9 Pests, Diseases and Weeds

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Introduction

Several recent in-depth reviews of pineapple pests and diseases have been published (Lim, 1985; Rohrbach and Apt, 1986; Broadley et al. 1993; Rohrbach and Schmitt, 1994). The focus of this chapter is on the interactions of populations of pineapple pests, disease pathogens and weeds with the pineapple production cycle. High population densities of pineapple pests, diseases and weeds occur at different times in the pineapple life cycle (shown by varying bar intensity for each insect and disease pathogen in Figs 9.1, 9.2 and 9.3), and therefore have varying impacts. Understanding the interactions of these pests and disease pathogens with their pineapple host is critical to an integrated pest, disease and weed management (IPM) programme.

Several characteristics of the pineapple plant and commercial pineapple production systems contribute to the severity of several pest and disease problems. The commercialization of pineapple required large capital investments in land and processing facilities, which has resulted in long-term monoculture. Long-term monoculture has contributed to severe nematode problems in many production areas and this has required the implementation of nematode-control strategies.

The pineapple plant is most productive under a xerophytic environment where low rainfall is supplemented by irrigation in well-drained soils. The adventitious roots arising from the lower portion of the pineapple stem are the only ones that become soil roots. Once the root system is damaged or destroyed, it does not regenerate significantly.

Indices for pineapple-plant diseases are the proportion of the plant population affected (incidence) and the effect of disease on each plant (severity). Severity may range from a reduction in growth rate, as indicated by a reduced plant size or weight, to a reduced fruit yield. Pineapple pest indices applicable to IPM systems have been developed for mealybugs, ants and mites.

In order to understand the epidemiology of pineapple-plant diseases and to develop management strategies, the probability of disease occurrence (frequency) and the level of disease occurring (incidence and severity) must be considered. Indices for fruit disease severity are shown in Figs 9.4 and 9.5. Factors of importance are the presence or absence of the causal organism, susceptibility of cultivars and optimum environmental conditions.

Fallow Period (Intercycle)

Intercycle pests

Nematodes, mealybugs and ants

In a monoculture pineapple production system, the fallow period or intercycle has historically ranged from years to as little as a
few weeks. Prior to the discovery of soil fumigants for nematode control, the fallow period was an important nematode-control strategy, particularly for the root-knot nematode. The fallow period is also important for the control of ants and mealybugs which are associated with mealybug wilt. Tillage must be thorough and frequent enough for the decomposition of the previous crop and its pests and for the elimination of weed growth.
during the fallow period. Weeds present during the fallow period may provide a carry-over host for nematodes and mealybugs. Thorough tillage can also eliminate ants within the fallowed field.

Ants present in intercycle fields are the big-headed ant, *Pheidole megacephala* (F.) (Plate 22), the Argentine ant, *Iridomyrmex humilis* (Mayer), and the fire ant, *Solenopsis geminata* (F.) (Rohrbach and Schmitt, 1994).
With deep, frequent intercycle tillage, most ant colonies can be eliminated.

Nematode populations during the fallow period will decline significantly if soil moisture is adequate. However, the presence of soil moisture increases the need for weed control. Dry fallow is not as effective at reducing the reniform nematode population as is wet fallow (Caswell and Apt, 1989).

Economic thresholds for nematodes are not well defined. Soil sampling is important because the qualitative occurrence of reniform, root-knot or root-lesion nematodes is generally interpreted as a potential problem that requires control (Caswell et al., 1990; Stirling and Kopittke, 2000).

**Souring beetles**

Small nitidulid beetles (c. 4.5–8.0 mm), known as souring beetles, sap beetles or dried-fruit beetles, are attracted to decomposing pineapple plant material (termed pineapple trash) following knock-down of the previous crop. The adult beetles are hard-bodied and dark brown (Hinton, 1945). Several different species may infest trash or overripe pineapple fruit, of which *Carpophilus humeralis* (F.), *Carpophilus hemipterus* (L.) (Fig. 9.6), and *Haptoncus ocularis* (Fairm) are the most common (Carter, 1967; Py et al., 1987). Fertile females may lay more than 1400 eggs and live as many as 115 days (Carter, 1967). Eggs usually hatch within 2 days after deposition. Hinton (1945) indicates that the life cycle of *C. humeralis* from egg to adult is about 21 days. While the larvae typically feed on decaying fruit, the adults may attack pineapple plants at every stage of growth (Hinton, 1945). They may congregate on seed plants placed in the field and feed on the exposed butts and starchy stalk material. However, the injury to the plant is not economically significant. Chang and Jensen (1974) have identified these beetles as being possible vectors of the fungus *Chalara paradoxa* (De Seynes) Sacc. (syn. *Thielaviopsis paradoxa* (De Seyn.) Hohn) (telemorph *Ceratocystis paradoxa* (Dade) C. Moreau) which causes black-rot disease.

Souring beetles are more of a social nuisance than an agricultural one, because they

**Fig. 9.5.** Pineapple disease index used to measure internal disease severity (e.g. internal browning) based on the proportion of fruitlets per fruit that show symptoms.
often land on humans in the vicinity of knocked-down fields and fruiting pineapple plantings. This has been a problem in places such as Hawaii, where recreational and tourist activities (e.g. golf) are enjoyed near pineapple-production areas. It has been reported (R. Heu, personal communication) that a single Maui resort company lost $50,000 weekly due to problems stemming from swarms of adult souring beetles. Given that these beetles do not have a significant impact on pineapple production, it is not economically feasible or environmentally desirable to control them with pesticides. However, to reduce their nuisance factor, the parasitic wasp Cerchysiella (= Zeteticontus) utilis Noyes (Hymenoptera: Encyrtidae) was collected in Israel and released in Hawaii in 1977 to control the immature larval stages of the beetles that infest rotting pineapple trash and fruit (Funasaki et al., 1988). The wasp established populations on the Hawaiian Islands of Oahu, Maui and Lanai (C. Nagamine, personal communication). The adult female parasitoid deposits her eggs into beetle larvae and the parasitized larvae mummify (i.e. turn hard and stiff) after 9–11 days. Fifteen days after egg deposition, an adult C. utilis emerges from the parasitized beetle. Sourcing-beetle numbers have been reduced somewhat, but the beetles still remain a problem in some areas.

**Intercycle cover crops**

While intercycle cover crops have not been utilized to any degree in commercial pineapple production, they offer some potential for controlling erosion and reducing nematodes (Ko and Schmitt, 1993). Their use has been uneconomic because adequate rainfall or irrigation is necessary to sustain cover crops in dry production areas.

**Seed Material – Collection, Handling and Storage**

Pineapple is vegetatively propagated, utilizing crowns, slips or suckers (Fig. 9.7). In general, these ‘seed materials’ are infested with the same pests as were present on the mother plants. The movement of seed materials from field to field or country to country has been the primary means of spread of the major pineapple pests and diseases (Rohrbach, 1983). Common pests infesting seed materials are mealybugs, scale and pineapple red mites. In addition to these pests, the diseases termed butt rot and *Fusarium* stem rot may be major problems when handling, storing or planting fresh seed materials. In the past 10 years, two types of plant viruses have been identified in pineapple, a closterovirus and a bacilliform
These viruses have been shown to occur in most pineapple plants with or without symptoms of mealybug wilt in several different countries (Sether and Hu, 1998). Recent evidence indicates that the closterovirus may actually consist of a group of viruses (J. Hu, personal communication). The role of these viruses in mealybug wilt has not been conclusively defined. Pest- and disease-free seed materials are critical to maintaining uniform and optimum plant growth throughout the pineapple cycle.

**Mealybugs**

The mealybug species associated with mealybug wilt are commonly found on pineapple seed material in most major production areas of the world. In order of importance worldwide, they are: pink pineapple mealybug, *Dysmicoccus brevipes* (Cockerell) (Plate 23), grey pineapple mealybug, *Dysmicoccus neobrevipes* Beardsley (Plate 23), and long-tailed mealybug, *Pseudococcus adonidum* (L.) (= *Pseudococcus longispinus* (Targioni-Tozzetti)). Insufficient mealybug control can lead to whole pineapple plantings being lost due to mealybug wilt, resulting in lost fruit production (Carter, 1933). The most common species found in Hawaii’s pineapple plantings are *D. brevipes* and *D. neobrevipes*. Plantings may be infested with only one mealybug species or multiple species (Gonzalez-Hernandez *et al.*, 1999). These species are not equally distributed worldwide. The pink pineapple mealybug may be found in all major pineapple-growing areas. In contrast, the grey pineapple mealybug has not been reported on pineapple in Africa, Australia, India, most of south Asia (except Thailand (G. Jahn, personal communication)), or the Mediterranean region (Beardsley, 1993).

The pink pineapple mealybug is commonly found on the lateral roots of the pineapple plant just below soil level. It can also be found on the aerial parts of the plant, mainly in the leaf axils and on the developing fruit. In contrast, the grey pineapple mealybug is never found on the pineapple roots, but may overlap the distribution of the pink pineapple mealybug on the aerial portions of the plant. In Hawaii, only the grey pineapple mealybug has both female and male individuals in the population, while the pink pineapple mealybug only has females. The male grey pineapple mealybugs spin white, silky cocoons before becoming small-winged insects, which seek females to mate. Mealybugs feed on plant sap in the phloem of their host plants. They produce honeydew (sweet, sticky liquid) as a by-product of their feeding. The honeydew often accumulates in large quantities around groups of mealybugs and may support the growth of sooty mould, *Capnodium* sp. Adult mealybugs are elliptical-shaped (top view), soft-skinned insects with waxy secretions, which give their body surfaces a chalky appearance. They also have white, waxy filaments of various lengths (depending on the species) extending from the lateral margins of their bodies. Although capable of movement, these insects are normally quiescent and congregate together in groups (e.g. > 20 individuals). The first-stage (or first-instar) crawlers (0.6–0.7 mm) are typically the most active stage, and they...
move around the plant host seeking a place to settle down to feed. After settling down, they do not normally move any great distance, unless disturbed or relocated by ant species (e.g. big-headed ant) that tend them for their honeydew.

The long-tailed mealybug and the citrus mealybug, *Pseudococcus citri* (Risso), may be found on pineapple, but do not cause significant injury. The adult of the former species has long filaments protruding from its posterior end, these are slightly longer than the length of the mealybug’s body. The immature stages of the citrus mealybug are similar in appearance to immature pink pineapple mealybugs, but the adult stage produces a fluffy wax mass which holds its golden-coloured eggs.

**Scale**

The pineapple scale, *Diaspis bromelia* (Kerner), is likely to be found on pineapple leaves and fruit worldwide (Plate 24) (Waite, 1993). Frequently, it builds up on the crown of the developing fruit and, at harvest, the seed material may be heavily infested. Other hosts likely to be found in areas where pineapple is grown include species of *Agave*, *Billbergia* and *Bromelia* (Petty, 1978b). Unlike mealybugs, the immature and adult female stages of scale insects do not move around except in the crawler stage, which is responsible for dispersal of the insect (Beardsley and Gonzales, 1975). Adult male scales have wings but fly only to locate females for mating. The crawlers commonly disperse by active wandering and wind currents. The newly hatched crawlers emerge from underneath the protective scale covering of their mothers.

Seed material should be as clean as possible, because scale densities can increase to high numbers (especially if infested planting material is piled up) and desiccate the planting material, thereby making it unusable (Waite, 1993).

**Butt rot**

Butt rot or ‘top rot’ of pineapple can be serious on pineapple ‘seed materials’ and occurs wherever pineapple is grown (Rohrbach, 1983). The causal fungus, *C. paradoxa*, is widespread in the tropics on pineapple, coconut and other palms, sugar cane as ‘pineapple disease’, cacao as ‘pod rot’, and banana as ‘black-head disease’ on rhizomes, suckers and roots, and as ‘stem-end rot’ on fruit (Dade, 1928).

The symptoms of butt rot are a soft rot and blackening of the basal portion of the stem tissue of vegetative seed material (Fig. 9.8). If infected seed material is kept wet, as in a pile of crowns, the infection may progress to rot the entire seed piece (stem and leaves) or even the entire pile. Severely rotted seed material is normally discarded prior to planting. Slightly to moderately infected seed material may be planted, but growth will be slow and plants will be stunted, due to loss of stem tissue, which contains carbohydrate reserves and the initial roots.

![Image of pineapple butt rot](image-url)
When uncured or untreated seed material is planted in soils with high inoculum levels of *C. paradoxa*, butt rot levels may reach 100%. Inoculum levels in pineapple soils in Hawaii varied from an average of 2630 propagules g\(^{-1}\) following field preparation to 280 propagules g\(^{-1}\) of soil at the end of the crop cycle. At planting, inoculum levels varied by field from a high of 12,969 to as low as 31 propagules g\(^{-1}\) of soil (Rashid, 1975).

**Fusarium stem rot**

*Fusarium* stem rot is caused by the fungus *Fusarium subglutinans* (Wollenw. & Reinking) Nelson, Tousson & Marasas comb. nov. (Matos, 1999). Recently, O’Donnell *et al.* (1998) renamed the pathogen *Fusarium guttiforme* Nirenberg & O’Donnell based on DNA sequence analyses of members of the *Gibberella fujikuroi* complex. Despite its obvious affinities with *G. fujikuroi*, no teleomorph has been reported for this pathogen.

In Brazil, the disease causes major losses in the three major cultivars, ‘Perola’, ‘Jupi’ and ‘Smooth Cayenne’ (Rohrbach, 1983). Levels of plant infections vary from 2 to 30% (Laville, 1980). Disease levels in commercial experimental ‘Smooth Cayenne’ plantings have been so high that foreign investments in pineapple production in Brazil have not developed, although attempts have been made (L. Cooksey, personal communication).

The disease is associated with the fruit-rot phase termed ‘fusariosis’. Stem infections of seed materials occur at leaf bases, with resulting rosetting and/or curvature of the plant, due to portions of the stem being girdled or killed (Fig. 9.9; Laville, 1980).

Once the developing fruit is infected, secondary infections can occur on the developing slips or suckers. The infected seed material is then distributed to new planting areas, thus infesting new sites. Soils can remain infested for several months. Spread within infested fields is primarily by insects but may also be by wind (Laville, 1980). Free conidia of *Fusarium subglutinans* can survive for 6–13 weeks in soil, depending on moisture and temperature, with survival being highest in dry soils. Survival in infected pineapple tissue in soil is less than 10 months (Maffia, 1980). Optimum temperatures for growth are 25°C, with a range of 5–35°C (Camargo and Camargo, 1974).

**Mites**

Several mite species have been recorded on pineapple worldwide. Because of this, some mites have more than one common name and some names have been applied to more than one mite species. To reduce the confusion in the discussion below, the various common names applied to each mite species have been provided.

The pineapple red mite (also known as red spider or false spider mite), *Dolichotetranychus (= Stigmacus) floridanus* (Banks) (Acarina: Tenuipalpidae), is the largest mite found on pineapple and is conspicuous *en masse* because of its bright orange to red colour (Fig. 9.10). According to Jeppson *et al.*
(1975), it only occurs on pineapple and is found in Florida, Cuba, Puerto Rico, Panama, Honduras, Mexico, Central America, Hawaii, the Philippine Islands, Japan, Okinawa and Java. The adult mite is approximately 0.3–0.4 mm long and 0.1 mm wide. When present on the plant, the mite is always found on the white basal portion of the leaves, where it feeds, particularly on the crown. When pineapple red-mite populations build up under dry conditions, the mites are most commonly on the basal leaves of the crown and on stored seed material (Petty, 1975, 1978c).

The blister mite (also called pineapple fruit mite), *Phyllocoptruta* (= *Vasates* sakimurae) Kiefer (Acarina: Eriophyidae), is reportedly the smallest mite (0.1 mm long and 0.033 mm wide) found on pineapple in Hawaii (Carter, 1967). Individuals are chalky in colour and only have two pairs of legs located near the head. They may be found on detached crowns that are stored for planting. They originate from prior infestations on the ripe fruit from which the crowns were derived. They normally disappear after the crowns are planted, but may be found later on fruit after the flat-eye stage of fruit development (Carter, 1967). Jeppson *et al.* (1975) suggest that the mite originated in South America.

The pineapple mite, *Schizotetranychus asparagi* (Oudemans) (Acarina: Tetranychidae), is widely distributed and has been recorded in Hawaii, continental USA, Germany, Portugal, The Netherlands and Puerto Rico (Jeppson *et al.*, 1975). In colder climates, it may be found on asparagus ferns grown in greenhouses or lathhouses. In pineapple-production areas, it may frequently cause severe damage to recently established plants in the field. Plants that are infested in the early stages remain small and fruit production is either curtailed or non-existent. Heavily infested plants may die before producing fruit. The best management action is to plant only mite-free seed-plant material (Jeppson *et al.*, 1975).

The pineapple tarsonemid mite (also known as pineapple mite, pineapple fruit mite, pineapple false spider mite), *Steneotarsonemus ananas* (Tryon) (Acarina: Tarsonemidae), may be found infesting pineapple later in the plant’s phenological cycle (see discussion below) (Fig. 9.11).

Management of pests and diseases on seed material

Pest- and disease-free seed materials are critical to preventing the establishment of insects and pathogens in newly planted pineapple fields. The presence of mealybugs, scales and mites, as well as *Fusarium*-infected seed materials, must be monitored at the seed source before transport for planting, in order to implement effective controls. The pineapple red mite (*D. floridanus*) will only become a problem on stored seed under dry conditions. Mealybugs, scales and the red mite can be controlled by dipping seed in an approved insecticide, such as diazinon (Petty and Webster, 1979). Red mites can also be controlled by orientating seed material in its normal vertical position, so that the leaf axils collect natural rainfall or dew, or by methyl bromide fumigation of the seed material (Osburn, 1945). The blister mite (*P. sakimurae*) can be controlled by dipping seed materials in an approved miticide, such as endosulphan.
Fusarium-infected seed has been hot-water-treated at 54°C for 90 min with benomyl at 50 g 100 l⁻¹, but growth was retarded and up to 50% of the plants were killed (Maffia, 1980). Resistance to *F. subglutinans* occurs in *Ananas* and *Pseudoananas* (Laville, 1980). Resistant cultivars are being developed (Cabral *et al.*, 1997).

Butt rot is controlled by harvesting seed material during dry weather and curing it on the mother plants, where there is good air circulation and exposure to inoculum-infested soil is minimized (Fig. 9.12). Where mechanization has permitted immediate planting of freshly removed seed material, thus eliminating the time required for

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*Fig. 9.11.* Illustration of the pineapple tarsonemid mite, *Steneotarsonemus ananas* (male left, female right).

*Fig. 9.12.* Curing (drying) ‘seed material’ (crowns) on the mother plants and storage until collected for planting.
curing, seed must be dipped in an approved fungicide, such as benomyl or triadimefone within 12 h of removal from the fruit or, in the case of slips, from the plant (Fig. 9.13; Rohrbach and Schmitt, 1994).

Cultivars vary in susceptibility to butt rot with the ‘Red Spanish’ types being more resistant than ‘Smooth Cayenne’ (Smoot et al., 1971). Hybrid cultivars have also shown a wide range of susceptibility (K.G. Rohrbach, unpublished results).

The strong association of a complex of at least two closteroviruses with pineapple mealybug wilt indicates that virus-free seed may be important for wilt control (Sether and Hu, 1998; Melzer et al., 2001). Elimination of the virus from pineapple plants has been attempted with heat treatments (Ullman et al., 1991, 1993). Tissue-culture techniques have eliminated virus infection (Sether et al., 2001). Genetic engineering for virus resistance is also being attempted (Rohrbach et al., 2000).

Some pineapple insects and disease organisms may become quarantine issues if seed materials are transported between countries or production areas where pest organisms are present and areas where they are not established. With the increasing importance of low-acid, fresh-fruit cultivars for niche fresh-fruit markets, the potential for international movement of seed materials presents some significant quarantine issues, when specific pests and diseases are not established in the importing country. Potential quarantine insects and diseases because of limited distribution are the pineapple bud moth, *Thecla basilides* (Geyer), from Central America and the pineapple stem borers from South America and the Caribbean (*Castnia icarus* (Cramer), *Metamasius richiei* (Marshall) and *Paradiophorus crenatus* (Billberg)), *Erwinia chrysanthemi* (Burkholder et al.), causing bacterial heart rot, and *F. subglutinis* from South America, causing stem and fruit rot. Seed materials originating in areas where these pests and diseases are reported to occur should be excluded from areas where they are not established or should be quarantined before planting in production areas (Rohrbach, 1983).

**Planting and Early Growth (First 3 Months)**

Uniformity of early growth is critical to uniform forcing and harvest. Incipient butt-rot infections may severely affect early plant-growth uniformity (Plate 25). Depending on initial populations of root pathogens at planting and the soil environment, nematodes, symphylids and root-rot pathogens may begin to attack the newly developing root system by the end of the first 3 months of growth. Seed material infested with mealybugs and/or scale at planting provides a source of pests that only requires ants to begin to establish damaging mealybug populations throughout the field and the potential for development of mealybug wilt. Additionally, during early growth, plants are especially susceptible to the fungal and bacterial heart rots.

Above-ground symptoms of potential root health problems will not generally be evident during early plant growth. However,
nematode populations will begin to increase. Ants, if uncontrolled, will begin to move into the field from adjacent areas or from in-field colonies that were not destroyed by fallowing practices and will begin to expand. With increases in ant infestation, mealybugs will increase and, if uncontrolled, will have the potential to cause mealybug wilt.

The above-ground symptoms of root rot are similar to any symptom resulting from loss of a functional root system (e.g. mealybug wilt, nematodes, symphyllids, root rot and water stress). Infected plants are stunted, show signs of stress and may or may not be easily pulled out of the soil. Thus, symptoms must be associated with evidence of poor soil drainage for fungal root rot, nematode galls for the root-knot nematode, and ants and mealybugs for mealybug wilt. Soil and root sampling for nematodes should be done to confirm their presence during this period.

**Weeds**

Weed management in pineapple is especially important during early growth, because weeds compete for water, nutrients and light, are hosts for pineapple pests and viruses and interfere with production operations. Weed management includes soil tillage, mulches, and the use of pre-emergence (applied prior to weed-seed germination) and post-emergence herbicides (Fig. 9.14; Kasasian, 1971; Glennie, 1991). The efficiency of the pineapple weed-management system is affected by plant density, the degree of mulch cover, soil type and natural rainfall and/or the method of irrigation. Because the pineapple plant is relatively slow in establishing a complete ground cover, eliminating weed cover may result in high levels of soil erosion (El-Swaify et al., 1993).

Prior to the introduction of pre-emergence herbicides in the 1950s, weed management was primarily physical removal by tillage. The introduction of pre-emergence herbicides revolutionized weed control in pineapple, particularly the grasses. In general, the perennial grasses are much more difficult to control than the broad-leaved weeds. Important pineapple herbicides have been diuron, bromacil, amytryn, atrazine and paraquat (Glennie, 1991). No one herbicide will control all weeds in all situations.

**Fig. 9.14.** Application of pre-emergence herbicide or postplant nematocides or fungicides to young pineapple plants.
Each production area has its own particular spectrum of weeds, sometimes determined by historical weed-control practices (St. John and Hosaka, 1932; Barbier and Trapin, 1956; Py, 1959; Silvy, 1962), e.g. wild sugar cane (*Saccharum spontaneum* L.) in the Philippines (Sison and Mendoza, 1993). Species that are particularly difficult to manage are *Panicum maximum* var. *maximum*, *Sorghum halepense* and the paspalums, *Paspalum dilatatum* and *Paspalum urvillei*. The sedge *Cyperus rotundus* (nut grass) is also a serious pest. Significant broad-leaved weeds are the morning glories, *Ipomoea cairica*, *Ipomola plebeia*, *Ipomola indica*, *Ipomola purpurea* and *Ipomola triloba*. Perennial weeds (e.g. *S. spontaneum*, *S. halepense*, *Imperata cylindrica*) are destroyed by deep ploughing.

Pre-emergence herbicides are used most commonly in pineapple production. Effectiveness is dependent on proper seed-bed preparation, including no live weeds, adequate soil moisture, complete soil coverage and no subsequent soil disturbance following application (Dalldorf, 1985). Split applications of pre-emergence herbicides may be made to pre-mulched or mulched and postplanted fields to ensure adequate pre-emergence protection through the preplanting/planting period. Weed ‘escapes’ during the first crop are controlled with bromacil at 2–4 kg ha\(^{-1}\) or dalapon at 6–10 kg ha\(^{-1}\). *C. rotundus* and *Panicum repens* appearing in the next cropping cycle are controlled with bromacil at 2–4 and 10 kg ha\(^{-1}\), respectively. Other weeds (*I. triloba*, *Mimosa invisa*, *Crotalaria mucronata*, *Digitaria sanguinalis*, *Eleusine indica*, *Paspalum conjugatum*) are controlled by pre-emergence sprays of bromacil at 1–2 kg ha\(^{-1}\), diuron at 0.75–1.5 kg ha\(^{-1}\), ametryne or atrazine (Mendoza, 1979). A summary weed-control programme is identified for Brazil (Reinhardt and Cunha, 1999).

Once plants begin to grow, herbicide applications should be directed away from the plants and on to the soil and developing weeds. This is particularly true with herbicides such as bromacil (Dalldorf, 1985).

**Grasses**

Preventing grasses from producing seed both in the field and on field borders is critical to economically effective weed management. The adage of ‘1 year’s seeding means 7 years’ weeding’ holds true (Broadley et al., 1993).

**Broad-leaved weeds**

In contrast to grasses, broad-leaf weeds are relatively easy to control. However, some broad-leaved weeds, such as *Emilia sagittata*, may cause secondary damage in low population densities as alternative hosts for the yellow-spot virus.

**Nematodes**

Four species of nematodes have been associated most frequently with, and caused the most damage to, pineapple: the root-knot nematodes, *Meloidogyne javanica* ((Treub) Chitwood) and *Meloidogyne incognita* ((Kofoid & White) Chitwood), the reniform nematode, *Rotylenchulus reniformis* (Linford & Oliveira) and the root-lesion nematode, *Pratylenchus brachyurus* (Godfrey Filipjev & Schuurmans Stekhoven) (Caswell et al., 1990).

**Root-knot nematodes**

The most obvious symptom of root-knot nematodes, *M. javanica* and *M. incognita*, on pineapple is the terminal club-shaped gall resulting from infection of the root tip (Fig. 9.15). Less obvious symptoms include stunting of plants and water stress, with the terminally galled root resulting in poor plant anchorage. Nematode egg masses survive for relatively short periods (hours) in desiccated soils. Egg masses in galls may survive several days. Juveniles may survive several weeks to years in desiccated soils. Second-stage juveniles infect the pineapple root tip and become sedentary after 2–3 days. Vermiform males and saccate, sedentary females go through several molts. Surviving nematodes can tolerate a wide range of soil temperatures and pH.

**Reniform nematode**

The reniform nematode, like the root-knot nematode, causes stunting of plant growth,
with infected plants appearing to be under water stress, much the same as in drought, mealybug wilt or root rot. Symptoms are most severe in ratoon crops and may result in the total collapse and death of the plants. As with root-knot, above-ground symptoms are not diagnostic. In contrast to root-knot, however, pineapple plants infected with the reniform nematode have excellent anchorage because of the lack of terminal galling. Infected primary roots continue to grow but secondary root growth is severely limited. Infected roots appear to have nodules, which are actually soil clinging to the gelatinous matrix of females embedded in the roots (Fig. 9.16; Caswell and Apt, 1989). Reniform nematode eggs hatch when stimulated by root exudates of host plants. Second-stage juveniles in the soil undergo 3 molts without feeding, ending as either adult males or preadult females. The preadult females infect the root, where they establish sedentary feeding, become swollen mature adults and start producing eggs. The male does not feed.

**Root-lesion nematode**

The infection sites of the root-lesion nematode, *P. brachyurus*, are characterized by a black lesion that progresses along the root as the nematodes move for feeding. Secondary roots and root hairs are also destroyed. Initial inoculum comes from infested root fragments in the soil or infected roots on infested seed material. Once the plant is infected, the entire life cycle can be completed within the pineapple root. Reproduction is by mitotic parthenogenesis, with males being rare. Optimum soil temperatures are 25–30°C and populations do best in acid soils. In the highly acid Ivory Coast soils, the root-lesion nematode displaces the root-knot nematode. A combination of root-lesion nematode and *Pythium* species results in greater damage than either alone (Guerout, 1975).

**Other nematodes**

Spiral nematodes – *Helicotylenchus, Scutelolumna* and *Rotylenchus* spp., have been reported as problematic in South Africa (Keetch and Purdon, 1979). In Bahia, Brazil, *Aorolaimus* spp. have been reported to cause stunting (Costa et al., 1998).

**Ants and mealybugs**

Mealybug wilt of pineapple, with its leaf-tip dieback and plant yellowing and reddening, is a symptom associated with the feeding of mealybugs (Plate 26). The actual cause has not been conclusively demonstrated, but one or two closteroviruses have been implicated (Sether and Hu, 1999). Mealybug wilt is a universal problem; the only exception may be in parts of Thailand, where wilt does not occur even though mealybugs are present. Mealybug wilt is clearly one of the most destructive diseases of pineapple plants, and field controls must be initiated during the fallow period and continued to harvest. High mealybug populations are required to cause wilt. Ants are necessary for populations of mealybugs to develop and reproduce in pineapple fields, where mealybug
parasitoids and predators are present. At least three species of ants are associated with mealybugs in Hawaii: the big-headed ant, the Argentine ant and the fire ant (Rohrbach and Schmitt, 1994). Two other species – the long-legged crazy ant, *Anoplolepis longipes* (Jardon), and the white-footed ant, *Technomyrmex albipes* (Fr. Smith) – are clearly associated with mealybugs in pineapple fields and, although not demonstrated to be associated with wilt, may have a role because they clearly tend mealybugs (G. Taniguchi, personal communication). The ant association with mealybugs involves protection from predation and parasitism, removal of excess honeydew, which increases mealybug mortality and movement of the mealybugs into new areas. Preventing the establishment of new ant colonies in new plantings is critical to preventing mealybug wilt (Rohrbach and Schmitt, 1994).

**Symphylids**

Symphylids are wingless, soil-inhabiting arthropods (6–10 mm in length), which are distantly related to insects. Whereas adult insects typically have six legs, symphylids have more than six legs in the adult stage (normally adults have 12 pairs of legs, with larvae having six or seven pairs) (Borror and De Long, 1971; Py *et al.*, 1987). Symphylid adults are white, with relatively long antennae projecting from the head. Several species are found in pineapple plantings: *Hanseniella unguiculata* (Hansen), *Hanseniella ivorensis* Juberthie Jupeau and Kehe, *Scutigerella sakimurai* Scheller, and *Symphyrella tenella* Scheller (Carter, 1967; Py *et al.*, 1987; Waite, 1993). Previously, some species were misidentified as being pineapple pests: *Hanseniella caldaria* (Hansen), *Symphyrella simplex* (Hansen), and *Scutigerella immaculata* (Newport) (Carter, 1967). Additionally, Carter reports that, in Hawaii, *S. tenella* is basically a scavenger, while *H. unguiculata* is a root feeder. *S. sakimurai* tends to be less common.

These organisms are blind, avoid the light, absorb water from their environment and typically move through the natural cracks and crevices found in soils (Py *et al.*, 1987). Symphylids are only important in specific areas that are favourable to their reproduction and survival (Py *et al.*, 1987). They proliferate in well-aerated soils with high organic-matter content. They are most

Fig. 9.16. Pineapple root system showing soil sticking to reniform nematode egg masses (arrow) and the lack of secondary roots.
common in volcanic calcareous tufa or gravelly soils possessing a high percentage of clay. Easily compacted, sandy and clayey–sandy clay soils do not usually support large symphylid populations. Soil temperature influences daily movement of symphylids in the soil, whereas soil humidity affects seasonal migrations to more humid areas. These organisms may survive for up to 4 months without food if the humidity is suitable. They are also cannibalistic if their preferred foods are absent.

Those symphylids that are important pineapple pests feed on plant root tips and hairs (Carter, 1963; Py et al., 1987). Injury from their feeding disturbs the roots' abilities to absorb nutritive elements, which depresses plant growth and development (Plate 27). Where they do damage crops, they can cause dramatic yield decreases (Lacoeuilhe, 1977; Kehe, 1979). They have their greatest impact where soil humidity is a limiting factor, and plants cannot recover from the inflicted injury even if symphylid feeding is curtailed.

Depending on the age of a plant, different effects will be observed from symphylid feeding on roots. Usually, younger roots in the meristem region are preferred. Feeding on these tissues can lead to the formation of a ‘witches’ broom’ appearance in the roots (Kehe, 1979). Long-term feeding on the roots can make the root tips appear clublike. If feeding is intense on very young plants when roots are just emerging (within the first 2 months of planting), the roots will not grow more than a few centimetres. Where intense feeding occurs, roots will have a ‘bushy’ appearance around the stem base, have poor anchorage (an element of crop logging) (see page 144, Chapter 7, this volume) and not function efficiently (Kehe, 1980). Plants may lodge due to the lack of root support. Symphyllids may also be problematic 4–5 months after planting when a second flush of roots appear (Kehe, 1979). Symphylid-inflicted injury to the roots may also provide entrance to ‘wound’ pathogens, which can destroy the root (Sakimura, 1966).

Approved insecticidal controls (e.g. lindane) applied at planting are the best management tool at present available for symphylids (Py et al., 1987). If an infestation is verified, action should be taken to reduce symphylid densities, especially when roots are flushing. Very dry and wet periods do limit symphylid growth, but at other times are suitable for reproduction and survival (Py et al., 1987).

**White grubs**

The white grubs (i.e. larval stage) of several beetle species in the family Scarabaeidae commonly infest the roots of pineapple plants. Scarab species reported feeding on pineapple roots include, in Australia: the southern one-year canegrub (also known as rugulose canegrub, nambour canegrub), *Antitrogus mussoni* (Blackburn), Christmas beetle, *Anoplognathus porosus* (Dalman), *rhopaea canegrub*, *Rhopaea magnicornis* Blackburn, squamulata canegrub, *Lepidiota squamulata* Waterhouse (= *Lepidiota darwini* Blackburn, *Lepidiota leai* Blackburn, *Lepidiota rugosipennis* Lea), noxia canegrub, *Lepidiota noxia* Britton, and *Lepidiota gibbonis* Britton (Waite, 1993); in South Africa: *Adoretus ictericus* Burmeister, *Adoretus tessularius* Burmeister, *Trochalus politus* Moser and *Macrophylla ciliata* Herbst; and in Hawaii: Chinese rose beetle, *Adoretus sinicus* Burmeister, and *Anomala* beetle, *Anomala orientalis* Waterhouse (Carter, 1967). The species *Heteronychus arator* (Fabricius) is found in Africa and Australia, where it is referred to by the common names black maize beetle (Petty, 1976a) and African black beetle (Waite, 1993), respectively. The species above vary in the levels of damage they cause to pineapple. Additional scarab species that attack pineapple may also exist in these areas and other locations where pineapple is grown. Scarabs are not limited to pineapple in their feeding habits and may attack a wide range of plants. The various species of beetles can be separated in both the larval and adult stages by morphological characters on the body (Carter, 1967; Petty, 1977a).

In most cases, adult scarabs do not significantly damage the pineapple plant, if at all. Many species do not feed on pineapple plants as adults. However, exceptions do
exist, such as the adult stage of *H. arator* which occurs in Australia, New Zealand and South Africa (Waite, 1993; Petty, 1977a) and bores into the lower stems of the pineapple plant. Adults of *A. sinicus* in Hawaii may riddle or completely destroy pineapple leaves, while the larvae rarely attack the roots (Carter, 1967). Fortunately, adult *A. sinicus* infestations are typically spotty in an area. On the other hand, adults of *A. orientalis* typically remain in the soil and lay their eggs in the vicinity of where they developed (Carter, 1967).

Adult scarab females are free-flying and choose the locations where they will lay their eggs in moist soil. Egg deposition preferences for soil conditions and type vary among scarab species (Waite, 1993). Eggs are oval in shape and, after hatching, the first-instar larvae feed on organic matter in the soil. Older scarab larvae develop within the soil among the roots of their host plants (e.g. pineapple). They feed upon organic matter within the soil as well. Although white grubs are not immobile, they do not disperse far from where the eggs were laid. White grubs are easily identified by their white or ivory-coloured, ‘C’-shaped bodies, which are soft and plump. The posterior quarter to third of the larval abdomen is commonly a dark blue-grey colour, due to the contents of the digestive system. Grubs have three pairs of legs near their anterior end and a tan to dark brown head capsule (Waite, 1993). They may injure pineapple plants by: (i) feeding on the roots, which interferes with nutrient and water uptake and transport (Carter, 1967; Petty, 1978a; Waite, 1993); (ii) weakening or destroying the roots that anchor the plants in the soil (Waite, 1993); and (iii) wounding plant tissues, which enables secondary plant pathogens to enter the plant (Carter, 1967). If infestations are severe, a crop may be lost, especially in the ratoon crop (Waite, 1993). The length of the scarab developmental cycle varies among species and climatic conditions, but generally they grow slowly compared with most insect pests and may require 1–2 years to complete development to the adult stage (Waite, 1993).

Recognition of white-grub infestations is difficult until significant injury to pineapple plants becomes obvious, commonly in the ratoon crop (Waite, 1993). Plants may become stunted, wilted and chlorotic (Petty, 1978a). Severely affected plants are easy to pull out of the ground (Waite, 1993). Additionally, pathogens, such as *Pythium* fungus and root-knot nematode, may infect the plant (Carter, 1967). Areas designated for pineapple plantings should be inspected for the presence of white grubs prior to planting the seed crop. Larvae in the soil may be uncovered using a spade or found during cultivation of the soil (Waite, 1993). Adult beetles may be monitored using light traps (Petty, 1977a). Thorough cultivation of the soil will reduce white-grub populations. A preplant soil treatment with long-term residual activity is appropriate for areas where white grubs are historically a recurring problem (Waite, 1993). Given the long production cycle of pineapple (i.e. seed crop and ratoon crops), the long-term effectiveness of chemical soil treatments is limited. Discoveries of white-grub infestations after planting are problematic because of the difficulty in controlling them. Delivery of chemicals to the insects is a challenge. Natural enemies of these pests do exist (insect predators, parasitoids and pathogens, as well as birds, toads, wild pigs and rodents), but the levels of control are not typically adequate (Carter, 1967; Petty, 1976b). Petty (1976b) reviews other control methods, but none appear overly successful or practical.

### Scales

Pineapple scale, *D. bromeliea*, varies in its impact on pineapple. In some places (e.g. Australia), it does not typically reduce fruit yield directly, but affects fruit appearance so that the value is reduced (Waite, 1993). In other places (e.g. Hawaii, South Africa, etc.), high scale densities kill plants (Carter, 1967; Petty, 1978b; Py et al., 1987). Scales normally occur on leaf undersides but may be found on the upper leaf surfaces if plants are shaded. Yellow spots may develop on leaves when scale densities are low. Scales have their greatest impact on the ratoon crops, where suckers and fruit may be damaged if
shaded. Heavy pineapple scale infestations may weaken and stunt plants, producing a grey appearance and foliage dieback. Scale infestations may be found on the bottom eyes of mature fruit and all over lodged ratoon fruit (Waite, 1993). Cracks between fruitlets may develop when fruit are highly infested (Linford et al., 1949; Py et al., 1987). Volunteer plants that emerge next to ratoon plants may exhibit high scale densities.

In addition to chemical controls, this pest may be biologically controlled by natural enemies (Waite, 1993). Tiny wasps, including Aphytis chrysomphali (Mercet), Aphytis diaspidis (Howard) and Aspidiotiphagus citrinus (Craw) (Hymenoptera: Aphelinidae), parasitize the scales, resulting in scale death (Zimmerman, 1948). Ladybirds, such as Rhzobius lophanthe (Blasid. and Telsmis nitida (Chapin (Coleoptera: Coccinellidae), also prey upon the scales (Carter, 1967; Waite, 1993). Routine monitoring programmes should be implemented to detect pineapple scale throughout the crop cycle (Waite, 1993).

Other scales have been reported infesting pineapple but these are not normally a problem. The brown (or red) pineapple scale, Melanaspis bromeliae (Leonardi), is similar in appearance to D. bromeliea (pineapple scale), but it is a chocolate-brown colour with an elevated centre (Carter, 1967). The Boisduval scale, Diaspis boisduvalii (Signoret), may be found on numerous plant hosts and has been reported in Latin America, West Africa, Hawaii, Sri Lanka and Taiwan (Py et al., 1987). Nigra scale (also known as black-coffee scale), Parasaissetia nigra (Nietner), may be found on pineapple (Zimmerman, 1948).

**Rutherglen bug and grey cluster bug**

The Rutherglen bug, Nysius vinitor Bergroth, and the grey cluster bug, Nysius clevelandensis Evans (Hemiptera: Lygaedae), are found in most production areas where pineapple is grown, except Hawaii (Waite, 1993). These insects are similar in appearance. They are 4 mm in length in the adult stage, have narrow bodies and two pairs of transparent, shiny wings and are attracted to lights. The adults may lay as many as 400 eggs on the flowers and seeds of their crop hosts and weeds. Eggs hatch about 7 days after deposition. The immature nymphs are wingless and pass through five developmental stages (instars) before becoming adults, in about 4 weeks. If their food source diminishes prior to reaching the adult stage, the nymphs may crawl about 99 metres in search of acceptable plant hosts. Pineapple is not one of their preferred host plants (Waite, 1993).

These insects typically increase in numbers in the springtime, and that is when they are a problem (Waite, 1993). Populations initially develop in weeds during the winter and move into pineapple as weeds die off. Rutherglen bugs may be visible on roadside weeds before moving into pineapple plantings. The bugs suck sap from pineapple leaves, which exhibit severe yellow spotting (almost blistering) of the leaf surface. Under severe feeding pressure, leaves may wilt and die. Damaged fruit may exhibit gummosis.

Weather can have an impact on bug populations, and chemical controls are not normally needed (Waite, 1993). High densities are generated during periods of wet winters and hot, dry springs. However, heavy rains can decimate populations.

Good control of host weeds reduces the chances for problems from these bugs (Waite, 1993). Crops should be routinely monitored for these species, especially if large numbers of adult bugs are attracted to house lights at night in the area. Severe infestations may be suppressed with conventional insecticides (Waite, 1993).

**Root rots**

Root rots may be caused by Phytophthora cinnamomi and various Pythium species, with Pythium arrhenomanes Drechs. as the most common (Klemmer and Nakano, 1964). Initial symptoms are a reduction or elimination of growth, with subsequent reddening of the leaves, the leaf margins turning yellow and eventually becoming necrotic. With P. cinnamomi, which causes heart and root rot, the root-rot phase results in reduced plant
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Growth and yields and, in cooler environments, can result in a total loss of the ratoon crop. Root-rot symptom development is relatively slow in comparison with heart-rot symptoms. Disease from both pathogens is most severe when soils are cold and poorly drained. If environmental and soil conditions become dry following the infection period, affected plants may appear reddish, as if under severe drought stress. Plant anchorage in the soil is very poor following loss of roots.

**Early root-health management**

With the discovery of the soil fumigant 1,3-dichloropropene, 1,2-dichloro-propane, (DD mixture) pineapple nematodes were easily and economically controlled during the early stages of pineapple plant growth (Carter, 1943; Keetch, 1979; Johnson and Feldmesser, 1987; Caswell and Apt, 1989). Today, early nematode control is accomplished by clean fallow, preplant soil fumigation with dichloropropene at 224–336 l ha⁻¹ (Fig. 9.17) and postplant application of an approved nematicide (e.g. fenamiphos and oxamyl) by broadcast sprays or drip irrigation (Fig. 9.18; Rohrbach and Apt, 1986; Caswell et al., 1990). Effective soil fumigation requires good plant-residue management and soil preparation (Fig. 9.19). The discovery and use of the inexpensive DD control may have affected the development of other methods of nematode management for pineapple, such as cover crops, crop rotation and host-plant resistance. Crop rotations and resistance have been examined but not researched in depth or used (Caswell and Apt, 1989; Caswell et al., 1990). The root-knot, reniform and root-lesion nematodes have relatively large host ranges. Thus, crop rotations are of value only if crop susceptibilities are known.

Root rots are controlled by improving soil water management, including raised beds, deep cultivation and improving surface-water drainage. The fungicide fosetyl aluminium has shown good control of *P. cinnamomi* root rot (Rohrbach and Schenck, 1985). The soil fumigant mixture of DD (Telone) was shown to reduce root rot caused by *P. arrhenomanes* (Anderson, 1966).

Mealybug wilt is readily managed by controlling ants, which tend and protect mealybugs, with an approved insecticide bait (e.g. hydramethylnon) (Rohrbach et al.,

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**Fig. 9.17.** Nematode control using preplant soil fumigation under plastic mulch.
Heart rot can be caused by *Phytophthora nicotianae* B. de Haan var. *parasitica* Dast. Waterh., frequently called *Phytophthora parasitica* Dast. in the pineapple literature, *P. cinnamomi* Rands and *Phytophthora palmivora* (Butler) Butler. Heart-rot symptoms are the same, regardless of the *Phytophthora* species causing them. The most widely distributed species are *P. cinnamomi* and *P. nicotianae* B. de Haan var. *parasitica* (Rohrbach, 1983; Rohrbach and Apt, 1986). *P. palmivora* probably has a much more limited distribution (Boher, 1974; Rohrbach, 1983). Descriptions of the three pineapple pathogens can be found in Waterhouse (1963) and there is a useful key to identification in Newhook and Stamps (1990).

As pathogens of pineapple, *P. nicotianae* var. *parasitica*, *P. palmivora* and *P. cinnamomi* are not normally found together. *P. nicotianae* var. *parasitica* and *P. palmivora* are found at lower elevations in Hawaii and in the lowland tropics, where optimum temperatures for disease development are in the range of 25–36°C. In contrast, heart rot from *P. cinnamomi* is found under cooler conditions, such as the higher elevations of Hawaii and the cooler pineapple-production areas, such as Australia, where optimum soil temperatures for disease development are 19–25°C.

An initial heart-rot symptom is the failure of the young leaves to elongate. Later symptoms are yellowing to bronzing of the young leaves, which may then lean to one side of the plant (Fig. 9.20). A slight pull on the young symptomatic leaves will remove them from the plant, confirming the presence of the disease. *Phytophthora* infections are limited to the stem and basal white portion of the leaves.

The primary inoculum of the three *Phytophthora* species is chlamydospores, either alone or in infested plant debris in the soil, where they can survive for years. Chlamydospores of *P. cinnamomi* have been quantified in pineapple soils by sieving (McCain et al., 1967). Inoculum levels of five to ten chlamydospores per gram of soil have resulted in approximately 100% infections in non-pineapple hosts (Mitchell and Kannarischer-Mitchell, 1983). Sporangia produced from chlamydospores can be dissemi-
nated by splashing soil or by aerial wind dispersal. Infection by zoospores of *P. nicotianae* var. *parasitica* is most common through the leaf axils of the crown during the first 3–4 months following planting (H. Klemmer, unpublished results). Infection by *P. cinnamomi* is mostly through the roots, progressing up the root to the stem apex, causing the heart-rot symptom. With *P. cinnamomi*, germinating chlamydospores or zoospores from sporangia primarily infect root tips. Infection may also occur through the leaf axils. Little evidence exists for secondary spread from infected crowns (Chellemi et al., 1988).

Very little is known about the effects of soil moisture on infection. Infection by *P. nicotianae* var. *parasitica* is probably less dependent on high moisture than that by *P. cinnamomi* (Hine et al., 1964). In citrus, the duration of saturated soil conditions is more important than the frequency. High soil moisture (poor drainage) increases infection by *P. cinnamomi* but also reduces root growth. H. Klemmer (unpublished results) claimed that infections in the field can take place through leaf axils from soil splashed there and moisture from dews. Soil moistures below 15% reduce germinability of *P. cinnamomi* chlamydospores (McCain et al., 1967).

**Fig. 9.19.** Good (left) vs. poor (right) soil preparation prior to fumigation. Poor soil tilth with large clods results in significant loss of soil fumigant and ineffective nematode control.

**Fig. 9.20.** *Phytophthora* heart rot caused by *Phytophthora nicotianae* var. *parasitica*. 
Bacterial heart rot

Bacterial heart rot of pineapple is caused by the facultative anaerobe *E. chrysanthemi* Burkh. *et al.* The disease was first reported in Malaysia but has more recently been reported in Costa Rica (Chinchilla *et al.*, 1979), Brazil (Melo *et al.*, 1974), and the Philippines (K.G. Rohrbach, personal observation). The disease is of major importance in Malaysia but not as important as fruit collapse, caused by the same organism. Recently the disease has become a major problem in the Philippines (K.G. Rohrbach, personal observation).

In Malaysia, bacterial heart-rot incidence varies from 0 to 10% in the ‘Singapore Spanish’ cultivar and is as high as 30% in the ‘Gandul’ cultivar (Lim, 1985). Incidence in the ‘Smooth Cayenne’ cultivar is less because it is more resistant than the ‘Spanish’ types. Because the plant usually survives infection, the economic loss is attributed to ‘out-of-cycle’ fruiting on the lateral shoot, which arises from the remaining stem tissue. In mechanized production systems, this ‘out-of-cycle’ fruit is usually lost.

*E. chrysanthemi* is a pathogen of a wide range of plants in the tropics and subtropics. This may be due to its ability to grow at higher temperatures than the other soft-rot bacteria. Virulence is related to the ability of *E. chrysanthemi* strains to produce large quantities of endopolygalacturonic transeliminase (Perombelon and Kelman, 1980).

Bacterial heart rot is characterized first by a water-soaked lesion on the white basal portion of the leaves of the central whorl. The infection may spread to include the entire basal portion of all leaves of the central whorl. Spread may occur into the green midportion of the leaves, resulting in an ‘olive-green’ leaf colour and a bloated appearance (Plate 28). If the infection of the green portion of the leaf is arrested, a dark infection border forms (Lim, 1985). Symptoms of fungal heart rots can be distinguished from those of bacterial heart rot by the absence of extension of the infection into the mature green areas of the leaf (see Plate 28).

The main source of inoculum is thought to be infested juice from collapsed fruit. Infested seed material is probably not a major source of spread because bacteria do not survive long on leaf surfaces (Lim, 1985). According to Lim (1985), infection takes place through the stomata and the bacteria can be transmitted to the infection site by insects, most commonly ants (the big-headed ant and the Argentine ant), and by wind and wind-blown rain. Souring beetles (*H. ocularis* and *Carpophilus foveicolli*) have also been shown to be vectors, but are of minor importance (Lim, 1985). In the Philippines, the pineapple tarsonemid mite, *S. ananas*, has been associated with bacterial heart rot. Feeding by the mite probably produces wounds, because mechanical wounding is observed to increase disease (K.G. Rohrbach, personal observation). In Australia, urease in dirty water breaks urea down to NH₄OH, which causes burn and provides a point of entry for the bacteria (D. Bartholomew, personal communication). Plants that are 4–8 months old appear to be the most susceptible to infection. The plant crop is also more susceptible than the ratoon (Lim, 1985). Susceptibility appears to be related to the rate of plant growth, because low leaf water status slows the rate of infection (Perombelon and Kelman, 1980). When environmental conditions are optimum for disease development, the entire disease cycle may occur in 1–2 weeks (K.G. Rohrbach, personal observation).

Management of heart rots

Prior to the development of modern fungicides, any method of improving soil drainage was used to reduce disease. Raised beds, ranging from a few centimetres to 25 cm or more, have been used. Improvements in surface drainage, whereby depressions are drained by cutting of ditches or filling to eliminate standing water, have reduced disease levels (Pegg, 1969). Cultural practices such as pineapple-trash mulch have generally, but not always, increased disease incidence.

The addition of elemental sulphur to soil decreased heart rot when the soil bacteria *Thiobacillus* was present to oxidize the sulphur (Pegg, 1977). The addition of sulphur drastically lowers soil pH (below 3.8), which results in reduced sporangial formation and
an explosion of *Tricoderma* sp. Various copper fungicides have been tried for heart-rot control, but, due to the sensitivity of pineapple to elemental copper, have not been used.

Early organic fungicides used for heart-rot control were fenaminsulf (Dexon®), captan and the dithiocarbamates (Pegg, 1969). More recently captafol (Difolatan®), metalaxyl (Ridomil®) and fosetyl aluminium (Allette®) have been used (Rohrbach and Schenck, 1985). Currently, fosetyl aluminium is used very effectively as a preplant dip at rates of 2.24 kg active ingredient (a.i.) 935 l⁻¹ (see Fig. 9.13). Initial control from the preplant dip can be extended by foliar applications with rates of 6.72 kg ha⁻¹ in 2805 l of water at intervals of 3–6 months. Because fosetyl aluminium acts systemically in the pineapple plant, excellent control of *P. cinnamomi* root rot can be obtained (Rohrbach and Schenck, 1985; Rohrbach and Apt, 1986).

The active ingredient of fosetyl aluminium is phosphorous acid, which will result in comparable control to the parent material (Rohrbach and Schenck, 1985). In Australia, a formulation of phosphorous acid (Phos-folpine® or Fosjet 200®) is used. Because many growers do not have dipping equipment, preharvest sprays are used to systemically protect crowns for planting following fruit harvest (D. Bartholomew, personal communication).

The fungicide metalaxyl has also been shown to be very effective for heart-rot control as a preplant ‘seed-piece’ dip (Rohrbach and Schenck, 1985). Postplant foliar applications of metalaxyl, although effective, have not been recommended or registered because of the possibility of development of resistant strains of *Phytophthora*.

Several cultivars resistant to *Phytophthora* were developed at the Pineapple Research Institute of Hawaii (PRI). The cultivar designated ‘53–323’ with resistance to *P. cinnamomi* was a cross between ‘Smooth Cayenne’ and F-236. F-236 was an introduced native variety from Columbia called ‘Pina de Castilla’, which was collected for PRI by Harold St John. The cultivar ‘53–323’ is highly resistant to *P. cinnamomi* but highly susceptible to *P. parasitica*. A second cultivar, designated ‘59–656’, is resistant to both *P. cinnamomi* and *P. parasitica*. Both cultivars have fruit characteristics and quality similar to those of ‘Smooth Cayenne’ and yields at least equal to ‘Smooth Cayenne’ when that variety is grown without occurrence of heart rot or root rot (Pineapple Research Institute of Hawaii, unpublished results).

Sanitation is an important factor in preventing initial low incidences of bacterial heart rot from causing an epidemic. Infected plants should be destroyed or removed from the field, as they may provide a source for secondary inoculum. Crowns or slips from plants with symptoms of fruit collapse or from an area having high a incidence of fruit collapse should not be used as seed material. Mechanical leaf damage, such as occurs when entering a field for crop logging, should be minimized during periods of susceptibility and when low levels of disease are present (K.G. Rohrbach, personal observation).

Partial control of bacterial heart rot has been obtained with miticides (e.g. endosulphan) and insecticides in the Philippines (K.G. Rohrbach, personal observation). Bordeaux mixture has resulted in variable control (Lim, 1985).

In subtropical climates, where the disease is a problem, the resistant ‘Smooth Cayenne’ cultivar might be used rather than the much more susceptible ‘Spanish’ types (Lim, 1971). However, in the lowland tropics, ‘Smooth Cayenne’ is difficult to force and may have poor fruit quality, thus limiting its use.

**Yellow spot (tomato spotted-wilt virus)**

Yellow spot of pineapple occurs in all production areas of the world, with the exception of peninsular Malaysia (Lim, 1985). Infection by the tomato spotted-wilt virus always kills the pineapple plant. Therefore, vegetative propagation does not transmit the virus to subsequent plantings (Rohrbach and Apt, 1986).

Pineapple yellow-spot disease, caused by the tomato spotted-wilt virus, was first observed in Hawaii as a distinct disease in 1926 (Illingworth, 1931). During the next 4 years, the disease spread and became a serious problem, with considerable rotting of fruits in the field.

The initial symptom is a slightly raised
yellowish spot, with a darkened centre, on the upper surface of the leaf. Shortly after formation of the initial spot, a characteristic chain of secondary spots develop and progress into a basal leaf and stem rot. Frequently, particularly on young plants, the rotting and cessation of growth on one side of the stem cause the plant to bend severely, eventually killing the entire plant (Plate 29). The disease can occur on the developing crown, with the rot progressing into the fruit and frequently causing distortion of the fruit (Illingworth, 1931).

Infection occurs most frequently on pineapple plants during early growth. On occasion, crowns on developing fruit may also become infected (Linford, 1943). The transmission of the yellow-spot virus by the onion thrips, *Thrips tabaci* (Lindeman), was shown in 1932 by Linford. Pineapple is not a preferred host of thrips, but the thrips still move into pineapple fields from adjacent weed hosts and probe the plants, leaving the virus in the tissue (Linford, 1932). Later, the yellow-spot virus was shown to be identical to the tomato spotted-wilt virus (Sakimura, 1940).

**Thrips**

As many as 39 species of thrips have been reported worldwide in and around pineapple fields (Sakimura, 1937; Carter, 1939; Petty, 1978d). Wind currents may carry many individuals of these species from their host plants (e.g. domestic crops, ornamentals, weeds) into adjacent pineapple plantings (Carter, 1939). However, most of the thrips do not normally feed or reproduce on pineapple. Sakimura (1966) only reports six thrips species commonly living within Hawaiian pineapple plantings. These include the onion (or potato) thrips, *T. tabaci* (plant feeder), leaf thrips, *Frankliniella sulphurea* Schmutz (flower feeder), *Thrips hawaiiensis* (Morgan) (flower feeder), *Aleurothrips fasciapennis* (Franklin) (predator on scales), *Haplothrips melaleucus* (Bagnall) (predator on scales) and *Haplothrips goodeyi* (Franklin) (flower feeder). Species reported as vectors of tomato spotted-wilt virus, which causes yellow spot on pineapple, are the onion thrips and the common blossom thrips (also known as kromnek thrips, cotton-bud thrips, yellow-blossom thrips), *Frankliniella schultzei* (Trybom) (Sakimura, 1963; Petty, 1978d). Py et al. (1987) state that one of the vectors of yellow spot, the tobacco thrips, *Frankliniella fusca* (Hinds), is established in Hawaii (based on a reference by Sakimura, 1966) but this is incorrect (D. Tsuda, personal communication). Additionally, the western flower thrips, *Frankliniella occidentalis* (Pergande), is established in Hawaii (as indicated by Py et al., 1987), but has not been reported as a vector of yellow spot on pineapple.

Pineapple yellow spot can be controlled by maintaining a weed-free production system to eliminate the weeds that serve as virus reservoirs. Adjusting the timing of operations of adjacent crops as well as pineapple to minimize the movement of thrips vectors into the pineapple fields aids in the reduction of inoculum (Rohrbach and Apt, 1986).

**Three Months to Forcing**

**Weeds**

Depending on weed species present and rainfall during the first 3 months of growth, a second broadcast spray may be applied (e.g. diuron, ametryne). Most weed problems during this period are escapes from the initial application at planting and the 3-month application. Escapes are usually controlled by spot applications (Glennie, 1991).

**Nematodes**

The root-knot nematode may cause significant root damage during the first few months of root growth. Initial infections occur at the root tip in the meristematic region and result in termination of growth of the primary root. Unless plants are subjected to water and/or severe nutrient stress, above-ground symptoms of early nematode infection will not be evident (Caswell et al., 1990). Severely infected plants can be pulled from the soil and terminal galls will be evident on primary roots.

Root infection by the reniform nematode does not cause termination of primary root
growth, as does root knot, but affects secondary root growth. Thus, symptoms of reniform infection will not become evident until 6 or more months of growth and again only under water and/or nutrient stress (Caswell et al., 1990).

In Australia, yield losses occurred where root-knot nematodes were detected from 9 to 15 months following planting, suggesting that sampling may be important in determining the need for postplant nematicide applications (Stirling and Nikulin, 1993). While soil sampling during plant growth (to estimate nematode populations) should be important for nematode management, in practice postplant nematode control is frequently applied as ‘insurance’, based on qualitative data, along with historical yield and nematode population information. The non-volatile nematicides, such as oxamyl and fenamiphos, may be applied postplant as foliar sprays or through drip irrigation systems (Caswell and Apt, 1989).

**Ants and mealybugs**

Where adequate mealybug biological controls exist (see section above on mealybugs), controlling ants results in control of mealybugs and therefore mealybug wilt. Mealybug wilt is readily managed by controlling ants with an approved insecticide bait (e.g. hydramethylnon) (Rohrbach et al., 1988). Baits are primarily applied to field borders and only inside fields when ants have become established. The use of bait stations in an IPM approach to control increases the efficiency of insecticide use and reduces the environmental effects (G. Taniguchi, personal communication).

### Forcing to Flowering

Because of the anatomy and morphology of the pineapple inflorescence and fruit, a wide range of microorganisms can be found on the surface of the developing inflorescence and, following anthesis, inside the developing pineapple fruitlet (see Plate 30). Initially, the developing inflorescence is essentially sterile. As the inflorescence enlarges and extends out of the vegetative growing point or ‘plant heart’, the entire surface becomes contaminated with a multitude of microorganisms and fauna (Fig. 9.21) (K.G. Rohrbach, unpublished results).

**Fig. 9.21.** Commercial stages of pineapple inflorescence development denoted as 1.3 cm open heart, 2.5 cm open heart, early cone, mid-cone and late cone (left to right). Each stage is approximately 1 week’s growth from the previous one.
Fruitlet core rot, leathery pocket and interfruitlet corking

Three strains of *Penicillium funiculosum* have been reported associated with pineapple fruitlet core rot (FCR), leathery pocket (LP) and interfruitlet corking (IFC) and have been found on withered flowers, the plant heart, pineapple trash and insects and mites found in pineapple fields (Lim and Rohrbach, 1980).

The disease cycle of *P. funiculosum* starts with the presence and build-up of the pineapple tarsonemid mite, *S. ananas*, in the plant heart during growth. Mites feed on the developing trichomes on the basal portion of the leaf in the plant heart and on bracts and sepals of the developing flowers on the inflorescence. Mite populations peak at 6–7 weeks following forcing when the inflorescence is emerging (Plate 30; Fig. 9.21). The virulent strain (P1) of *P. funiculosum* must be present by 1 week following forcing in order to colonize the mite-injured trichomes and have sufficient inoculum potential to grow into the unopened flower. Infection occurs through the developing flower at 1–2 weeks prior to normal anthesis (Fig. 9.22; Rohrbach and Apt, 1986). The optimum temperature for infection is 16–21°C during the 6 weeks following forcing. Moisture does not appear to be critical during this period (Petty, 1978c). Following infection, the fungus develops in the internal flower parts.

*F. subglutinans* is a soil fungus, but, like *P. funiculosum*, may also colonize the heart of the growing pineapple plant. *F. subglutinans* may survive for up to 12 months in pineapple tissues. In contrast to *P. funiculosum* growing into the unopened flower, infection by *F. subglutinans* apparently takes place only through the open flower, although colonization in the heart of the plant and on the inflorescence must occur prior to open flower (Ventura et al., 1981).

Cultivars vary in their symptom responses to infection by *Penicillium* and *Fusarium*. In Hawaii, the ‘Smooth Cayenne’ cultivar generally has relatively low levels of FCR but high levels of IFC and LP from *Penicillium* infection. In contrast, the hybrid ‘53–116’ (‘NCGR No. 159’) has high LP and IFC but low FCR. The hybrid cultivar ‘58–1184’ (‘NCGR No. 160’) has very little IFC and high FCR, especially when infections are caused by *Fusarium*.

Mites

The pineapple tarsonemid mite, *S. ananas*, only infests pineapple plants (see Fig. 9.11; Jeppson et al., 1975). It occurs universally on...
the growing plant, developing inflorescence, fruit and crown. The pineapple tarsonemid mite is most abundant from just prior to flower induction (forcing) through the 12.7 mm and 25.4 mm open-heart stages of inflorescence development (see Fig. 9.21) and flowering. It is grey in colour and the body of the adult mite is oblong, 0.125 \times 0.25 \text{ mm} and flat. The life cycle is 7–14 days, depending on temperature. Pineapple tarsonemid mites feed on developing trichomes on the white basal-leaf tissue and flower bracts and sepals, causing light brown necrotic areas. Mites may also enter the infected flower and feed on internal flower parts. The young developing inflorescence cone seems to be the preferred feeding site (Petty, 1975, 1978c; Rohrbach and Schmitt, 1994).

Very high populations of pineapple red mite, *D. floridanus*, are always associated with epidemics of *Fusarium* fruitlet core rot in Hawaii (see Fig. 9.10; K.G. Rohrbach, personal observation). The association between the pineapple red mite and *F. subglutinans* FCR is not understood. No cause-and-effect association has been demonstrated.

Control of the pineapple tarsonemid mite is important to the control of *P. funiculosum*-induced FCR, LP and IFC. Endosulphan (Thiodan®) applications at 3 weeks prior to and 1–5 weeks following forcing have resulted in the best control of *P. funiculosum*-induced diseases (Le Grice and Proudman, 1968; Le Grice and Marr, 1970; Rohrbach et al., 1981). Petty (1990) also reported reductions in the incidence of disease symptoms (leathery pocket) caused by *P. funiculosum* following applications of the miticide endosulphan, which suppressed the pineapple tarsonemid mite in South African pineapple plantings. Jeppson *et al.* (1975) observed that species in the genus *Steneotarsonemus* are not typically controlled by sulphur but show great susceptibility to organophosphate acaricides or the halogenated thioether group.

**Flowering to Harvest**

The pineapple flower is a primary portal for the entrance of several fruit-disease pathogens (Fig. 9.23). At anthesis, openings occur via the stylar canals and nectary ducts into the locules and nectary glands, respectively. These openings become the primary sites for infection by the bacterial and fungal fruit-disease pathogens. The susceptibility of these infection sites depends on environmental conditions, as they affect the predisposition of the flower and the occurrence of the pathogen on the flower. Occurrence of the pathogen on the flower may be dependent on an insect vector or development of the pathogens on the inflorescence prior to anthesis.

The multiple requirements for flower infection are: (i) a means of getting the pathogen to the susceptible flower; (ii) a susceptible flower at the right time; and (iii) optimal environmental conditions for disease development for each factor. These multiple requirements have resulted in complex aetiologies and very sporadic occurrence of the fruit diseases.

**Pink-disease, fruit-collapse and marbling-disease bacteria**

*Pink disease*

Pink disease is of little importance in fresh fruit, but can be a very serious sporadic problem in processed fruit because of the lack of...
detection prior to canning. It was first reported in Hawaii by Lyon (1915) and is now known in Australia, the Philippines, South Africa and Taiwan (Rohrbach, 1983). Cultivars vary in their susceptibility (Rohrbach and Pfeiffer, 1975). At least three genera of bacteria have been reported to cause pink disease: Erwinia, Gluconobacter and Acetobacter (Rohrbach, 1976a; Kontaxis and Hayward, 1978). Species of the remaining genera are the acetic acid bacteria Gluconobacter oxydans and Acetobacter aceti (Plate 31; Cho et al., 1980).

Pink-disease bacteria are vectored to the pineapple flowers by insects and mites, probably attracted to the nectar. Honey-bees may play a role as important vectors of Gluconobacter and a lesser role for Acetobacter (Gossele and Swings, 1986). The nectar is thought to provide a nutrient source for the survival of the bacteria until they become latent in the nectary gland or stylar canal or locule. Gossele and Swings (1986) suggest that the bacteria may actually overwinter in honey-bee hives. Once the bacteria are inside the flower, they remain latent until the fruit matures, sugar concentrations increase and translucence occurs.

**Fruit collapse**

Bacterial fruit collapse, caused by *E. chrysanthemi* Burkh. *et al.*, is only economically important in peninsular Malaysia, although the bacteria have been reported elsewhere on pineapple (Melo *et al.*, 1974; Chinchilla *et al.*, 1979; Rohrbach, 1983). The disease is thought to be indigenous to Malaysia (Lim and Lowings, 1979b). The economic importance of fruit collapse in Malaysia is probably due to the use of the much more susceptible ‘Singapore Spanish’ cultivar (Lim, 1985).

Symptoms of fruit collapse usually appear on maturing fruit 2–3 weeks prior to normal ripening (Plate 32). Infected fruit are characterized by exudation of juice and release of gas, as evidenced by bubbles. Fruit shell colour becomes olive-green. Dissection of completely infected fruit shows only cavities within the skeletal fibres of the fruit (Lim, 1985). Bacterial fruit collapse is caused by *E. chrysanthemi* Burkh. *et al.*, and the initial inoculum comes from other infected fruit. Insects such as ants, beetles and flies, are vectors of the bacteria, transporting them to flowers from other collapsed fruit or from plants with bacterial heart rot. Ants, as well as other insects, are thought to be attracted to the nectar available there. Open flowers are the infection site where the bacteria enter the developing fruit. The bacteria remain latent in the ovary until 2–3 weeks before normal ripening when sugar levels begin to increase rapidly and polyphenoloxidase levels decline (Lim and Lowings, 1978).

**Marbling disease**

Marbling disease is a sporadically occurring pineapple disease of the hot, humid, lowland tropics. Symptoms include a brown granular appearance (Plate 33). Marbling disease is caused by the acetic acid bacteria *Acetobacter peroxydans* Visser ’t Hooft and *E. herbicola* var. *ananas* (Serrano) Dye. As in pink disease, infection by marbling bacteria occurs through the open flower (Rohrbach and Pfeiffer, 1974). Infection has also been reported within 7 weeks of harvest through growth cracks in the fruit (Yow and Wu, 1972), although this was not confirmed in Hawaii (Rohrbach, 1989). Speculation exists that the bacteria are vectored to the flowers by insects, as in pink disease (Serrano, 1928). The fact that application of surfactants prior to and during flowering significantly increases disease in Hawaii without inoculation indicates that the bacteria are ubiquitously present on the plant and that the limiting factor is whether they get into the flower. Once in the flower, as with pink disease, they apparently remain latent until approximately 1 month before fruit maturity. Symptoms develop during the last month of fruit maturation (Rohrbach, 1989).

**Management of bacterial diseases through flowering to harvest**

Pink disease has been controlled with insecticides, which are thought to control insect
vectors. Where pink disease occurs sporadically, insecticide applications have not been economic. In the Philippines, where pink-disease epidemics are seasonally predictable, pink disease has been controlled with applications of disulphoton. Disulphoton at 0.83 kg a.i. ha$^{-1}$ per application starting at the red-bud stage and with three additional applications at 5-day intervals (throughout flowering), has resulted in the highest level of control (Kontaxis, 1978).

Applications of ethephon to inhibit flower opening and reduce nectar flow have resulted in partial but significant control of fruit collapse (Lim and Lowings, 1979a) and pink disease (K.G. Rohrbach, unpublished results). Forcing plantings, so that flowering does not coincide with fruiting in adjacent plantings, which may have fruit collapse, can reduce disease development. Applications of Bordeaux mixture have resulted in variable control (Lim, 1985). Any treatment that reduces bacterial heart rot may reduce primary inoculum levels for flowering plants. Sanitation is an important factor in initial low incidences of fruit collapse. Infected plants and fruit should be destroyed or removed from the field, as they may provide a source for secondary inoculum.

Currently, no known controls of marbling exist. When epidemics occur, infected fruit can be detected and excluded prior to going through the cannery by external appearance and a test to measure fruit firmness, such as sticking a knife into the fruit. If incidences are extremely high, all fruit must be discarded. In contrast to pink disease, infected fruit tissues that are not discarded before processing can be discarded before packing in cans.

**Lepidopterous stem and fruit pests**

*Bud moth, pineapple borer*

The bud moth (also known as pineapple borer, pineapple caterpillar), *Thecla basilides* (Geyer), is found throughout Central and South America wherever pineapples are grown (Py *et al.*, 1987; Sanches, 1999). While *Thecla* is a tropical species, it could cause problems if imported into the southern USA, particularly Florida, because it has been observed to feed on maize, cacao, *Heliconia* and several other bromeliads (Rohrbach, 1983).

The adult stage of the bud moth deposits its eggs on the inflorescence prior to anthesis. The larva infests the fleshy parts of the bracts and feeds inside the developing inflorescence. Buds and open flowers are entered directly, with larvae penetrating developing fruit and digging out holes of varying depths. This results in malformed fruit, which is unmarketable (Py *et al.*, 1987). In response to the actions of the larvae, the pineapple fruit forms an amber-coloured gum (gummosis), which exudes and hardens on contact with the air (Fig. 9.24). This resembles the resin exuded by pine trees (sometimes called ‘resinous’ by Brazilians). When secondary infections are due to *F. moniliforme* var. subglutinans, the exudate is more fluid and glassy, characteristic of fusariosis disease. The pathogen can penetrate the
inflorescence without the bud-moth larva, but the bud moth makes it easier to do so. Adult bud moths may help disperse the pathogen when visiting healthy plants after visiting diseased ones. Following a 13–16-day feeding period, the larvae emerge and pupate in the leaf axils. Control with insecticides is relatively easy if flowering is uniformly induced with forcing agents. Predators exist in Trinidad, including the vespid wasp *Polistes rubiginosus* Lepeletier and a predator of larvae, *Heptamicra* sp. Another predator reported is *Metadonta curridentata*. No organized biological-control campaign has been undertaken for the bud moth (Py et al., 1987).

**Fruit-piercing moth**

There are numerous species (> 90) of moths in the lepidopteran family Noctuidae in which the adult stage (i.e. moth) pierces many types of fruit with a specially adapted proboscis (Banziger, 1982). The well-known pest called the ‘fruit-piercing moth’, which attacks pineapple, is *Eudocima (= Othreis) fullonia* (Clerck) (also known as *Ophideres fullonica* L.). It does not limit its adult feeding to pineapple and may attack numerous fruits (e.g. oranges, guavas, star fruit, mangoes, bananas, coffee, passion-fruit, lychee, etc.) if available (Waterhouse and Norris, 1987). It may be found in many areas where pineapple is grown (Australia, Asia, Hawaii). The larval stages of the moth do not feed on pineapple, and outside the Pacific Basin they attack at least 30 species of creepers belonging to the plant family *Menispermaceae*. Within the Pacific Basin, the larvae are normally found feeding on coral trees in the genus *Erythrina* (Fabaceae) (Cochereau, 1977). They may be found on a creeper, *Stephania foresteri*, which is now rare in New Caledonia. The larval stages feed on the foliage of their host plants, where the yellowish green eggs are also laid. An individual female moth may lay as many as 750 eggs, either singly or in batches of up to 100–200 eggs (Waterhouse and Norris, 1987). Several generations are possible during a year.

Injury to fruit is caused by strongly sclerotized appendages (maxillae) at the end of the approximately 25.4 mm proboscis. The tips of the maxillae are equipped with a series of teeth and spines, which enable the adult moth to rasp a hole through the tough skin of the pineapple fruit. The act of piercing the fruit requires little time, from several seconds to a few minutes (Cochereau, 1977).

Controlling *E. fullonia* is difficult, with pesticides normally being ineffective, since the larval stages of the pest are not within the pineapple crop. Pesticides applied to the ripe fruit can also cause human-health concerns, due to the presence of toxic residues (Waterhouse and Norris, 1987). Several approaches have been tried for the control of fruit-piercing moth, but none are especially effective or, if so, they are impractical or expensive to implement. These include use of poison baits for control of the adult stage; confusing searching adults by masking fruit volatiles in orchards with smoke; use of potential repellents; orchard sanitation to reduce quantities of decaying or fallen fruit; early harvest of fruit; hand-capturing and killing of moths; bagging of fruit; using floodlights to disrupt moth flight behaviour; and eradication of host plants (Baptist, 1944; Cochereau, 1972a; Banziger, 1982). Where natural enemies exist and conditions are favourable, biological control has proved effective in New Caledonia (Cochereau, 1972b, 1977). Natural enemies include parasitoids and predators of eggs and larvae, as well as a fungal disease of the eggs (*Fusarium* sp.). Egg parasitoids in the genera *Ooencyrtus* (Hymenoptera: Encyrtidae) and *Trichogramma* (Hymenoptera: Trichogrammatidae), as well as the larval–pupal parasitoid *Winthemia caledoniae* Mesnil (Diptera: Tachinidae), are excellent candidates for introductions into areas where biological control of the pest is poor. Additionally, reduction in the abundance of the larval host plants could help suppress adult numbers within an area (Waterhouse and Norris, 1987).

**Giant moth borer**

The giant moth borer, *Castniomera (= Castnia) licus* (Drury) (Lepidoptera: Castniidae), is found in South America (e.g. Brazil), where it is a minor pest of little economic conse-
quence on pineapple (Collins, 1960). The mature larvae of this species live up to their common name and are about 7.6 cm in length. Larvae may enter the stem of the pineapple plant and burrow vertically into the peduncle, which supports the fruit. This action disrupts fruit production (Collins, 1960). Adult moths have a wing spread of about 12.7 cm.

**Pineapple stem borer**

An additional lepidopterous pineapple stem borer, *Castnia penelope* (Schauffuss) (= *Castnia icarus* (Cramer)) (Lepidoptera: Castniidae), is reported to occur in several localities in Brazil on pineapple and banana (Sanches, 1981, 1999).

**Mites**

The blister mite, *P.* (= *V.*) *sakimurae*, may be found on fruit after the flat-eye stage and may eventually become abundant on ripe fruit (Carter, 1967). It prefers to feed within the narrow spaces deep in the interfruitlet grooves, where it attacks hard epidermal tissues. Individuals possess a tiny but powerful piercing stylet and sap is evidently sucked from pierced cells, but no scars are produced (Carter, 1967). These mites can disperse to the pineapple crowns, which are eventually used for seed material (see section above on seed material).

**Other stem borers**

The larva of the weevil *M. ritchiei* (Marshall), found in the Caribbean, can bore into the pineapple stem of young suckers and emerge from the fruit, completely destroying the plant (Carter, 1967). Another weevil found in South America, *P. crenatus* (Billberg), can cause pineapple stem damage (Sakimura, 1966).

**Harvest to Consumer**

Most symptoms of pineapple fruit diseases are exhibited following harvest. Many fruit disease symptoms have been described on pineapple (Collins, 1960; Rohrbach and Apt, 1986). The ‘Smooth Cayenne’ cultivar is relatively resistant to most pineapple fruit diseases. Historically, only black rot and the chilling injury termed ‘internal browning’ or ‘black heart’ have been of sufficient economic importance and occurrence to warrant control practices. In a study of disorders of pineapple coming into the New York market between 1972 and 1985, black rot was the most common problem, occurring in 70.3% of the shipments. Severity in affected shipments varied from 11% to 50% rot. Brown rot or fruitlet core rot occurred in only 6.5%. Internal browning occurred in 19.5% of the shipments (Cappellini, 1988). In developing countries, pineapple losses can be as high as 70% (Salunkhe et al., 1991).

As with the pineapple plant diseases, fruit diseases are measured by seasonal frequency (occurrence of disease), incidence (presence or absence of disease in a single fruit) and severity (degree of infection or number of affected fruitlets in a single fruit). An index scale (Fig. 9.4) has been developed to quantitatively measure pineapple fruit diseases (Rohrbach and Taniguchi, 1984). The scale is based on the high economic impact of relatively low blemish levels on losses in the cannery, the need to discard severely infected fruit tissue, to increase labour to remove low to moderate blemish levels from fruit cylinders prior to or following slicing and to downgrade the remaining product. Thus, a single blemish in one fruitlet of the fruit cylinder (index value of 1) may downgrade the entire slice from a fancy whole slice to chunks or crush and require additional labour to remove the blemish. Ratings of 2 or 3 essentially eliminate all of the economically more valuable fancy slices from the fruit. Ratings of 4–5 essentially cause the entire fruit cylinder to be discarded. This disease index has been used for all major fruit diseases.

The frequency and incidence of fruit diseases are extremely variable with high levels occurring only sporadically. The sporadic occurrence has severely limited the ability to do research on the aetiology and control of all the fruit diseases. In Hawaii three techniques
have been used to increase the frequency, incidence and severity of the major pineapple fruit diseases for research purposes. First, hybrid cultivars have been identified which are more susceptible to the test pathogens than the relatively resistant ‘Smooth Cayenne’ cultivar. Secondly, multiple forcing at 2–4-week intervals are used in any single test to increase the probabilities of having susceptible stages of the inflorescence and flowers at times of optimal environmental conditions. Thirdly, inoculations with the test pathogen prior to or at anthesis are made. These techniques have greatly increased the frequency of test conditions and have added considerably to the information about the aetiology of the major pineapple fruit diseases.

**Black rot**

Black rot, also called *Thielaviopsis* fruit rot, water blister, soft rot or water rot, is caused by the fungus *C. paradoxa* (De Seynes) Sacc. (syn. *T. paradoxa* (De Seyn.) Hohn (telemorph *C. paradoxa* (Dade) C. Moreau). The disease is a universal fresh-fruit problem but normally not a problem with processed fruit, because times from harvest to processing are too short for infection. The severity of the problem is dependent on the degree of bruising or wounding during harvesting and packing, the level of inoculum on the fruit and the storage temperature during transportation and marketing. Black rot does not occur in the field unless fruit is overripe or injured.

Black rot of the pineapple fruit is characterized by a soft watery rot, which usually starts at the point of detachment of the fruit (Fig. 9.25). Diseased tissue turns dark in the later stages of the disease because of the dark-coloured mycelium and chlamydospores.

Infection of the pineapple fruit occurs through wounds resulting from harvesting and postharvest handling. Susceptibility varies, with the ‘Red Spanish’ types being more resistant than ‘Smooth Cayenne’. Under conditions of high humidity, conidia may readily be produced on pineapple residue and be disseminated by wind to the unharvested fruit. Inoculum levels on fruit at harvest vary according to the environmental conditions prior to harvest (Rohrbach and Schmitt, 1994). The high correlation between moisture (rainfall duration) prior to harvest and disease following harvest has resulted in the name ‘water rot’. Infection occurs within 8–12 h following wounding. Refrigeration at 9°C during transportation will slow development of the disease, but, when fruit are returned to ambient temperatures, disease development will resume (Rohrbach and Phillips, 1990).

**Fruitlet core rots (black spot)**

FCR (Oxenham, 1962; Rohrbach and Apt, 1986) or black spot (Keetch, 1977) (also called fruitlet brown rot and eye rot (Snowdon, 1990)) is a descriptive term for a brown to black colour of the central part of an individual fruitlet (Fig. 9.26). FCR is caused by an infection by a pathogen or, more commonly, a group of pathogens. Botanically the central area of the fruitlet core is the septa (inverted Y) between the three seed cavities or locules (Fig. 9.27).
Because individual or mixtures of pathogens may be associated with the FCR symptom, there is considerable confusion in the literature. The *Penicillium* and *Fusarium* fungi (Rohrbach and Apt, 1986), the round yeasts (M. Okimoto, unpublished results) and bacteria (D. Gowing, H. Spiegelberg, I. Yanagihara and J. Darroch, unpublished results) have been associated with the FCR symptom. In addition to the multiple pathogens, two mites have also been reported to be associated with the occurrence of FCR epidemics (Rohrbach and Apt, 1986; K.G. Rohrbach, unpublished results).

Two additional symptoms – IFC (Fig. 9.28) and LP (Fig. 9.29; Hepton and Anderson, 1968; Petty, 1977b) – are clearly associated with FCR caused by *Penicillium* infection (Rohrbach and Apt, 1986). The degree to which these symptoms develop appears to depend on the time of infection, the pathogen or mixture of pathogens present, the cultivar and environmental conditions. The IFC symptom can also be caused by boron deficiency in which case the symptoms are indistinguishable (K.G. Rohrbach, personal observation).

Two distinct levels of FCR occur in commercial production of ‘Smooth Cayenne’
(K.G. Rohrbach, personal observation): (i) a very low incidence of one to five fruitlets per 100+ fruits; (ii) a true epidemic, in which every fruit will have at least some FCR and many fruits will have multiple fruitlets infected (25 or more). It is theorized that the very low levels are the result of botanical malformations of individual fruitlets caused by disruptions in the normal phyllotaxis of the fruit (Kerns et al., 1936). Malformation of the fruitlet allows infection of the stylar canals and nectary ducts by a range of pathogens. In contrast, true epidemics result from the coincidence of optimum environmental conditions resulting in predisposed flowers, production of inoculum of the pathogen(s) and transport of the inoculum to potential infection sites.

Each major pineapple production area appears to have characteristic pathogens associated with the FCR symptom, probably as a result of the environmental conditions of the area (Rohrbach, 1980). For example, in Hawaii, *Penicillium* and *Fusarium* species are most commonly associated with FCR (Rohrbach and Apt, 1986). In South Africa, *Penicillium* species are most commonly found (Keetch, 1977), while, in Brazil, *Fusarium* species are most commonly associated with the FCR symptom (Bolkan et al., 1979).

FCR and associated symptoms are of major economic significance only as epidemics, not at endemic levels. Fortunately, true epidemics are relatively sporadic in the ‘Smooth Cayenne’ cultivar and in the major commercial pineapple areas of the world. The disease could become more important if some of the more susceptible, low-acid ‘Smooth Cayenne’ cultivars and hybrid cultivars are grown commercially for fresh-fruit markets.

The FCR symptom is generally characterized by browning of the inverted ‘Y’ tissues.
(septa) between the locules (Fig. 9.27). The degree of discoloration may vary from a very slight brown to dark brown or black. As mentioned previously, the FCR complex involves the fungi *P. funiculosum* and *F. subglutinans*, and the round yeast *Candida guilliermondi*. The pineapple tarsonemid mite, *S. ananas*, and the pineapple red mite, *D. floridanus*, are also associated with the FCR complex. While all of these organisms have been associated with the FCR symptom, little information has been published on the role of the yeasts as pathogens and the role of the pineapple red mite in *Fusarium* FCR. Considerable information is known and published on the *Penicillium-* and *Fusarium*-induced fruit diseases and the role of the pineapple tarsonemid mite (Rohrbach and Pfeiffer, 1976b; Rohrbach and Taniguchi, 1984).

FCR symptoms produced by *Penicillium* species are dark to medium brown in colour, usually with a grey, water-soaked centre (Fig. 9.26). The colouring may extend into the non-carpellary tissue. Blue-green sporulation is frequently observed in the locules on the ovules (see Fig. 9.22). FCR symptoms caused by *Fusarium* species vary in colour from light through medium to dark brown and extend partially to completely down the fruitlet core (Fig. 9.26). FCR caused by *Fusarium* species is usually a ‘dry’ type of rot (see Fig. 9.26). In Brazil, the symptom is not limited to a single infected fruitlet, as in typical FCR reported in other pineapple production areas. Fruit symptoms involve multiple fruitlets, with the infected area of the fruit surface appearing off-colour initially and later becoming sunken, with profuse pink sporulation and exudation of gum (Fig. 9.30). Gum exudation can be confused with the exudation from *Thecla* wounds (see Fig. 9.24; Laville, 1980).

In Brazil, the disease causes major losses in the three major cultivars, ‘Perola’, ‘Jupi’ and ‘Smooth Cayenne’ (Rohrbach, 1983). Levels of fruit infection can vary from 5 to 75% (Laville, 1980). Infection is thought to occur through open flowers, although major levels of disease also occur from inoculations to the developing inflorescence (Ventura et al., 1981). Infection of the inflorescence and fruit also occurs from injuries caused by insects, particularly the bud moth, *T. basilides*. Once the developing fruit is infected, secondary infections can occur on the developing slips or suckers. The infected seed material is then distributed to new planting areas, thus infesting new sites. Soils can remain infested for several months. Spread within infested fields is primarily by insects but may also be by wind (Laville, 1980). Free conidia of *F. subglutinans* can survive for 6–13 weeks in soil, depending on moisture and temperature, with survival being highest in dry soils. Survival in pineapple tissue in soil is less than 10 months (Maffia, 1980). Optimum tempera-
Fig. 9.30. Pineapple fruit in Brazil showing fusariosis caused by *Fusarium subglutinans*.

**Pink fruit**

Pink disease of pineapple fruit is characterized by the typical symptom of brown to black discoloration of the fruit tissue when heated during the canning process. Depending on the bacterial strain and the severity of the disease, symptoms in uncooked fruit may be completely absent or may include extremely severe fruit translucence, light pinkish to brownish colour of the fruit cylinder, and/or a ‘cantaloupe-like’ odour (Rohrbach and Apt, 1986). *E. herbicola* in uncooked pineapple fruit is essentially symptomless and very difficult to detect. *G. oxydans* in uncooked fruit induces pinkish brown to dark brown discolorations and may have a ‘cantaloupe-like’ odour. *A. aceti* – more recently classified as *Acetobacter liquefaciens* (Gossele and Swings, 1986) in uncooked fruit with only a few fruitlets infected can be symptomless. However, in moderately to severely infected fruit (many fruitlets infected), symptoms range from pinkish brown to dark brown (Rohrbach and Pfeiffer, 1976a; Kontaxis and Hayward, 1978). The symptom is reported to be caused by the bacteria producing 2,5-diketogluconic acid, which reacts with amino acids to form brown to black pigments (Buddenhagen and Dull, 1967). Strains of the acetic acid bacteria, such as *A. liquefaciens*, have been reported to produce browning and rotting of apples and pears and to have been isolated from guava, mango and Surinam cherry (Gossele and Swings, 1986).

In contrast to the other fruit diseases, the economic significance of pink disease is the inability to detect diseased fruit prior to processing, with the result of brown to black slices in a sealed can. Thus, quality control during processing is critical to detection of low levels and management of diseased fruit in the cannery (Rohrbach and Apt, 1986). In fresh-fruit production, low levels of pink disease are not of major economic importance. However, when high incidences occur, with strains having symptoms prior to cooking, economic loss can occur.

**Marbled fruit**

Marbling disease is caused by the acetic acid bacteria *A. peroxydans* Visser ’t Hooft and *E.*
herbicola var. ananas (Serrano) Dye. Marbling disease has been reported in essentially all pineapple production areas of the world (Rohrbach, 1983). However, epidemic levels occur only in the lowland tropics, where temperatures remain above 21–27°C during fruit development (Rohrbach and Apt, 1986). In production areas such as Thailand, where disease incidence is high, from 5 to 20% of the slices in the cannery will be marbled. In Thailand, the incidence and severity of marbling can be high enough in October and November to close down processing operations (K.G. Rohrbach, personal observations). In Hawaii, highest levels occur in April and May although the disease may occur at any time. Low fruit acid and brix are also associated with high levels of the disease.

The fruit disease of pineapple termed ‘marbling’ is represented in the literature by a wide range of symptoms. The most common symptom is a yellowish to reddish brown to very dark dull brown discoloration of the infected fruit tissue. Infected tissues generally become hardened, granular and brittle in texture, with colour variation in the form of speckling (Rohrbach and Apt, 1986). The disease may affect individual fruitlets but more typically affects a group of fruitlets or the entire fruit. Frequently, the speckled appearance will occur in vascular tissues in the core of the fruit. The diseases reported as bacterial fruitlet brown rot (Serrano, 1928) and fruitlet black rot (Barker, 1926) have generally been considered to be a variation of marbling. An additional symptom, termed ‘brown and grey rot’, has also been associated with marbling disease. The causal organism of brown and grey rot will also cause marbling symptoms. In general, much less is known about marbling disease than about pink disease.

Currently, no known controls of marbling exist. Differences in cultivar susceptibility have been noted, with the ‘Smooth Cayenne’ variety being moderately resistant (K.G. Rohrbach, unpublished results). When epidemics occur, infected fruit can be detected and excluded prior to going through the cannery by external appearance and a test to measure fruit firmness, such as sticking a knife into the fruit. If incidences are extremely high, all fruit must be discarded. In contrast to pink disease, marbled-fruit tissues can be discarded before being packing in cans.

**Internal browning**

Internal browning, also termed endogenous browning or black heart, is a physiological disorder of pineapple fruit. The disorder is of major significance in Australia, Taiwan, Kenya and South Africa, where fruit are grown and harvested at or near frost conditions (0–10°C). The disorder is also very important in the marketing of fresh fruit when refrigeration is used to extend shelf-life.

Internal browning is of economic importance only where fruit are grown under very cool conditions or are refrigerated for long periods through marketing channels prior to consumption (Paull and Rohrbach, 1985).

Internal browning is characterized initially by a small greyish translucent zone beginning at the base of the fruitlet (see Fig. 9.31) adjacent to the fruit core. This zone later darkens, becoming brown to black. When symptoms are severe, the entire internal fruit tissues are brown to black, thus giving rise to the name ‘black heart’ (Fig. 9.31; Paull and Rohrbach, 1982).

No organisms have ever been shown to be associated with the internal browning symptom. Internal browning is thought to occur from increased polyphenol oxidase activity (Teisson, 1979; Paull and Rohrbach, 1985). Low ascorbic acid levels have been associated with symptom expression (Paull and Rohrbach, 1985).

Symptoms may develop in fruit that has matured in the field at low temperatures in the range 5–10°C. Symptoms may also develop within 4 days of ambient temperatures following refrigeration at common commercial shipping temperatures of 7°C (Rohrbach and Apt, 1986).

**Mites**

Severe damage when fruit mature under drought conditions may cause death of the
basal crown leaves, thereby affecting freshfruit quality and enhancing the potential for quarantine examinations (Rohrbach and Schmitt, 1994).

Scale

Normally, in Hawaii, pineapple scale is not a major problem in the field, probably because of scale parasites and predators. However, because of the quarantine requirement to have fruits insect-free, even low levels of pineapple scale at harvest may present quarantine problems.

Miscellaneous Fruit Diseases, Pests and Deformities

Numerous pineapple fruit diseases and blemishes of minor occurrence and importance have been noted and described, much of it in unpublished form. The minor importance of these symptoms and abnormalities results from their sporadic occurrence and lack of economic effects on pineapple production. Thus, little has been done to determine the cause and aetiology of these symptoms and abnormalities.

Yeasty fermentation

Yeasty fermentation is caused by the yeast species Hanseniaspora valbyensis (M. Okimoto, unpublished data) and can be a major problem in overripe fruits. A dry yeast rot has been attributed to Candida intermedia var. alcoholophila (M. Okimoto, unpublished data). Occasionally, the disease will occur in green fruit, having severe interfruitlet corking symptoms with associated fruit cracking (K.G. Rohrbach, personal observation). The disease has also been associated with high incidences of fruit sunburn (Lim, 1985). Losses can be minimized by reducing sunburn and harvesting fruit before they are overripe.

Glassy spoilage

Glassy spoilage is caused by infections with the yeast C. guilliermondii and may be associated with fruitlet core rots (M. Okimoto, unpublished data) caused by mixed infections of yeast and Penicillium or Fusarium species. As with yeasty fermentation, losses can be minimized by harvesting before fruit are overripe.

Acetic souring

Acetic souring is caused by bacteria and is characterized by an offensive odour similar to that of a mixture of organic acids, including acetic acid. Juice of infected fruit may be very viscous and cloudy with bacteria. No controls are known.

Miscellaneous fruit rots

Fruit rots caused by Aspergillus flavus, Botryodiplodia theobromae and Rhizopus oryzae.
or *Rhizopus stolonifer* have been reported as postharvest diseases (Snowdon, 1990). A fruit rot caused by *Hendersonula toruloidea* (Natt.) has been reported by Lim (1985) on the Mauritius cultivar. Green fruit rot caused by *Phytophthora* species occasionally causes large losses of lodged first-ratoon fruit in Australia under very wet conditions. These pathogens generally require some form of wounding for infection. Commercially, these diseases are of very minor importance.

**Miscellaneous physiological fruit diseases**

**Woody fruit**

Woody fruit is a disease of unknown cause. The disease is characterized by brown streaks distributed throughout the fruit tissue, which is very woody and hard in consistency. The disease is associated with certain clones of ‘Smooth Cayenne’ and therefore is assumed to be of genetic origin. Roguing at harvest is used to eliminate seed material from plants showing symptoms.

**Sun scald and frost injury**

Sun scald is characterized by a discoloration of the fruit shell, which ranges from yellow to tan or black on the side of the fruit exposed to the sun. The internal tissues are usually a pale grey colour, but, when severe, the affected area becomes sunken and desiccated. Fruits that fall into an exposed or reclining position are much more susceptible. On clear, calm days, temperatures of 50–54.4°C have been recorded in exposed fruit (K.G. Rohrbach, unpublished results). Where sun scald is a problem in summer months (e.g. Australia, South Africa, Taiwan and Brazil) straw, weeds or shredded paper may be used to cover the exposed side of the fruit for control (Lim, 1985). Sprays of a 4:1 mixture of talc and bentonite are used by larger growers in Australia to reduce incidence of injury.

Frost injury occurs occasionally in some areas in Australia. Symptoms are shell discoloration and cracking between the eyes.

**Fasciation/multiple crowns**

Multiple crowns (two or more) develop when young fruit are exposed to high temperatures early in the development stage. Because nothing is known about the stage of fruit development most susceptible to high temperatures, no controls are available. The problem is mainly important where fruit are to be sold fresh with the crowns attached. In Australia, multiple crowns are trimmed to one to improve appearance and to facilitate packing in boxes.

Fasciation is an abnormal development of the inflorescence and crown, resulting in a flattening of the upper part of the fruit with multiple crowns ranging from two to many. Fasciation has been associated with genetic and environmental conditions, although Py (1952) has indicated that the phenomenon is not hereditary. Cultivars such as the ‘Smooth Cayenne’ are less susceptible than the ‘Singapore Spanish’. Within the ‘Smooth Cayenne’ cultivar, certain clones are much more susceptible than others.

**Trephritid fruit flies**

Prior to 1953 methyl bromide was used to treat pineapple imported into continental USA. Since then, it has been demonstrated that ‘Smooth Cayenne’ pineapple cultivars (low- and high-acid types, with at least 50% ‘Smooth Cayenne’ parentage) are not hosts for the tephritid fruit flies: Mediterranean fruit fly, *Ceratitis capitata* (Wiedermann), melon fly, *Dacus cucurbitae* (Coquillet), and the oriental fruit fly, *Dacus dorsalis* Hendel (Bartholomew and Paull, 1986).

**Management of postharvest diseases and pests**

Black rot is commercially managed by minimizing bruising of fruit during harvest and handling, by refrigeration and with chemicals. Fruit must be dipped in an appropriate fungicide within 6–12 h following harvest prior to packing and shipping (Rohrbach Phillips, 1990).
Internal-browning symptom development can be reduced by waxing with paraffin-polyethylene waxes at wax-to-water ratios of 1:4–9 (Rohrbach and Apt, 1986). Waxing has been shown to increase internal CO₂ concentrations, thereby lowering O₂ concentrations, which results in reduced polyphenol oxidase (Paull and Rohrbach, 1985).

The *Penicillium*-induced FCR, LP and IFC fruit diseases have been reduced by applications of endosulphan (3.35 kg a.i. ha⁻¹ in 2338 l water) at forcing and 3 weeks following forcing. Reductions have been significant but only under low to moderate disease levels (Le Grice and Marr, 1970; Rohrbach *et al.*, 1981; Rohrbach and Apt, 1986). Fungicides, such as benomyl, have not been effective unless applied directly into the open heart as the inflorescence emerges (K.G. Rohrbach, unpublished results).

Control of typical FCR induced by *F. subglutinans* has not been demonstrated. Control of fusariosis is most effective by planting disease-free seed material and by controlling insects, particularly the bud moth (Laville, 1980). Hot-water treatment of seed material at 54°C for 90 min with benomyl at 50 g 100 l⁻¹ is effective for disinfestation but will retard growth and kill up to 50% of the plants (Maffia, 1980). Fungicides, such as captafol, at 700 g a.i. ha⁻¹, starting at differentiation through harvest at 20-day intervals, have given good control of the fruit-rot phase in Brazil (Bolkan *et al.*, 1978). Resistance to fusariosis occurs in *Ananas* and *Pseudoananas* (Laville, 1980).

Scale can be controlled relatively easily by preharvest applications of an appropriate registered insecticide, taking into consideration last application to harvest residue restrictions.

**Ratoon Crops**

In general, control of weeds, insects (ants, mealybugs, scales), nematodes and diseases (root rots, fruit diseases) in ratoon crops is very much dependent on the efficiency of controls that were applied during the development of the plant crop. Postplant applications of nematicides (e.g. fenamiphos) following plant-crop harvest have not resulted in yield increases in Hawaii but have increased yields in Ivory Coast (Caswell *et al.*, 1990).

**Integrated Pest Management**

Environmental and food-safety concerns have focused attention on IPM. The concept of IPM is to employ several techniques simultaneously to solve specific pest and disease problems for the long term rather than in the short term. Success relies on an in-depth understanding of the pineapple production system and the ecology and biology of each pest or disease and associated organisms (e.g. vectors, natural enemies). Emphasis must be placed on the importance of each pest or disease from an economic, biological and ecological perspective (Pedigo, 2002). In order to evaluate the importance of the pest or disease, efficient techniques are needed to monitor changes in populations of pest and levels of diseases or pathogen populations. The changes must be correlated with yields and quality.

In most pineapple production systems throughout the world, mealybug wilt must be controlled by the management of ants and mealybugs. Severe infestation may have an impact on the production system and the final product in several ways. As a direct pest, feeding reduces plant growth, fruit quality and yield. The presence of mealybugs on fresh fruit may become a quarantine issue, as well as a quality issue when present in the canned product. The indirect effect and the most severe impact are the resulting mealybug wilt, with high rates of field infestation.

Ants play a major role in the impact of mealybugs and mealybug wilt on pineapple. Soil tillage during fallow eliminates essentially all in-field ants, and new infestations must move into the newly planted field from field border areas. The rate of establishment of permanent ant colonies and mealybug wilt is relatively slow (Beardsley *et al.*, 1982). When ants are controlled, the parasitoid *Anagyrus ananatis* Gahan (Fig. 9.32) and other biological control agents can maintain
populations of the pink mealybug below damage thresholds in Hawaii. The use of Amdro® is efficacious, allowing natural biological control agents to function while reducing overall insecticide usage.

Techniques for monitoring ants, using trap stakes, have been developed (Fig. 9.33; Beardsley et al., 1982). Recommendations are to use trap stakes baited with peanut butter/soybean oil at intervals of 30 m (100 ft) along field borders of new plantings. Trapping must be done in late afternoon, with data being taken after darkness occurs. The first monitoring should start at 3 months following planting and be repeated at 3-month intervals thereafter. When ants are detected, they may be controlled with site-specific applications of ant baits or insecticides. Other monitoring techniques, such as pit-fall traps, honey-vial traps and pineapple-juice traps, have also been used. Threshold levels of ants have not been very well defined and the presence of any ants is considered problematic.

Populations of mealybugs have been monitored with sticky tape placed in the lower part of the pineapple plant (Fig. 9.34; M.W. Johnson, unpublished results). Relatively high levels of mealybug are required for mealybug wilt. Diagnosis of mealybug wilt virus-infected seed material can be done rapidly and inexpensively, using a tissue-blot immunoassay system (Hu et al., 1993), in order to establish virus-free plantings. Evaluation of the impact of virus-free plants on growth and yield has not been completed, but studies are under way (D. Sether, personal communication).

Reniform and root-knot nematode threshold levels at planting for pineapple production in Hawaii have not been well defined.

Fig. 9.32. The parasitoid Anagyrus ananatis on a pink pineapple mealybug, Dysmicoccus brevipes.

Fig. 9.33. Field sampling for ants using white stakes with the base painted with honey/water (50:50) or peanut butter/soybean oil and placed out from 3 to 6 p.m. and read at 7–10 p.m.
Reniform nematode populations in soil stay low until 6–9 months following planting and then peak at 12 months (Sipes and Schmitt, 1994). The field history of nematode populations and their impacts on yield is important in nematode management.

Nematodes are currently managed primarily by soil fumigation and postplant nematicides. A clean fallow period is also used to reduce populations. Crop rotation was used in the early part of the century in Hawaii but has not generally been practised since the discovery of soil fumigants. Crop rotation has not been practical in recent years, because of the high cost of planting and maintaining (irrigation) the rotation crop, along with the inability to develop marketable rotation crops. Non-host cover crops, either within the growing crop or during fallow, have been studied with varying degrees of success (Caswell et al., 1991). Cover crops may be feasible only in high-rainfall areas. Fumigation efficacy is influenced to a major degree by the soil-tillage practices prior to fumigation and soil moisture during tillage and at fumigation (Caswell and Apt, 1989). The use of plastic mulch reduces fumigant losses to the atmosphere, as well as reducing the amounts of herbicides required. Efficient nematode control integrates all the above strategies.

Phytophthora heart rot and root rots of pineapple are diseases limited to fine-textured, high-pH soils under wet environmental conditions. Control strategies involve improving surface and internal soil drainage. Raised planting beds have provided good control under wet conditions but poorer growth under dry conditions. Fosetyl aluminium and ridomil are very effective as preplant dips. Fosetyl aluminium also provides good heart-rot control as a foliar application at 3–6-month intervals and excellent control of P. cinnamomi root rot (Rohrbach and Schmitt, 1994). Resistant cultivars to both P. cinnamomi and P. nicotianae var. parasitica exist but are not commercially viable, due to low yields or poor fruit quality (Rohrbach and Schmitt, 1994).

Both pineapple butt and black rot are caused by the fungus C. paradoxa. The severity of the problem in fresh fruit is dependent on the degree of bruising or wounding during harvesting and packing, the level of inoculum on the fruit and the storage temperature during transportation and marketing. Currently, these diseases are controlled by dipping the crown or fruit in a fungicide prior to planting or shipping of the fruit (Cho et al., 1977). Treatment must be done in 12 h or less from the time the crown or fruit is removed from the plant (Rohrbach and Phillips, 1990).

Inoculum levels on fruit at harvest vary according to the environmental conditions prior to harvest. The high correlation between moisture (rainfall duration) prior to harvest and disease following harvest has resulted in the name water rot. Storing seed material on the mother plants during dry weather, where there is good air circulation and minimal exposure to inoculum-infested
soil, provides excellent control. However, stored seed results in poor uniformity of early plant growth and can reduce crop yields. Planting fresh planting material results in more rapid uniform growth. Freshly removed seed material for immediate planting must be dipped in a fungicide within 12 h of removal. Currently, seed materials are dipped in triadimefon.

Black rot is commercially controlled in fresh fruit by minimizing bruising of fruit during harvest and handling, by refrigeration and with chemicals. Fruit must be dipped in a fungicide within 6–12 h following harvest prior to packing and shipping. Currently fruit can be dipped in triadimefon. The ‘Red Spanish’ cultivar is generally more resistant to *C. paradoxa* than ‘Smooth Cayenne’, but, due to low yields and poor quality, this is not an economically viable cultivar.

Pineapple scale only becomes a problem when the balance of biological control is upset, for example by the application of residual, broad-spectrum insecticides (Sakimura, 1966). Quantitative monitoring techniques have not been developed. While a monitoring technique has been developed for the tarsonemid mite (Fig. 9.35), correlation with the *Penicillium*-induced fruit diseases has not been well enough established to predict disease.

IPM for pineapple production systems has met with varying success and has not been broadly implemented for several reasons. First, less expensive alternatives are still available. The annual application of Amdro® for ant control in pineapple is much less expensive than the labour required for a detailed ongoing monitoring programme. As long as other alternatives are available, farmers will not learn and implement monitoring activities. Second, in Hawaii, the importation and development of biocontrols have essentially reached a standstill because of environmental concerns for non-target species. Until agriculture is forced by economic or regulatory incentives to implement IPM, traditional pest and disease strategies will be used. Thirdly, IPM does not generally reduce pest and disease levels low enough to meet quarantine requirements, thus requiring other pest- and disease-control strategies.

In Hawaii, an IPM verification programme has been established, which was modelled after the national IPM protocol for potatoes. Multidisciplinary teams, including members from industry, research and extension, identify pests and diseases and recommend IPM practices. IPM protocols are developed based on establishing the best management approaches. Verification of producer practices is done by farm visits and review of records, in order to assign points in relation to each IPM protocol. High scores allow producers to use IPM as a marketing tool and to better educate farmers and consumers as to the value of products grown under IPM principles (A. Hara and R. Mau, personal communication).
References


