IPM for Banana

Banana Pest and Disease Management in the Tropical Pacific

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Banana Pest and Disease Management in the Tropical Pacific

A guidebook for banana growers

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Chapter I

Importance of an Integrated Pest Management Program for Banana

Banana (*Musa* sp.) is among the most important fruit crops in Hawai‘i in terms of economic, cultural, and nutritional value, and Hawai‘i ranks at the top within the United States in banana production (NASS 2012). Commercial banana production occurs on all major Hawaiian Islands, with 80% of the production located on the islands of Hawai‘i and O‘ahu (Constantinides and McHugh 2003). In 2011, Hawai‘i growers generated 17.4 million pounds of fresh market banana on 1,300 acres of land, producing a farm-gate value of $11.3 million (NASS 2012). However, banana yields in Hawai‘i have declined since the year 2000, when 29 million pounds of fresh market banana were produced (NASS 2008). Much of the decline is attributed to *Banana bunchy top virus* (BBTV, Nanoviridae), transmitted by the banana aphid, *Pentalonia nigronervosa* (Hu et al. 1996), which has resulted in the cessation of production in many areas and significantly reduced production on farms that have persisted. However, a recent survey also suggests that although this continual decline is largely caused by BBTV, plant-parasitic nematodes are playing a role (Wang and Hooks 2009). Drought conditions in 2011 exacerbated the damage caused by the nematodes.

Despite hardships caused by drought and diseases, banana revenues increased 7% from 2010 to 2011 due to a price increase for banana, from 60 cents per lb. in 2010 to 65 cents in 2011. The current lifting of fruit fly quarantine restrictions has also generated an increased opportunity for Hawai‘i banana growers to export bananas to the continental U.S. This can significantly increase profits for banana growers in Hawai‘i and other underrepresented Pacific Islands. Increasing local food production and consumption is another driving force for the recovery of banana industry in this region. The Integrated Pest Management (IPM) program for banana set out here aims to reduce the production cost and increase the profitability of banana cultivation and ultimately to encourage more self-sustainable rural banana producers in the Pacific Islands.

IPM is an effective and environmentally sensitive approach to pest management that takes into consideration pest biology, economic thresholds, environment factors, and host plants' resistance if feasible. IPM relies on comprehensive knowledge of the pests and their interaction with the environment, in combination with multiple pest-control methods to manage pests through the most economical means, with the least risk to people and the environment.

Based on the U.S. EPA IPM Principles factsheets, there is a four-tiered approach to IPM: setting an action threshold, monitoring and identifying the pest, prevention, and control.

The **action threshold** is the pest infestation level or environmental conditions at which the pest will become an economic threat. It is not necessary to kill all known pests in a field unless the pest population densities are reaching an economic damage threshold. The population densities of certain pests, i.e., fungal or bacterial pathogens, are difficult to monitor, thus knowing the relationship between the environmental conditions and the pest population development could be another way to determine action threshold. For example, to manage yellow Sigatoka disease in Australia, banana growers are recommended to trim excess banana leaves if more than 15% of the leaf is showing visible symptoms during the wet season, but only trim if more than 30% of the leaf is symptomatic during the dry season (State of Queensland 2003).

Appropriate and accurate **identification and monitoring** of pests are essential for making management decisions. In conjunction with ascertaining the action threshold, monitoring and identification avoid the possibility of unnecessary pesticide use, which can reduce costs for producers. Most importantly, reducing the amount of unnecessary pesticides will minimize the development of pesticide resistance, a common dilemma of the pesticide treadmill.

The **pesticide treadmill** is a situation in which pesticides have become a regular and indispensable part of an agricultural cycle, partly due to failure of natural remedies. An escalated form of the pesticide treadmill is when the effective elimination of one target pest population allows another pesticide-resistant population to thrive, resulting in the farmer's having to use other pesticides to eliminate the new pest population.

Prevention should be the first line of defense in IPM. Pest avoidance, or preventing pests from entering your fields, can be accomplished by quarantine; planting clean propagules; practicing field sanitation, such as removing diseased crop residues; using clean tools and equipment; making the environment less conducive to pests and pathogens by adjusting row spacing or trimming leaves; selecting pest-resistant varieties; or instituting a crop rotation sequence.

Once the pest reaches the economic threshold, and prevention is no longer effective, the next logical step in IPM is to identify effective **control** measures. Integration of multiple approaches that pose low risk to humans and the environment should be the preferred control strategy. Broadcast spraying of non-specific pesticides should be used as a last resort. Examples of less risky methods include using pheromones for mating disruption or to trap insects, and planting cover crops that release toxic compounds to suppress plant-parasitic nematodes.

This banana production guidebook aims to help banana growers practice a **whole-farm management approach**. Several pests and pathogens are simultaneously occurring in many banana orchards or gardens in the Pacific Islands. A versatile banana IPM program should be beneficial in managing multiple pests while compatible with profitable marketing. Contact the extension service in your area for more details on how to practice IPM in your area. For growers

in Hawai‘i, you can visit locations of Cooperative Extension Offices and Research Stations at http://www.ctahr.hawaii.edu/site/map.aspx.

Home Gardener’s Corner: Banana is a hardy plant and can be grown successfully by home gardeners. How to manage banana pests is often the question most frequently asked by banana gardeners. Most of the IPM principles outlined in this publication can be applied to home gardeners. Contact your local Master Gardener Helplines at http://www.ctahr.hawaii.edu/uhmg/helpline.asp if you are in Hawai‘i.

Web Resources:

Video on growing bananas in Hawai‘i: https://www.ctahr.hawaii.edu/bbtd/video.asp

University of Hawai‘i general information on bananas: http://www.extento.hawaii.edu/kbase/crop/crops/i_banana.htm

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Chapter II

Key Pests and Pathogens of Banana in the Pacific

II-1. *Banana Bunchy Top Virus* (BBTV)

Banana bunchy top disease (BBTD) caused by *Banana bunchy top virus* (family *Nanoviridae,* genus *Babuvirus,* BBTV), is one of the most economically important diseases of bananas in most production regions including Asia, Africa, and the South Pacific (Dale 1987, Dale and Harding 1998). The virus was first reported in Hawai'i in 1989 (Ferreira 1991) and has since progressively spread throughout banana-growing areas along the island chain. BBTV is one of the greatest challenges to local banana production in Hawai'i (Robson et al. 2007). In March 2003, a pest-management strategic plan for banana production in Hawai'i (http://www.ipmcenters.org/pmsp/pdf /HIBananaPMSP.pdf) listed managing BBTV as the top priority of banana research. Plants infected early with BBTV do not bear fruit, and fruit of later-infected plants is typically stunted and unmarketable. Additionally, the virus spreads to suckers via the rhizome; thus, the entire banana mat eventually becomes infected (Dale and Harding 1998). *Banana bunchy top virus* is transmitted in a circulative, persistent, non-propagative manner by the banana aphid, *Pentalonia nigronervosa* Coquerel (Hemiptera: Aphididae) (Magee 1927, Hafner et al. 1995, Hu et al. 1996). Most recently, Watanabe et al. (2014) reported that another closely related aphid, *Pentalonia caladii*, though preferring to feed on taro, ginger, or heliconia, can also transmit the virus if force-fed BBTV-infected banana leaves. The virus was first reported on O'ahu in 1989 (Conant 1992) and has since progressively spread throughout banana-growing areas in Hawai'i. Statewide reductions in harvested acreage were reported to be 26 and 16% in 2004 and 2005, respectively (Anonymous 2005, 2006). Much of this continual decline in acreage and output has been attributed to the progressive spread of BBTV on O'ahu and the windward side of Hawai'i Island in 2004.

Persistent viruses, once acquired by the virus vector, are associated with the vector for the remainder of its life. These viruses require long acquisition and inoculation times (hours to days) and latency periods of 1 day to several weeks before symptom expression. Successful transmission of persistent viruses requires that the ingested virus be internalized, which means that the virus is actively transported across multiple cell membranes and is found in the hemocoel (vector body cavity), and ultimately must associate with the vector's salivary system to be inoculated into a plant host. These viruses are at this point referred to as **circulative viruses**. They can be further divided into **propagative** viruses, which replicate in their insect vector in addition to their plant hosts, and **non-propagative viruses,** which replicate only in their plant hosts.

Infected banana plants in abandoned fields or residential backyards serve as an infection reservoir, making the battle against BBTV more challenging for actively engaged commercial farmers. Early detection followed by prompt destruction of the diseased plants is the key to the successful mitigation of BBTD. Fig. 2-1 provides a pictorial guide from early symptom development to severe disease symptoms.

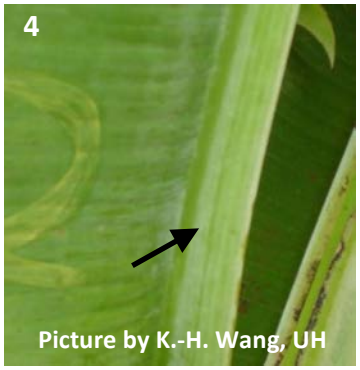
Fig. 2-1. Symptoms of BBTV-infected plants

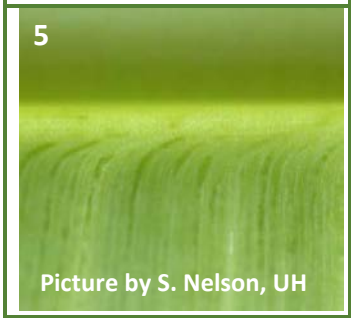
1. Initial symptoms after BBTV infection: slightly chlorotic leaves with pale leaf margins and prolonged unfolding of cigar leaves (> 5 days).

2. Infected leaves are lighter in color compared to healthy leaves, as chlorophyll content is much lower in BBTV-infected plants (Hooks et al. 2007, 2009).

3. Dark-green streaks ("Morse code," or intermittent dark and light green leaf vein coloration) will show on the under leaf surface soon after infection (Magee 1927).

4. Characteristic streaking with darker green lines also shows on the petiole on BBTV-infected plants.





5. "J hooks" are found close to the leaf center. They are a continuation of the "Morse code" found in BBTV-infected banana leaves.

6. Leaf shoots appear bunchy and upright.

7. Infection on older plants produces narrow, stiff, and upright leaves.

8. These stiff leaves curl inward, with wavy leaf edges.

Once BBTV symptoms are detected in a plant in a banana mat, the whole banana mat should be considered infected and be destroyed. Some BBTV-infected plants may not show symptoms in early stages or non-conducive environments (for example, plants growing in very healthy growing conditions). These plants may continue to grow and produce marketable fruits. However, a plant infected with BBTV will typically show chlorotic symptoms about 30 to 40 days after inoculation (Fig. 2-2). Quite often, newly planted healthy-looking suckers have been found to be infected with BBTV in Hawai'i. It was previously believed that the incubation period for BBTV was 125 days, but visible symptoms of infection become obvious from 20 to 85 days after aphid inoculation, with most plants displaying symptoms 50 days after infection (Hooks et al. 2008, 2009). BBTV-infected but symptomless plants are infectious. If farmers are using symptomless but BBTV-infected suckers (keiki) to propagate a new field, BBTV can be spread to the new field. Therefore, planting virus-free materials is critical. If in doubt, send leaf samples to the Agricultural Diagnostic and Service Center (ADSC) at the University of Hawai'i for molecular diagnosis. For more information on how to submit disease samples, please visit http://www.ctahr.hawaii.edu/site/adsc.aspx.

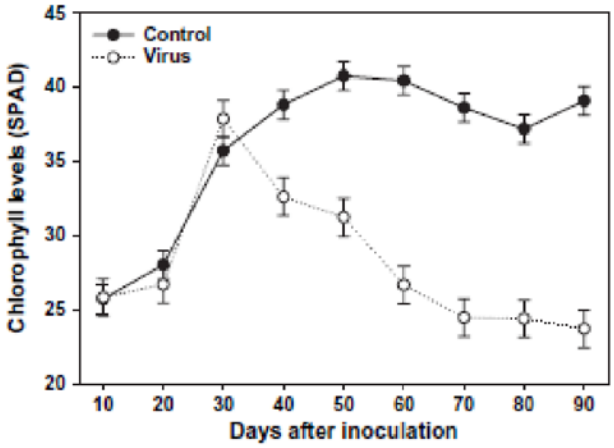


Figure 2-2. Estimate of chlorophyll levels in *Banana Bunchy Top Virus*-infected (virus) and healthy (control) banana plants at different times after inoculation. Chlorophyll estimates were obtained using a SPAD-502 [SPAD (Special Products Analysis Divison) units] chlorophyll meter (Hooks et al. 2007).

Aphids as the vector of BBTV

Banana bunchy top virus is transmitted by the banana aphid, *Pentalonia nigronervosa* (Fig 2-3). Banana aphid management is a key factor in BBTV control. When a banana aphid feeds on a BBTV-infected plant and moves to a healthy banana plant, it can transmit the virus through its piercing and sucking mouthparts. Banana aphid colonies are often found under leaf petioles or in other hidden, tender areas of the banana plant (Fig. 2-4). It is accepted by growers and Extension personnel that inspecting the most recently unfurled leaf (i.e., cigar leaf) of a banana plant is a good way to check for the presence of banana aphids. However, a study conducted by Robson et al. (2006) at the University of Hawai'i found that checking only cigar leaves for the presence of banana aphids led to false negatives in more than 50% of plants inspected in Hawai'i. Banana aphids are found all over the banana plant, from the flowers to below the soil level on the pseudostem (Robson et al. 2007).

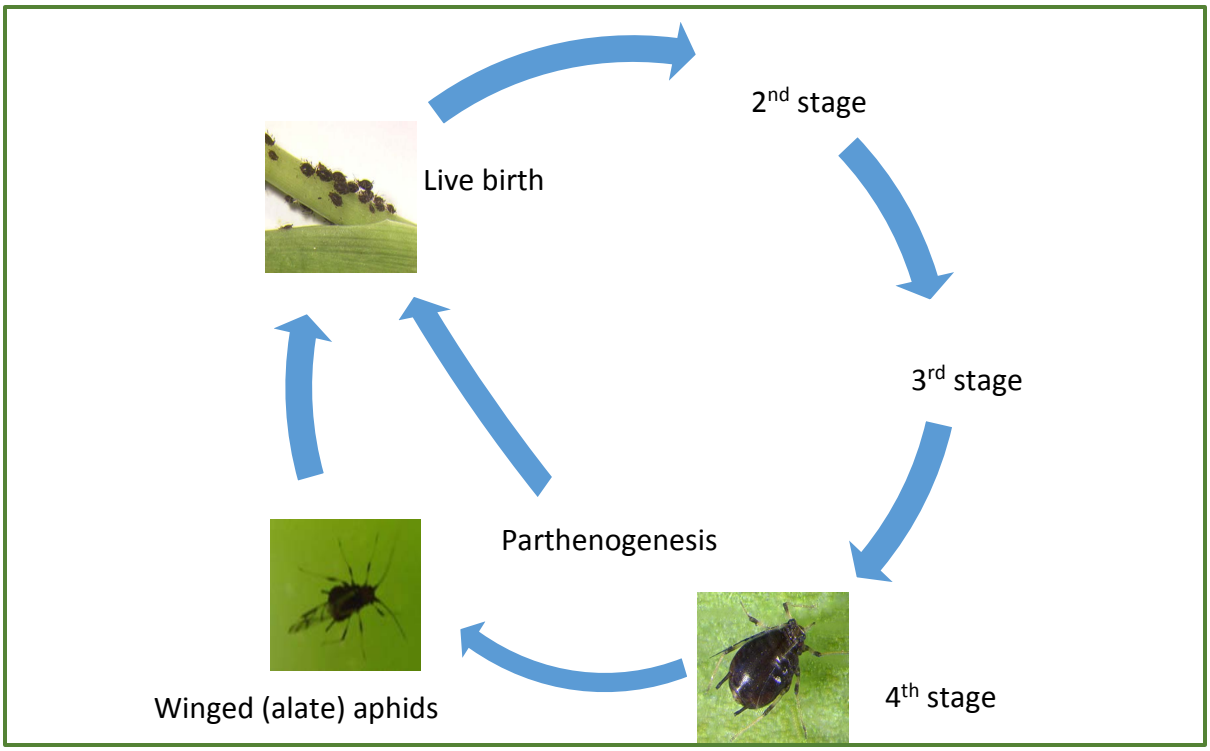


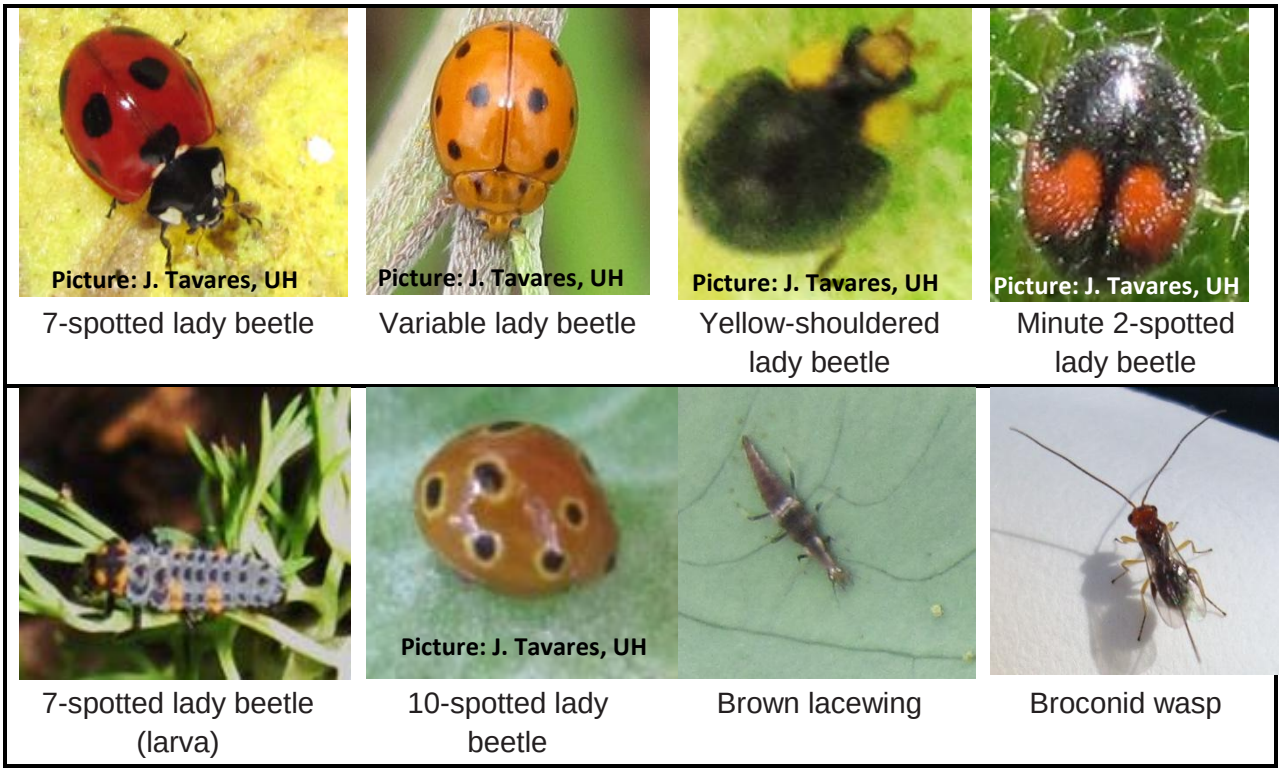
Fig 2-3. Life cycle of banana aphids (Pentalonia nigronervosa). Reproduction in the banana aphid is entirely parthenogenic (without mating). Females give birth to live female young; there is no egg stage. Males are not known for this species. The life cycle (nymph to adult) is completed in 9–16 days. The adult life span is 8–26 days. There could be as many as 30 generations per year and 14 offspring per female in Hawai‘i, where typical temperatures are above 25□C (pictures from S. Nelson, UH).

Fig. 2-4. Banana aphid colonies are often found under leaf petioles.

Winged adults often develop after 7 to 10 generations of wingless individuals (Mau et al. 1994). Dispersing winged adults help to establish new colonies on new host plants. Although not strong fliers, winged adults may be carried long distances by light winds. Banana aphids produce offspring with wings when conditions are crowded or when the plant host is under stress, such as when BBTV infection has severely stunted a plant.

Ants tend aphids, protecting them from predators and unfriendly environmental conditions, and in return the aphids provide the ants with honeydew. Several natural enemies of banana aphids have been introduced into Hawai‘i by the Hawai‘i Department of Agriculture, including braconid wasps (*Lysiphlebius testaceipes*), 7-spotted lady beetles (*Coccinella 7-punctata* var brucki), variable lady beetles (*Coelophora inaequalis*), ten-spotted lady beetles (*Coelophora pupillata*), convergens lady beetles (*Hippodamia convergens*), yellow-shouldered ladybeetles (*Apolinus lividigaster*), and minute two-spotted lady beetles (*Diomus notescens*) in the order of Coleoptera: Coccinelidae, as well as brown lacewing (Neuroptera: Hemerobiidae) (Fig. 2-5).

Although parasitized banana aphids were not commonly seen during a statewide survey (Hooks et al. 2011), all of these introduced natural enemies have been reported to parasitize or prey on banana aphids in Hawai'i (Waterhouse 1987).



7-spotted lady beetle | Variable lady beetle | Yellow-shouldered lady beetle | Minute 2-spotted lady beetle

7-spotted lady beetle (larva) | 10-spotted lady beetle | Brown lacewing | Broconid wasp

Fig. 2-5. Natural enemies of banana aphids present in Hawai'i.

Home Gardener's Corner:

Nelson, S., L. Richardson, et al. 2006. BBTV in Hawaii. University of Hawai'i at Manoa. https://www.ctahr.hawaii.edu/bbtd/video.asp

Videos on BBTV in Australia: http://abgc.org.au/projects-resources/industry-projects/banana-bunchy-top-virus/

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Waterhouse, D.F. 1987. Chapter 6. *Pentalonia nigronervosa* Coquerel. pp. 42–49 *In*: Biological Control: Pacific Prospects. (D.F. Waterhouse & K.R. Norris, eds.) Inkata Press: Melbourne. 454 pp.

II-2. Plant-parasitic nematodes

Plant-parasitic nematodes are microscopic roundworms that feed on plants. Most species feed on roots, but some feed on plant foliage. Among those nematodes infecting plant roots, some are **ectoparasitic** and others are **endoparasitic**. Ectoparasitic nematodes feed on plant tissues from outside of the plant, whereas endoparasitic nematodes feed from within the plant. Nematodes can be further categorized as **migratory** and **sedentary**. If the adult female moves freely through the soil or plant tissues, the nematode is referred to as migratory. An adult female that is immobile and remains in one area of the root is termed sedentary. Three **migratory endoparasitic** nematodes that feed on the root cortex of banana plants are the **burrowing** (*Radopholus similis*), **spiral** (*Helicotylenchus multicinctus*), and **lesion** (*Pratylenchus* spp.) nematodes. Their feeding results in dead root cells, or lesions (Fig.2-6A). **Sedentary endoparasitic** nematodes that feed on banana include the root-knot (*Meloidogyne* spp.) and reniform (*Rotylenchulus reniformis*) nematodes (Fig. 2-7). They penetrate banana roots, migrate and settle at a feeding site, and cause the surrounding cells to enlarge. Although root galls are not commonly seen on banana roots, heavily root-knot nematode-infected banana roots become swollen (Fig. II-6B). A nematode survey conducted between 2007 and 2008 throughout Hawai‘i revealed five major genera of nematodes that are commonly associated with banana roots: spiral, burrowing, root-knot, reniform, and lesion nematodes (Figs. 2-7 A -F).

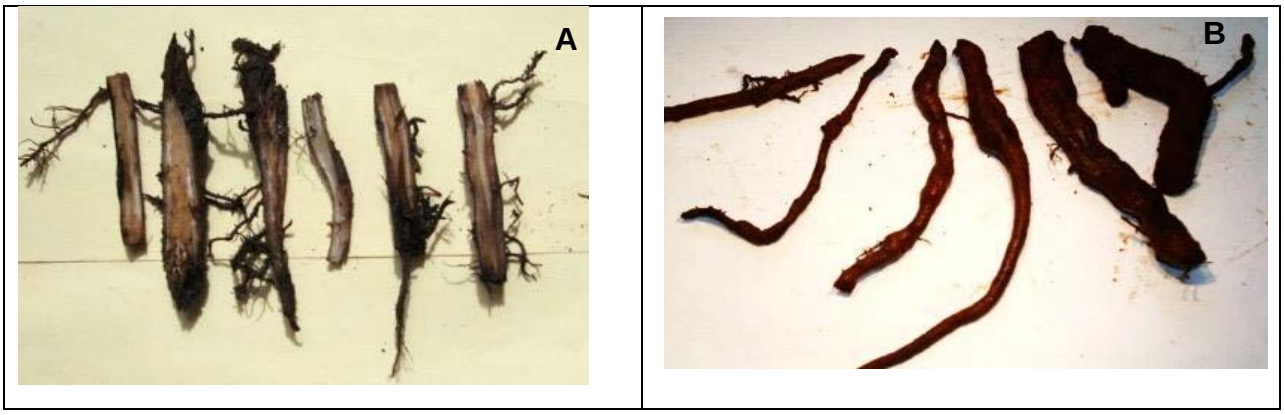
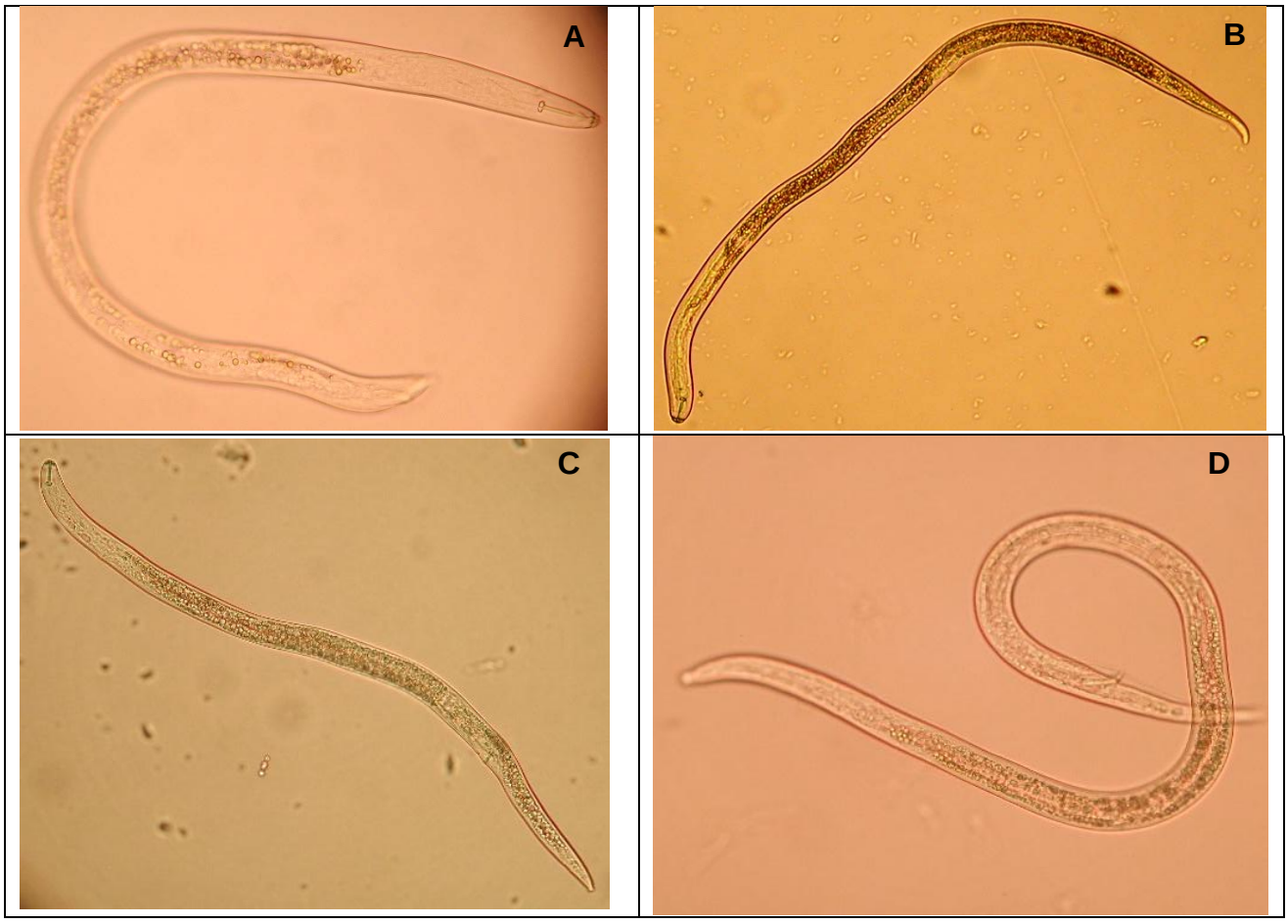


Fig. 2-6. A) Root lesions caused by endoparasitic nematodes, and B) root galls caused by root-knot nematodes on banana.



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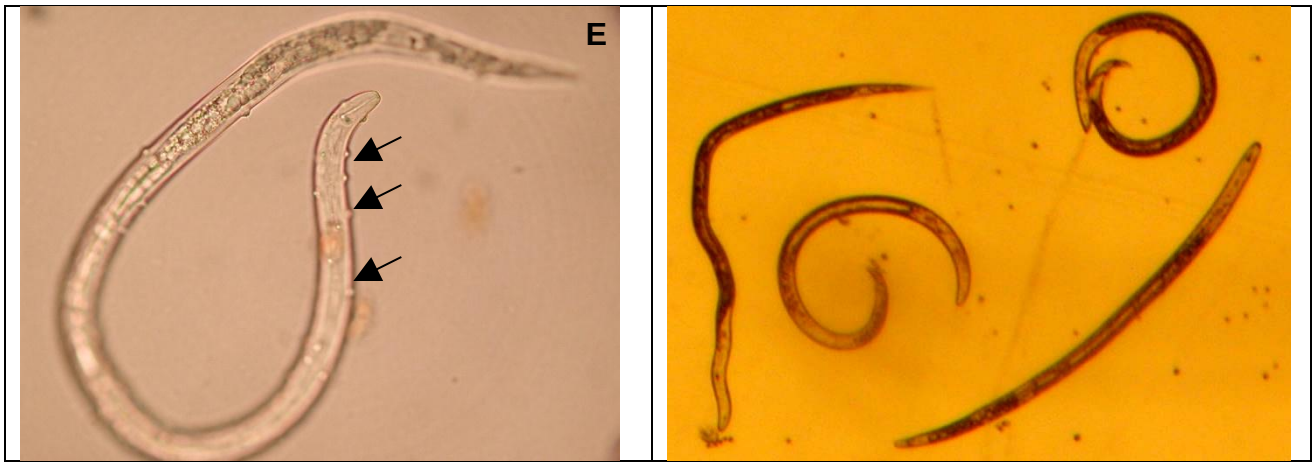

Fig. 2-7. A) Spiral nematode (*Helicotylenchus multicinctus*); B) female burrowing nematode (*Radopholus similis*); C) lesion nematode (*Pratylenchus coffeae*); D) male burrowing nematode; and E) juvenile *Meloidogyne* sp. infected by bacterial parasite, *Pasteuria penetrans* (arrows). F) Mixed population of nematodes including root-knot, reniform, and lesion nematodes extracted from the rhizosphere of a banana (pictures by K.-H. Wang).

Damage caused by plant-parasitic nematodes on banana

Fig. 2-8. Severe infection of plant-parasitic nematodes causes banana plants to topple.

Although plant-parasitic nematodes behave like hidden pests and are often ignored, damage caused by nematodes on banana is well documented, resulting in significant yield loss in banana production worldwide (Davide & Marsigan 1985, Speijer et al. 1999). Burrowing and spiral nematodes are reportedly responsible for yield losses of 30–50% in Costa Rica and Panama, 40% in Africa, 30–60% in India (Davide 1995) and more than 50% in East Africa (Speijer & Kajumba 1996, Kashaija et al. 2004). Banana nematodes attack root and corm tissue, causing damage that can reduce bunch size, shorten production life, prolong the vegetative cycle, and cause banana plants to topple (Fig. 2-8) (McSorley and Parado 1986, Bridge 1988, Chabrier and Quénéhervé 2003). Although limited studies are available on nematode damage on banana in the Pacific Islands, recent publications from American Samoa, Mariana Islands, and Hawai‘i showed that mixed populations of nematode species dominated by spiral nematode (*H. multicinctus*) commonly occur in banana fields (Brooks 2004, Quintanilla unpublished, Wang & Hooks 2009).

To estimate banana growth reduction caused by a combination of plant-parasitic nematodes commonly found in Hawai‘i, field soil was collected from an established banana field (> 5-years old) in Wai‘anae, HI. A greenhouse experiment was conducted to compare plant growth of tissue-cultured apple banana in 5.6-L pots containing autoclaved or non-autoclaved soil. Autoclave-sterilizing soil was used to render soil free of plant-parasitic nematodes. The non-autoclaved soil contained 18,368 spiral, 15,232 root-knot, 672 burrowing, and 6,720 reniform nematodes per one 5.6 L-size pot. At 7.5 months after planting, all the banana plant growth measurements (Fig. 2-9) were higher in the autoclaved soil than in the non-autoclaved soil ($P < 0.10$). One measurement, plant height, was approximately 20% reduced in the banana plants grown in the non-autoclaved soil. By the end of the experiment, root-knot nematodes had become the most dominant nematodes, followed by spiral and burrowing nematodes. A few plant-parasitic nematodes were also recovered from the autoclaved pots.

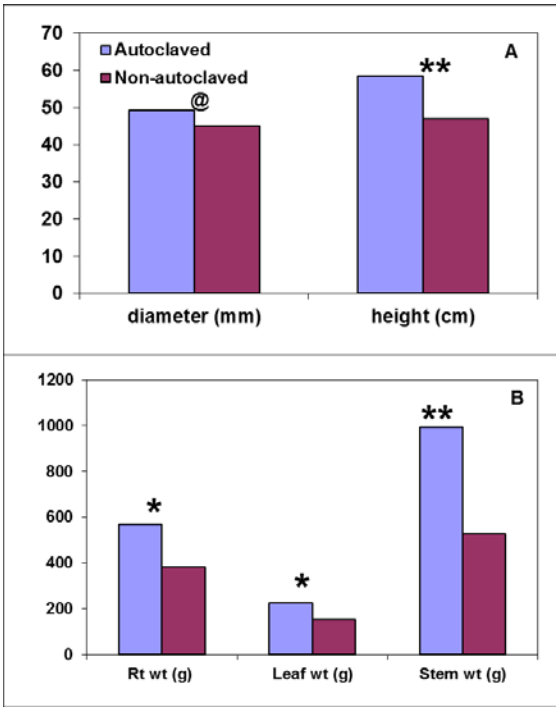

Fig. 2-9. Plant growth of tissue-cultured banana in autoclaved and non-autoclaved soil previously infested with nematodes. Means are average of 5 plants. @, *, and ** indicate significant difference between autoclaved and control soil at $P < 0.10$, 0.05, and 0.01 levels, respectively.

When subjected to regression analysis between plant growth parameters (root weight, leaf weight, stem weight, pseudostem diameter, and plant height) and nematode numbers (root-knot, spiral, and burrowing nematodes), significant regression relationships were found between many of these parameters (Table 2-1). Among the three most dominant nematode species, only spiral nematodes' numbers correlated significantly to with plant height ($R = - 0.25$, $P < 0.05$), indicating that spiral nematode infection significantly reduced plant height. The combination of spiral and burrowing nematodes also regressed negatively to plant height to a greater extent than a combination of all three nematode species ($R = - 0.26$, $P < 0.05$). This indicated that infection with root-knot nematode did not reduce plant height. Similar regression analysis was observed between stem, leaf, and root weights with all three nematodes, alone and in combination, except there was no regression between root-knot nematodes and leaf weight. The combination of burrowing and spiral nematodes in a model often improves the *R*-value when regressed with all plant growth parameters. This indicates that burrowing and spiral nematodes were the main contributors to the decline in growth of banana in this nematode-infested soil.

Table 2-1. Correlation analysis between plant growth parameters and root-knot, burrowing, and spiral nematode numbers.

Nematode	Plant height	Pseudo-stem diameter	Root weight	Leaf weight	Pseudo-stem weight	Root damage index	Root gall index
Root-knot	-0.1186[z]	**-0.5596**	-0.2409	-0.2176	**-0.5420**	**0.8473**	**0.6045**
	0.1915	**0.0009**	0.0536	0.0686	**0.0011**	**0.0001**	**0.0004**
Burrowing	-0.2042	**-0.5644**	**-0.3085**	**-0.3550**	**-0.6512**	**0.9256**	**0.7483**
	0.0788	**0.0008**	**0.0255**	**0.0149**	**0.0002**	**0.0001**	**<0.0001**
Spiral	**-0.2480**	**-0.4046**	**-0.3342**	**-0.2737**	**-0.3846**	**0.4962**	**0.3235**
	0.0496	**0.0081**	**0.0190**	**0.0375**	**0.0104**	**0.0023**	**0.0215**
Root-knot +	-0.2072	**-0.5816**	**-0.3303**	**-0.3150**	**-0.5962**	**0.8573**	**0.6268**
burrowing + spiral	0.0765	**0.0006**	**0.0199**	**0.0237**	**0.0005**	**<0.0001**	**0.0003**
Burrowing +	**-0.2632**	**-0.5661**	**-0.3755**	**-0.3679**	**-0.6008**	**0.8206**	**0.6093**
spiral	**0.0421**	**0.0008**	**0.0116**	**0.0127**	**0.0004**	**<0.0001**	**0.0004**

[z]Values are Pearson correlation coefficients (*R*) followed by P-value. N=24. All nematode numbers are log (x+1) transformed to obtain normal distribution prior to the correlation analysis.

Natural enemies of plant-parasitic nematodes in banana fields

During the 2007–2008 survey conducted in Hawai‘i, several commonly found natural enemies of plant-parasitic nematodes in the state included predatory nematodes, nematode-trapping fungi (Fig. 2-10), and a bacterial parasite of root-knot nematode, *Pasteuria penetrans* (Fig. 2-7 E). These naturally occurring predators or parasites of nematodes may not contribute significantly to the suppression of plant-parasitic nematodes below the economic threshold level, especially in intensively managed, long-established banana farms, but they could potentially keep the population of the nematode pests in check to a certain extent. A correlation analysis based on the survey results indicated that most farms that received high-input practices such as the application of synthetic fertilizers, glyphosate, and various types of fungicides generally had lower abundance of omnivorous and predatory nematodes (Wang and Hooks 2009).

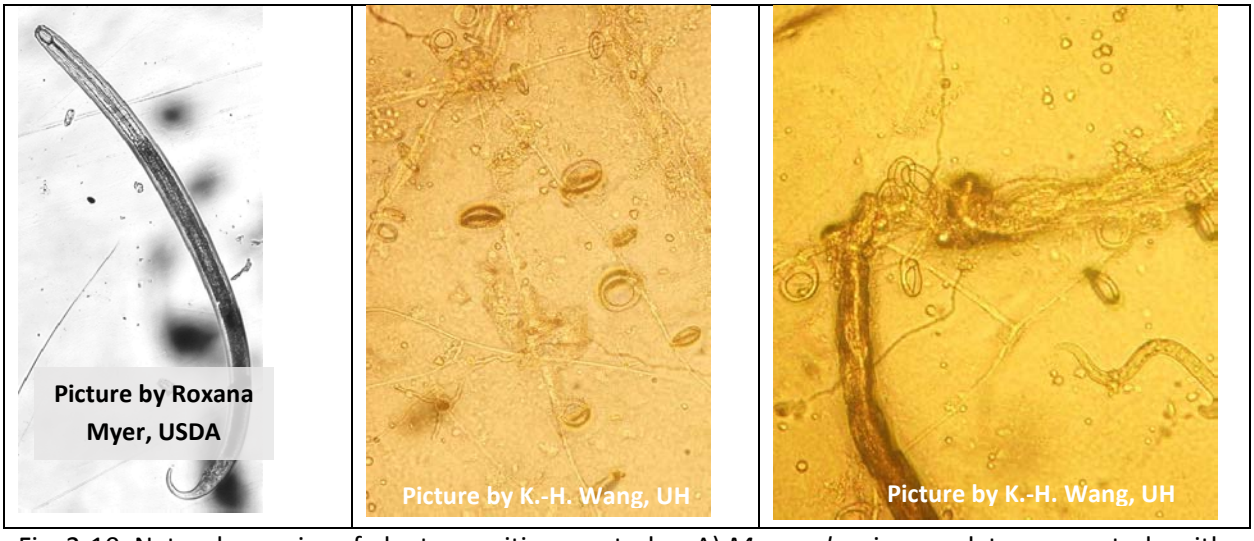

Fig. 2-10. Natural enemies of plant-parasitic nematodes: A) *Mononchus* is a predatory nematode with an open mouth cavity armed with a tooth. B) *Arthrobotrys dactyloides* is a nematode-trapping fungus forming constricting rings that wait for nematodes to be trapped. C) Here nematodes are trapped by the constricting rings of *A. dactyloides* and colonized by the fungal hyphae.

Web Resources:

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Gowen, S.R., P. Quénéhervé, and R. Fogain. 2005. Nematode parasites of bananas and plantains. In: Plant Parasitic Nematodes in Subtropical and Tropical Agriculture. M. Luc, R.A. Sikora, and J. Bridge, 2nd edition. CAB International Edit, Wallingford, Oxon, UK. p. 611–643.

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Speijer, P.R., C. Kajumba, and F. Ssango. 1999. East African Highland banana production as influenced by nematodes and crop management in Uganda. *International Journal of Pest Management* 45:41–59.

Wang, K.-H., and C.R.R. Hooks. 2009. Plant-parasitic nematodes and their associated natural enemies within banana (*Musa* spp.) plantings in Hawaii. *Nematropica* 39: 57–73.

Home Gardener's Corner:

Banana suckers from an established banana mat will most likely carry endoparasitic nematodes such as burrowing, spiral, and lesion nematodes in the root system. Various precautions can be taken (see Chapter V) to mitigate the problem. Keep the banana root system in good health by periodically adding organic compost as mulch under the banana canopy. Reduce disturbance to the root system by minimizing the use of pesticides and tillage around the root system. Remove excess suckers; keep no more than 3–5 plants per

banana mat. These steps can decrease the damage to banana from plant-parasitic nematodes. Refer to Chapter V for how to plant marigold as a living mulch to manage plant-parasitic nematodes after planting banana. If banana yields decline over time, it may be due to damage from plant-parasitic nematodes. Replanting with new, healthy banana plants may be worthwhile.

II-3. Black Leaf Streak or Sigatoka Disease

Sigatoka disease is another commonly encountered problem on banana in tropical areas, especially in high-rainfall regions like the windward sites of the southern Pacific Islands. Two fungal pathogens cause similar but slightly different Sigatoka diseases. Black Sigatoka is caused by the plant-pathogenic fungus *Mycosphaerella fijiensis*, whereas yellow Sigatoka is caused by *M. musicola* (Bennett and Arneson 2003).

Fig. 2-11. Black Sigatoka disease in dense banana canopy of a banana orchard on windward site of O'ahu, HI.

Black Sigatoka or black leaf streak (BLS) is the most important fungal disease of banana (*Musa* species) worldwide. The disease only affects banana, and through reduced photosynthesis and defoliation can severely reduce banana bunch yield and fruit quality (Fig. 2-11). Although both Black and Yellow Sigatoka form leaf streaks, BLS's early streaks and spots streaks are black and lack the distinct yellow halo that is present in young streaks of yellow Sigatoka (Fig. 2-12).

Disease symptom and development

Fig. 2-12. A) Early symptom of black leaf streak on older banana plants of with minute chlorotic flecks on the under-surface of the third or fourth fully expanded leaf. B) The flecks develop into narrow rusty brown streaks that often have truncated ends and have sides that are sharply limited by the leaf veins, resulting in a streaky

appearance. C) Streaks rarely form on suckers, instead there are circular leaf spots ranging in color from black to brown to grayish, depending on the stage of plant and lesion development (Nelson 2008).

Most dessert bananas, cooking bananas, and plantains are susceptible to Black Sigatoka disease, whereas most cooking bananas and plantains (AAB and ABB) are moderately to highly resistant to Yellow Sigatoka (Bennette and Arneson 2003). 'Cavendish' banana types are generally susceptible to Yellow Sigatoka. However, in a conducive environment, symptom development will still be apparent in an 'Apple' banana (AAB) field.

The pathogen

The scientific name of a fungus changes whether it is in its sexual (teleomorph) stage or its asexual stage (anamorph). *Mycosphaerella fijiensis* is the sexual stage of the pathogen of Black Sigatoka. The asexual form (anamorph) of this fungus is called *Pseudocercospora fijiensis* and produces conidia spores. The conidia germinate during periods of high relative humidity (92–100% RH) and infect the leaf through leaf openings such as the stoma. This infection will form lesions on the undersurface of the leaf. As the lesion matures, conidia and hyphae cluster together to form spermagonium (fungal structures that produce male reproductive cells, spermatia). Spermatia fertilize receptive neighboring female hyphae, and form pseudothecia that contain sexual spores (ascospores). For a more detailed description of the life cycle of this fungus, please see the illustration by Bennett and Arneson (2003). A similar life cycle can be seen for Yellow Sigatoka, in which the teleomorph is *M. musicola* and the anamorph is *P. musae*. Windborne ascospores are the major inoculum for Black Sigatoka, whereas the inoculum of Yellow Sigatoka consists of both conidia (water-dispersed) and ascospores. The first symptom (chlorotic flecking) appears about 15–20 days after infection. The fungus survives on dead banana leaves as spores or mycelium and will reinocuate healthy tissues.

Although both pathogens prefer high humidity, black sigatoka is more common in warmer environments, whereas Yellow Sigatoka is more common in cooler environments. Black Sigatoka produced ascospores 2 weeks after the appearance of leaf streaks, but Yellow Sigatoka produced them about 4 weeks after the streaks appear. In general, Black Sigatoka is a more challenging pathogen to manage than Yellow Sigatoka.

Depending on factors such as cultivar, location, cultural practices, and fungicide(s) selected, up to 24 fungicide spray applications per year may be needed to produce acceptable banana yields at large plantations in Hawai'i. However, with a sufficient fertilizer plan and the use of sound cultural practices, the average backyard grower can cope with BLS fairly well. Chapter VI discusses an economical approach to managing black leaf streak more efficiently in the Southern Pacific.

References:

Bennett, R. and P.A. Arneson. 2003. Black sigatoka of bananas and plantains. The American Phytopathological Society. DOI: 10.1094/PHI-I-2003-0905-01. http://apsnet.org/edcenter/intropp/lessons/fungi/ascomycetes/Pages/BlackSigatoka.aspx.

Nelson, S. 2008. Black leaf streak of banana. CTAHR Cooperative Extension Service publication PD-50, 10 pp.

Home Gardener's Corner

Sigatoka diseases might not be a severe problem for home gardeners who have only a few banana plants. Since fungicide treatment is not a good option for home gardeners, they should learn to recognize the disease and practice good sanitation practices (see Chapters V and VII).

II-4. Fusarium wilt of banana or Panama Disease

Fusarium wilt or Panama disease is among the most destructive plant diseases of banana. The original strain of Fusarium wilt, Race 1 ravaged 'Gros Michel' banana trades worldwide until the cultivar was replaced by resistant Cavendish cultivars. However, a new strain of *Fusarium oxysporum* f. sp. *cubense* (*Foc*) Tropical Race 4 (TR4) was identified in Southeast Asia in 1992 and has spread throughout the region, threatening the production of Cavendish banana in Southeast Asia, impacting the subsistence banana production in the region. Now there is a huge concern that TR4 will further disseminate in Africa and possibly in Hawaii. It has already been found in Latin America as of November 2013 and would thereby threatening other vital banana-growing regions.

The pathogen

Panama disease of banana is caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *cubense* (*Foc*) that enters the plant through the roots and colonizes the xylem vessels thereby blocking the flow of water and resulting in total plant wilt. The fungus persists in soil for an indefinite period of time and cannot be managed using chemical pesticides. This is a pathogen of bananas that has spread globally. The pathogenic isolates of *Foc* are classified into races based on the susceptibility of different banana cultivars to the pathogen. Race 1 is pathogenic to cultivars in the Gros Michel, Silk and Pome subgroups. When Cavendish cultivars exhibiting symptoms of Fusarium wilt were first observed, the isolates were classified as race 4. They were later subdivided into subtropical race 4 (STR4) and tropical race 4 (TR4). Tropical race 4 is the fungal strains that readily cause Fusarium wilt on Cavendish bananas without the requirement of predisposing factors such as low temperatures and waterlogging, whereas STR4 requires these predisposing factors to cause disease.

Symptoms of Fusarium wilt of banana (Pictures are credited to Jari Sugano)

<table>
<tr>
<td>  </td>
<td>1. Initial symptom of the disease is wilting and yellowing of the older leaves around the margins.
2. Leaves collapse at the petiole and hanging down like a skirt. Some-time, the leaves remain green, except for spots on the petiole, but still snap. Eventually, all the leaves hang down and dry up.</td>
<td>  </td>
</tr>
<tr>
<td>  </td>
<td>3. The internal symptom is vascular discoloration varies from pale yellow to dark red or
4. almost black in later stages.</td>
<td>  </td>
</tr>
<tr>
<td>  </td>
<td>5. Splitting of the base of the pseudostem is common.
6. Infected suckers do not start showing symptoms until they are about 4 months old, a situation that has contributed to the spread of the disease through planting material.</td>
<td>  </td>
</tr>
<tr>
<td>  </td>
<td>7. The fruit does not show any specific disease symptoms.
8. However, if infected earlier, Foc will cause the plant fail to flower or set fruits.</td>
<td>  </td>
</tr>
</table>

Symptoms of Fusarium wilt can be confused with Moko disease which is caused by *Ralstonia solanacearum* race 2 that also causes vascular discoloration. Unlike Moko, Fusarium wilt does

not cause wilting and blackening of young suckers or a dry rot in the fruit. The first symptoms of Moko on rapidly growing plants are the chlorosis, yellowing and collapse of the three youngest leaves, not the older leaves as with Fusarium wilt. Finally, with Moko the vascular discoloration is concentrated near the center of the pseudostem and not peripherally, which is common with Fusarium wilt.

Transmission

The pathogen is most often transmitted by planting infected planting material and responsible for the local, national and international spread of the disease. Tissue culture plantlets free of *Foc* is critical to stop the spread of the disease. Fusarium spores can be carried in surface run-off water, or contaminated irrigation water. Most importantly, the fungus can persist in soil for decades, even in the absence of susceptible bananas. It can survive in infested plant debris and in the roots of alternative hosts.

Economic Impact of TR4

The emergence of TR4 started affecting commercial plantations of Cavendish cultivars, which is currently the dominant commercial banana in the world. Banana production in Taiwan decreased from about 50,000 hectares in 1960 to only about 6,000 ha in 2000 due to *Foc*. In Indonesia and Malaysia, the arrival of TR4 in the early 1990s destroyed recently established export plantations within a few years. The fungus did the same to the banana industry in Australia. In mainland China, about 6,700 ha had been severely affected by TR4 in Guangdong province based on 2006 survey and more extensive damage was reported in 2012. Thus, it is important to not let this pathogen become widespread in Hawaii.

References:

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García-Bastidas, F. et al. 2014. First Report of *Fusarium oxysporum* f. sp. *cubense*. Tropical Race 4 associated with Panama disease of banana outside Southeast Asia. Plant Dis. 98: 694. https://doi.org/10.1094/PDIS-09-13-0954-PDN.

Ploetz, R.C. and Churchill, A.C.L. 2011. Fusarium wilt: the banana disease that refuses to go away. Pp. 519-526. In: Van den Bergh, I., Smith, M., Swennen, R. and Hermanto, C. (eds.). Proceedings of International ISHS-ProMusa Symposium on Global Perspectives on Asian Challenges, Guangzhou, China, 14-18/09/2009. Acta Horticulturae 897. ISHS, Leuven, Belgium.

Chapter III

Other Pests and Pathogens of Banana

1. **Banana aphids** (*Pentalonia nigronervosa*)
   - Piercing and sucking mouthparts.
   - Feed on the pseudostem and leaves.
   - Winged aphids (alates) form with high population densities.
   - Ants protect them from natural enemies.
   - Peak season: dry, warm conditions (February to April).
   - Hosts: Banana, ginger, heliconia, and taro.
   - Vector of *Banana bunchy top virus* (BBTV).
   - For greater detail please refer to Chapter II-1, Banana Aphid section.
   - Web resource: www.extento.hawaii.edu/Kbase/crop/Type/pentalon.htm

Fig 3-1. Banana Aphids, Pentalonia nigronervosa. Right: a winged adult (alate); left: a non-winged individual. Images by Scot Nelson, University of Hawai'i

2. Banana rust thrips (*Chaetanophothrips signipennis)*

- Rasping/sucking mouthparts.
- Feed on the pseudostem and fruit.
- Peak season: dry periods or in low-rainfall areas.
- Leaf symptoms: dark, v-shaped marks on the outer surfaces of leaf petioles.
- Fruit symptoms: water-soaked appearance, oval-shaped reddish "stains" where fingers touch.

Web resources: http://www.extento.hawaii.edu/Kbase/crop/Type/BR_thrips.htm and http://www.ctahr.hawaii.edu/oc/freepubs/pdf/IP-10.pdf

Fig 3-2. Banana rust thrips causing a) oval-shaped reddish “stains” where fingers touch, and b) v-shaped marks on leaf petiole.

3. Banded greenhouse thrips (*Hercinothrips femoralis)*

- Rasping/sucking mouthparts.
- Symptoms: Silver and bronze scars, reddish discoloration on fruit.
- Control: Insecticides, bagging, oils, soapy water.
- Web resource: http://www.extento.hawaii.edu/Kbase/crop/Type/h_femora.htm

Fig 3-3. Banded greenhouse thrips causing silver and bronze scars on fruit.

4. Hawaiian flower thrips (*Thrips hawaiiensis)*

- Feed on flowers.
- Symptoms: Flecked, spotted, deformed flowers, pimple-like bumps on fruit, damage inside flower bell.
- Prefer wet and shady areas.
- Control: remove older leaves and avoid shady conditions.
- Difficult to control, because damage is done inside flower bell.

Web resource:
http://www.extento.hawaii.edu/Kbase/crop/Type/t_hawai.htm

Fig 3-4. Flickers on banana caused by flower trips.

5. Banana weevil (*Cosmopolites sordidus)*

- Bore through the corm, suckers, and roots of living and decaying plant material.
- Symptoms: root destruction, slowed plant growth, reduced fruit production, and toppled plants.
- Young banana plants at risk.
- Feed and breed at night.
- Control: hot water, trapping, sanitation, minimizing root exposure.

Web resource: *http://www.extento.hawaii.edu/Kbase/crop/Type/cosmopol.htm*

Fig. 3-5. Banana weevil (a) bores into a banana corm (b) and causing banana plant to fall down due to root destruction.

6. Banana skipper (*Erionota thrax)*

- Symptoms: Rolled leaves originating from the midrib of plants, resulted in severe defoliation.
- Web resource: http://www.extento.hawaii.edu/kbase/crop/Type/pelopida.htm.

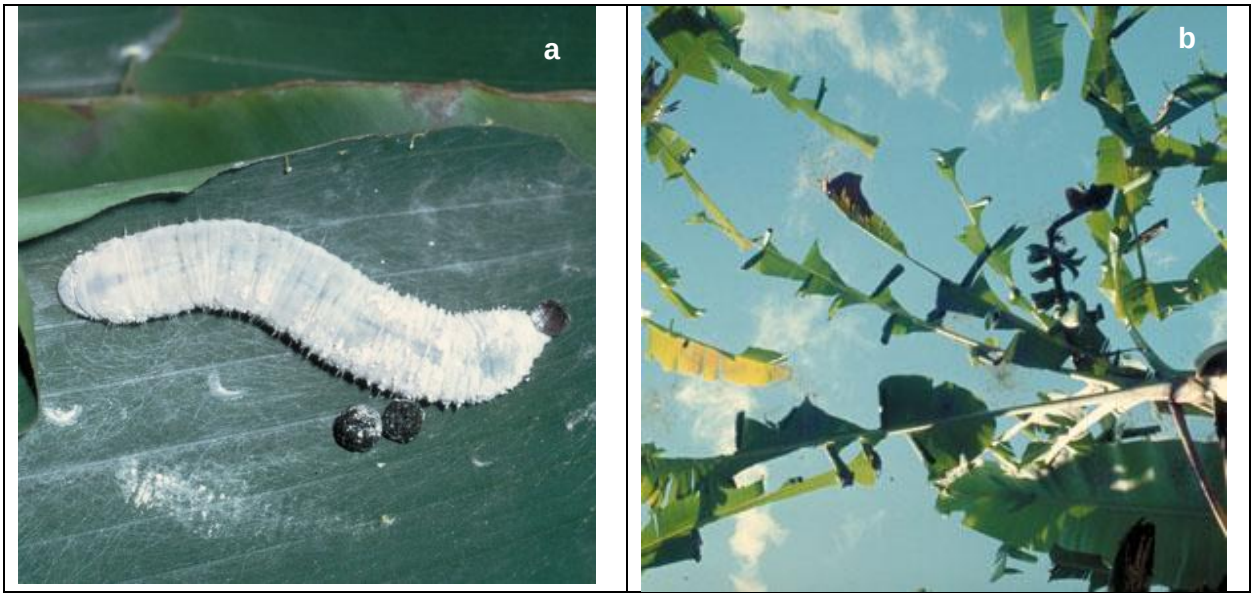

Fig. 3-6. a) Caterpillar of banana skipper shreds and rolls up banana leaf to feed safely inside the leaf, and result in b) severe defoliation of banana plants.

7. Long-legged ant (*Anoploepis longipes)*

- Love sugar.
- Move and protect aphids.
- Release a toxic chemical causing dry, necrotic lesions on the fruit surface.
- Prefer wet, high-rainfall areas.
- Peak season: June through October.

Web resource:
http://www.extento.hawaii.edu/kbase/crop/Type/A_longip.htm

Fig 3-7. Long-legged ants.

8. Big-headed ant (*Pheidole megacephala*)

- Move and protect aphids.
- Also protect other honeydew-producing insects such as scales and whiteflies.
- Love grease.
- Peak season: May through October.

Fig 3-8. Big-headed ant.

9. Chinese rose beetle (*Adoretus sinicus)*

- Damage is done by the feeding of the adult beetle.
- Nocturnal feeder of leaves and interveinal tissue.
- Peak season: May through November.

Web resource:
http://www.extento.hawaii.edu/kbase/crop/Type/adoretus.htm

Fig 3-9. Chinese rose beetle.

10. Banana moth (*Opogona sacchari*)

Fig 3-10. Banana moth.

- Lay eggs on senescing flowers, decaying leaves, pseudostems, or fruit.
- Larvae feed on decaying plant material.

Web resource: http://www.ctahr.hawaii.edu/sustainag/extn_pub/fruitpubs/Banana%20Moth.pdf

11. Spiraling whitefly (*Aleurodicus disperses*)

- Sap-suckers that damage and discolor plant leaves and tissue.
- Excrete honeydew that can cause black sooty mold.
- Protected by ants.

Web resource: http://www.extento.hawaii.edu/kbase/crop/Type/a_disper.htm

Fig. 3-11. a) Egg spiral deposits, adults and nymphs of spiraling whitefly on banana foliage often lead to b) colonization of black sooty mold.

12. Banana fruit-piercing moth (*Othreis fullonia*)

- Adults puncture and feed on ripening fruit.
- Larvae feed on *Erythrina* (wiliwili).
- Symptoms: premature ripening and fruit drop, secondary infections caused by fungus and bacteria.

Web resource: http://www.extento.hawaii.edu/kbase/crop/Type/othreis.htm

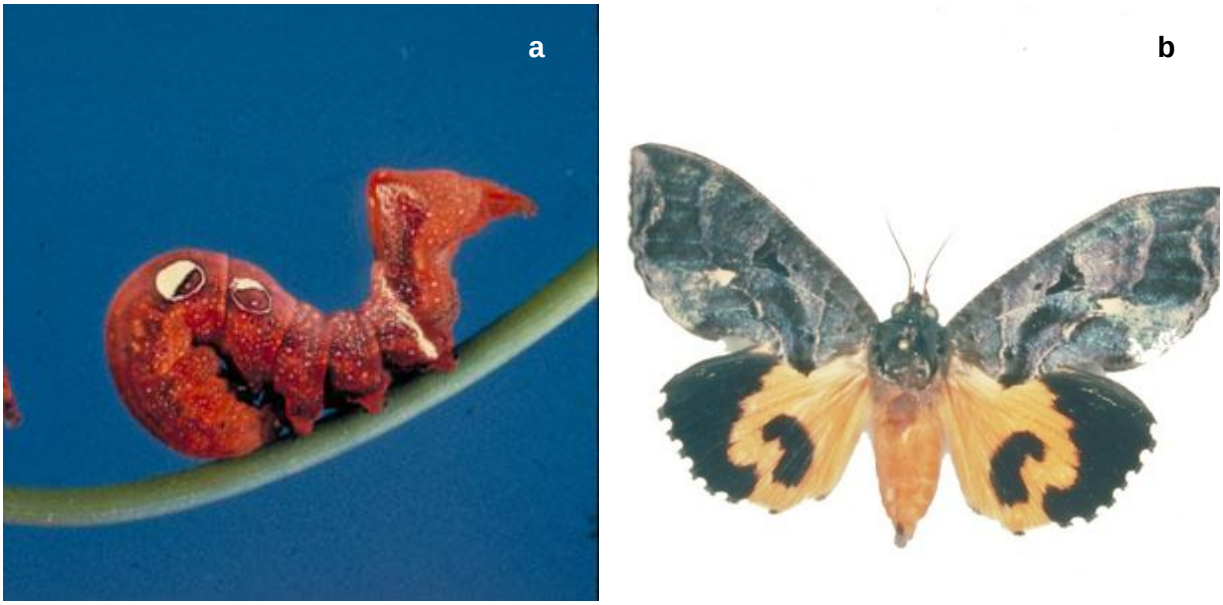

Fig. 3-12. Banana fruit piercing moth a) caterpillar and b) adult.

13. Mites (Various species)

- Piercing and sucking mouthparts.
- Symptoms: damage to plant tissue and fruit.

Web resource:
http://www.extento.hawaii.edu/kbase/crop/Type/mitemenu.htm

Fig 3-13. Banana moth.

V-2. Fungi

Black pitting caused by *Verticillium theobromae*

Widespread in the tropics, this fungus initially causes black pitting and spot of banana fruit. It is presumably dispersed by air and through banana debris. The powdery, greyish conidia form on the shriveled black end of the fruit, giving rise to what is called “cigar end rot” on immature fingers. The corrugated necrotic tissues become covered with fungus and resemble the greyish ash of a cigar end (Holiday 1980).

V-3. Bacteria

Moko disease of banana is a deadly disease of banana and plantains. It is caused by a bacterium, *Ralstonia solanacearum* (Race 2). It can cause wilting and blackening of young suckers or a dry rot in the fruit. The first symptoms of Moko on rapidly growing plants are the

chlorosis, yellowing and collapse of the three youngest leaves. Infection in the vascular system resulted in discoloration concentrated near the center of the pseudostem.

Resources: http://www.padil.gov.au/pests-and-diseases/pest/main/136650/3651

Fig. 3-14. Banana Moko disease a) attacking suckers of banana causing youngest leaves to collapse first, and b) resulted in discoloration concentrated in the center of pseudostem (picture credit from PaDIL).

Web Resources:

Insect and other pests of banana: http://www.extento.hawaii.edu/kbase/crop/crops/banana.htm

CTAHR Leaf Doctor app: https://sites.google.com/a/hawaii.edu/leafdoctor/

References:

Holiday, P. 1980. Fungus diseases of tropical crops. Press Syndicate of the University of Cambridge, New York, NY. 555 pp.

Chapter IV

IPM Strategies against BBTV

Banana bunchy top virus (BBTV) is a circulative, persistent, but non-propagative virus (as described in Chapter II on page **) in the family *Nanoviridae,* genus *Babuvirus,* BBTV, transmitted specifically by the banana aphid, *Pentalonia nigronervosa* Coquerel (Hemiptera, Aphididae). This means that the virus, once acquired by the aphid vector, will persist in the vector throughout the life of the aphid, but the virus will not reproduce in the aphid. Instead, the virus will reproduce to a higher titer concentration in the banana plant. Farmers should be aware that once a banana plant is infected, the virus will be translocated through the phloem tissue of the plant and travel throughout the entire plant mat. Since there is no therapeutic remedy for BBTV once a plant is infected, IPM strategies against BBTV should focus on stopping the spread of the disease.

Current tactics recommended for mitigating BBTV spread in Hawai‘i include: 1) early detection of virus-infected plants, 2) timely destruction of virus-infected plants with a bananacide (herbicide), 3) insecticidal treatment on virus-infected plants, 4) managing banana aphid populations on banana, 5) replanting with virus-free banana plants (Hooks et al. 2014); 6) managing banana aphids on alternative hosts, 7) controlling ants, and 8) growing tolerant varieties (Nelson et al. 2006). Some of these recommendations are being verified and improved by researchers at the University of Hawai‘i and are summarized in this chapter.

Early detection of virus-infected plants

Early symptom expression of BBTV is described in Chapter II Fig. 2-1. Unfortunately, a banana infected by BBTV will go through a latent period before showing symptoms. A report from Australia estimated that the incubation period for BBTV is 125 days (Allen 1978), but in Hawai‘i, the range is 20 to 85 days after aphid inoculation, with most plants displaying symptoms by 50 days after inoculation (2008; 2009). While early detection of BBTV infection through molecular diagnostics is available, it will not be feasible for farmers with acreages of banana plants to submit every plant for testing. Thus, an IPM program for BBTV management should go beyond early detection and removal of BBTV symptomatic plants.

Destruction of BBTV-infected plants with a bananacide

Once a banana plant is diagnosed with BBTV, it should be destroyed immediately to mitigate the spread of the virus. BBTV-infected plants can be destroyed by injecting them with **bananacide** (an herbicide registered for killing banana plants). A list of bananacides registered for use in Hawai‘i can be found at the Hawai‘i Pesticide Information Retrieval System (HPIRS) (http://pesticides.hawaii.edu/hipmrinn/hipmrinn.html). Previously, it has been suggested that if a symptomatic plant is found, growers should consider rogueing healthy neighboring plants (Allen 1978; Magnaye and Valmayor 1995). In a study where Hooks and Wang closely monitored and destroyed BBTV-infected plants weekly and recorded BBTV movement in banana plantings for

3 years, they found that banana plants neighboring BBTV infected plants remained healthy throughout the 3-year study (Hooks and Wang unpublished data). The practice of destroying healthy plant mats next to BBTV-infected plant mats has most likely resulted in unwarranted labor and loss of income. A better strategy is to scout for BBTV-symptomatic plants regularly, promote timely destruction of infected plants, and replant with BBTV-free planting materials such as tissue-cultured plants as illustrated here.

Fig 4-1. Commercial banana farm workers scouting for BBTV-symptomatic plants during their weekly harvesting trip. They marked the diseased plants and prepared to destroy the symptomatic plants soon after the harvest.

Fig. 4-2. To determine the amount of glyphosate (bananacide) to destroy banana, measure the trunk diameter of the plant at 1 ft (30 cm) above soil line.

Fig. 4-3. Use a screwdriver to make a hole into the trunk at 45^{o} angle at a height and depth of 30 cm and 10 cm, respectively, and inject glyphosate into the hole at 1 ml per 2-in (5-cm) diameter of the trunk using a pipette.

Fig. 4-4. All banana plants within an infected mat need to be treated. For small plants, inject the bananacide into the plant vertically after cutting.

Fig. 4-5. Any fruits on a plant should be removed before bananacide injection as required by the pesticide label. Allow plants to die back completely before replanting with a healthy, virus-free plant. Caution should be exercised, as banana plants can remain virulent (able to transmit BBTV) 6 weeks after the bananacide injection (Hooks et al. 2009).

Insecticidal treatment

To prevent the spread of BBTV, managing the population densities of banana aphids is key to an IPM program against BBTV. A list of insecticides registered for use on banana in Hawai‘i can be found at the Hawai‘i Pesticide Information Retrieval System (HPIRS) (http://pesticides.hawaii.edu/hipmrinn/hipmrinn.html). Among the insecticides listed in HPIRS that are effective against banana aphids, imidacloprid is a systemic insecticide that acts as an insect neurotoxin. Users must follow the label to apply the insecticide, including method of application, number of permitted applications per year, application rate, personal protective equipment (PPE) required, preharvest (PEI) and restricted-entry intervals (REI), etc. Since this insecticide is systemic, it is not necessary to spray the entire plant to reach effective control of the pest. However, ensuring the permeability of the insecticide into the banana plants will increase the effectiveness of the insecticide. This can be done by adding compatible spreader stickers and removing leaf residue that will block the spray contact (Fig. 4-6). Newly registered systemic insecticides for banana are in development, and growers are encouraged to develop an insecticide-rotation program to avoid the buildup of pesticide-resistant aphid populations. An insecticide rotation program should include insecticides with different modes of action that can usually be identified by Group number on the label (Fig. 4-7). Pesticides with different modes of action kill insects differently and thus are less likely to create a pest population resistant to pesticides. Other insecticides listed on HPIRS to combat banana aphids include neem products, fine-spray oil, potassium salts of fatty acids, etc. These are broad-spectrum insecticides that can kill aphids through contact, which can be integrated into a pesticide rotation program.

Fig. 4-6. Untrimmed leaves block insecticide from reaching the trunk where aphids are hiding.

Fig. 4-7. Mode of action group of an insecticide can be found on its label.

Insecticides can be used to manage aphid populations when BBTV is detected and at the time of rogueing. This strategy of **spraying only BBTV-infected plants** may be extended to neighboring banana mats in the likelihood that a neighboring plant is infected. This practice will reduce the risk of secondary virus spread without the wasteful destruction of neighboring healthy banana plants, and thus help improve the efficiency of rogueing with bananacide (Hooks et al. 2009). Compared to preemptive sprays of insecticide directed at the entire banana

plantation, this approach is more cost effective.

The importance of BBTV-infected but asymptomatic banana plants to the spread of BBTV is unknown. Thus, managing banana aphid populations may be important even if disease incidence is unknown. It is understandable that farmers who have suffered from heavy infestation of BBTV may wish to spray preemptively as crop insurance. However, a versatile IPM program emphasizes pest biology, economic thresholds, environmental factors, and host plant resistance if feasible. It is important to prevent the development of a pesticide-resistant pest population and avoid the over-application of insecticides.

A **sampling plan** and **economic threshold** for banana aphids on banana was developed by researchers at the University of Hawai‘i (Robson et al. 2006, 2007). Previously, growers and Extension personnel inspected the most recently unfurled leaf (i.e., cigar leaf) of a banana plant to check for the presence of banana aphids. However, a study conducted by Robson et al. (2006) found that inspecting only cigar leaves for banana aphids led to 59% false negatives. However, they found that if they sampled the bottom two leaves, only 6% came back as false negatives for banana aphids. Thus, if farmers sample the bottom two leaves for banana aphids, they can determine whether they should treat with insecticides based on the binomial sequential sampling plan shown in Fig 4-8.

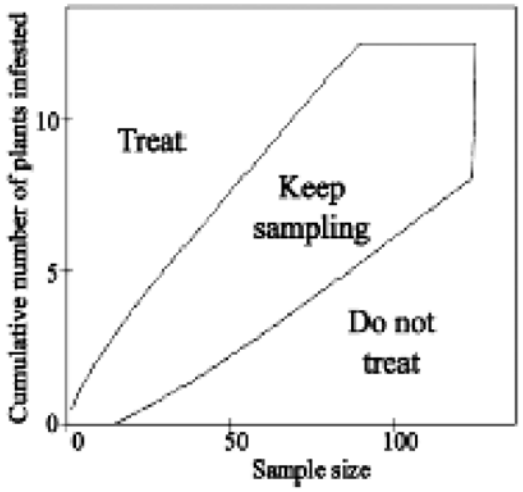

Fig. 4-8. Binomial sequential sampling plan for banana aphids on banana to determine when to treat the plant with imidacloprid. Sampling size is the number of banana plants examined for aphids on the lower two leaves. (Note: Perhaps more explanation of what “binomial sequential sampling” is.)

However, there is an important addition to this recommendation. Robson et al. (2007) later reported that while imidacloprid foliar application on bananas resulted in effective control of aphids on old and new leaves that come in direct contact with the insecticide over a 4-week testing period, the pesticide does not become thoroughly systemic within the plant. New leaves that emerge after spraying will not be completely protected from aphids because imidacloprid is not truly a systemic insecticide, but rather a membrane-permeable insecticide. Thus, regular scouting for aphids on newly unfolded leaves should still be implemented when applying imidacloprid specifically.

In terms of **spray coverage**, conservative farmers tend to think that total coverage with insecticide is needed to control an aphid population. A study on the distribution of banana aphids within a banana mat through a survey conducted on 25 banana farms in Hawai‘i (20–45 banana mats per farm) showed that only 7.6% of the plants examined had aphids distributed higher than 2.5 m (8.2 ft) from the base of the plant (Hooks et al. 2011). Depending on plant biomass and planting densities, full spray coverage of banana crops could reach > 200 gal per acre. The drawback of spraying with such a high spray volume is 1) potential dilution of

allowable insecticide application rate and 2) waste of pesticide spray in areas where aphids are not found. Population densities of banana aphids are higher in plants < 1.5 m tall than in those > 1.5 m tall (Hooks 2011). Understanding the distribution of banana aphids on banana plants can provide farmers a better pest management strategy.

The strategy of injecting bananacide and spraying insecticide only on infected plants could 1) significantly reduce the cost of pesticide applications, 2) eliminate preemptive insecticidal spraying throughout the entire orchard, 3) reduce the potential for the banana aphid to develop insecticidal resistance, and 4) avoid unwarranted destruction of healthy plants.

Replanting with virus-free plants

In a BBTV-infested site in Hawai‘i, if 50 newly transplanted symptomless suckers are examined, 100% of them tend to have aphids, 92% have winged aphids, and 20% of those aphids are infected with BBTV (Hooks personal communication). The probability that newly planted, apparently healthy suckers are infected with BBTV is high. If visible symptoms of infection only become obvious at 20 to 85 days after aphid inoculation (Hooks et al. 2008 and 2009), planting virus-free tissue-cultured plants is an important aspect of reviving a BBTV-infested site. A banana tissue-culture program was established 2007 to early 2014 at the University of Hawai‘i Seed Lab to distribute BBTV-free tissue-cultured banana. Lack of financial support resulted in the closing of this service, but the program demonstrated to farmers the value of establishing virus-free planting materials. Farmers in need of tissue-cultured banana plantlets are learning to work with other tissue-culture laboratories that provide the services. The Hawai‘i Agriculture Research Center (HARC) provides micro-propagation services upon special order. If resources are available, some banana farmers can establish their own tissue-culture laboratories to mass-produce banana varieties of their interest. Please refer to Chapter VIII on how to initiate a banana tissue-culture program.

Managing banana aphids on alternative hosts?

BBTV is usually only transmitted by banana aphids (*P. nigronervosa*). A close relative of banana aphid, *Pentalonia caladii*, has become a concern as another BBTV vector, but the concern may have been blown out of proportion. Both *P. nigronervosa* and *P. caladii* are believed to reproduce exclusively asexually in most subtropical and tropical regions, including the Pacific. In nature, they occupy different hosts. *Pentalonia nigronervosa* primarily colonizes banana (*Musa* spp.) and taro (*Colocasia esculenta*) plants, whereas *P. caladii* chiefly colonizes ginger (*Zingiber officinale*, *Alpinia purpurata*, *Hedychium coronarium*), heliconia (*Heliconia* spp.), and taro plants (Foottit et al. 2010). However, some sexually reproductive forms of *Pentalonia* aphids have been reported in northeast India and Nepal (Blackman and Eastop 2000), and both aphid species have the potential to exploit common hosts (Bhadra and Agarwala 2010). In addition, researchers at the University of Hawai‘i showed for the first time that *P. caladii* is a competent vector of BBTV and is capable of acquiring the virus from infected banana plants and transmitting it to other banana plants (Watanabe et al. 2014). Ginger, heliconia, and taro plants

often grow in close proximity to banana fields in Hawai‘i, which raises a concern about the need to manage *Pentalonia* aphids. However, Hu et al. (1996) conducted transmission experiments showing that taro and ginger plants cannot serve as hosts for BBTV, and *P. caladii* displays a strong host plant preference (Foottit et al. 2010). Therefore, the belief that managing BBTV also requires managing aphids on ginger, heliconia, and taro is a myth.

Is ant control necessary?

Previously it was recommended that controlling ants was important to lower aphid populations. However, Hooks et al. (2011) reported that the probability of observing ants on banana plants without aphids was 41, 49, and 63% on suckers < 1.5 m tall, suckers 1.5–2.5 m tall, and the mother plant (> 2.5 m tall), respectively. This would mean that 41–63% of the time farmers would be trying to control ants on banana that are not associated with aphids. Thus, managing ant populations is not necessary as long as the aphid population is not high.

Grow BBTV-tolerant varieties

Hawai‘i stakeholders commonly believe that the variety ‘Dwarf Brazilian’ or ‘Santa Catarina’ (locally known as “dwarf apple”) is less susceptible to BBTV than the ‘Williams’ banana. Hooks et al. (2009) reported that banana aphids transmitted BBTV to both cultivars at a similar rate (>90% for both cultivars) in a laboratory experiment. Field results, however, showed a lower percentage of dwarf apple (39%) plants infected with BBTV compared to ‘Williams’ (79%), despite the similar incubation period (time required from BBTV infection to symptom expression). It has been speculated that the waxy surface of the dwarf apple banana plant caused the banana aphids to fall off more easily. This made a difference in the field infection rate of BBTV between the two varieties (Hooks et al. 2009). Screening of banana cultivars for resistance to BBTV is currently underway at the University of Hawai‘i (Sachter-Smith and Manshart, personal communication). A preliminary comparison of banana cultivar susceptibility to BBTV infection at 6 months after inoculation is shown in Fig 4-9.

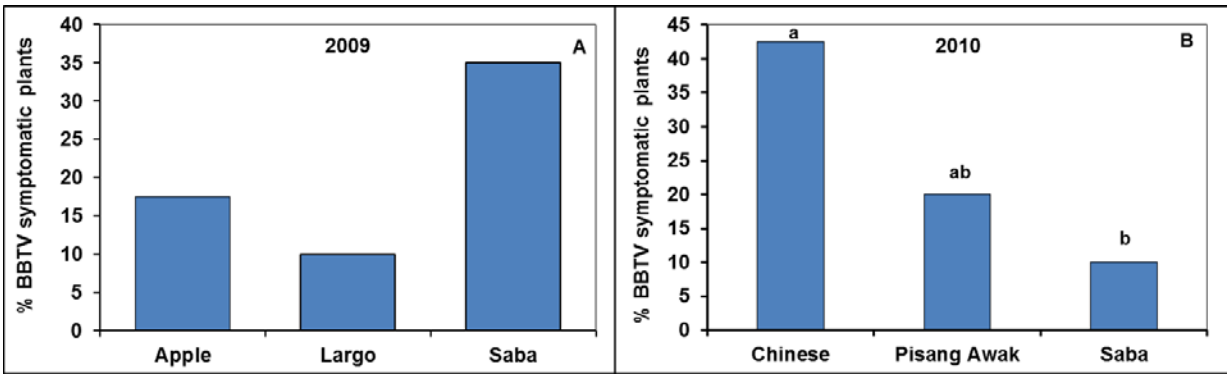

Fig. 4-9. Percentage of banana plants showing symptoms of BBTV infection on different cultivars tested at the Poamoho Experiment Station in 2009 and 2010. Means are observation of 20 plants per cultivar. Columns followed by the same letter are not different according to Waller-Duncan *k*-ratio (*k*=100) *t*-test.

Home Gardener's Corner:

It is equally important for home gardeners to rogue out, or find and destroy, BBTV-infected banana as it is for the commercial banana growers. This will have a big impact on the effort to safeguard the banana industry in Hawai'i.

Web Resources:

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CHAPTER V

IPM Strategies against Plant-Parasitic Nematodes on Banana

Common control measures for banana nematodes practiced by farmers

Banana is a perennial crop, which makes management of nematodes on it more challenging than for annual crops. Although pre-plant treatments such as soil fumigation with Telone II® (1,3-dicloropropene) are very effective in suppressing nematode populations, such treatments are short lived compared to the life of a banana plot. Plant-parasitic nematodes tend to repopulate an area gradually after fumigation. Telone potentially contaminates groundwater, is a restricted-use pesticide, and is also rather costly. Because banana is usually cultivated as a perennial crop, a post-plant treatment is essential for nematode management. In terms of post-plant nematicides, fenamiphos (Nemacur®) is environmentally harsh and hazardous to applicators, thus its Special Local Needs label for Hawai'i has expired. Although erthoprop (Mocap®) and *Myrothecium verrucaria* (DiTera®) are also effective post-plant nematicides, they are difficult to handle. In 2003, CTAHR and the Hawaii Banana Industry Association developed an integrated pest management program for banana production in Hawai'i. This includes selecting banana cultivars resistant to or tolerant of plant-parasitic nematodes. Two banana hybrids from the Fundacion Hondureña de Investigacion Agricola (FHIA) breeding program with resistance to black leaf streak disease were tested for their resistance to plant-parasitic nematodes of banana in American Samoa (Brooks 2004). The **FHIA-01 hybrid** was relatively resistant to burrowing nematodes, whereas **FHIA-25** was relatively resistant to all plant-parasitic nematodes commonly feeding on banana in American Samoa.

Most banana growers in Hawai'i select banana varieties based on their market demand or their tolerance to key pest organisms. Banana farmers prefer to prop up fruiting plants to prevent toppling (Fig. 5-1), treat banana keiki (suckers) to reduce nematode infection, mulch under the plant, or use fertilizer to increase plant vigor rather than using nematicides. The unintentional planting of keiki already infected with nematodes is the principal means of nematode dispersal to uninfested sites. Obtaining nematode-free planting material is therefore the first line of defense to restrict the spread of nematodes. This chapter will review and discuss multiple strategies to reduce initial nematode infection of banana planting materials.

Fig. 5- 1. An old banana farm with plants propped up with sticks to avoid toppling due to severely nematode-damaged root systems that cannot handle heavy bunch weight.

Clean propagative materials

Banana tissue culture

Preventing the spread of pests and diseases is one of several advantages of using tissue-cultured plantlets. Using known nematode-free banana plantlets for planting material is an important mechanism to ensure that nematodes are not being spread around an infected field or introduced to a new field. Since the majority of banana fields in Hawai‘i are already infested with plant-parasitic nematodes (Wang et al. 2009), micro-propagation from disease-free materials using sterile techniques offers a good way to obtain nematode-free planting materials. A banana tissue-culture facility that provided a reliable source of *Banana bunchy top virus*-free and nematode-free planting material was set up at the University of Hawai‘i at Mānoa Agriculture Diagnostic and Service Center (http://www.ctahr.hawaii.edu/oc/freepubs/pdf/BIO-8.pdf), though unfortunately, due to lack of funding, the program has recently been terminated. For more details on how to tissue-culture banana, please refer to Chapter VIII of this book.

Hot-water treatment

A hot-water dip has been successfully used to control burrowing nematodes in anthurium and root-knot nematodes in ginger. Although treatment recommendations from researchers in different parts of the world vary from 5 minutes at 50°C to 25 minutes at 55°C, CTAHR researchers recommend disinfesting banana suckers by soaking them for 10 minutes at 50°C. A recent experiment with keiki collected from a farm heavily infested with spiral nematodes, combined with low numbers of burrowing nematodes, showed that this hot water treatment was sufficient to kill all nematodes in roots if the size of the corm ranged from 2 to 6 inches in diameter (Table 5-1). In another study, where burrowing nematodes were abundant and had penetrated into the corm, the hot water treatment did not kill the nematodes inside the corm. However, all of the heat-treated keiki grew well when planted in the field. One drawback of this method is that it requires the use of a hot water tank with heater and temperature-control capability (Fig. 5-2), which might not be feasible for small-scale growers to set up.

Fig. 5-2. Hot water tank with heater and temperature-control device.

Table 5-1. Numbers of nematodes in banana roots after hot water treatment of keiki.

	Root-knot nematodes/g root	Spiral nematodes/g roots	Pf/Pi for Root-knot	Pf/Pi for Spiral
Control	19 a	562 a	0.05 a	10.47 a
50°C 10 min	0 b	4 b	0.00 b	0.00 b
50°C 20 min	0 b	1 b	0.00 b	0.00 b
50°C 30 min	0 b	0 b	0.00 b	0.10 b

Means are the average of 6 replications. Means followed by the same letter in a column are not different, according to the Waller-Duncan *k*-ratio (*k*=100) *t*-test. Pf/Pi = final population of nematodes after treatment / initial population of nematodes prior to treatment.

Sodium hypochlorite dip

Currently, some banana growers in Hawai‘i concerned with nematode damage treat their suckers by dipping in a diluted household bleach solution—consisting of one part bleach (6.0% sodium hypochlorite or NaOCl, unscented and without other additives) and nine parts water—for 10 minutes prior to planting. Results indicate that such a NaOCl dip reduces 85% of spiral nematodes in the roots as compared to roots that are untreated (Table 5-2). Dipping in bleach may reduce plant vigor, but it is an easily accessible method for most farmers.

Table 5-2. Number of nematodes in banana roots after keiki are solarized (1.5 hours) or dipped in bleach.

	Root-knot nematodes/ g root	Spiral nematodes/ g roots	Burrowing nematodes/ g roots	[y]Pf/Pi for root-knot	Pf/Pi for spiral	Pf/Pi for burrowing
Control	446	164	93	1.00 a	1.00	-
Clorox	1	148	9	0.02 b	0.15	-
Solarization (small keiki) [x]	0	9	0	-	0.12	-
Solarization (big keiki)	5	26	2	0.01 b	0.43	-

[z] Means are an average of 3 replications. Means followed by the same letter in a column are not different, according to the Waller-Duncan *k*-ratio (*k*=100) *t*-test.
[y] Pf/Pi = final population of nematodes after treatment / initial population of nematodes prior to treatment. - is due to undetectable level of nematodes at the beginning of the experiment.
[x] Small keiki = 1–3 inches in diameter; big keiki = 3–6 inches in diameter at top of corm.

Modified solarization

Soil solarization involves heating the soil beneath a clear (transparent) plastic sheet to reach temperatures lethal to soilborne pests. The method has been successfully used against plant-parasitic nematodes and other soilborne pathogens and pests in the top 4 inches (10 cm) of soil, but pests can rebound from a deeper soil layer. A study was conducted using solarization plastic (low-density, 25-µm-thick, UV-stabilized, polyethylene mulch) to suppress nematodes infecting banana keiki collected from the field (Fig. 5-3). Keiki were solarized for different length of times and subsamples of roots were collected before and after solarization. Nematodes were extracted from the roots using the Baerman technique and counted. Although the suppressive effect varies, there was a clear trend that all solarization reduced nematodes in the roots even at 4 hours of exposure time, the shortest time tested in this trial (Table 5-3).

Fig. 5-3. Roots of banana keiki infected with plant-parasitic nematodes are wrapped in solarization plastic so as to suppress pests and pathogens. Control was wrapped in black plastic.

Table 5-3. Number of nematodes in banana roots after solarization of keiki.

Time	Hours of solarization					
Nematode	4	28	32	52	56	80
	----------Numbers per g roots----------					
Root-knot						
Before	1	4	1	26	3	0
After	0	0	0	0	1	0
Burrowing						
Before	73	84	0	52	1	0
After	0	1	0	0	1	0
Spiral						
Before	0	21	22	7	6	5
After	0	1	2	6	0	0

Means are average of 3 replications.

A second experiment was conducted to examine a shorter solarization time (1.5 hours) with different keiki sizes (1–3" vs. 3–6" diameter) and compared to dipping in bleach and untreated control. Results revealed that 1.5 hours of solarization treatment could suppress the plant-parasitic nematodes present significantly as compared to the control for both sizes of keiki (Table 5-2).

Pesticides

As mentioned in the introduction section of this chapter, soil fumigants or nematicides are no longer available for banana production in Hawai'i except for one biologically based nematicide, Melocon WG® (Certis, Bonita, CA) that contains *Paecillomyces lilacinus* strain 251 as its active ingredient (HPIRS 2011). *Paecilomyces lilacinus* is a common soil fungus that has been isolated from many different habitats around the world. It is well known as a facultative egg pathogen of sedentary nematodes and also an important option to control juvenile and adult burrowing nematodes in banana. This nematode-antagonistic fungus may be used in an integrated approach to control plant-parasitic nematodes of banana. Mendoza et al. (2004) demonstrated that nematode activity decreased in the presence of this fungus. For effective control, banana plantlets should be inoculated with *P. lilacinus* and re-inoculated into the soil at transplanting (Mendoza et al. 2004).

On the other hand, since the most damaging nematodes on banana spend a significant amount of their life cycle inside root tissue, killing nematode-infected plants with bananacide (glyphosate) also kills the endoparasitic stage of the nematodes and thus greatly improves the potential of the successive fallow practice to reduce nematode infestation without nematicides (Chabrier & Quénéhervé 2003). Commercial banana growers in the Caribbean and Africa are recommended to integrate bananacide application as part of their banana IPM program to combat plant-parasitic nematodes. In fact, in Martinique, bananacide injection to kill old and yield-declining banana plants, followed by a fallow period and replanting with tissue-cultured banana plants, has extended banana field longevity from 3–4 to 6–10 years, and in some cases contaminated fields have been totally freed from burrowing nematodes (Chabrier & Quénéhervé 2003).

Cover-cropping

Since banana is a perennial crop, managing nematodes over a longer period of time after planting is critical. Planting low-growing cover crops that release nematode-allelopathic compounds is an ideal option. Allelopathy is a biological phenomenon by which an organism produces one or more biochemicals that negatively affect the growth, survival, and reproduction of other organisms. Example of cover crops with allelopathic effects against plant-parasitic nematodes include sunn hemp (*Crotalaria juncea*), marigold (*Tagetes* spp.), rapeseed (*Brassica napus*, Wang et al. 2001), velvetbean (*Mucuna pruriens*, Zasada et al. 2006), sorghum-sudangrass (*Sorghum bicolor* × *Sorghum arundinaceum* var. *Sudanense,* Widmer and Abawi 2000). Among these cover crops, marigold stands out as an especially suitable candidate for banana cropping systems due to its low-growing habit and because it does not require soil incorporation to be allelopathic. The allelopathic effect of marigold varies according to marigold and nematode species, cultivar, and soil temperature (Ploeg and Maris 1999). In field trials, *Tagetes patula* 'Single Gold' consistently suppressed a diverse range of plant-parasitic nematodes. Only living marigold root systems exhibit nematicidal properties; incorporation of 'Single Gold' residues into the soil does not suppress root-knot nematode (Ploeg 2000).

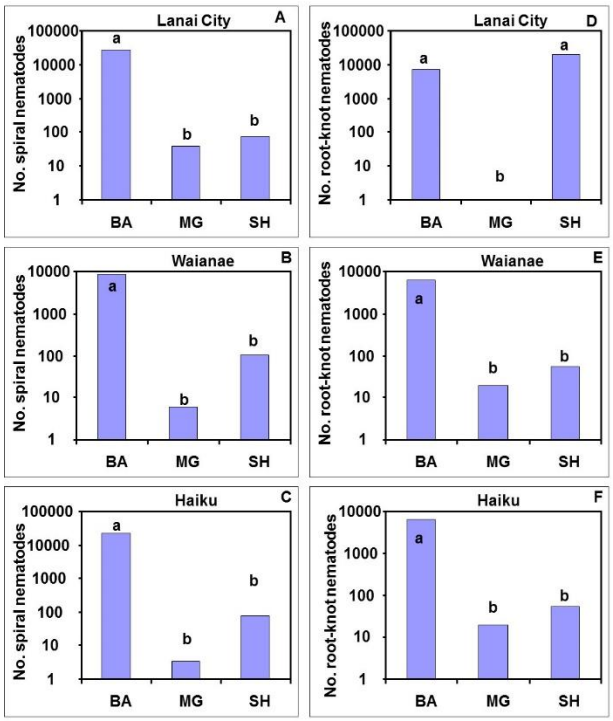

Fig. 5-4. Numbers of plant-parasitic nematodes in soils collected from banana farms in Lanai City, Waianae, and Haiku and planted with banana (BA), marigold (MG) or sunn hemp (SH) for 5 months.

Planting of *T. patula* and *C. juncea* in field soil infested with plant-parasitic nematodes significantly reduced the nematode population densities after 5 months as compared to continuous planting of banana into these soils in a greenhouse experiment (Fig. 5-4). Thus, both of these cover crops can be planted prior to banana crop planting to reduce population densities of plant-parasitic nematodes (Fig. 5-5). Since marigold can be planted as a low-growing living mulch, and because it releases its nematicidal compounds while growing, it is more compatible with the banana crop than sunn hemp. The next logical step is to determine the optimum planting time of marigold as a cover crop after banana planting so as 1) not to compete with banana growth and 2) not to be shaded by banana canopy.

Two field trials indicated that marigold could not survive if transplanted into an 18- or 36-month-old banana field, mostly due to shading. A second experiment was conducted to compare banana and marigold growth if the marigold was transplanted within 6 months of banana planting. Marigold was planted at monthly intervals. At 8 months after transplanting, banana grown in conjunction with marigold seedlings that were planted 4 to 6 months after the banana grew better than the no-marigold control (Fig. 5-6). Marigold grew better when planted 4 to 5 months after banana planting (Fig. 5-7). Therefore, if using marigold as a post-plant cover crop, farmers should aim to plant it at 4 to 5 months after banana planting to maximize marigold growth and minimize competition from banana growth (Fig. 5-8).

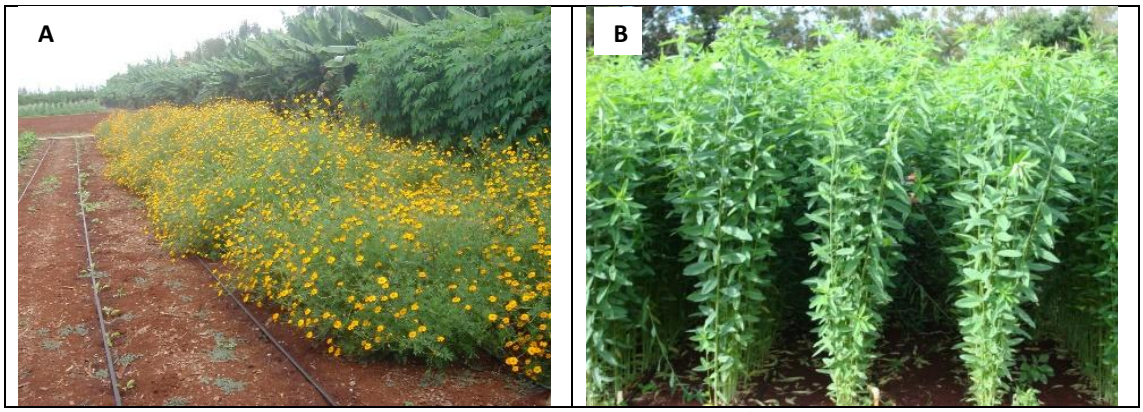

Fig. 5-5. A) Marigold (*T. patula* 'Single Gold') seeded at 20 plants / m^2 and B) sunn hemp (*Crotalaria juncea*) seeded at 30 lb/acre and grown for 2–3 months prior to banana crop planting.

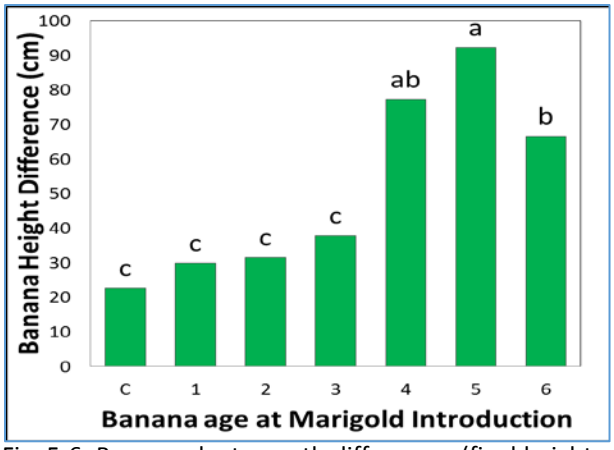

Fig. 5-6. Banana plant growth differences (final height - initial height) affected by months since marigold transplanting. Means are average of 4 replications. Columns with same letters are not different according to Waller-Duncan *k*-ratio (*k*=100) *t*-test. C=control with no marigold.

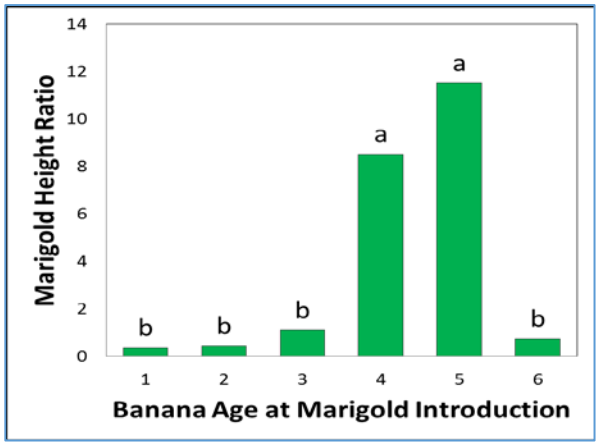

Fig. 5-7. Marigold growth [(Final height - initial height)/initial height] under banana plants affected by months since marigold transplanting. Means are average of 4 replications. Columns with same letters are not different according to Waller-Duncan *k*-ratio (*k*=100) *t*-test.

Although plantings of marigold under the banana canopy will slowly decline over time as the banana canopy fills in, marigold nonetheless will reduce the population densities of plant-parasitic nematodes infecting the banana over a longer period of time compared to no marigold planting. Data from the Caribbean revealed that longevity of banana in a nematode-infested field is generally 3–4 years (Chabrier & Quénéhervé 2003). Concerned farmers would replant their field every 3–4 years. A similar trend is observed in Hawai'i: a banana farmer in Lana'i has observed that their banana plants decline in yield over time, and they generally replant every 5 years to maintain a stable yield (de Jetley, personal communication). We anticipated that efficient management of plant-parasitic nematodes at pre-plant, followed by post-plant management with marigold planting, would prolong the longevity of banana with good yield beyond 5 years in Hawai'i.

Home Gardener's Corner:

Home gardeners should take advantage of the reduced shading from the banana canopy, as only few plants will be planted in home yards. It is recommended to plant French marigold as a ground cover surrounding the perimeter of a banana mat. Gardeners should keep up with a good banana management practice and maintain a banana mat with no more than 3 plants per mat. This will ensure better banana bunch yield and also allow marigold to have access to sunlight over a longer period of time and thus continue to suppress the population densities of nematodes.

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Chapter VI

IPM Strategies against Black Leaf Streak Disease

Important facts about the biology of *Mycosphaerella fijiensis*

As mentioned in Section II-3, black Sigatoka or black leaf streak (BLS) disease is a more challenging banana fungal disease than yellow Sigatoka disease. One of the key reasons is that the pathogen of BLS (*M. fijiensis*) produces more sexual spores (ascospores) than asexual spores (conidia), whereas the reverse is true for yellow Sigatoka disease (*M. musicola*). Recombination of genetic materials during the sexual reproduction allows for the possibility of selecting progeny that can overcome fungicide toxicity. Table 6-1 summarizes several facts about the biological differences between black and yellow Sigatoka diseases.

Table 6-1. Differences between yellow and black Sigatoka diseases (Bennett and Arneson 2003).

	Yellow Sigatoka	Black Sigatoka
Pathogen	*Mycosphaerella musicola* (*Pseudocercospora musicola*)	*Mycosphaerella fijiensis* (*Pseudocercospora fijiensis*)
Asexual stage	Produces abundant conidia on conidiophores in dense clusters (sporodochia) on dark stromata on both leaf surfaces.	Produces only small groups of conidiophores, and only on lower leaf surfaces.
Host	'Cavendish' bananas (AAA) are generally susceptible; most cooking bananas and plantains (AAB, ABB) are relatively resistant.	Most bananas (dessert, cooking, and plantains) are susceptible.
Symptoms	Early streaks are pale yellow.	Early streaks are dark brown.
Epidemiology	More common in cool weather.	More common in warmer weather.
Inoculum	Water-dispersed conidia and wind-dispersed ascospores; conidia cannot be dislodged by wind. Ascospores mature 4 weeks after the appearance of leaf streaks.	Mainly windborne ascospores. Conidia can be water- and wind-dispersed. Ascospores mature 2 weeks after the appearance of leaf streaks.

A good understanding of the biology of the black leaf streak disease can help farmers to improve their disease-management strategies against BLS more cost-effectively and sustainably. Ganry et al. (2012) categorized the symptom development of black leaf streak into 6 stages (Fig. 6-1): stage 1 = yellowish depigmentation spots and stage 2 = extension of the lesions to brown streaks on the under-surface of a leaf due to the formation of conidiophores. Stages 1 and 2 are easy to miss with the naked eye. Stage 3 = elongation and enlargement of the lesion visible on the under and upper leaf surface and stage 4 = brown oval lesion; stages 3 and 4 are manifestations of the formation of conidiophores along with spermagonium, the male

reproductive structure, on the lower leaf surface and perithecium, the female reproductive structure, on the upper leaf surface. Stage 5 = obvious black lesions on leaf surface and stage 6 = gray necrotic lesions where leaf streaks coalesce and yellow halos for isolated lesion. This is when perithecia mature, are fertilized, and emit ascospores (sexual spores). Ascospores are windborne and can achieve longer-distance dispersal than the water-dispersed conidia. In addition, ascospores go through genetic recombination and thus could develop fungicide-resistant populations. Therefore, a more versatile IPM strategy against BLS should be focused on mitigating the spread of ascospores.

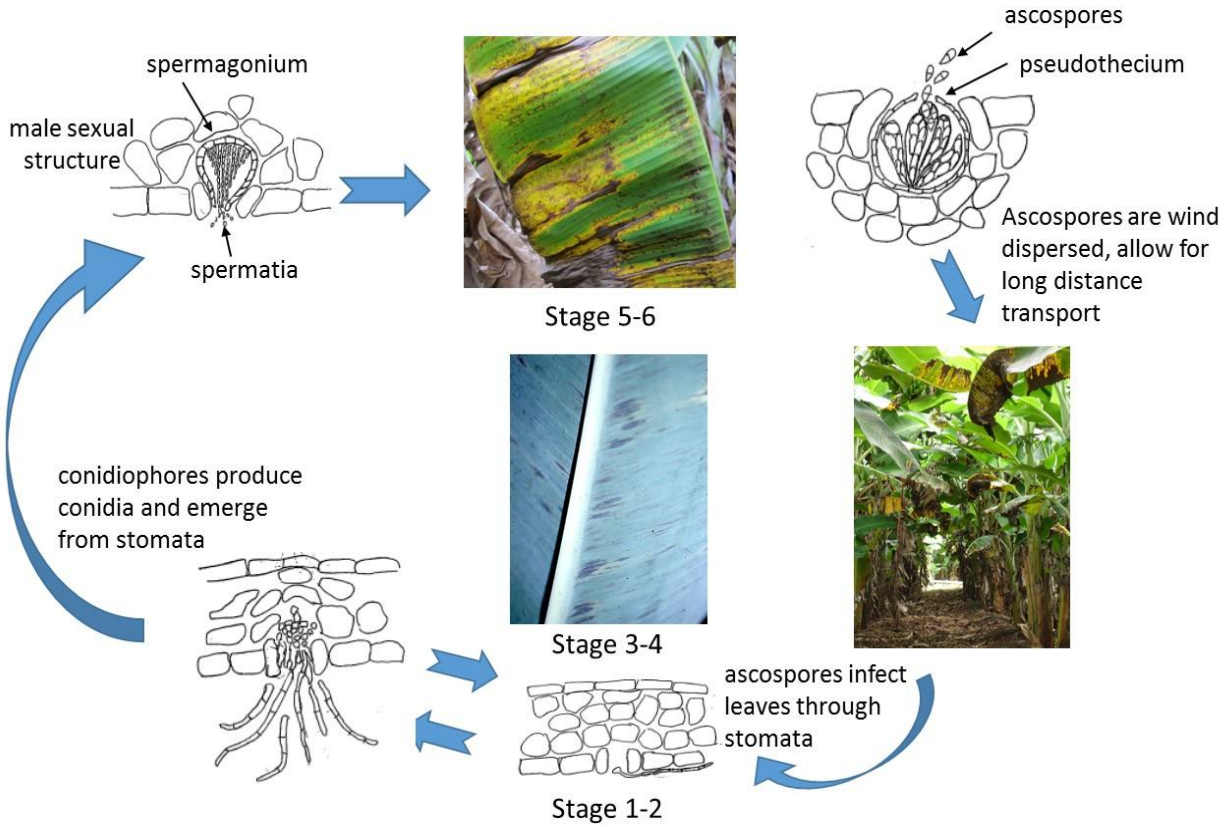

Fig. 6-1. The biological cycle of the banana black leaf streak diseases.

Fouré & Ganry (2008) developed a fungicide-based BLS-management program driven by a forecasting system in Guadeloupe and Martinique. However, this forecast system assumes a limited or nonexistent fungicide-resistant population and relies on not only the availability of several effective systemic fungicides but also the cooperation of area-wide banana growers in managing fungicide resistance. Fouré & Ganry emphasized that fungicide rotation works efficiently if the pathogen pressure is not too high. Some of the practices supplemental to fungicide application include sanitation practices consisting of removal of necrotic and pre-necrotic leaves to eliminate new sources of inoculum; planting resistant or tolerant cultivars; and managing plant nutrition, crop density, and irrigation. This chapter will review some of these practices that are applicable to banana production in Hawai‘i.

Sanitary leaf removal

Sanitary leaf removal means removing BLS-contaminated leaves or leaves showing necrosis or pre-necrotic symptoms. Scientists working with banana research have validated that 5–7 leaves per plant are sufficient to support production of a healthy banana bunch (Ramsey 1990, Daniells et al. 1994, Vargas et al. 2009). Removal of BLS-symptomatic leaves not only is one key practice for removing the inoculum of the disease; it also increases the efficiency and sustainability of chemical control strategies by minimizing the exposure of ascospores to fungicide application. Indirectly, removal of contaminated leaves will also reduce the spray coverage needed, thus reducing the cost and labor of fungicide application. Even if BLS disease is not severe, it is a good IPM practice to routinely maintain only 5–7 leaves per plant to reduce humidity in the crop canopy, which can in turn reduce the infection rate of fungal spores. Guidelines below are "Good sanitary leaf removal" practices for banana growers (Ganry et al. 2012):

1. Complete sanitary leaf removal before a fungicide spray, especially if fungicides that are known to trigger fungicide-resistant *M. fijiensis* populations are used.
2. Remove leaves that have reached stages 3, 4, or beyond (see Fig. 6-1).
3. In a highly infested field, removal of most of the leaves on the plant might be necessary to revive the plot.
4. Cut leaves showing BLS necrosis should be placed upside down, with the upper side against the ground. This is because ascospores are produced on the upper leaf surface (Fig. 6-1). Under very severe conditions, during the first cycle of sanitary leaf removal growers should pile all the cut leaves at the end of a row. This is because only the top leaf in a pile is likely to emit spores, whereas the leaves within the pile are relatively contained.
5. Sanitary leaf removal should be practiced weekly, especially in wetter regions where fungus-infection rate is high, and should be treated as the priority control practice.
6. This practice should also be accompanied by desuckering to maintain only 3–5 plants per banana mat to further decrease canopy humidity.
7. If farmers are seeking to reestablish a severely BLS-infested banana field, rapid conversion to fallow by injecting plants with bananacide (glyphosate) and burying them 2 weeks after the bananacide injection is recommended.

Sanitary leaf removal practices, done correctly and regularly, can reduce more than 80% of spore production of *M. fijiensis* (Ganry et al. 2012). A banana leaf with BLS that remains hanging on the pseudostem produces spores for 4 to 5 months, while one that is covered on the ground produces spores for 2 to 3 weeks. Area-wide removal of necrotic leaves may be necessary in high-infestation areas for this practice to be effective, so that spores will not be spread from neighboring farms.

BLS-resistant varieties

Planting resistant banana varieties restricts the reproduction of *M. fijiensis*. However, only few banana varieties are commercially planted in Hawai‘i. Among the two most commonly planted commercial banana varieties in Hawai‘i, ‘Cavendish’ types and ‘Dwarf Brazilian’, locally called “apple banana,” the ‘Dwarf Brazilian’ is more tolerant of BLS disease. However, *M. fijiensis* can still reproduce on ‘Dwarf Brazilian’. A true BLS-resistant variety is ‘Yangambi Km 5’, an AAA dessert banana. A hypersensitive reaction of the resistant host occurs when the pathogen infects the resistant plant, resulting in blockage of BLS symptoms at an early stage (Fouré et al. 1990). Various diploid banana varieties are used in breeding programs as a source of resistance, such as ‘Paka’ (AA) and some genotypes from the Mlali group, originating from the Comoros archipelago (Beveraggi et al. 1995). Several BLS-resistant hybrids were developed in Honduras by Fundacion Hondureña de Investigacion Agricola (FHIA). In tests conducted in Pohnpei using these hybrids, FHIA-01 (‘Goldfinger’) and FHIA-02 are listed as highly resistant, FHIA-03 (‘Sweetheart’) and FHIA-18 are listed as resistant, and FHIA-23 (progeny of ‘Highgate’, which is a dwarf ‘Bluefields’) is listed as tolerant to BLS (Nelson and Javier 2007, Nelson 2008).

Since *M. fijiensis* has the ability to overcome selection pressure, a more sustainable approach is to plant partially BLS-resistant banana cultivars that have multiple resistant genes (polygenic) rather than a single resistant gene (monogenic). Fortunately, some of these cultivars have already been introduced into Hawai‘i. These include the banana subgroups ‘Pisang Awak’ (ABB, i.e., ‘Fougamou’) and ‘Mysore’ (AAB).

Crop densities

Growers in Hawai‘i generally plant about 500–700 plants per acre. Planting densities higher than this can create more BLS disease problems. Wider row spacing allows for better airflow and reduced relative humidity within the crop canopy, thus resulting in less infection of the fungus. In Hawai‘i, farmers use either single-row or double-row planting systems. If BLS disease intensity is expected to be high in a region, a single-row planting system might help to avoid severe disease outbreak.

Plant nutrition

Maintaining adequate nutrition of banana plants speeds up their growth so they can outgrow the younger and more susceptible stages quickly. After flowering, banana plants stop producing leaves, they are most vulnerable to BLS. Banana production is generally more productive on the windward side of an island in Hawai‘i; usually banana fields in these areas require 300–650 lbs of nitrogen, 60–120 lbs of phosphorous, and 600–700 lbs of potassium per acre per year. Beside these key macronutrients, banana also requires other macro- and micronutrients (Nelson 2009).

Chemical management of BLS (fungicides)

Although organic farming has gained popularity among new farmers in recent years, effective options for combatting BLS in commercial-scale banana production—which primarily relies on monoculture of banana varieties that are usually not resistant to BLS—are limited. Researchers in Cameroon have experimented with organic fungicides or bio-fungicides such as various essential oils, alimentary additives, organic acids, potassium carbonates, leachates of decomposed banana material (bunch stems, fruits), and bio-control agents. None of these fungicides gave good control of BLSD under high inoculum pressure. However, de Lapeyre de Bellaire et al. (2009) recently demonstrated that the combination of some bio-control agents (*Bacillus subtillis* and *B. pumilis*) applied in mixtures with contact fungicides (many of which are OMRI labeled) could allow growers to reduce the amount of fungicide applied.

However, farmers should also not consider conventional fungicides as magic bullets to manage BLS. As explained in the introduction, M. fijiensis has a high capability to evolve due to its preference for sexual reproduction. Depending on the type of fungicides used in a region and on the frequency of applications creating selection pressures against the BLS pathogen, there is a high risk of developing a fungicide-resistant population of M. fijiensis. When resistant populations occur in a region, chemical control will slowly lose its efficacy, leading to a pesticide treadmill phenomena, as described in Chapter I.

Types of fungicides

Fungicides fall in two categories: protectants, or contact fungicides, and systemic fungicides.

Contact fungicides (mancozeb, chlorothalonil) have only a preventive effect and do not penetrate into the banana leaf. They are applied weekly in a systematic manner so that all newly unfurling banana leaves will be protected from new sources of BLS inoculum that come in contact with them. Contact fungicides have a multi-site effect on fungal biology, and therefore strains resistant to these fungicides have never been reported. Their drawback is that the frequency of application is higher, and full coverage of banana leaves is required.

Systemic fungicides penetrate the banana leaf. The systemic properties of these fungicides are variable: some have only a translaminar penetration effect and others have systemic translocation effect throughout the whole plant. Regardless, the mode of action of these fungicides are usually curative. The curative effect is more pronounced on young streaks (stages 1, 2) and lower on older lesions (stages 3, 4), but there is no effect on necrotic stages (stages 5, 6).

Table 6-2. Mode of action of systemic fungicides effective against black leaf streak of banana.

Active ingredient of fungicide	Mode of action	Risk of resistance
Benzimidazole	Antimitotic products that inhibit tubuline polymerization; highly curative	Very high
Triazole family (DMI fungicide)	Inhibitors of ergosterol biosynthesis (IBS) in group 1 that inhibit eburicol demethylation (DMI)	High
Strobilurin family (QoI inhibitors)	Mitochondrial respiration inhibitors that bind to the cytochrome b-complex	Very high
Sterol inhibitors	Inhibitors of several enzymes such as reductases and isomerases (amines)	Moderate
Pyrimethanil	Inhibitor of methionine biosynthesis whose mode of action is still not clearly established	Moderate

Managing fungicide resistance

To avoid the development of a fungicide-resistant *M. fijiensis* population, farmers can either mix contact fungicides with systemic fungicides in a tank or rotate these two types of fungicides. For example, contact fungicides (e.g., mancozeb or manzate) are commonly rotated with systemic fungicides (e.g., fenbuconazole or tebuconazole). In Hawai‘i, the primary risk of fungicide-resistance development in populations of the BLS pathogen in banana crops is where triazole fungicides (e.g., Enable and Elite) are used. A “block spraying” program rotation was developed by the Hawai‘i banana industry for prudent use of the effective triazole fungicides (Nelson 2009).

For a more efficient fungicide-spraying program,

1. Use contact fungicides during the dry season and systemic fungicides mainly in the rainy season.
2. Always add penetrants or a spreader sticker in the fungicide spray tank.
3. Always conduct sanitary leaf removal before spraying fungicide.
4. Develop a disease forecast program to determine when spraying is needed. A BLS disease forecast program is described in detail by Ganry et al. (2012). However, this forecast system is challenged by many factors and is difficult to implement consistently.
5. Avoid planting banana suckers contaminated with fungicide-resistant *M. fijiensis*. Nurseries for planting material must be established in areas where resistant strains have not been found.
6. Monitor fungicide resistance of BLS fungal population routinely in your field if possible.
7. Special attention should be paid to the management of fungicide resistance that might develop following the repetitive use of curative fungicides.

Monitoring fungicide resistance: The basic methodology relies on the comparison of the sensitivity to different fungicides in fungal populations (50–100 spores) sampled in commercial farms that use these fungicides versus fungal populations sampled in untreated locations. The monitoring of sensitivity is based on germination tests: the germination of spores grown on agar media to which different concentrations of fungicides have been added is compared with the germination of spores grown on agar to which no fungicides have been added (de Lapeyre de Bellaire et al., 2010).

Such an approach was adopted for BLS management when the disease appeared in Gabon on plantains for domestic markets, in Cameroon's banana-export industry, and on the Ivory Coast and in Ecuador on banana and plantain (Ganry et al. 2012). Through a collaborative area-wide BLS-management program, BLS in these countries has been effectively controlled with an average of 10 to 15 fungicide treatments per year, as compared to 30 to 60 fungicide applications in some Latin American countries where strains resistant to curative (systemic) fungicides had emerged (Carlier et al. 2000, Romero & Sutton 1997). When resistance to systemic fungicides emerges, non-curative contact fungicides are often applied more frequently and at higher dosages (de Lapeyre de Bellaire et al. 2009).

Challenge of Disease Forecasting for BLS Disease: A forecast program that can predict optimal times to apply fungicide for BLS management is based on the earliest visible detection of infection on a banana plant, streak/spot density on cigar leaf (categorized into five stages), and the stage of BLS symptoms (6 stages). However, Ganry et al. (2012) discussed the challenges of this forecast program for fungicide application insofar as it relies on a number of factors:

- Little to no resistance to the available fungicides
- Availability of systemic fungicides with different modes of action
- Logistic capacity to apply fungicides when necessary without delay
- Strong area-wide cooperation of farmers and residents in the neighborhood
- Access to aircraft for aerial fungicide application.

Not all of the programs are successful in avoiding the development of resistant strains of *M. fijiensis*. The logistics of flying aircraft for aerial fungicide applications are especially challenging in islands where residential areas are in close proximity to banana farms. Backpack mist blowers provide inferior coverage and control of BLS compared with tractor-drawn mist blowers (Nelson 2009). Calibration of spray coverage is a key component in pesticide efficacy, especially for backpack blowers. For instructions on how to calibrate a backpack mist blower, please refer to "Motorized Back-Pack Mist Sprayer: Sprayer Calibration Using the 1/128th Method" (Uyeda et al., 2013).

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Chapter VII

IPM Strategies against Panama Wilt Disease

Resistant cultivars

Since the fungus can persist in the soil for a long time, and cannot be control by any fungicide or chemical, the best solution is replacing the susceptible cultivars with resistant ones when planted in a Foc infested soil. 'Gros Michel', 'Silk', 'Pome' and 'Pisang Awak' are generally resistant to race 2 but susceptible to races 1 and 4. Cavendish cultivars are generally resistant to races 1 and 2 strains but susceptible to race 4. Plantain and East African highland bananas (EAHB) cultivars are generally resistant to race 1.

Fortunately, the FHIA improvement program has produced hybrids that are resistant to races 1 and 4, while the Taiwan Banana Research Institute (TBRI) has released Giant Cavendish tissue-culture variants (GCTCV) that display varying levels of resistance to TR4. In field trials conducted in China, FHIA-01, FHIA-02, FHIA-18, FHIA-25, Pisang Jari Buaya, Rose (AA), and to a lesser extent GCTCV-119 and FHIA-03, have shown resistance to TR4. In addition, preliminary study in the Philippines in 2011-2012 suggest that EAHB and Plantain might be resistant to TR4 except for Ibwi (ITC1465). In a separate field trial conducted in the Philippines, only 1% of the GCTCV-219 plants exhibited symptoms of Fusarium wilt in the second cropping cycle, whereas none of plants of the Cardava cultivar (Saba subgroup) did.

Crop Rotation

Crop rotation can be a viable option if the non-banana crop has anti-fungal activity. In China, farmers have been able to grow bananas in the presence of TR4 by rotating them with Chinese leek (*Allium tuberosum*). Chinese leeks has also been used as an intercrop.

Biological control

Drainage, environmental conditions and soil type influence the host-pathogen interactions between banana and *Foc*. Soils that suppress the disease have been reported in Central America, the Canary Islands, Australia and South Africa. However, the chemical, biological and physical factors responsible for this phenomenon are not well understood. The wide spread of TR4 definitely reignited interest in biological control and the role of the soil microbial community in suppressing the pathogen. A preliminary study in South Africa showed that application of humic acid in *Foc* infested soil shifted the soil microbial population towards more beneficial bacteria including Cynobacteria and *Rhodopseudomonas palustris*, but less *Foc.*

Exclusion

A comprehensive IPM strategy against Fusarium wilt of banana should also include planting disease-free planting materials either through tissue culture or by other means. How long the plantation remains productive will depend on the efficiency of the quarantine and exclusion measures implemented to prevent the entry of the pathogen.

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Chapter VIII

Tissue Culture of Banana

Tissue culture is the growth of tissues or cells separate from the organism. This is typically facilitated via the use of a liquid, semi-solid, or solid growth medium, such as broth or agar, in vitro under sterile growing conditions. Banana is typically propagated vegetatively; thus tissue culture as a propagation technique provides a robust means to prepare disease-free planting materials that can provide the first line of defense in developing an integrated disease-management program for banana. Tissue-culture techniques established for banana include shoot and meristem culture, callus culture, somatic embryogenesis, cell suspension, and protoplast cultures. However, commercial tissue-cultured banana seedlings are not always conveniently available. Larger-scale banana farmers may wish to establish a banana tissue-culture facility in-farm to ensure availability of disease-free seedlings for replanting in conjunction with a practice of rogueing (destroying) diseased plants. This book chapter will describe a banana shoot tip culture technique developed by Damasco (2005).

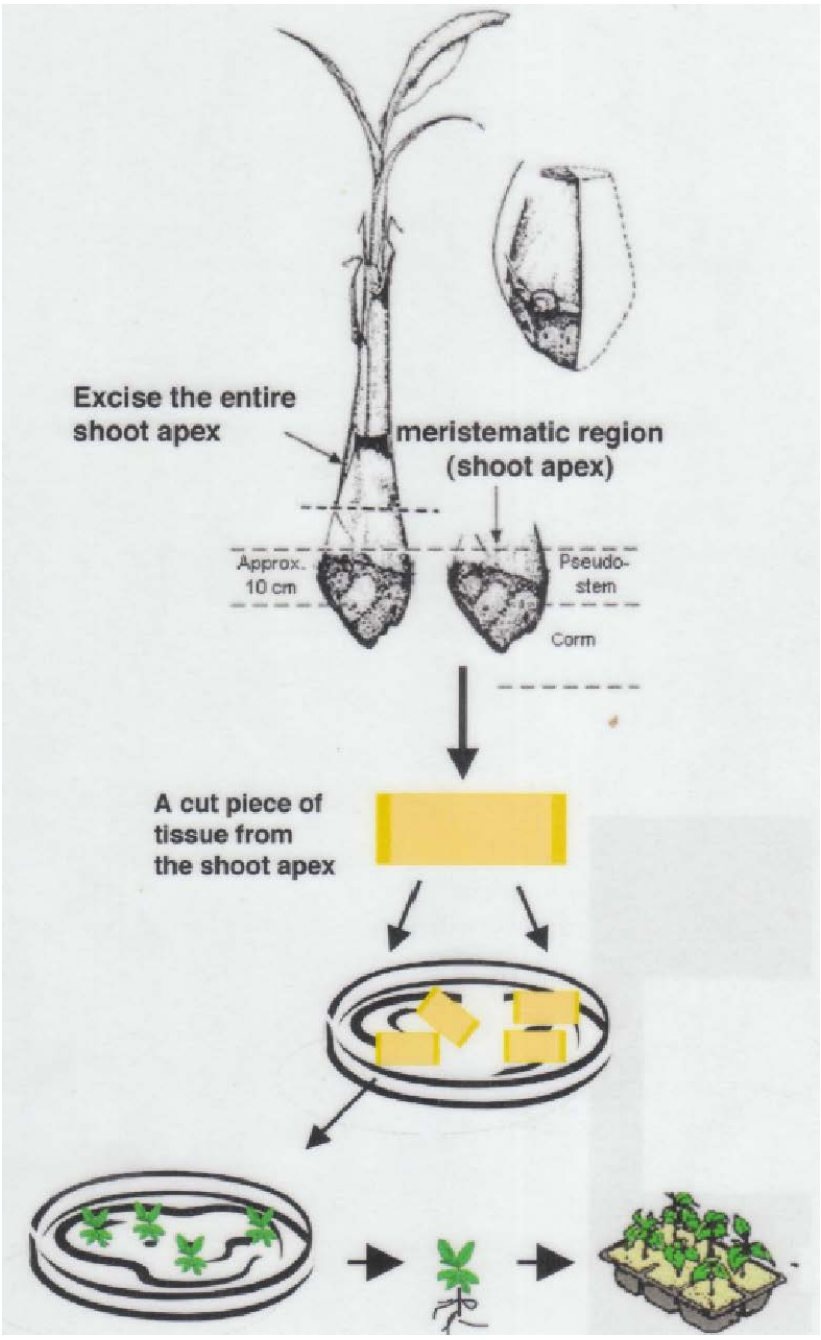

Fig. 8-1. Illustration of banana shoot tip culture (Hooks and Perez).

Collection of suckers

1. Different stages of banana keikis (peepers, sword, or maiden suckers) about 1–3 ft (40–100 cm) tall that are free of BBTV symptoms can be collected for tissue culture.

Fig. 8-2. A) Banana keiki is separated from the main stem using a desuckering bar (right); roots and lower corm section are excised from the keiki. B) Segment of pseudostem containing meristem tissues is harvested. C) Outer pseudostem tissues are peeled off. D) About 4 inches (10 cm) of meristematic region of the inner pseudostem is harvested and E) packed into a plastic bag to be brought back into the laboratory for tissue culture (Pictures by K.-H. Wang, UH).

2. Separate the desired keiki from the main stem without cracking the corm of the keiki. Collect at least two suckers from each plant source, one for micropropagation and the other for a nursery farm for future keiki needs.
3. Banana suckers selected are excised to obtain approximately 4 inches (10 cm) of inner pseudostem tissue containing the banana meristem, as described in detail in Fig. 8-2. To ensure the plant is BBTV-free, it is recommended to collect a newly unfolded banana leaf from the keiki and submit it to a plant disease diagnostic laboratory such as the Agriculture Diagnostic Service Center (ADSC) at the College of Tropical of Agriculture and Human Resources (CTAHR) to check for BBTV.

Disinfection of propagule

1. Wash the pseudostem collected from the field with running water to remove adhering soil.
2. Immerse the excised pseudostem in a container of undiluted household bleach (5.25% NaOCl) for 30–45 minutes.
3. Decant the bleach solution and keep the surface-sterilized pseudostem in the container.

Tissue-culture medium for shoot growth (based on Damasco and Barba's (1984) recipe.

Table 8-1. Ingredients of tissue-culture medium for banana shoot proliferation (pH 5.7).

Ingredient	Concentration of stock solution	Amount needed to prepare 1 L of medium
MS macronutrients (0.5 ×)	25 ×	20 ml
MS micronutrients (0.5 ×)	100 ×	5 ml
MS vitamins (1 ×)	100 ×	10 ml
Fe-EDTA (1 ×)	200 ×	5 ml
Sugar		30 g
BAP	100 mg/L	50 ml (5 mg)
Coconut water (optional)		100 ml
Agar		6 g

MS = Murashige and Skoog's medium

Inoculation

1. Mix the medium according to Table 1. Autoclave medium scalpels, forceps, cutting plates, and Magenta boxes (Fig. 8-4) according to standard autoclaving procedure.
2. Work under surface-sterilized laminar flow hood.
3. Trim the surface-sterilized banana pseudostem, peeling off the outer leaf sheath that come in contact with the bleach. Transfer to a clean cutting dish and continue cutting until the shoot measures 1×1 cm, with the corm tissue as thin as possible.
4. Transfer the shoot tip to a fresh cutting dish and cut the shoot into quarters longitudinally, through the center. Transplant each quarter onto a solid culture medium.

Maintenance of shoot cultures

1. Keep shoot cultures in an air-conditioned room under a 16-hour photoperiod 40 $\mu E/m^2S^{-1}$ (provided by two 40-watt fluorescent tubes).

2. Observe the cultures for contamination. Discard contaminated cultures as soon as contamination is noted.
3. Observe for browning and bulging of corm tissue, greening of leaf tissues, and growth of new shoots during the first month of culture.
4. When shoots coming out from the apex of the leaf axis are almost 2 cm tall, the shoot tips are ready for subculture.

Proliferation of shoots (subculture)

1. Transfer the shoot or sections of shoot to fresh culture medium in vitro whenever the propagules are about 2 cm tall. Overgrown shoots are less proliferative. If shoots are beyond 2 cm, make a longitudinal cut through the apex of the growing shoot.
2. Subculture onto half-strength MS medium supplemented with 5 mg/l BAP and 100 ml/l coconut water. This medium, without auxins, is used to avoid early forming of nubbins at high frequencies. All subculturing needs to be conducted in sterile conditions.
3. Subculture about 3–4 weeks until desired number of shoots is obtained.
4. Record number of proliferated shoots.
5. Repeat the subculture for no more than 5 cycles. A higher number of subculturing cycles will lead to off-type banana mutations such as dwarfism, elongation, or other abnormalities.
6. When sufficient shoots have proliferated as nuclear stock, proceed with rooting.

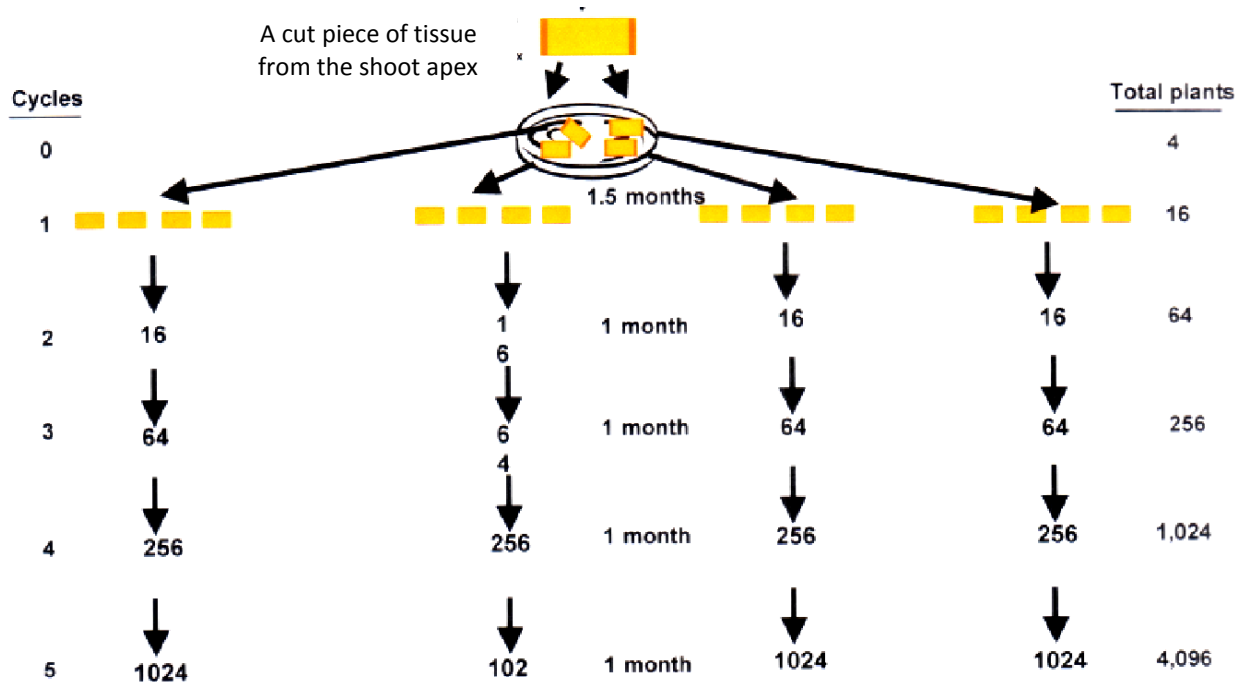

Fig. 8-3. Subculturing of banana shoot apex. Each propagule is cut into four pieces. Thus, 5 cycles of subculturing will generate 4,096 plantlets from one mother shoot apex.

Rooting

1. Prepare rooting medium in Table 2 (Damasco 2005) and use within a week of preparation for best results.

Table 2. Banana rooting medium.

Ingredient	Concentration of stock	Amount for 1 L of medium
MS macronutrients (0.5 ×)	25 ×	20 ml
MS micronutrients (0.5 ×)	100 ×	5 ml
MS vitamins (1 ×)	100 ×	10 ml
Fe-EDTA (1 ×)	200 ×	5 ml
Sugar		30 g
Coconut water (optional)		100 ml
Agar		6 g

MS = Murashige and Skoog's medium

Fig. 8-4. Tissue-cultured banana plantlets in Magenta boxes ready for acclimatization in the nursery (picture: K.-H. Wang, UH).

2. Let the last cycle of the shoot subculture establish 3–4 week (proliferation period) so as to obtain small plantlets.
3. Separate individual shoots from a cluster of shoots and transfer them onto rooting medium.
4. Roots will form in 3–4 weeks.
5. When the plantlets have 3–4 expanded leaves and are well rooted, they are ready to be planted into soil.

Preparing tissue-cultured banana plantlets for field planting

1. Prior to planting tissue-cultured banana plantlets into soil, the seedlings need to be hardened or acclimatized to the external environment. This can be done by transferring them to a liquid medium (without agar), or exposing them to partial sunlight in the tissue-culture vessel under greenhouse conditions for a few days.
2. Any agar medium adhering to the tissue-cultured plantlets should be gently washed off, after which they are ready to be planted into potting media in a nursery.
3. Choose a potting mix with good moisture-holding and drainage characteristics, for example 2 parts Sunshine Pro mix, 1 part perlite, and 3 parts medium- to coarse-grade vermiculite. Keeping the media moist to maintaining the health of the tissue-cultured seedlings.
4. Fertilize with slow-release or liquid fertilizer.
5. Place banana seedlings in a partially shaded area (50% shade) for 2 weeks before exposing them to full sunlight.
6. Plants should be placed in a BBTV-free and banana aphid-free area. Other aphids, whiteflies, and spider mites are commonly found on banana plants in greenhouses and clustered nurseries, and these should be managed by employing insecticide when populations are high. However, after the plants are transplanted into the field, these pests are typically not problematic.
7. The full acclimatization process should take about 2 months, or until seedlings reach about 8 inches or taller, depending on variety, before field planting.

8. If using tissue-cultured banana to replace plants in a BBTV-infected field, an aggressive scouting program for BBTV should be in place. This includes inspecting young plants every 5 days, as new leaves unfold every 5 days.
9. The length of time to harvest after transplanting tissue-cultured banana depends on the cultivar. In general, 'Dwarf Apple' bananas may be harvestable within 9–10 months after transplanting into the field.

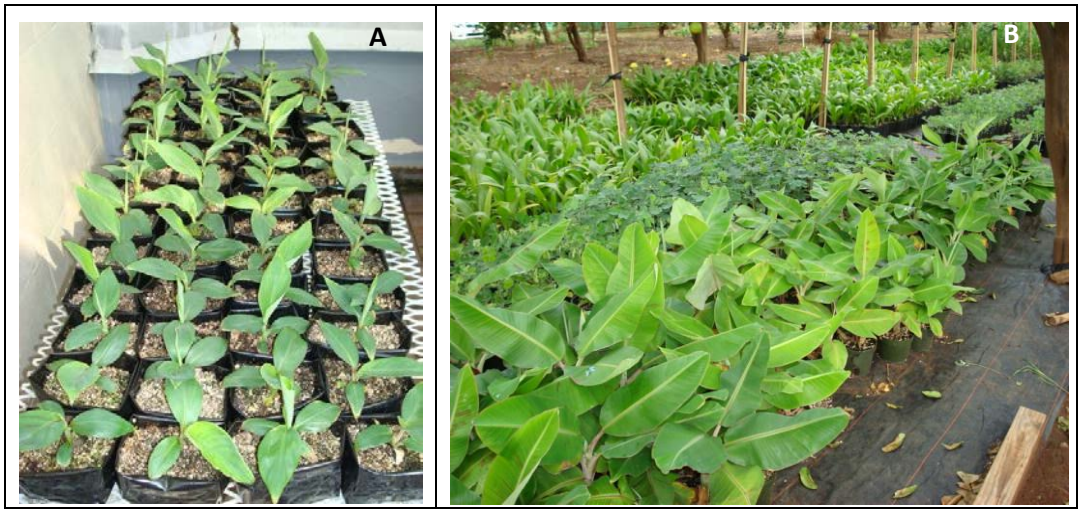

Fig. 8-5. Tissue-cultured banana plantlets are A) acclimatized in a partially shaded greenhouse and B) further acclimatized in an outdoor nursery prior to field planting (picture by K.-H. Wang, UH).

Home Gardener's and Farmer's Corner:

Tissue culture of plants requires a sterile working environment to avoid contamination of the growing medium. Commercial tissue-culture laboratories are generally equipped with laminar flow hoods and autoclaves, and they operate using sterile techniques. Home gardeners can purchase tissue-cultured banana at plant sales if available. Farmers who are interested in propagating tissue-cultured banana but do not have the right facilities to do their own tissue-culture production can contact tissue-culture laboratories that provide these services. For example, Hawaii Agriculture Research Center (HARC) provides micropropagation services upon special order.

Web Resources:

Sathes, R. 2010. Banana culture. http://www.slideshare.net/sathes32/tissue-culture-techniques-of-banana

Jamale, A.V. 2011. Micropropagation for production of quality banana planting material. http://www.slideshare.net/ajamale7/micro-propagation-of-banana.

References:

Damasco, O.P. 2005. Tissue culture of banana. pp. 59-62. *In*: F.S. dela Cruz et al. (eds). Towards management of *Musa* nematodes in Asia and the Pacific. International Plant Genetic Resources Institute (INIBAP), Laguna, Philippines.

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Chapter IX

Macropropagation of Banana

Fig. 9-1. Macropropagation chamber with mature plants.

Introduction

Although field obtained banana keiki (sucker) are preferred by growers as planting materials, they often have a higher risk of harboring disease and insect pests that can lead to decreases in productivity. Thus, demand for high quality disease- and insect-free planting material is increasing. Tissue culture (micro-propagation) can be a viable alternative to planting keiki but require sterile laboratories and highly trained technicians to avoid contamination and guarantee success. Many labs that provide tissue culture services may be expensive and/or require large quantities be purchased making it impractical. To address these challenges, macro-propagation has been introduced as an alternative. Macro-propagation can be done with little capitol cost and minimal skill. This chapter describes how to construct a macro-propagation house and the steps required to prepare the planting material and harvest clean banana plantlets.

Construction of Macropropagation Chamber

1. Determine the size of the propagation chamber desired. A convenient size for the chamber is 4 ft wide × 8 ft long × 4 ft tall but smaller units can be constructed.
2. Cut plywood to the desired area and elevate plywood off the ground using eight CMU's.
3. Build frame of the structure using 2" × 2" lumber and 1" × 12" lumber shown in Fig. 9-1. Ensure that the rib spacing on the roof is 2 feet or less. Uprights should be cut to allow the roof to slope (Fig. 9-1 C, D).
4. Construct a door using 2" × 2" lumber and attach using door hinges to one of the cross bars.

5. Line the inside of the bed and the outside of the structure with polyethylene plastic and secure using staples 1” × 2” lumber and screws (Fig. 9-3).

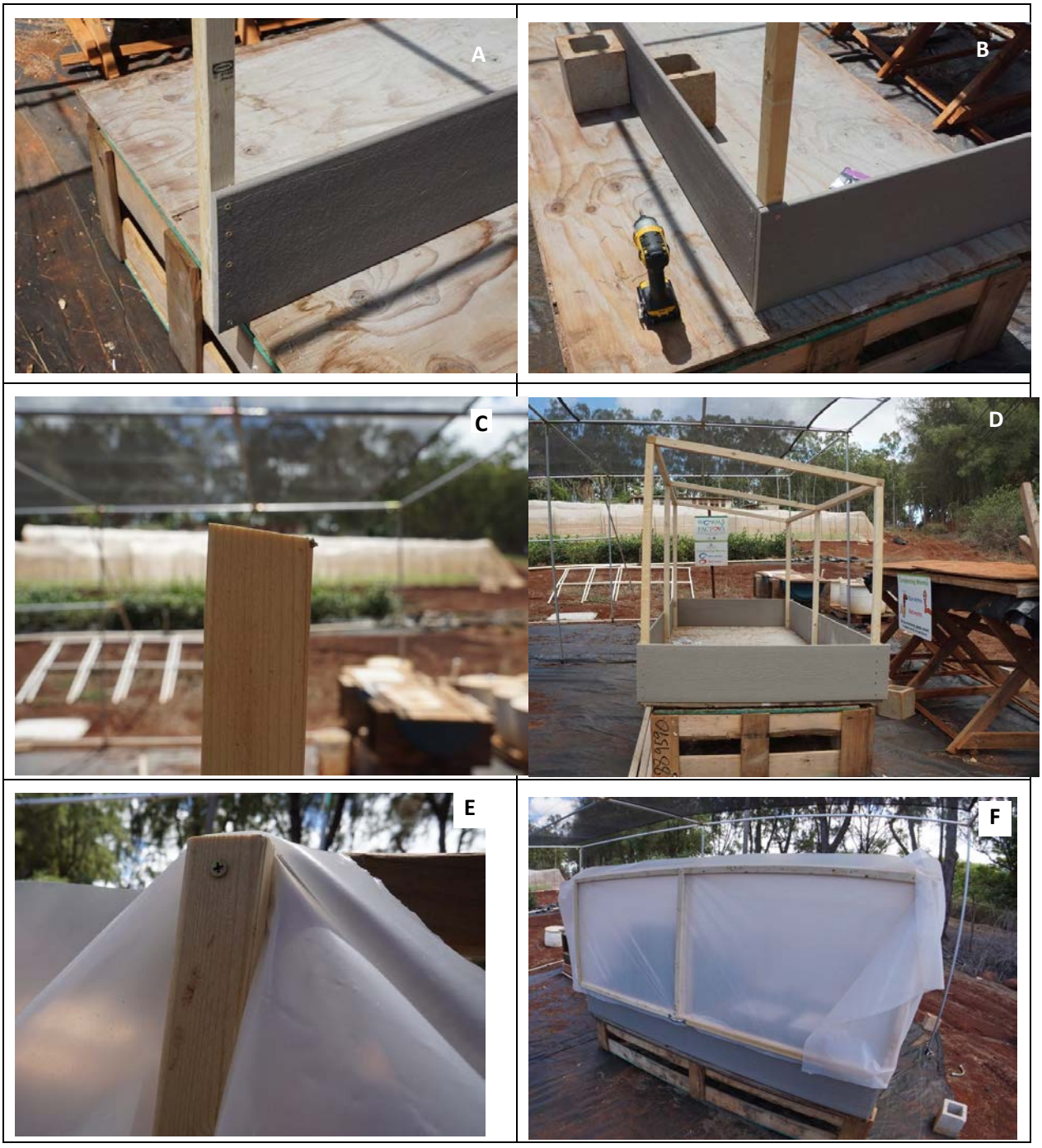

Fig. 9-2. Construct the frame of the macropropagation chamber by A and B) attaching the 1” × 12” siding to the 2” × 2” lumber, C and D) constructing the roof at a slant, E) covering the chamber with polyethylene using 1” × 2” lumber screwed into the 2”× 2” frame, and F) open the front of the chamber with a flapping door.

6. Moisten coconut coir and fill in lined structure with six to eight inches of media.

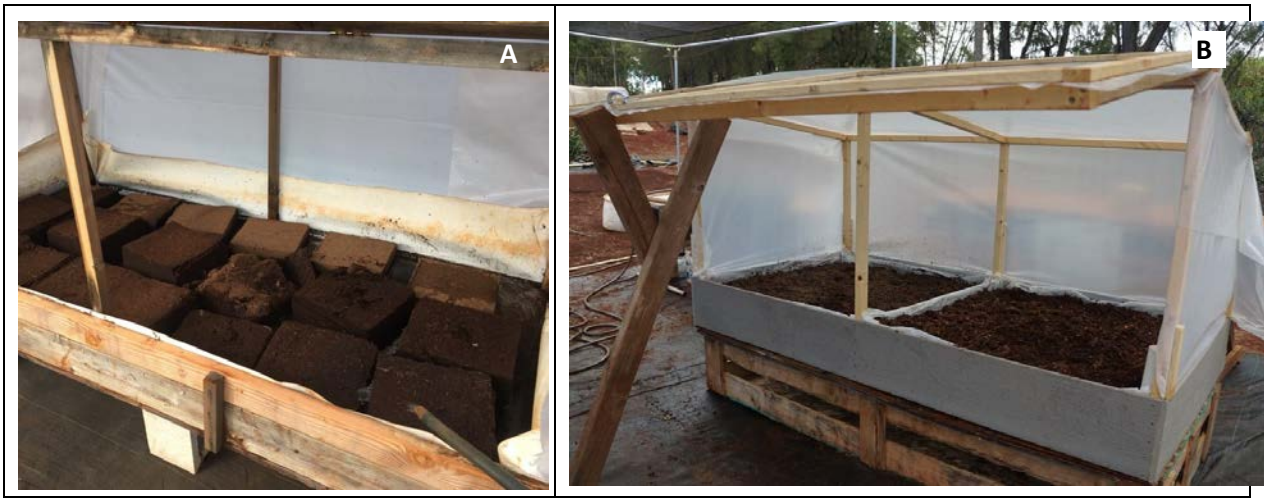

Fig. 9-4. A) Soak compressed coco coir media and allow media to breakup. B) Fill the chamber with 8-10" of media.

Preparing the Planting Material

1. Select clean and healthy banana suckers from desired mats. Test plant material to ensure they are banana bunchy top virus free. Using a knife remove all soil and roots from the corm of selected disease-free suckers.

Fig. 9-5. Clean up the A) disease-free planting material collected from the field, using B) a cleaned and sanitized knife to remove soil and roots from the corm.

2. Boil water in a large pot. When water has reached a rolling boil, submerge cleaned banana corms into boiling water for 30 seconds (Fig. 9-6). Remove treated corms and place on clean polyethylene plastic sheeting. This step will help to sanitize corms and reduce the chance of spreading nematodes and soil borne diseases.

Fig. 9-6. A) Place cleaned banana keiki on a sheet of polyethylene plastic sheeting. B) Sanitize corms in boiling water to minimize nematodes and soil borne diseases.

3. Wash and then sanitize knife and remove each leaf sheaths at the base. After each sheath is removed, use the knife to cross cut each bud. After majority of the leaf sheaths have been removed cut the remaining leaf sheath at the base.

Fig. 9-7. A) Sanitize knives, B) Removal of leach sheaths. C) Cross cutting side buds. D) Removal of remaining leaves.

4. After removing all the leaf sheaths, use the knife to terminate the apical meristem (main shoot) (Fig. 9-8).
5. Place the prepared corm into the growth chamber and burry with coconut coir.

Fig. 9-8. A) Termination (removing) of the apical meristem. B) Corms ready for planting. C) Corm planting in coir media.

Managing Shoots and Harvesting Propagules

1. As single shoots emerge from the planted corm use a sanitized knife to cut the shoots off at the base and then cross cut the base to stimulate more shoot division (Fig. 9.9 A-C).
2. When multiple shoots emerge, remove using a sanitized knife and then plant into one gallon pots filled with potting media. Allow shoots to acclimatize and develop a strong root system for at least one month. Fertilize plants weekly using a complete fertilizer (Fig. 9.9 D).
3. Once plants have hardened off plant out into the field (Fig. 9.9 E, F).

Fig. 9-9. A and B) Remove new shoots from the planted corm. C) Cross cut the recovered shoots. D) Collect shoot clumps from the corm. E) Transplant keiki into individual pots, acclimatize for one month before F) field planting.

References:

Baiyeri, K.P., and S.C. Aba. Almeida. 2007. A Review of Protocols for Macropropagation in *Musa* Species. *Fruit, Vegetables and Cereal Sci. and BioTech*. 1(2): 110–115.

Njukwe, E., E. Ouma, P.J.A. van Asten, P. Muchunguzi, and D. Amah. 2013. Challenges and opportunities for macropropagation technology for *Musa* spp. among smallholder farmers and small- and medium-scale enterprises. *Banana Systems in the Humid Highlands of Sub-Saharan Africa.* 8: 65-71.

Chapter X

Integrated Disease Management against Key Pests and Pathogens on Banana in the Pacific

Introduction

This chapter will summarize the basic information discussed in previous chapters and integrate this knowledge together to develop an environmentally friendly and practically feasible integrated disease management (IDM) program specifically targeted at the three groups of diseases that trouble banana production in the Pacific Islands: *Banana bunchy top virus* (BBTV) transmitted by banana aphids; plant-parasitic nematodes; and black Sigatoka disease. The following guidelines are especially applicable to farmers looking to reestablish an old banana farm challenged by these three diseases.

Cleaning an old banana field for new crop planting

1. Inject infected banana plants with bananacide to kill BBTV and nematodes. This will remove the sources of inoculum for both pathogens for the next crop's planting. Killing nematode-infected plants with bananacide was demonstrated to improve the potential of the successive fallow practice to reduce nematode infestation without nematicides (Chabrier & Quénéhervé 2003).
2. Grow sunn hemp (*Crotalaria juncea*), marigold (*Tagetes patula*), rapeseed (*Brassica napus*), velvetbean (*Mucuna pruriens*), sorghum-sudangrass (*Sorghum bicolor* × *Sorghum arundinaceum* var. Sudanense) and other nematode-suppressive cover crops for 3 months or more before preparing the field for banana planting.

Obtain clean planting materials

3. ***Use disease-free micropropagated (tissue-cultured) banana plants for replanting.*** This is one effective tactic to prevent the inadvertent spread of BBTV and plant-parasitic nematodes. Two of the most damaging nematodes on banana, spiral nematode (*Helicotylenchus multicinctus*) and burrowing nematode (*Radopholus similis*), are endoparasitic nematodes.

The strategy of planting **disease-free tissue-cultured banana** plantlets has been successfully adopted in banana production in areas with high BBTV or nematode pressure in Taiwan, the Philippines, and Australia (Espino et al. 1998). In 2007, a banana tissue-culture facility was established in Hawai'i by Hooks and colleagues in cooperation with the University of Hawai'i's Agriculture Diagnostic Service Center. More than 200,000 tissue-cultured plantlets were distributed within the first 2 years of the initiation of the project. Due to lack of funding, the program was closed in 2014. Through close collaboration with CTAHR Cooperative Extension agents Sugano, Fukuda, and others, significantly greater numbers of stakeholders in Hawai'i are now more aware of using disease-free plants through micro- or macro-propagation (Chapter VIII and IX).

This means that, similar to BBTV, they can survive in the banana plant and be transferred to a new field if infected plants are used as replanting material.

4. If obtaining tissue-cultured banana plantlets is not feasible, ***planting symptomless banana suckers*** is another choice. However, the risk of farmers inadvertently transplanting BBTV-infected symptomless suckers is high. Hooks et al. (2008, 2009) found that BBTV has a long incubation period (20–85 days) in Hawai‘i climates. As such, infected plants may appear healthy for a lengthy time period. A survey of 50 symptomless banana suckers newly transplanted at a commercial banana farm on O‘ahu revealed that 100% of the suckers contained banana aphids, 92% were infested with winged morphs, and 20% of the suckers contained aphids that tested positive for BBTV (Hooks unpublished).
5. Planting of symptomless banana suckers should be accompanied by **weekly scouting** for BBTV symptoms after transplanting to ensure timely removal of newly symptomatic BBTV-infected plants.
6. To reduce the viability of nematodes in banana keiki that are to be transplanted, farmers can refer to the **hot water treatment** (55°C for 10 min) or **banana keiki solarization** techniques (1.5 hours) described in Chapter V.
7. Although banana root weevil is not among the top 3 pests of concern targeted in this chapter, farmers should **examine the corm of the banana keiki** before planting for any damage caused by this weevil (see damage of banana corm weevils in Chapter III).

Crop maintenance after transplanting

Fig. 10-1. Well-maintained banana field with no excessive leaves and 3–5 plants per mat.

1. **Maintain only 5–7 leaves per plant.** This is sufficient to support banana bunch development. Remove excessive leaves to allow pesticides to come into contact with the targeted pests (banana aphids or black Sigatoka, etc.).

Fig. 10-2. A thick banana mat is extremely difficult to manage and produces poor bunch yield.

2. **Maintain only 3–5 plants per mat.** This will allow better banana bunch development. A thick mat is difficult to manage (Fig. 10-2).
3. **Scout and destroy BBTV-infected plants regularly**. Identify and destroy virus-infected plants as early as possible (refer to Chapter II Table II-1 for early BBTV symptoms). Banana takes 5 days to unfold a new leaf in the tropical climate of Hawai‘i. You should suspect BBTV infection if new leaves do not unfold within this time. Scout for banana aphids and always spray insecticides on BBTV-infected plants before rogueing to avoid spread of viruliferous aphids.
4. Once a BBTV-symptomatic plant is detected, **destroy the plant with bananacide** (see Fig. 4-1 to 5 for instructions). However, it will take the banana plant approximately 6 weeks to die back after the bananacide injection. During this period, the banana plants should be left intact in the field, as removing the plant will cause the remaining aphids on the sick plant to spread. New healthy plants can be replanted in the same planting spots after ensuring the injected plants are dead.
5. **Manage nematodes after planting by using marigold.** Plant marigolds 4 months after banana transplanting to reduce nematode damage and to avoid competition in growth between banana and marigold (see Chapter V for the justification for this practice). However, the marigolds might not last too long, as the banana canopy closes up and begins to shade them. Nonetheless, this provides a good approach for post-plant nematode management that might lead to prolonging productivity of the banana crop.

Fig. 10-3. French marigold ‘Single Gold’ (*Tagetes patula*) planted as under-canopy living mulch to suppress plant-parasitic nematodes in a banana orchard.

Insecticide treatment

1. Scout for banana aphids using a binomial sequential sampling plan (see Fig. 4-8) to determine when to treat the plant with insecticide. Count the number of banana plants with aphids present on the lower two leaves to determine whether insecticide spray is needed.
2. Insecticides allowed for banana in Hawai'i are listed in the Hawaii Pesticide Information Retrieval System: http://pesticides.hawaii.edu/hipmrinn/hipmrinn.html
3. Insecticide spray should be focused on <2.5 m-tall plants, in the area between the leaf petioles and pseudostem of banana.
4. Most importantly, farmers should spray insecticide on BBTV-infected plants that are injected with bananacide as well as their neighboring plants. Once the vectors of BBTV is killed on the main source of BBTV in a field, this may eliminate preemptive spraying of insecticide throughout the entire orchard, thus saving money for the farmers.
5. If the aphid population is low, managing ants in banana fields is not necessary.

Fungicide treatment

1. If field sanitation can mitigate the spread of Sigatoka diseases, use of fungicide spray should be the last resort. In Australia, banana growers are recommended **to trim excess banana leaves** if more than 15% of the leaf is showing visible symptoms of yellow Sigatoka during the wet season, but only trim if more than 30% of the leaf is symptomatic during the dry season (State of Queensland 2003).
2. Repeated use of fungicides with the same mode of action could trigger the buildup of a fungicide-resistant population of *Mycospharrella fijiensis* or *M. musicola*. Follow the instructions in Chapter V as to a recommended fungicide-rotation program for banana growers in Hawai'i. Most importantly, rotate fungicides with and without triazole. Add spreader sticker to fungicide spray to improve the performance of the fungicide.

Maintenance of banana fruits

1. Cut off flower raceme after 7 hands of fruits have developed per bunch. A longer flower raceme (Fig. 10-4) will act as a nutrient sink and rob nutrients from harvestable fruits.
2. Bag the fruits after raceme removal to protect the fruits, and label each bunch for convenience of harvest (Fig. 10-5).
3. Track bunch weight over time. If yield is declining significantly, it is time for replanting.

Web Resources:

Nelson, S., L. Rishardson, and T. World. 2009. Banana farming in Hawaii. University of Hawai'i at Manoa. https://www.ctahr.hawaii.edu/bbtd/video.asp

Australian Banana IPM guide: http://bmp.abgc.org.au/downloads/abgc-bmp-guide.pdf

Fig. 10-4. Flower racemes should be cut back to allow more nutrients for fruit development.

Fig. 10-5. Banana bunches are bagged after raceme removal and tagged with anticipated harvesting dates.

References:

Ferreira, S.A, E.E. Trujillo, and D.Y. Ogata. 1997. Banana Bunchy Top Virus. http://www2.ctahr.hawaii.edu/oc/freepubs/pdf/PD-12.pdf

Hooks, C.R.R., M.G. Wright, D.S. Kabasawa, R. Manandhar, and R.P.P. Almeida. 2008. Effect of Banana bunchy top virus infection on morphology and growth characteristics of banana. *Annals Appl. Biol*. 153: 1–9.

Hooks, C.R.R, S. Fukuda, E.A. Perez, R. Manandhar, K.-H. Wang, M.G. Wright, and R.P.P. Almeida. 2009a. Aphid transmission of *Banana bunchy top virus* to bananas after treatment with a bananacide. *J. Econ. Entomol*. 102: 493–499.

Hooks, C.R.R., R. Manandhar, E.P. Perez, K.-H. Wang, and R.P.P. Almeida. 2009b. Comparative susceptibility of two banana cultivars to *Banana bunchy top virus* under laboratory and field environments. *J. Econ. Entomol*. 102: 897–904.

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Robson, J.D., M.G. Wright, and R.P.P. Almeida. 2007. Biology of *Pentalonia nigronervosa* (Hemiptera, Aphididiae) on banana using different rearing methods. *Environmental Entomology* 36: 46–52.

Vezina, A. 2013. Bunchy Top in Australia: 100 not (quite) out! *Australian Bananas* 39.

Wang, K.-H., and C.R.R. Hooks. 2009a. Survey of Nematodes on Banana in Hawaii and Methods Used for their Control. University of Hawai‘i CTAR, Plant Disease, PD-69.

Wang, K.-H., and C.R.R. Hooks. 2009b. Plant-parasitic nematodes and their associated natural enemies within banana (*Musa* spp.) plantings in Hawaii. *Nematropica* 39: 57–73.

Appendix I: Banana Cultivars & Ploidy Levels

AA

Pisang Mas/ Sucrier

Zebrina

Most cultivated bananas are hybrids of two wild species of banana, *Musa acuminate* (A) and *Musa balbisiana* (B). Cultivated bananas are usually tripoid or tetraploid of the genetic inheritance from these two wild parents. The numbers of A and B designated are based on the degree of chromosomes (ploidy) level the hybrid inherited from its parents.

ABB/BBB

Saba #1 - Dippig
ABB/BBB

Saba #2 - Compact
ABB/BBB

Williams
AAA

Philippine Lakatan
AA/AAA

AAB

"Dwarf Apple" /Santa Catarina
AAB

Tall Brazilian
AAB

ABB

Ice Cream
ABB

AAA

Chinese
AAA

Dwarf Red
AAA

"True Apple"/ Amorosa/Manzano "Lady Finger"/
AAB

Mysore
AAB

San Juan/ Largo
ABB

Valery
AAA

Bluefields
AAA

Putalinga Kula /Tonga
AAB

Putalinga Hina /Tonga
AAB

Pisang Awak/ Ducasse
ABB

(Picture credit: Koon-Hui Wang, Cerruti Hooks, Angela Kapler, Frank Rust)

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