots may vary from pinpoint to ½ inch in size with a reticulate pattern. Frequently, a large irregular-shaped, water-soaked or greasy spot area may engulf several smaller dark spots. The spots are essentially brown in color on the green or maturing fruit. In the larger

spots the central portion may take on a grayish cast. Freckles are more prevalent on the exposed surface of the fruit as it hangs on the tree.

Repeated isolations have failed to consistently yield an organism of a possible parasitic nature.

Lumpy Fruit

Hard portions of tissue are frequently encountered in the flesh of ripe papaya fruits. This disease of unknown origin has been found in orchards on the islands of Oahu and Hawaii and is referred to as "lumpy" fruit. There are three types of symptoms associated with the problem: (1) large platelike areas in the fleshy portion of the fruit, (2) small grainlike lumps, and (3) rounded hemispherical lumps attached to the rind.

Lumps can be artificially induced in papaya fruit by injections of a variety of chemicals including water, indoleacetic acid, and maleic hydrazide, or by physical injury. The presence of lumps in fruit from the field can only be determined after the fruit is fully ripened.

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UNIVERSITY OF HAWAII
COLLEGE OF TROPICAL AGRICULTURE
HAWAII AGRICULTURAL EXPERIMENT STATION
HONOLULU, HAWAII
