Biological Control of Phytophthoı

Wen-hsiung Ko
University of Hawaii,
Beaumont Agricultural Research
Center, Hilo

The papaya (*Carica papaya* L.), a large herbaceous plant native to tropical America, can attain a height of 7 m or more under favorable environmental conditions. In addition to the popularity of ripe papaya fruit as a dessert, latex from green papaya fruit is an important source of papain, a proteolytic enzyme commonly used as a meat tenderizer and as a drug for digestive ailments. In Hawaii, commercial cultivation of papaya is mainly for production of fresh fruit for export to the U.S. mainland and Japan.

Papaya Replant Problem

Most of Hawaii's papaya is grown on approximately 3,000 acres of lava rock land in the southeastern corner of the island of Hawaii. Within 3 to 4 years after planting by direct seeding, replanting is necessary because of decline in yields and difficulties in managing tall trees. Efforts to establish new orchards in second plantings usually fail, however, because of the low survival rate of seedlings, a phenomenon commonly called "papaya replant problem." The unhealthy appearance of surviving seedlings in replant fields is frequently associated with severe root rot. The papaya replant problem has been shown to be caused by *Phytophthora palmivora* (Butl.) Butl., previously referred to as *P. parasitica* Dast. (3,8).

In new plantings on virgin land, which is usually derived from an ohia (*Metrosideros collina* (Forst.) Gray subsp. *polymorpha* (Gaud.) Rock) forest, initial infections of papaya by *P. palmivora* occur on fruit (Fig. 1) and the upper portion of the trunk during rainy periods. If the rainy season is prolonged, some growers may be forced to abandon their fields within 2 years after planting because of heavy infection. Nearly all papaya trees in the abandoned fields may be infected shortly by the fungus (Fig. 2). Diseased fruit covered with sporangia and chlamydospores of *P. palmivora* fall to the ground and serve as an important source of inoculum in the soil (Fig. 3). The fungus persists in the soil and causes root rot and death of seedlings when papaya seeds are subsequently planted in the same field. No resistant papaya cultivar has yet been developed. Because of the extremely rocky and porous nature of lava land, it is very difficult to control *P. palmivora* in replant fields with fungicides and fumigants.

Clues from Field Observations

A frequent observation in abandoned papaya fields is that even though the fruit and upper portion of the papaya trees are severely infected by *P. palmivora*, the infection does not spread down the trunk and the trees remain alive and are able to produce new shoots from the lower portion of the trunk (Fig. 2). This suggests that only certain portions of the trees are susceptible to the pathogen. Furthermore, papaya roots in direct contact with fallen diseased fruit carrying numerous spores of *P. palmivora* remain healthy in the abandoned fields. This is in great contrast to the widespread occurrence of root rot on papaya seedlings in replant fields.

One simple explanation for these observations is that papaya roots are susceptible to *P. palmivora* only during the juvenile seedling stage. This hypothesis was tested in the greenhouse by establishing papaya seedlings in soil of stony, sandy loam in 10-L plastic containers at 1-month intervals for 5 months and by inoculating seedlings with the same amount of *P. palmivora* spores. Two weeks after inoculation, 94% of the 1-month-old and 47% of the 2-month-old seedlings had been killed by *P. palmivora* but all of the plants 3 months old or older at the time of inoculation survived (4). Most of the taproots and part of the lateral roots of the surviving 1- and 2-month-old seedlings were completely rotted, whereas only small, restricted brown lesions occurred on the lateral roots and lower portion of the taproots of older plants. Results of this greenhouse test are compatible with the hypothesis that roots of papaya are susceptible to *P. palmivora* only during the early stage of growth. However, ability of large plants to generate more roots may also contribute to the tolerance of older plants to the pathogen.

Applying Field Observations

Because papaya roots were found to be susceptible to *P. palmivora* only when the plants are young, it was considered possible that the disease could be controlled by protecting the roots during the early stages of growth. Growers in Hawaii usually make planting holes about 30 cm in diameter and 10 cm deep for papaya seeds in the field. Papaya seeds were therefore sown in virgin soil placed in planting holes in replant fields to see if seedlings started under these conditions would remain healthy after their roots extended into infested soil. Seeds sown in planting holes without virgin soil—identical to the regular practice of papaya growers—were used as controls. Virgin soil, defined as soil collected from any land that has never been used for growing papaya, is generally free from infestation by *P. palmivora* because Phytophthora root rot of papaya seedlings occurs only in the replanting fields.

In three separate experiments, 37, 21, and 42% of the papaya trees in control plots were dead 3 months after planting, whereas all trees growing in small islands of virgin soil survived (Fig. 4). Growth of surviving control plants was very poor, and *P. palmivora* was consistently isolated from roots of dying plants. In one experiment, the average height of papaya trees growing in virgin soil and of control trees was 60.8 and 39.3 cm, respectively. All trees in the islands of virgin soil were healthy and produced a large crop of fruit similar to those growing in the virgin fields, while additional loss of control plants continued for up to 20 months.

The virgin soil technique was subsequently tested on a 5-acre replant field (Fig. 5). None of the papaya seedlings growing in virgin soil placed in planting holes in the replant field were killed by *P. palmivora*; they were as vigorous and productive as those growing in first-planting fields. In contrast, more than 50% of papaya seedlings planted in a nearby field using the regular practice were killed by Phytophthora root rot within 3 months, and many of the surviving plants were chlorotic and stunted. This field was eventually abandoned.

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Fig. 1. Papaya fruit infected with *Phytophthora palmivora*.

Fig. 2. An abandoned field of papaya trees infected with *Phytophthora palmivora*. Note healthy young shoots on trunk of infected tree in right foreground.

Fig. 3. An important source of soil inoculum is fallen papaya fruit covered with sporangia and chlamydospores of *Phytophthora palmivora*.

Fig. 4. Papaya seedlings (3 months old) in left and right rows are established on small islands of virgin soil placed in planting holes; no virgin soil was used in center row of plants.

Fig. 5. Papaya fields replanted (left) with and (right) without virgin soil technique.

Extension Program

After the virgin soil technique was developed, experimental results were presented at papaya growers' meetings in cooperation with county extension agents, and field trips were arranged for growers to see the test results. They were very impressed by what they saw but could not believe that such a simple treatment could solve their long-standing problem. Consequently, no grower was willing to give the technique a try. The County of Hawaii subsequently provided a grant to the Cooperative Extension Service of the University of Hawaii to encourage papaya growers to adopt the method. Three growers were selected and each was given a subsidy of $900 to replant 3 acres of papaya with the virgin soil technique. To their pleasant surprise, all were able to establish healthy papaya trees in their replant fields just by sowing seeds in virgin soil placed in planting holes.

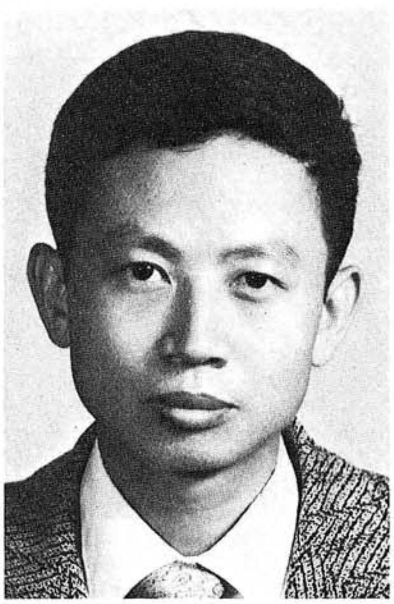
The virgin soil technique has now been adopted by the papaya growers as a standard method for replanting papaya fields. The technique has the advantages of being relatively inexpensive, very effective, and nonhazardous. It is very important that enough virgin soil is used; insufficient quantities may result in poor growth of plants. The minimum amount of virgin soil recommended for each planting hole is about 9 L (6).

Bases of Biological Control

The principle involved in this biological control is to protect roots of young seedlings by sowing seeds in small quantities of pathogen-free natural soil placed in pathogen-infested fields. Because of the nutrient deprivation imposed by microbial competition, most fungi are unable to germinate and grow in natural soil (7). Virgin soil, therefore, remains free from fungal pathogens in infested fields. Garrett (2) broadly classified root-infecting fungi into primitive (unspecialized) and advanced (specialized) pathogens (parasites) according to their degree of advancement toward parasitism. Primitive pathogens are characterized by destructiveness to host plants during the immature stage and restriction by mature host tissues. Advanced pathogens, on the other hand, are capable of infecting host plants at all stages of growth. In principle, therefore, the virgin soil technique is most effective in controlling primitive pathogens.

Continuous cropping of cucumber at the same locations on the island of Hawaii caused drastic increases in the incidence of damping-off incited by *Pythium splendens*. The pathogen was found to be destructive to cucumber plants only during the young seedling stage, and the disease was also effectively controlled by sowing seeds in virgin soil placed in planting holes (W. H. Ko and B. A. Kratky, *unpublished*).

Rhizoctonia solani is an exception to the generalization. It is a primitive pathogen, but the virgin soil technique is ineffective in controlling the disease caused by this fungus (5) because of its unique ability to grow in natural soil (1).



Wen-hsiung Ko

Dr. Ko is a professor in the Department of Plant Pathology at the University of Hawaii at Beaumont Agricultural Research Center, Hilo. He received his B.S. degree from National Taiwan University and his Ph.D. from Michigan State University in 1966. He conducts research on soil microbiology and soilborne diseases and is also interested in the biology of *Phytophthora*.

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